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Low-Cost Universal Motor Chopper Drive System

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Introduction

This application note describes the design of a low-cost chopper motor control drive system based on the MC68HC705MC4 microcontroller, the MGP7N60E IGBT (insulated gate bipolar transistor), and the MSR860 ultra-fast soft diode. This low-cost, single-phase power board is dedicated for universal brushed motors. Such a low-cost microcontroller is powerful enough to do the whole job necessary for driving a closed loop chopper drive.

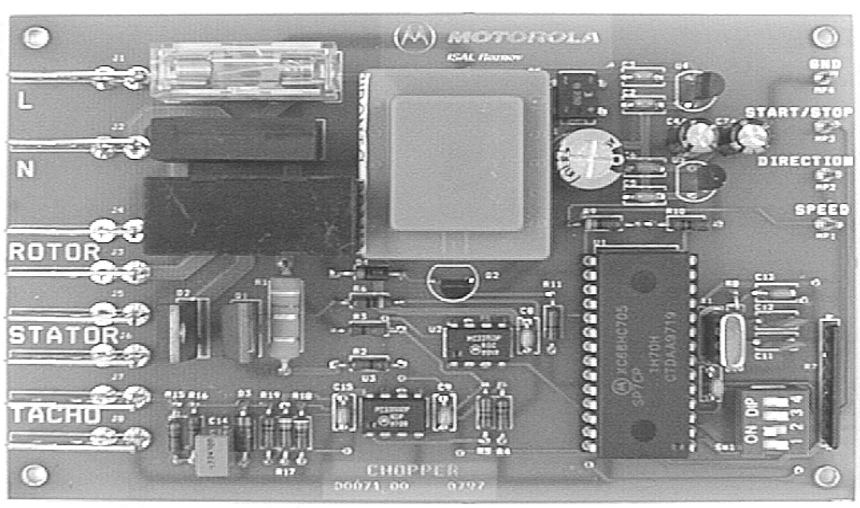

Figure 1. Low-Cost Motor Control Chopper Board

This application note also explains how to design the software implementation using an M68HC05 microcontroller (MCU).

Today the universal motor is the most widely used motor in home appliances such as vacuum cleaners, washers, hand tools, and food processors.

The operational mode, which is used in this application, is closed loop and regulated speed. This mode requires a speed sensor on the motor shaft. Such a sensor is usually a tachometer generator. The kind of motor and its drive have a high impact on many home appliance features like cost, size, noise, and efficiency. Electronic control is usually necessary when variable speed or energy savings are required.

MCUs offer the advantages of low cost and attractive design. They can operate with only a few external components and reduce the energy consumption as well as cost.

This circuit was designed as a simple schematic using all features of a simple MCU. The MCU and this board may be used in a wide variety of applications.

The pulse-width modulation (PWM) technique is used to adjust the voltage applied to the motor (refer to **Figure 2**). Modulation of the PWM's duty cycle allows the effective voltage, seen by the motor, to be varied. The PWM technique is often termed "chopper" because of the chopped drive signal which is created. Compared to a phase angle drive, a chopper drive requires a more complicated power stage with an input power rectifier, a power switch, and a power fast diode. The advantage is higher efficiency, less acoustic noise, and better EMC (electromagnetic compliance) behavior.

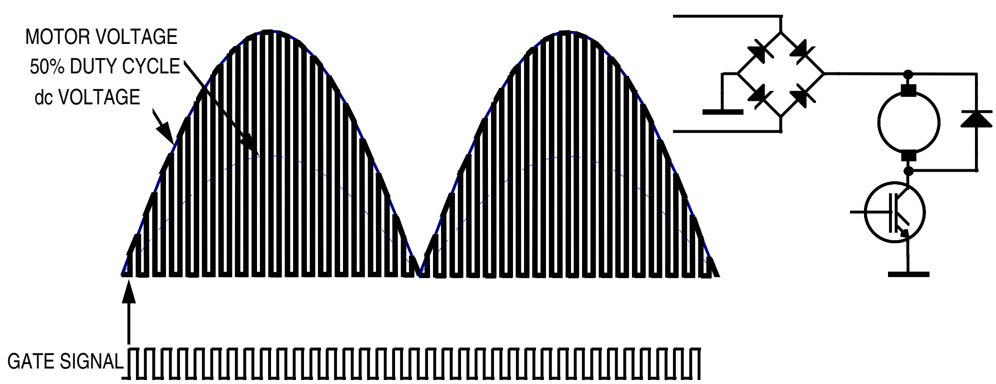

Figure 2. Pulse-Width Modulation Technique — Chopper

Added Value Using a Microcontroller

Compared to a poor analog solution, an MCU-based drive shows many advantages. Some of them are:

- Choice between different control algorithms
- Choice between any shape of speed command (acceleration and deceleration phase)
- Choice between any type of tachometer
- Software that can make the hardware simpler
- Diagnostic functions
- Remote control by wire and communication protocol
- Open for innovation

Devices

Universal motors are still used where brushes are accepted, and universal motors driven by power switches are used where a low price is required. This section contains information and descriptions about all features of a suitable MCU, IGBT, and diode.

The MC68HC705MC4 is an M68HC05-based MCU designed for motor drive applications. General features include:

- 3.5 Kbytes of EPROM
- 176 bytes of RAM
- 6-bit timer including an output compare and two input captures
- Four general-purpose input/output (I/O) pins
- Serial communications interface (SCI) (UART, universal asynchronous receiver transmitter) port in a 28-pin SOIC (small outline integrated circuit) or a DIP (dual in-line) package

In addition, the MC68HC705MC4 has specific features including:

- 2-channel, 8-bit PWM module
- High-current source port
- 6-channel, 8-bit analog-to-digital (A/D) module

The MC68HC705MC4 is well suited for motor drive applications with its A/D converter and with its PWM block.

ON Semiconductor's series of IGBTs offered are specially designed for efficient motor drives. Switching times, saturation voltage, and short circuit capability have been optimized for these applications. The higher threshold eliminates the need for negative gate drive. With a fast switching and short circuit capability, the E Family of IGBTs fits well in high-performance, line-operated, pulse-width modulated, variable speed motor drives. This family includes the single IGBTs (without copackaged freewheeling diode) in the current range of 5 A to 20 A in a TO220 package. Some parameters of the chosen IGBT are shown in **Table 1**.

The MC33153 driver is specially designed to drive the gate of an IGBT used for high-power applications, such as motor drive. It can be used with discrete IGBTs and IGBT modules up to 100 A. Device protection features include the choice of desaturation or overcurrent sensing plus undervoltage lockout optimized for IGBTs.

Table 1. Electrical Characteristics of the MGP7N60E

Parameter	Value
Collector-emitter voltage VCES	600-V max
Collector current continuous IC90	7-A max
Collector-to-emitter on-state voltage (IC = 4 A) VCE (on)	2.2-V typ
Gate threshold voltage VGE(th)	6-V typ
Turn on/Turn off delay time td(on)/td(off)	59/150-ns typ

Circuit

In **Figure 3**, the schematic of a chopper motor control board is shown. The six major parts are:

- Power stage
- Relay
- Current measurement
- Circuitry for a tachometer connection
- Power supply
- Microcontroller

The power stage is composed of the input power bridge rectifier D1 with the capacitor C16, the power transistor Q1, and the freewheeling diode D2. There is no bulk electrolytic capacitor because of cost and size. The MCU can change direction of the motor with help of the relay K1.

The current measurement consists of the voltage drop resistor R1 and the differential amplifier U3A. In this part, the low-voltage, rail-to-rail operational amplifier MC33502 is used. The MC33502 is a new device with rail-to-rail operation on both the input and output. The output can swing within 50 mV of either supply. Such a device makes it possible to build a low-cost circuit to amplify the signal from the voltage drop resistor. The only errors exist for very low currents and can be eliminated by the software.

Because this board provides the control algorithm in closed loop mode, some devices allow connection of a tachometer. The most frequently used tachometer has 16 poles and an output voltage of 5-volt to 20-volt RMS for full-scale working speed. An input filter protects the operational amplifier U3B against high voltage at high speed, and diode D3 protects the operational amplifier against negative voltage. The output square wave signal from the comparator is connected to pin PD7. By using this arrangement, the input capture feature of the MCU can be used.

The power supply produces two voltages: +12 volts for the driver of the IGBT and the relay and +5 volts for the rest. The structure with the input transformer T1, the bridge rectifier D5, and the voltage regulators U4 and U5 has been chosen.

The MCU’s A/D convertor provides the conversion of three input voltages. An external speed command is connected to pin PC4. Two other signals, PC5 motor current and PC3 mains information, are prepared for future use. Pins PC6–PC7, as reference inputs for the A/D convertor, are connected to appropriate levels of the power supply.

WARNING: ***This circuit is powered directly from the line. To avoid electrocution, do not touch any parts of this board. The control panel must be isolated from the user under all possible circumstances. When working with this board, do not connect any computer, scope, or development system. This could damage the equipment and the board. In this case, it is necessary to use an isolation transformer.***

The speed command can be set externally in the range of 0 volts to 5 volts. A simple external control panel (refer to **Figure 4**) should be linked with the chopper power stage when external commands are needed. The connectors MP1-speed, MP2-direction, MP3-start/stop, and MP4-GND are provided on-board.

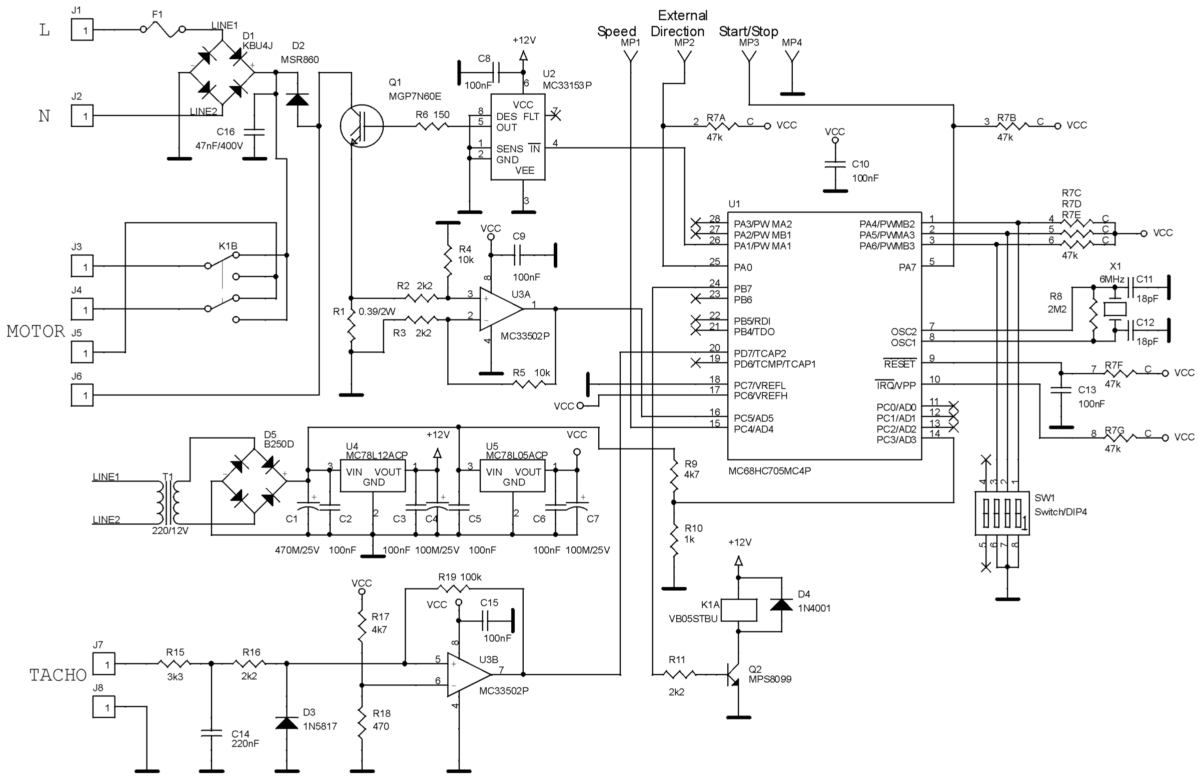

Figure 3. Low-Cost Motor Control Chopper Drive

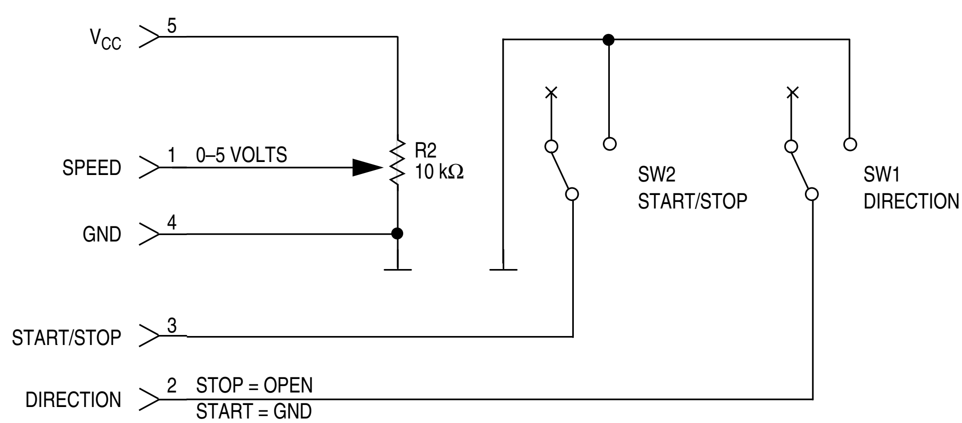

Figure 4. External Control Panel

The DIP switch, SW1, allows some options of the drive's functionality and is discussed later in this application note.

Pullup resistors R7A–R7E are on-board to provide the proper level of input signals for the MCU.

Control Algorithm

The basic principle of the chopper control technique is simple: The speed can be controlled by adjustment of the voltage applied to the motor performed by the change of the PWM duty cycle (see **Figure 2**). The universal motor is supplied in dc mode through the power stage.

Figure 5 shows a state diagram. The software consists of a control block and some subroutines like: MAKE_PI, RAMPE, watchdog and interrupt services routines. The control block is, in fact, a relatively short loop which makes a decision on which subroutines will be called.

There is also a universal timing routine, which works with the hardware (HW) timer and a unique register for every timed subroutine. The timing routine calculates the difference between the hardware timer and a particular register and, in case of coincidence with the given number (time interval), calls the appropriate subroutines.

The same principle is used for all time conditions.

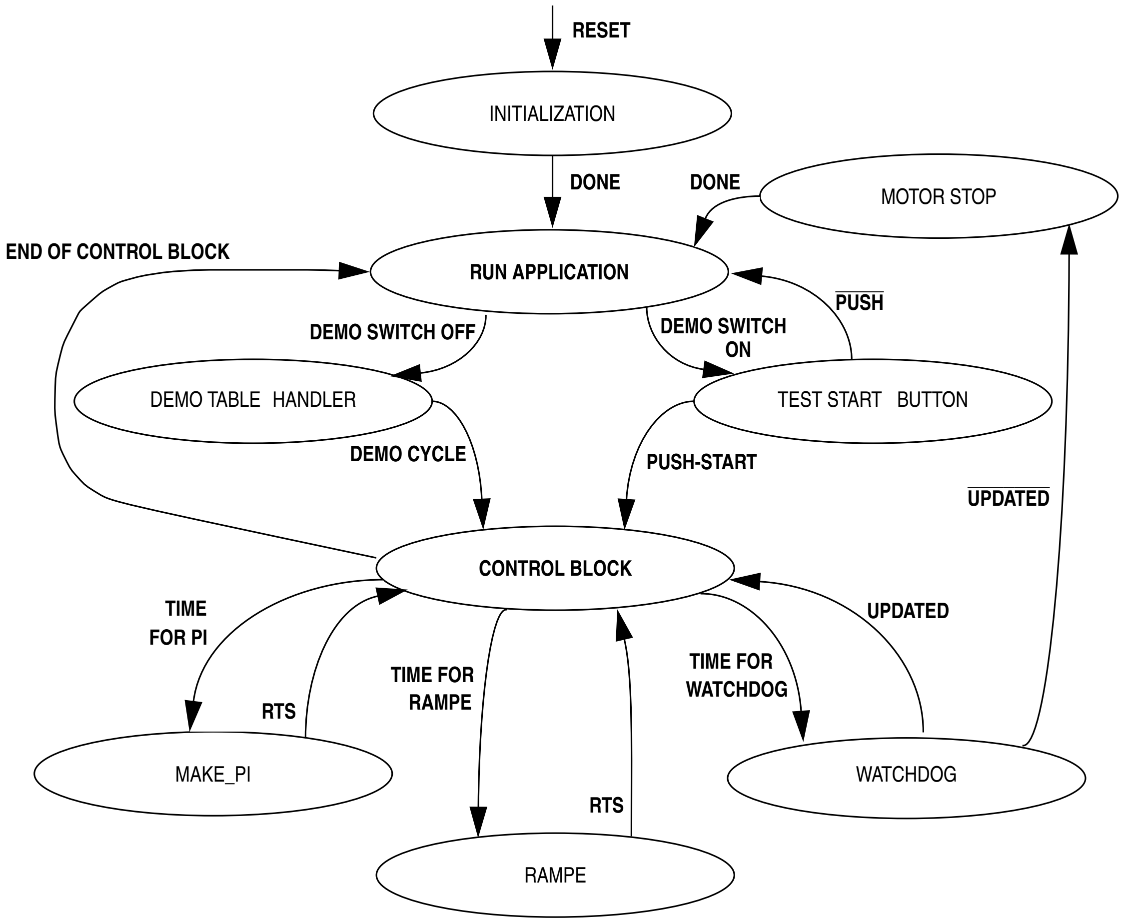

Figure 5. Program State Diagram

A DIP switch with three connected switches (refer to **Figure 6**) is available on the board. One of the switches (2) is tested by the discussed software and two are free for customer use (1 and 3). The control block tests the switch number 2. This switch toggles between demo mode and start/stop mode.

In demo mode, the drive starts automatically and runs in a 3-step endless loop. In start/stop mode, the external START command and the analog external speed command are necessary.

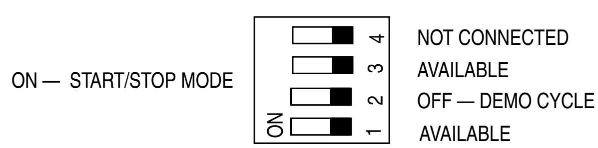

Figure 6. DIP Switch SW1

MAKE_PI Subroutine

The MAKE_PI subroutine is entered when a time event occurs. The main job is the calculation of the actual speed and the calculation of the PI controller. The input value for the speed calculation is a good filtered 16-bit output value from the input capture interrupt. A 32/16-bit division is used where the 32-bit number is a constant and the 16-bit number is the output from the input capture interrupt.

The constant can be calculated from this expression:

$CONST = N \times INCAP_{MIN}$

Where:

CONST = Constant for division

N = Maximal number of result 255

$INCAP_{Min}$= Minimal number of counts between two edges of tachometer signal (376 for 15,000 RPM and 6-MHz crystal)

CONST = 255 x 376 = 95,880 (00017688 hex)

For the PI controller, a well-known equation is used:

V = VZ_1 + P_CONST x (E - EZ_1) + I_CONST x E

Where:

V = Actual new value

VZ_1 = V in last step

P_CONST = Proportional constant

E = command_speed — actual_speed

EZ_1 = E in last step

I_CONST = Integration constant

The output from the PI controller is the input value for the MCU's PWM peripheral block.

RAMPE Subroutine

The RAMPE subroutine is entered when a time event occurs. In fact, this subroutine changes the slope of the command speed's signal. The slope is the same for the rising and falling edges and can be modified through a change in the time interval for the RAMPE subroutine.

Watchdog Subroutine

The watchdog subroutine is entered when the watchdog register has not been updated for approximately 4 seconds. The input capture interrupt service routine, as a result of the running motor, takes the responsibility for the watchdog register. By this arrangement, it is possible to protect the motor when the shaft is blocked. In this case, the watchdog will turn off the IGBT and will wait for a new START command.

Interrupts

In this application, the MCU can be interrupted in these two different ways:

- The simplest interrupt is the timer overflow interrupt. The appropriate service routine is the timer overflow interrupt service routine (TOISR), and it enables the input capture interrupt and starts the A/D convertor.
- The input capture interrupt service routine (ICISR) is allowed to run six times every 87 ms (TOISR occurred), and it calculates an average value of the time interval between the rising edges of the tachometer signal.

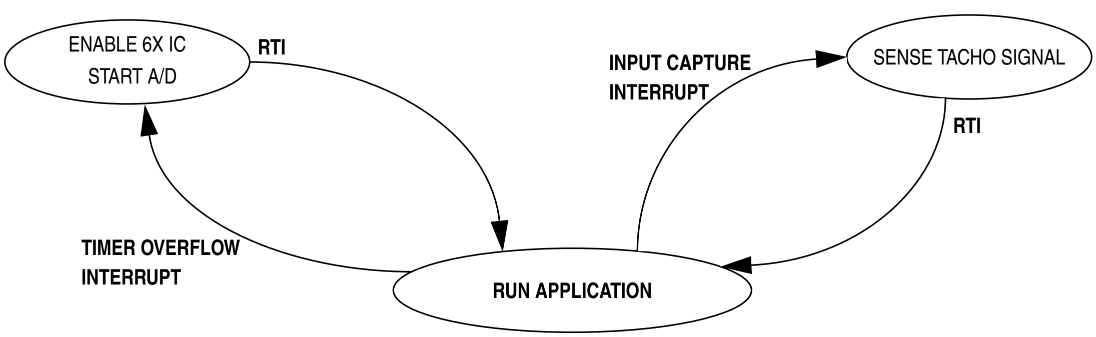

Figure 7. Interrupt Service Routines

Microcontroller Usage

Total RAM and ROM Used

Table 2 shows how much memory is needed to run the chopper drive. A significant part of the memory is still available.

Table 2. Memory Usage

Memory	Available	Used
SRAM	176 bytes	33 bytes
ROM	3.5 Kbytes	1.1 Kbytes

I/O Use

Table 3 summarizes the use of the I/O pins. Nine pins are still available.

Table 3. I/O Pin Usage

I/O	Available Pins	Used Pins	Purpose
Port A	PA0–PA7	PA0 PA1 PA4–PA6 PA7	Ext. direction PWM output DIP switch Ext. start
Port B	PB4–PB7	PB7	Relay
Port C	PC0–PC7	PC3 PC4 PC5 PC6–PC7	Mains Ext. speed Motor current References
Port D	PD6–PD7	PD7	Tachometer

Parts List and PCB

Component parts are listed in Table 4. Figure 8 and Figure 9 show the printed circuit board (PCB) layout.

Table 4. Parts List

Component	Quantity	Value/Rating	Description
U1	1	—	IC, MC68HC705MC4P
U2	1	—	IC, MC33153P
U3	1	—	IC, MC33502P
U4	1	12 V, 100 mA	IC, MC78L12ACP
U5	1	5 V, 100 mA	IC, MC78L05ACP
Q1	1	8 A, 600 V	IGBT, MGP7N60E
Q2	1	80 V, 500 mA	Transistor, MPS8099
X1	1	6 MHz	Resonator
D1	1	4.0 A, 600 V	Bridge recti er , KBU4J
D2	1	8.0 A, 600 V	Fast diode MSR860
D3	1	1.0 A, 20 V	Schottky diode 1N5817
D4	1	1.0 A, 50 V	Diode, 1N4001
D5	1	1.0 A, 500 V	Bridge recti er , B250D
R1	1	0.39 Ω, 2 W	Resistor
R2, R3, R11, R16	4	2.2 kΩ, 1/4 W	Resistor
R4, R5	2	10 kΩ, 1/4 W	Resistor
R6	1	150 Ω, 1/4 W	Resistor
R7	1	47 kΩ, 1/4 W	Resistor
R8	1	2.2 MΩ, 1/4 W	Resistor
R9, R17	2	4.7 kΩ, 1/4 W	Resistor

Table 4. Parts List (Continued)

Component	Quantity	Value/Rating	Description
R10	1	1.0 kΩ, 1/4 W	Resistor
R15	1	3.3 kΩ, 1/4 W	Resistor
R18	1	470 Ω, 1/4 W	Resistor
R19	1	100 kΩ, 1/4 W	Resistor
C1	1	470 mF, 25 V	Capacitor electrolytic
C2, C3, C5, C6, C8, C9, C10, C13, C15	9	100 nF, 50 V	Capacitor
C4, C7	2	100 µF, 25 V	Capacitor
C11, C12	2	18 pF, 50 V	Capacitor
C14	1	220 n, 50 VF	Capacitor
C16	1	47 nF, 400 V	Capacitor
F1	1	4 A	Fuse
T1	1	220 V/12 V, 1 VA	Transformer
K1	1	5 A, 240 VAC	Relay
J1–J8	8	—	Connector
SW1	1	—	DIP switch
MP1–MP4	4	—	Connector

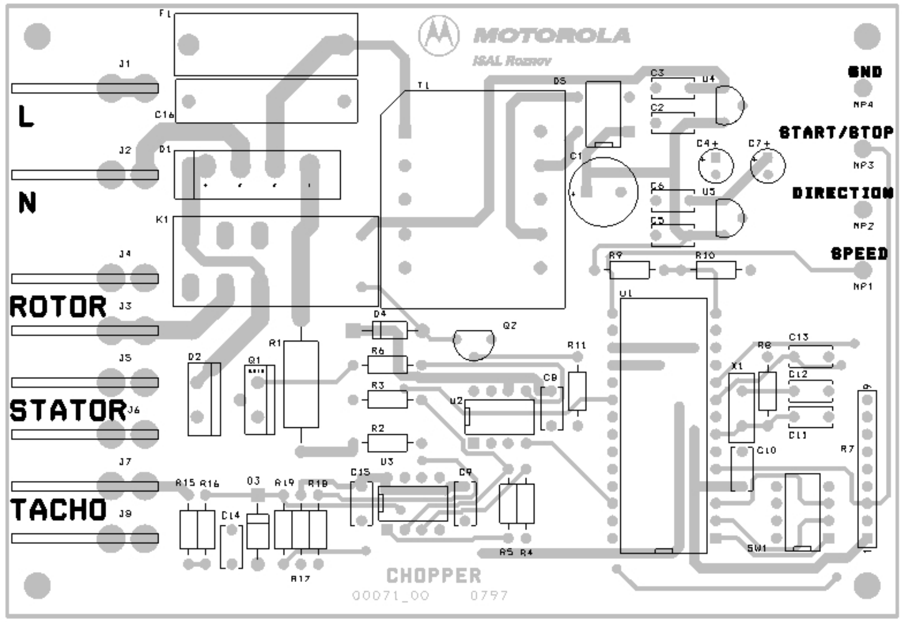

Figure 8. PCB Layout Component Side

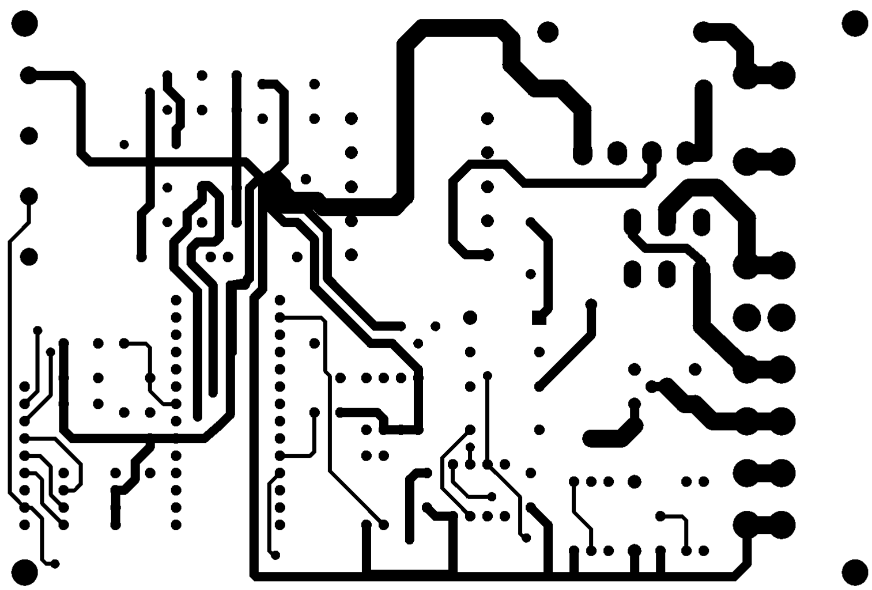

Figure 9. PCB Layout Copper Side

Performance of the Sample Design

The sample design performed with these measurements:

- Input voltage — 220-volt RMS
- Input current — 1-A RMS without heatsink and without load
- Motor — 400 W with tachometer
- Demo mode — Automatic start; no speed reference needed
- Start/Stop mode — Start, external 0 volt, external speed reference 0 volt to 5 volt
- Speed — 500 to 15,000 RPMs

Conclusion

This application note describes a real application, which can be used in a low-cost product. The unused memory and some performance capacity are still available for other customer purposes. These facts make this application especially suitable for the appliance market.

References

The World Wide Web page for this application is found at http://www.freescale.com/semiconductors

The following documents can be obtained from ON Semiconductor at www.onsemi.com:

- *Insulated Gate Bipolar Transistor N-Channel*, document order number MGP7N60E/D
- *Single IGBT Gate Driver*, document order number MC33153/D
- *One Volt SMARTMOS™ Rail-to-Rail Dual Operational Amplifier*, document order number MC33502/D

This document can be ordered from Freescale's Literature Distribution Center:

- *MC68HC705MC4 General Release Specification*, document order number HC705MC4GRS/D

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