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*Single Phase AC
Induction Motor
Control
Reference Design*

*Designer Reference
Manual*

*DRM039/D
Rev. 0.0, 3/2003*

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Freescale Semiconductor, Inc.

Single Phase AC Induction Motor Control

Reference Design

Designer Reference Manual — Rev 0

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Motorola Ltd

Freescale Semiconductor, Inc.

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Designer Reference Manual — DRM039

Section 1. General Description

This application note describes a new control technique of the single-phase a.c. induction motor. It presents a design of a low-cost, high-efficiency drive capable of supplying a single-phase a.c. induction motor with a PWM modulated sinusoidal voltage. The circuit operation is controlled by a tiny MC68HC908QT4 MCU.

The device is aimed at substituting the commonly used triac phase angle control drives. The circuit is capable of supplying a single-phase a.c. induction motor (or general a.c. inductive/resistive load) with varying a.c. voltage. The same as in triac control, the voltage applied to the load can be varied from zero to maximum value. On the other hand, it uses a pulse width modulation technique (PWM), and when compared with the phase angle control used for triacs, produces much lower high harmonic pollution.Thus, it suits EMC/EMI regulations much better.

Because the circuit is aimed at low-cost, low/medium-power applications, it does not use a conventional converter topology to produce the output voltage waveform. It directly modulates the mains a.c. voltage. Compared with the converter, it requires a lower number of active and passive power components. Thus, the price of the drive can be kept at a reasonable level.

In summary, the device described in the application note takes advantage of both the low price of the phase angle control and the low harmonic content and high efficiency that we can get with standard converter topology. The drives based on this new control technique are targeted for use in consumer and industrial products: washing machine, dishwashers, ventilators, compressors, and wherever the system cost is a consideration.

1.1 Background of Single-Phase Drives Control

Single-phase motors are widely used in home and industrial appliances. The main advantage of these motors is their ability to operate from a single-phase power supply. Therefore, they can be used wherever a single-phase power is available. There are also other aspects for their popularity: low manufacturing cost, reliability, and simplicity. However, compared with three-phase systems, they offer lower efficiency.

1.1.1 Single-Phase Motor

Because the single-phase motor is supplied from a single-phase current source, the motor produces an alternating magnetic field. At zero speed, the torque produced is zero. To start such a motor, it is necessary, besides a main winding, to have an auxiliary winding to help to generate the phase-shifted magnetic field. Typical construction of the single-phase motor is shown in Figure 1-1. The auxiliary winding is placed in quadrature with the main winding. The current flowing to the auxiliary winding has to be phase shifted from the current flowing through the main winding. There are several ways to do this.
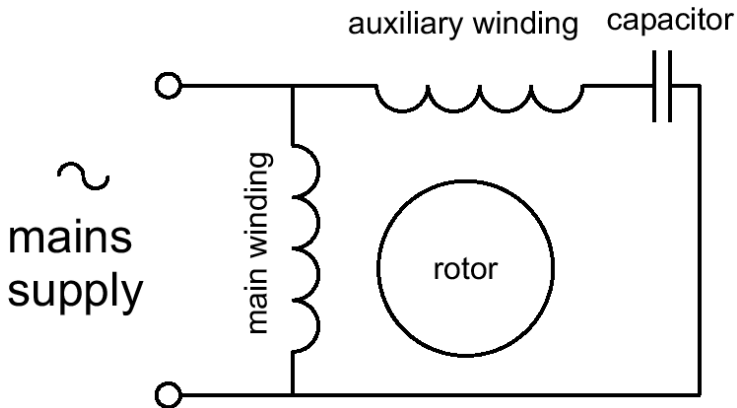

Figure 1-1. Single-phase a.c. induction motor

Usually there is a capacitor connected in series with the auxiliary winding. Thus, we can generate magnetic fields of main and auxiliary windings shifted 90°. Such a field appears to rotate the same as for a

field in three-phase motors. It causes the motor to start rotating. The capacitor and auxiliary winding may be disconnected when the motor reaches 75% of nominal speed. Usually a centrifugal switch is used. Then the motor continues running with the main winding. This configuration produces high starting torque and is ideal for applications such as compressors, refrigerators, etc.

If the high starting torque is not required, the starting capacitor may also be left connected in normal operation. Then no centrifugal switch is required. The capacitor and an auxiliary winding have to be designed for continual operation. The starting torque of such a motor is low, making the motor suitable for use in low-inertia loads such as fans and blowers.

The simplest method to start a single-phase motor is to use a shaded-pole motor. This construction does not require a starting winding and capacitor. The stator poles have a short copper ring placed around a small portion of each pole. The magnetic field of the shaded part of the pole is delayed in relation to that from the non-shaded part. The magnetic field appears to be rotating and the motor can start rotating. The shaded-pole motors are very simple and inexpensive when produced in high volumes. Against these advantages, they have also a number of disadvantages: very low efficiency (below 20%), low starting torque and high slip. They have a limited range of use, i.e. in small home appliances such as fans or blowers.

1.1.2 Varying Speed of Single-Phase Motors

In many applications it may be desirable to change the speed of the motor e.g. if we want to control the air-flow of a ventilator. Then it is useful to use some techniques for varying a.c. induction motor speed. The speed of the single-phase a.c. induction motor can be adjusted either by applying the proper supply voltage amplitude and frequency (called volt-per-hertz control) or by the changing of supply voltage amplitude with constant frequency (slip control).

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1.1.3 Conduction Angle Control

Because of its very low cost and simplicity, the most popular technique of supplying single-phase a.c. motors is the conduction angle control. To carry out this control, a triac device is used. The conduction angle is adjusted by changing the switching instant of the triac device. In such a way, the conduction angle can be varied from 180° to 0°. The voltage r.m.s. value is a function of the conduction angle. Basic principles of this technique are shown in Figure 1-2. Using the conduction angle control, we can adjust only the output voltage amplitude and not the frequency, therefore only the slip control can be used.
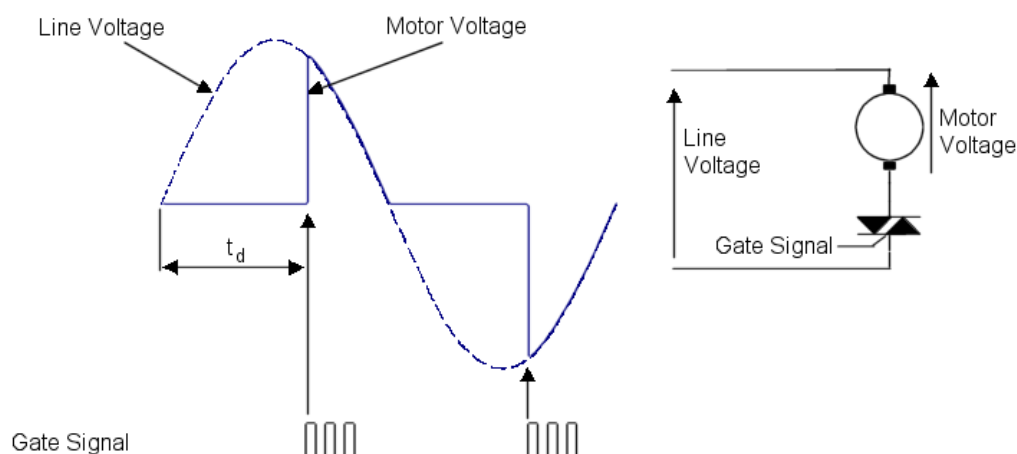

Figure 1-2. Triac conduction angle control

This method represents a cost-effective solution. It is the most used technique for low-cost appliances, widely used in modern consumer products. For the low cost, we pay a high price with this method. It produces very high harmonic content in both motor and supply current waveforms. The effects of these are low efficiency of the drive and transmission lines, acoustic noise, and electromagnetic interference. For these reasons, the conduction angle control is not preferred for the latest designs. The high harmonic pollution does not comply with strict European EMI/EMC regulations.

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1.1.4 Converter Topology

The three-phase drives are usually based on complex converter topology. The converter topology can also be used for supplying single-phase a.c. motors. The block diagram of such a drive is shown in Figure 1-3.
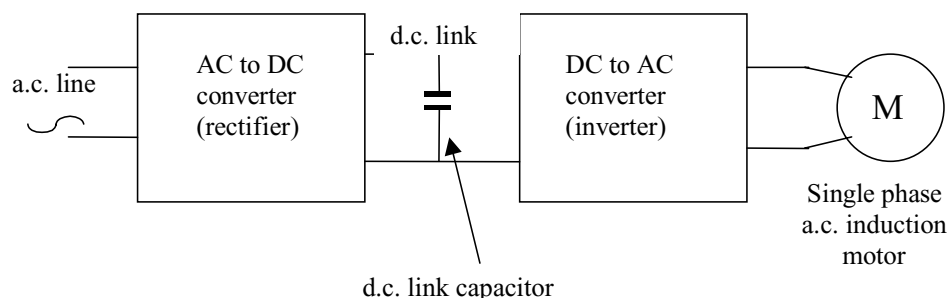

Figure 1-3. Converter topology block diagram

In a conventional converter, the a.c. line voltage is converted into d.c. voltage using the diode bridge rectifier at the input. The d.c. voltage is then filtered by the filter capacitor in the d.c. link. Finally, the d.c. voltage is converted back to an a.c. voltage of the desired amplitude and frequency by the inverter. The inverter is usually implemented as a single-phase bridge. PWM modulation is used to generate an output voltage waveform. The advantage of this topology is the ability to generate both the amplitude and frequency of the output voltage independently. The converter systems have one big disadvantage – high cost. They require numerous active and passive power components. Another problem is the diode bridge rectifier at the input. The current drawn from the a.c. line by this system is non-sinusoidal, with high and narrow current spikes. To eliminate this, some power correction circuits need to be implemented. This increases the overall system cost. Converter systems are not suitable for low-cost, high-volume products. It fits best mainly for use in high power and high efficiency drives.

1.2 Motorola Circuits for Single-Phase A.C. Induction Motor Control

The new circuits are designed to provide a cost-effective solution for driving a.c. induction motors with varying r.m.s. voltage value. The circuits modulate the a.c. line voltage directly. The input sinusoidal waveform is chopped using a bi-directional switch and applied to the load. The switching frequency is fixed at 16 kHz. The r.m.s value of output voltage is proportional to the duty-cycle of the modulation signal (PWM modulation). The first harmonic of the output waveform remains unchanged and is the same as the line voltage. Therefore the circuits are suitable for applications where the voltage of variable amplitude and constant frequency is required (e.g. slip control of a.c. induction motors).

Motorola offers two practical circuits for supplying single-phase a.c. induction motors. Both circuits are based on the same topology, which is shown in Figure 1-4.

The topology uses two bidirectional switches. A bidirectional switch is a device capable of switching on and off both polarities (i.e. positive and negative) of an a.c. voltage and current. The a.c. load is connected to the a.c. line by means of the bidirectional switch S1. According to the input control signal, switch S1 connects and disconnects the load to/from the a.c. line. Thus, the input sinusoidal waveform is chopped and the r.m.s. value of the voltage applied to the load is controlled. An example of the chopped line voltage is shown in the diagram.

In instances when the load is disconnected from the a.c. line, the current flowing through the load needs to be freewheeled. Therefore the other bidirectional switch S2 is connected across the load. It is switched on when S1 is switched off, and vice versa. That means that switches S1 and S2 have to be switched complementarily.
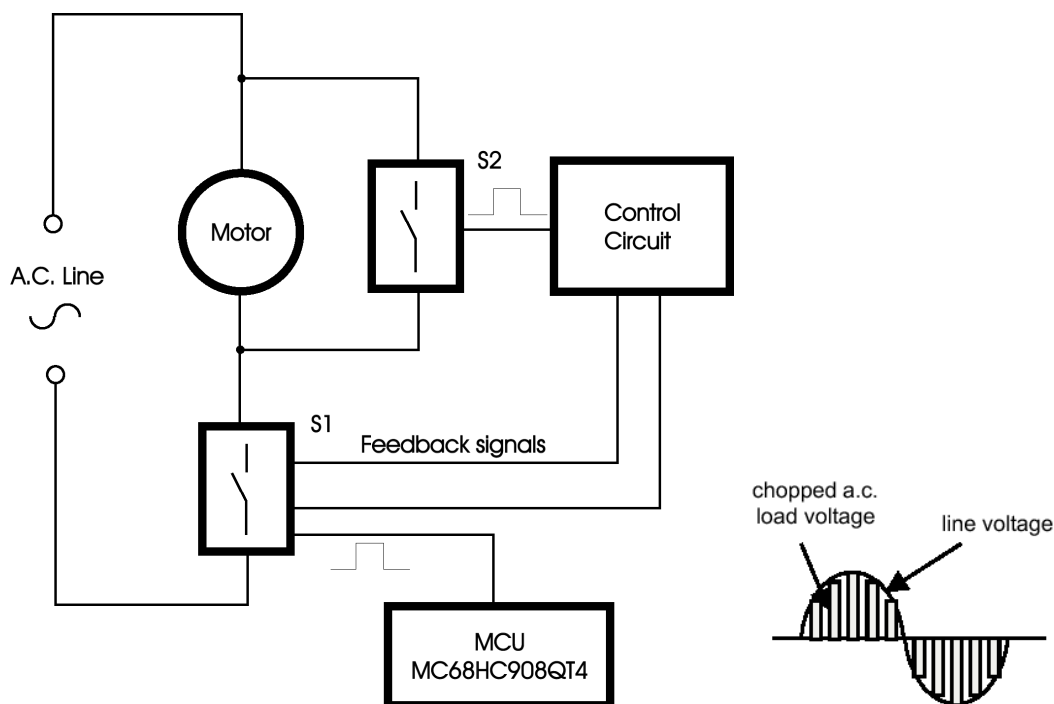
Figure 1-4. Block diagram of the single-phase drive

The bidirectional switches S1 and S2 are both implemented as a rectifying bridge. The input terminals of the rectifying bridge are connected to the load. The output terminals (rectified side) has a power transistor (IGBT, MOSFET or bipolar) connected across them. When the power transistor is off, current cannot flow through the rectifying bridge and the bidirectional switch is in an off-state. When the power transistor is on, output terminals are short-circuited, and current can flow through the rectifying bridge. The bidirectional switch is in an on state. The switching state of the bidirectional switch is determined by the power transistor. The function of the bidirectional switch is shown in Figure 1-5.

The power transistor is controlled by the electric signal applied across the transistor gate (base) and source (emitter) electrodes. In the circuit topology as shown in Figure 1-4, the source electrodes of the power transistors in switches S1 and S2 are alternate to each other. Therefore it is not possible to get an inverted electric signal simply from one to the other.

General Description

This application note presents two different approaches to solve this task and properly control switches S1 and S2.
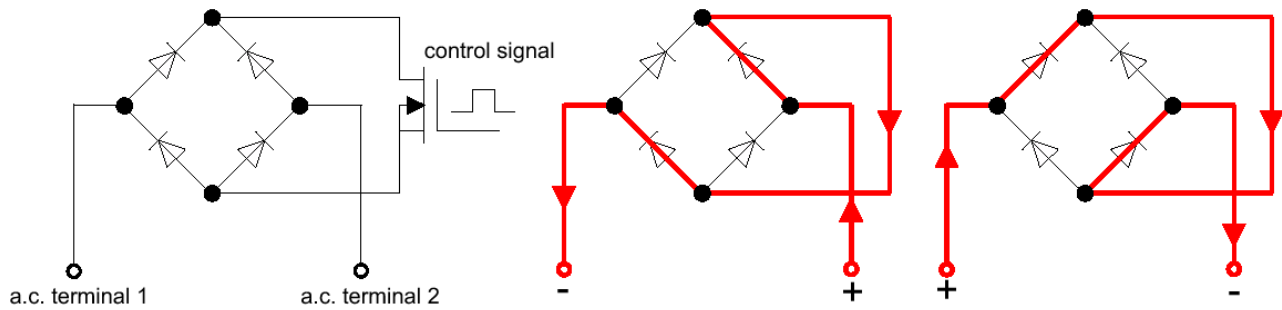

Figure 1-5. The bidirectional switch

Section 2. Hardware Design

Motorola designed two circuits, which are based on the topology of two bidirectional switches shown in Figure 2-4. Each of the circuits solves the switching of the bidirectional switches in a different way. The first circuit utilizes feedback signals to control freewheeling of the load current. The switching of switch S2 is not controlled directly by MCU signal, but according to the feedback signals taken from switch S1.

The other circuit takes a different approach. The switches S1 and S2 are controlled directly by an MCU signal. To drive the power switches, two opto gate-drive devices are used. They provide optical isolation between the control signal and power switches and between the power switches themselves. Thanks to this, the bidirectional switches can be controlled directly. The opto gate-drive devices are connected in such a way to ensure S1 and S2 switches are switching complementarily.

2.1 Design Features

Both designs provide the following features:

- Input voltage 230V AC r.m.s.

- Maximum output current 4A AC r.m.s. (peak current 8A)

- Varying output r.m.s voltage in range 0 – 230 V

- PWM switching frequency 16 kHz

- Capable of supplying general single-phase induction/resistive loads

- MCU based control

- Control interface (START/STOP switch, speed command input, ON/OFF LED)

2.2 Controller Part

The controller part is identical for both designs. Figure 2-2 shows schematics of the controller part and on-board power supply. The circuit is controlled by a tiny but powerful microcontroller, MC68HC908QT4. The MCU reads the state of the START/STOP switch, which is connected to PTA3 pin. The speed of the motor can be adjusted by a variable resistor P1. The variable resistor is connected to PTA4 pin and sampled by an A-to-D converter. The state of the drive is displayed by LED D1 connected to PTA1 (MOTOR RUNNING signalization). The MCU generates a PWM signal, which controls switching of the power circuit. The switching frequency is fixed at 16 kHz. The duty cycle is adjusted according to the speed command input.

The board is equipped with the Bootloader Connector (J1) and a simple interface to be able to use features of the Developer's Serial Bootloader (see AN2295). This tool allows the developer to perform MCU on-board programming via an RS232 serial communication without any additional hardware.

2.3 Control Circuit with Feedback Signals

This circuit utilizes feedback signals to control freewheeling of the load current. The block diagram illustrating the basic principles of this control technique is shown in Figure 2-1.

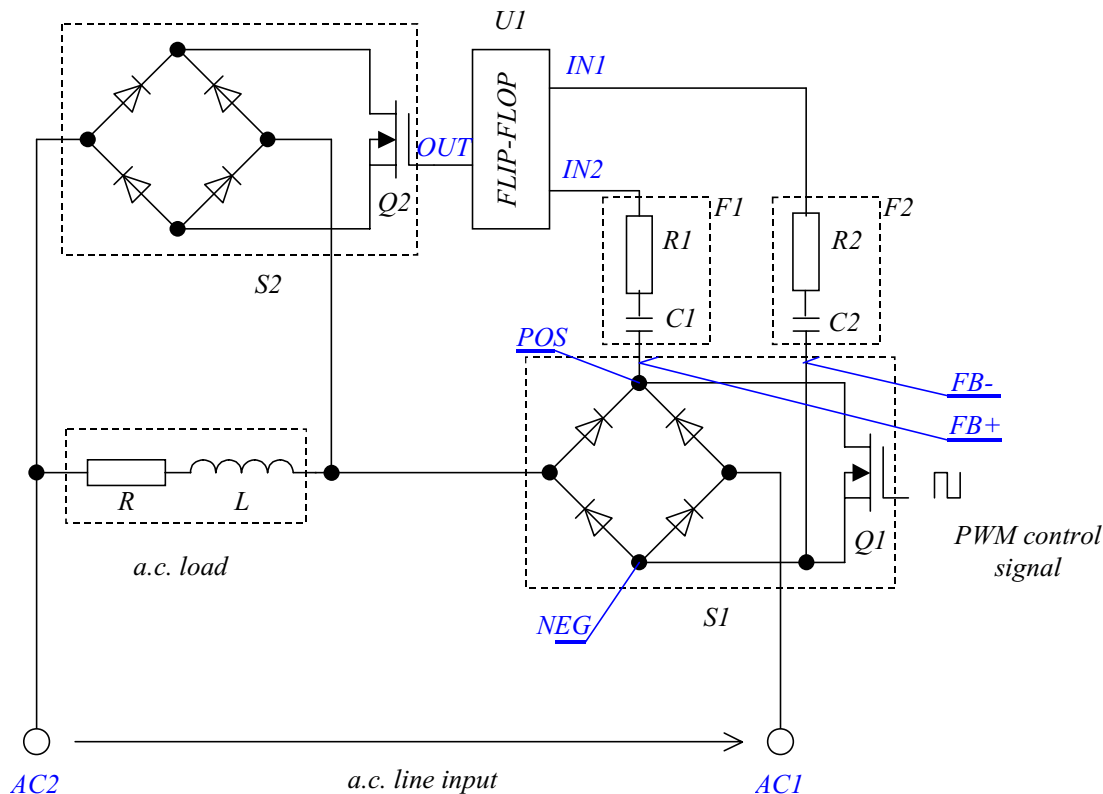Freescale Semiconductor, Inc.

Figure 2-1. Control Technique Utilizing Feedback Signals

Two feedback signals, *FB+* and *FB-,* are taken from the bidirectional power switch *S1*. The pulses on the positive side *(POS)* and negative side (*NEG)* of the output terminals of the bidirectional switch *S1*'s rectifying bridge are used as control signals for flipping the flip-flop circuit *U1* (FLIP-FLOP). The output signal *OUT* of the flip-flop circuit *U1* is a control signal, which switches power transistor *Q2* on and off.

The rising edge on the feedback signal *FB+* or the falling edge on the feedback signal *FB-* switches the flip-flop on. The falling edge on the feedback signal *FB+* or the rising edge on the feedback signal *FB-* switches the flip-flop off. Using both signals is not necessary, but it increases speed of flip-flop switching, mainly in regions where one of the control signals is poor. The capacitive coupling, which is set up by *R1,C1* and *R2,C2* elements, separates the disturbing 50/60Hz signal from the a.c. mains.

2.4 Practical Realization of the Circuit

Figure 2-3 shows a practical realization of the circuit. The a.c. line input is connected to *JP1* terminals. The output terminals of the circuit *JP2* are connected to the single-phase load (a.c. motor). The bidirectional switch S1, which chops the a.c. mains voltage, consists of diodes *D16, D17, D20, D21* and power MOSFET *Q7.* The control signal switching the power transistor *Q7* is amplified by a driver circuit. It includes *Q6, Q8* and *Q9* transistors. The resistors R17 and R19 allow the turn on/off times of the power MOSFET to be adjusted.

The bidirectional switch S2, which provides a freewheeling load current, consists of diodes *D9, D10, D12, D13* and power MOSFET *Q2.* The control signal switching the power transistor *Q2* is amplified by a driver circuit. It includes *Q1* and *Q4* transistors. The resistors *R11* and *R12* allow the turn on/off times of the power MOSFET to be adjusted. Inductor *L1* and diode *D8* limit the current during commutation of the load current from the power MOSFETs *Q7* and *Q11*. They are connected to the drain terminal of *Q2.* Depending on the characteristics of the power components and parameters of the load, this protective circuitry can be omitted.

The flip-flop circuit is realized by small signal transistors *Q4 and Q6*. The feedback signals are taken from the source and drain terminals of power MOSFET *Q7*. They are coupled by means of *C12, R15* and *C14, R20*. The capacitor *C5* with resistor *R9* and resistor *R8* set up a positive close loop typical for a standard monostable flip-flop. The capacitor *C5* is added to separate the d.c. component from the feedback signal. Because the *R9 C5* time constant is much longer than the switching period, the circuit behaves as bistable for the given high switching frequency.

The over-current protection circuitry consists of the sensing resistor R27, and transistors Q11 and Q10. It protects the circuit from accidental short-circuiting caused by the concurrent turning on of Q7 and Q2 power MOSFETs. In case of over-current, the circuit turns off the MOSFET *Q2.*
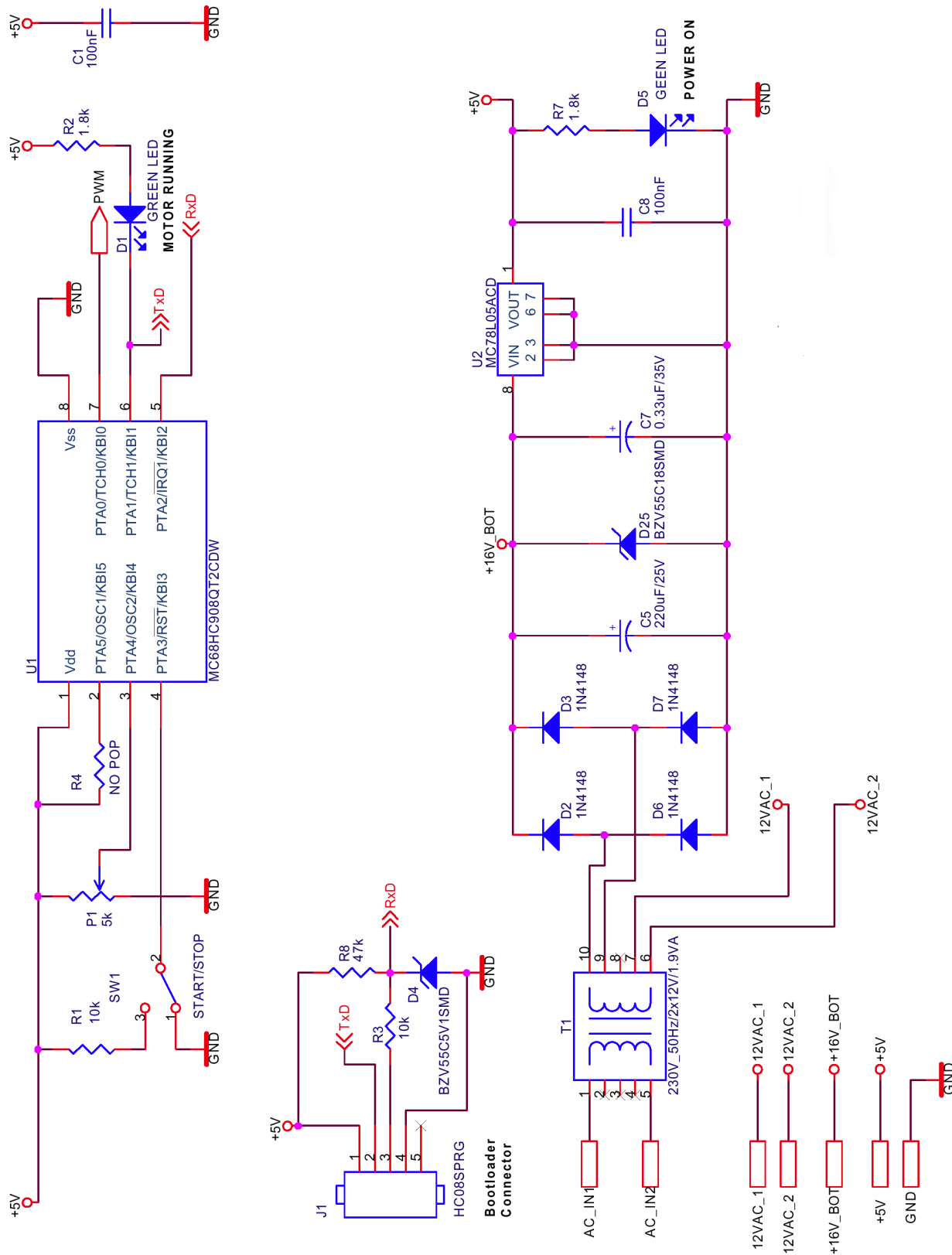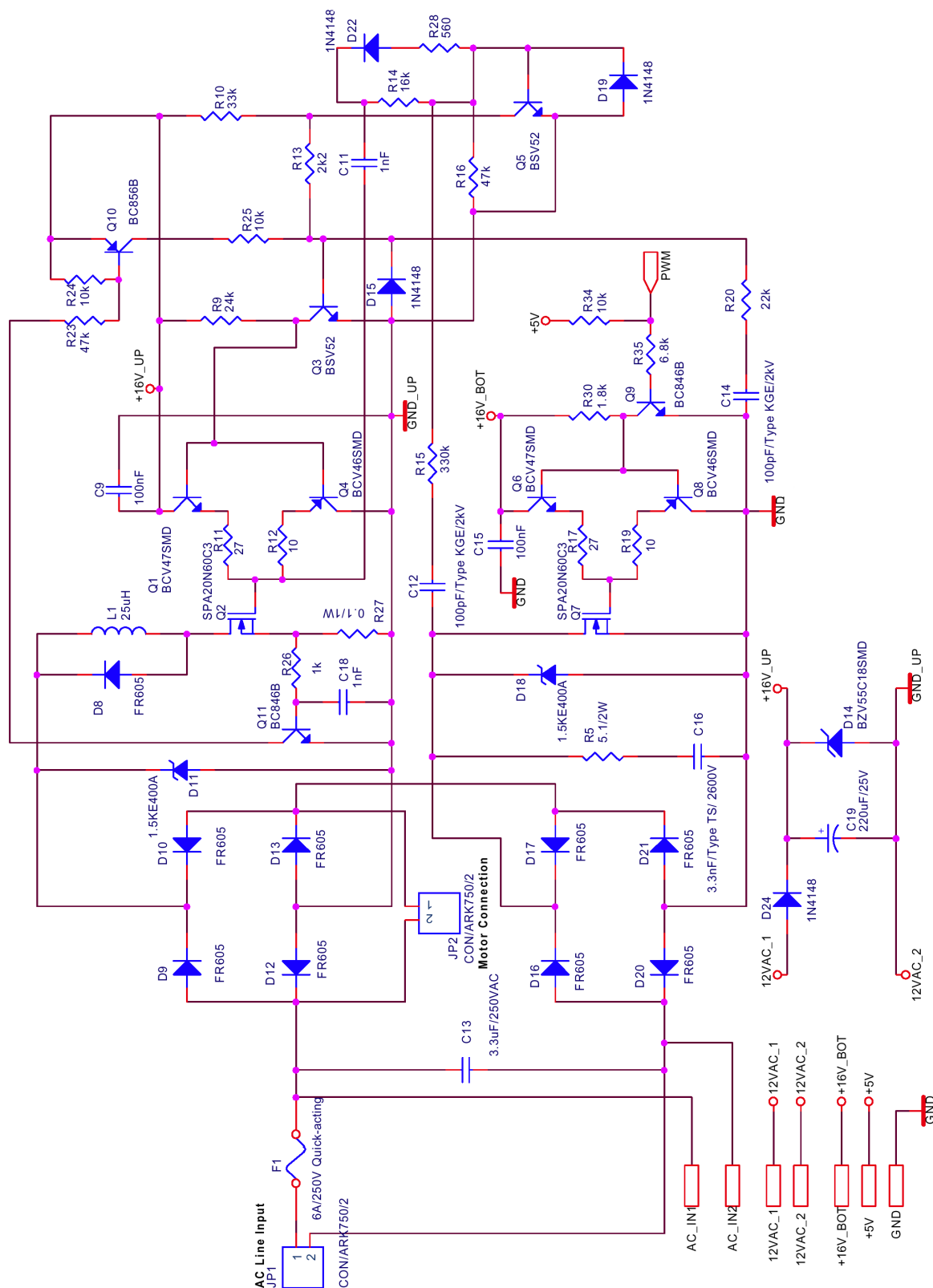
Figure 2-2. MCU + Power Supply

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Figure 2-3. Power Circuit with Feedback Signals

> *NOTE:* Please note that capacitor C13 is connected across the a.c. line input. It filters the input voltage. It is necessary to ensure that feedback signals are not influenced by ripples in the supply voltage. Its size depends on parameters of the load. In the design that is the subject of this application note, the capacitor value was experimentally set to 3.3 µF.

> *NOTE:* To protect MOSFETs from over-voltage, transient voltage suppressors (D11, D18) are connected across the drain and source terminals.

2.5 Freewheeling Circuit with Direct MCU Control

The second circuit developed for single-phase drives uses the same topology of power circuit as the circuit described above, i.e. two bidirectional switches as shown in Figure 2-4. The approach to the control of the freewheeling switch *S2* is different. Both switches *S1* and *S2* are controlled directly by the PWM signal generated by the MCU. According to the control signal, the switches are switching complementarily. In order to be able to connect control signals of both switches to the same potential level, it is necessary to use an galvanic insulation between the control signals and gate-driving signals on the power transistor gates.

The practical realization of the circuit is shown in Figure 2-4. The same as in the previous circuit, the input a.c. line voltage is connected to the terminals of JP1. The output terminals of JP2 are connected to the load.

The bidirectional switch S1 consists of diodes *D16, D17, D20, D21* and power IGBT *Q7.* The bidirectional switch S2 consists of diodes *D9, D10, D12, D13* and power IGBT *Q2.*

The galvanic insulation between the gate-driving and control signals is provided by the dual IGBT gate drive optocoupler device *U2* (HCPL-314J). The device integrates two independent optically insulated gate-drives in one package. The power IGBT *Q2* gate terminal is connected to the output pin *VO1* of the first driver and the gate terminal of the power IGBT *Q7* is connected to the output pin of the other driver *VO2*. The resistors *R8* and *R11* allow the turn on time of each power IGBT to be set.

The optocoupler has an LED at the input of each gate-drive. The PWM signal generated by the MCU is linked directly to these inputs. The switching instants of the IGBTs are adjusted by means of *R9*, *C14* and *R10*, *C16* RC filters. Thus, the propagation delay difference between the two channels can be compensated.

This solution requires three insulated on-board power supplies. The optocoupler high voltage side is supplied from the two independent 15 volt dc power supplies. The controller side is supplied from the third 5 volt dc power supply. Such a solution offers a safe galvanic insulation between the control and power parts. This brings an advantage for applications where the control part is designed to be part of a user interface.

Figure 2-4. Power Circuit with Direct MCU Control

NOTE: *Compared with the control circuit with feedback signals, the circuit with direct MCU control does not require as large a filtering capacitor at the a.c. line input. The size of the capacitor should be between 0.47 – 1 µF.*

NOTE: *To protect the circuit from overcurrent during commutation of the load current, a current limiting inductor with an antiparallel diode can be added to the drain terminal of power transistor Q2.*

Section 3. Software Design

The application control is implemented on the MC68HC908QT4 microcontroller. It is a member of the small and low-cost Nitron family.

To minimize external components, the MCU uses an internal oscillator. The generated internal clock frequency is 12.8 MHz, resulting in a bus speed (internal clock ÷ 4) of 3.2 MHz. Untrimmed internal clock tolerance is less than ±25%. The application uses an OSCTRIM register to adjust the clock tolerance to less than ±5%. For more details on oscillator trimming, refer to the MC68HC908QT4 datasheet.

The MCU pin functional assignment is as follows:

- PTA0 – PWM signal generation

- PTA1 – Green LED control, Bootloader TxD pin

- PTA2 – Bootloader RxD pin

- PTA3 – Start/Stop switch

- PTA4 – Speed command from potentiometer P1
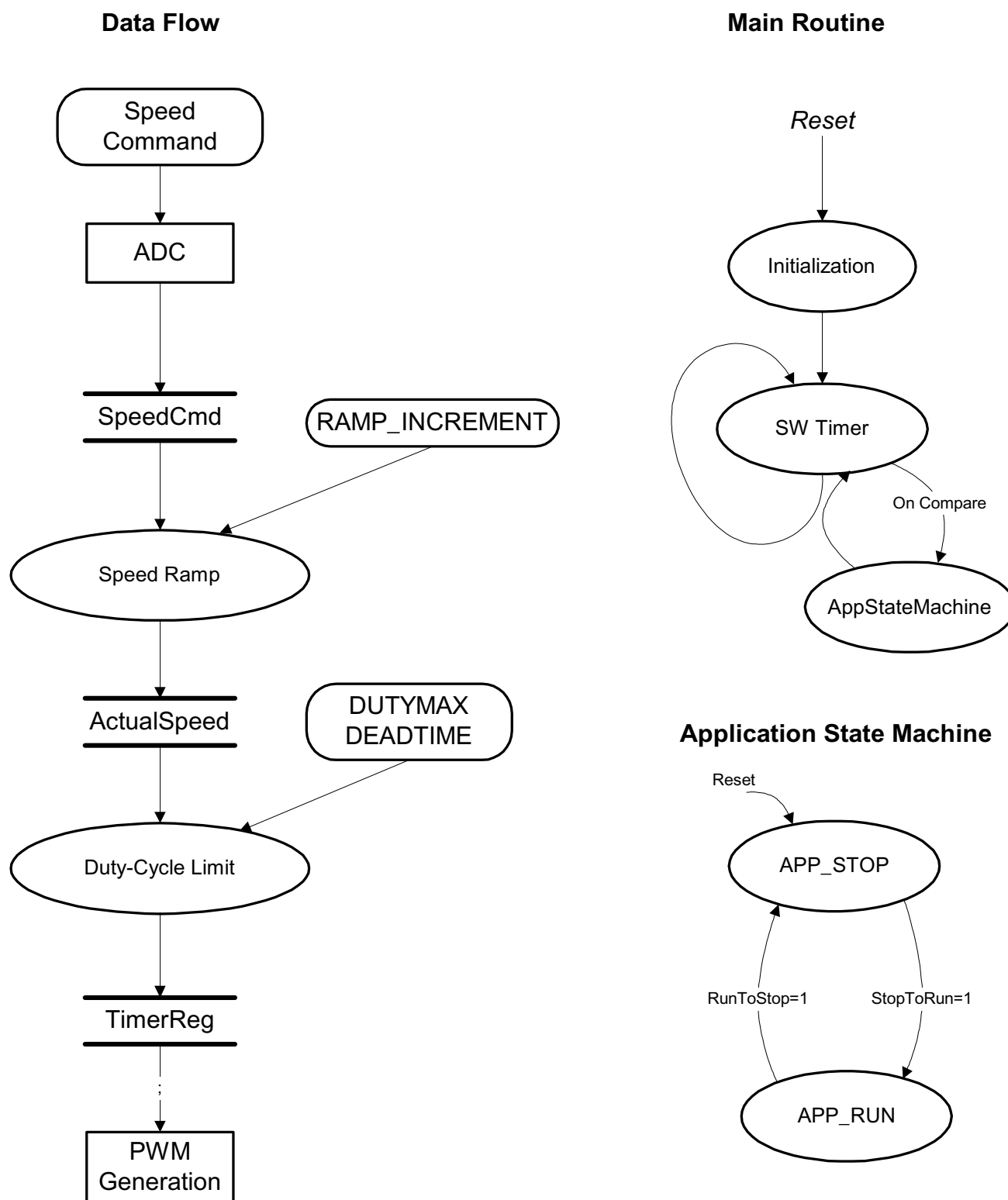
The software dataflow diagram is shown in Figure 3-1.

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Data Flow

Main Routine

Speed
Command

Reset

ADC

Initialization

SpeedCmd

RAMP_INCREMENT

SW Timer

Speed Ramp

On Compare

AppStateMachine

ActualSpeed

DUTYMAX
DEADTIME

Application State Machine

Duty-Cycle Limit

Reset

APP_STOP

TimerReg

RunToStop=1

StopToRun=1

PWM
Generation

APP_RUN

Figure 3-1. Software Flow Chart

3.1 Initialization

After reset, the MCU is initialized and the peripherals are configured. The MCU pins are configured according to assigned functions. The timer interface module is configured to generate buffered PWM. The prescaler register and timer modulo register are set to generate a fixed output PWM frequency at 16kHz.

The ADC is set to run in continuous conversion mode. It periodically scans the speed command set by an analog voltage value (in range 0 – 5V) connected to channel 2.

Finally, application variables are initialized and interrupts are enabled.

3.2 Main Routine

After initialization, the application enters an endless background loop, which is interrupted by interrupt service routines. In the background, a so called "software timer" is executed. The SWCounter is a time base variable of the software timer. It is incremented in the interrupt service routine called on timer module overflow. The period at which the software timer executes background tasks is defined by the EXEC_CONST constant. It is set to approximately 10 ms. On every compare of the software timer, the following actions are performed:

- ADC data register is read for actual speed command
- Application state machine is executed
- New PWM duty-cycle is set

The application state machine can be seen in Figure 3-1. The application enters two states APP_STOP and APP_RUN. The transition from one state to another is done according to bits in the AppControl control byte . After reset the application enters the APP_STOP state regardless of the Start/Stop switch position. To start the motor, toggle the switch first to Stop and then back to Start. This safety feature prevents the motor from starting when the application is reset.

The maximum rate of the PWM duty cycle change (increment/decrement) is determined by the ***speed ramp*** function. The rate of change is defined by RAMP_INCREMENT.

3.3 Interrupts

The timer overflow interrupt calls an interrupt service routine. In the ISR, the SWCounter variable is incremented to provide a time-base for the software counter.

3.4 PWM Generation

The required actual speed sets the duty cycle of the PWM. The PWM can use both positive and negative logic. The control circuit with feedback signals uses a negative logic. If the PWM output is set to logic 1, the power switch S1 is off; if set to logic 0, the power switch S1 is on. The freewheeling circuit with direct MCU control uses a positive logic (1= switch S1 is on, 0 = switch S1 is off). The output PWM logic is defined by a constant PWM_POLARITY in main.h.

If the motor is stopped, the power switch is fully closed. If the motor is running at full speed, the switch S1 is fully open. According to the output logic, the PWM duty-cycle is either 100% or 0%.

In the case of a 0% or 100% duty-cycle, the PWM pin is constantly held either at high or low level, e.g. in the case of a freewheeling control circuit with feedback signals: if the motor is stopped, the output pin is held at high level (logic 1), if the motor is running at full speed, the output pin is held at low level (logic 0). In the case of a freewheeling circuit with direct MCU control, the pin output is set vice versa.

Transition to and from fully-closed and fully-open modes is handled in the background loop.

The ***duty-cycle limit*** process limits the minimum and maximum duty-cycles generated by PWM. The minimum generated PWM duty cycle is set by the DEADTIME constant. The maximum duty-cycle is set by the DUTYMAXL and DUTYMAXH constants. The constant

DUTYMAXL sets the maximum limit for transition from fully-open to PWM modulation, and DUTYMAXH sets the limit for transition from PWM modulation to fully-open.

The timer module is configured to run in buffered PWM mode. The timer module channel registers (0 or 1) are written alternately.

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Section 4. Conclusion

New EMC standards bring strict limits for higher harmonic pollution. A conduction angle control technique, which was popular for a long time in industrial and home appliances, does not comply with these new standards. The manufacturers will have to look for new solutions to replace triacs in the near future, and keep the manufacturing costs at a reasonable level.

The presented circuits are aimed to be such a solution. The same as in triac control, it is able to supply a single-phase a.c. induction motor of all kinds (or general a.c. inductive/resistive load) with varying a.c. voltage. The voltage applied to the load can be varied from zero to maximum value. The cost of the drive based on this new technique is kept low. Therefore, it is suitable mainly for low-cost designs, where triacs and conduction angle control were used in the past.

The proposed circuits overcome drawbacks of conduction angle control – harmonic pollution, low efficiency, and acoustic noise caused by non-sinusoidal motor current. The PWM modulation considerably reduces the harmonic content of the line current. Only high harmonics, which correspond to the switching frequency at 16kHz, are present and can be filtered using a simple EMC filter at the input. Current of the load remains sinusoidal throughout the range of the output voltage.

The main advantages of the proposed solution:

- **Line current harmonic content reduction** – the harmonic content of line current is significantly reduced, mainly compared with the most common triac conduction angle control. PWM modulation is used, and the higher harmonic content that is injected to a.c. line is low.

- **Low cost** – the circuit offers a significant reduction in the system cost compared with other commonly used techniques based on PWM modulation. The proposed solution takes advantage of high-end converter topology while keeping the overall cost at a reasonable level.

- **Sinusoidal load current** – in the proposed circuit, the load current is not disturbed by a high level of higher harmonics. The higher harmonic injection to the load current waveform causes problems mainly when supplying electric motors. Non-disturbed motor current benefits are a smooth motor torque, low acoustic noise produced by the motor and a higher efficiency of the whole system.

- **No limitation of cos** φ – the circuit is not limited by the cos φ of supplied loads. The feedback signals that control the load current freewheeling are designed to work under all conditions on the a.c. load. The proper signal is generated for all combinations of the a.c. load voltage and current polarities. The proposed circuit is capable of driving all types of common a.c. loads (inductive or resistive).

- **Minimal number of power components** – the proposed circuit requires a low number of power components.

- **Minimal cost of the components** – the power components represent the most expensive part of the system. A lower number of power components reduces not only the cost of the components, but because of the lower requirements for cooling, it also reduces the cost of the heat sink, thus also increasing the efficiency of the system. The printed circuit board size requirements are also lower, again reducing the cost.

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Section 5. Appendix A

The list of measured waveforms:

- Figure 5-1 shows the load voltage and current waveforms

- Figure 5-2 shows feedback signals (flip-flop inputs IN1, IN2) when S1 turns-off

- Figure 5-3 shows harmonic content in load current when using PWM control

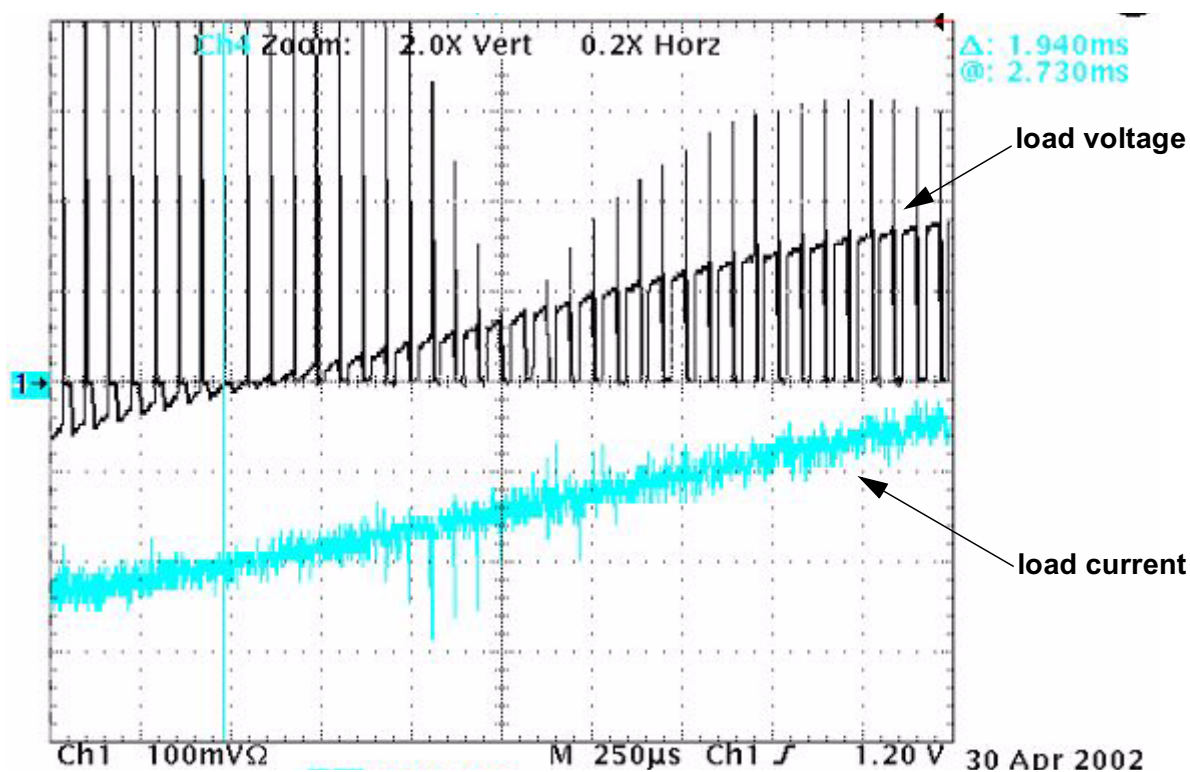- Figure 5-4 shows harmonic content in load current when using triac phase-angle control
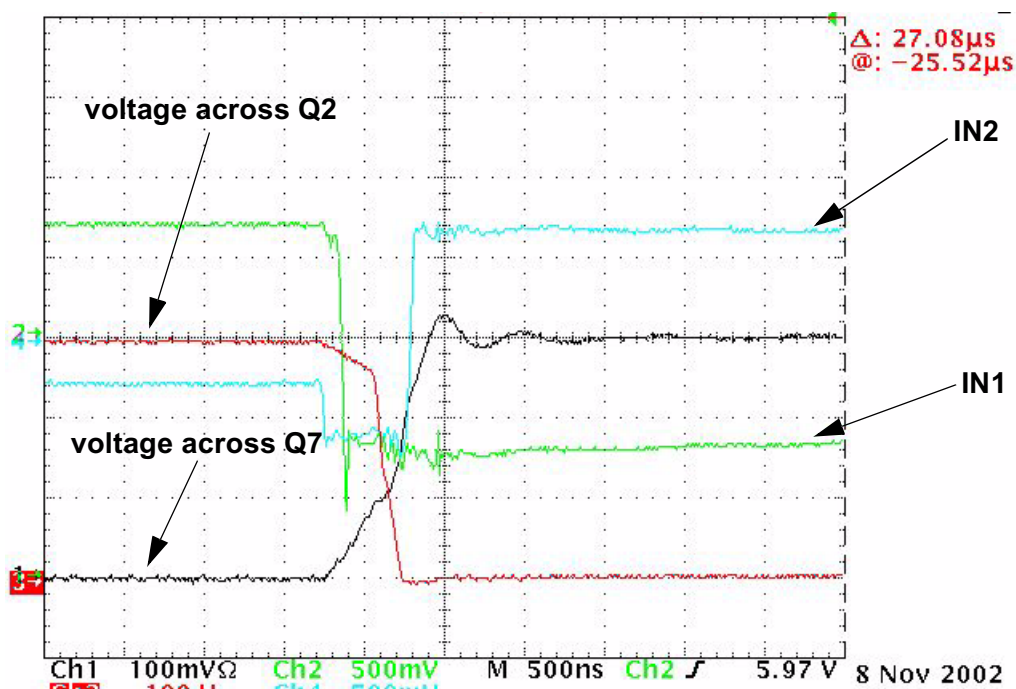

Figure 5-1Load voltage and current waveforms

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Figure 5-2Feedback signals (IN1, IN2) when S1 turns off
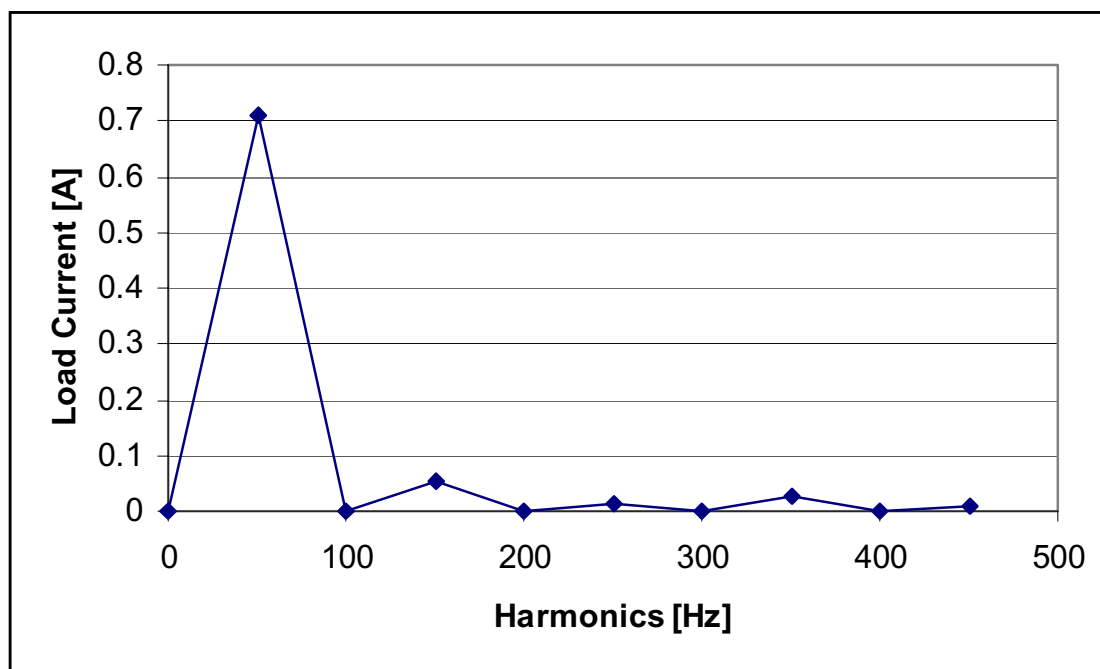
Figure 5-3PWM control – load current harmonic content
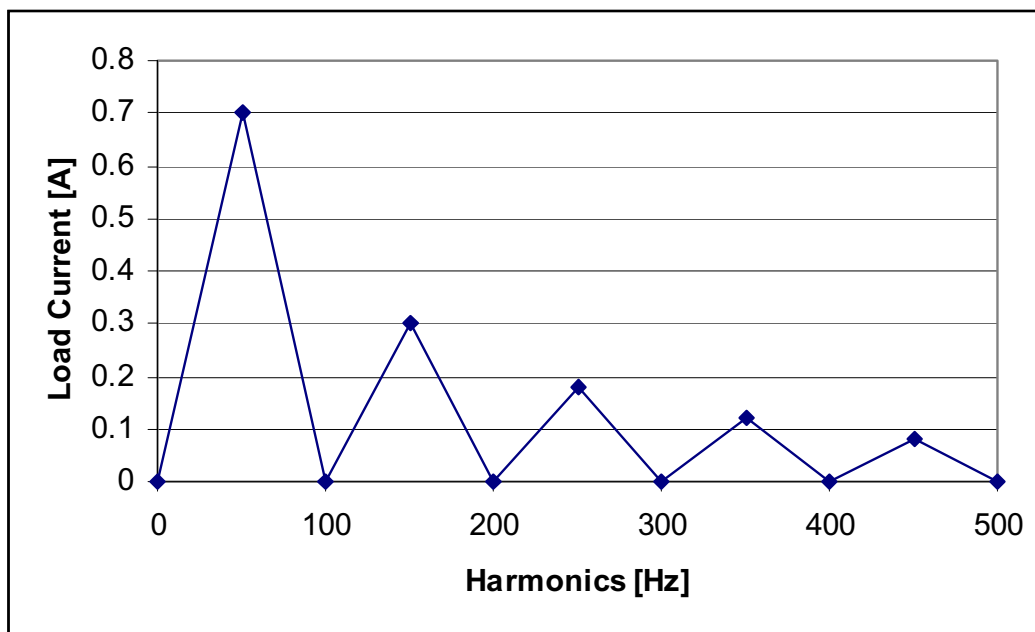
Figure 5-4Phase-angle control – load current harmonic content

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Appendix A. Glossary

AC — Alternating current

analogue-to-digital converter (ADC) — The ADC module is an 10-channel, multiplexed-input successive-approximation analog-to-digital converter

brush — A component transferring electrical power from non-rotational terminals, mounted on the stator, to the rotor

byte — A set of eight bits

central processor unit (CPU) — The primary functioning unit of any computer system. The CPU controls the execution of instructions

clear — To change a bit from logic 1 to logic 0; the opposite of set

commutation — Passing from one conduction state to another

commutator — A mechanical device alternating DC current in DC commutator motor and providing rotation of DC commutator motor

comparator — A device that compares the magnitude of two inputs. A digital comparator defines the equality or relative differences between two binary numbers

computer operating properly module (COP) — A counter module that resets the MCU if allowed to overflow

converter — An electrical device that converts alternating current into direct current or vice versa

COP — Computer Operating Properly timer

DC — Direct Current

DT — See "Dead Time (DT)"

Dead Time (DT) — Short time that must be inserted between the turning off of one transistor in the inverter half bridge and turning on of the complementary transistor due to the limited switching speed of the transistors

duty cycle — A ratio of the amount of time the signal is on versus the time it is off. Duty cycle is usually represented by a percentage

EMI/EMC — Electromagnetic Interference/Electromagnetic Compatibility

feedback — The return of part of the output of a circuit to the input in a way that affects its performance

GPIO — General Purpose Input/Output

harmonic distortion— the presence of unwanted frequencies at the output of an electronic device

IGBT — Insulated Gate Bipolar Transistor

interrupt — A temporary break in the sequential execution of a program to respond to signals from peripheral devices by executing a subroutine

interrupt request — A signal from a peripheral to the CPU intended to cause the CPU to execute a subroutine

input/output (I/O) — Input/output interfaces between a computer system and the external world. A CPU reads an input to sense the level of an external signal and writes to an output to change the level on an external signal

induction motor — A type of alternating-current motor comprising two wound members, one stationary, called the stator, and the other rotating, called the rotor

inverter — A device used to convert direct current into alternating current

LED — Light Emitting Diode

logic 1 — A voltage level approximately equal to the input power voltage (V_{DD})

logic 0 — A voltage level approximately equal to the ground voltage (V_{SS})

MCU — Microcontroller unit. See "microcontroller"

memory map — A pictorial representation of all memory locations in a computer system

microcontroller — Microcontroller unit (MCU). A complete computer system, including a CPU, memory, a clock oscillator, and input/output (I/O) on a single integrated circuit

modulo counter — A counter that can be programmed to count to any number from zero to its maximum possible modulus

MOSFET — Metal-Oxide Semiconductor Field-Effect Transistor

PI controller — Proportional-Integral controller

peripheral — A circuit not under direct CPU control

phase-locked loop (PLL) — A clock generator circuit in which a voltage controlled oscillator produces an oscillation which is synchronized to a reference signal

port — A set of wires for communicating with off-chip devices

program — A set of computer instructions that cause a computer to perform a desired operation or operations

PWM — Pulse Width Modulation

PWM period — The time required for one complete cycle of a PWM waveform

read — To copy the contents of a memory location to the accumulator

rectifier — A device, such as a diode, that converts alternating current to direct current

register — A circuit that stores a group of bits

reset — To force a device to a known condition

RPM — Revolutions per minute

SCI — See "serial communication interface module (SCI)"

serial communications interface module (SCI) — A module that supports asynchronous communication

serial peripheral interface module (SPI) — A module that supports synchronous communication

set — To change a bit from logic 0 to logic 1; opposite of clear

single-phase — Generating, or powered by a single alternating voltage

software — Instructions and data that control the operation of a microcontroller

software interrupt (SWI) — An instruction that causes an interrupt and its associated vector fetch

SPI — See "serial peripheral interface module (SPI)"

stack — A portion of RAM reserved for storage of CPU register contents and subroutine return addresses

subroutine — A sequence of instructions to be used more than once in the course of a program. The last instruction in a subroutine is a return from subroutine (RTS) instruction. At each place in the main program where the subroutine instructions are needed, a jump or branch to subroutine (JSR or BSR) instruction is used to call the subroutine. The CPU leaves the flow of the main program to execute the instructions in the subroutine. When the RTS instruction is executed, the CPU returns to the main program where it left off

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timer — A module used to relate events in a system to a point in time

triac — The triac is a three terminal semiconductor device for controlling current in either direction. It controls and conducts current flow during both alternations of an ac cycle

variable — A value that changes during the course of program execution

waveform — A graphical representation in which the amplitude of a wave is plotted against time

word — A set of two bytes (16 bits)

write — The transfer of a byte of data from the CPU to a memory location

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