THIS SPEC IS OBSOLETE

Spec No: 001-43679

Spec Title: PSOC(R) 1 INDUSTRIAL STEPPER MOTOR CONTROLLER - AN43679

Sunset Owner: Wanchun (Ronny) Liu (RLIU)

Replaced by: None

AN43679

PSoC® 1 Industrial Stepper Motor Controller

Author: Dino Gu, Bill Jiang, Jemmey Huang
Associated Project: Yes
Associated Part Family: CY8C27x43, CY8C29x66
Software Version: PSoC® Designer™ 5.1
Related Application Notes: AN2229, AN41949

AN43679 demonstrates the PSoC® 1 implementation of a microstepping industrial stepper motor controller. Microstepping control and limiting the current are explained in detail.

Contents

Introduction

The stepper motor is a brushless electromechanical device, which converts electric pulses into discrete mechanical movements. The rotation of the stepper motor is typically divided into 200 steps, called “full steps.” A full step occurs when full current is switched from one winding to the next. Higher precision of the position is achieved by using microstepping. In microstepping, the rotor’s angle between two full steps is proportional to the relative current present in two adjacent windings. Stepper motors are widely used in low-cost and open-loop position-control applications, such as ink jet printers, CNC machines, and volumetric pumps.

The stepper motor has the following features:

1. **Open-Loop Positioning**. Precise positioning and repetition without speed and position sensors. The rotor’s tuning angle is defined by the number of pulses delivered to the motor.
2. **High Holding Torque**. Holds the shaft stationary and provides full torque when stopped.
3. **High Reliability**. Because the stepper motor is brushless, the life span of a stepper motor depends on the bearings.
4. **Excellent Response**. Quick start, stop, and reverse capability.

Types of Stepper Motors

There are three basic types of stepper motors based on construction of rotor and the stator:

Permanent Magnet Motor

In this motor, the stator is made up of an electromagnet and the rotor is made up of a permanent magnet. The application of an alternating signal to the stator results in the rotation of the rotor. The number of pole pairs on the rotor and the stator determine the step angle. The higher the number of pole pairs, smaller the step angle. This motor exhibits residual torque, which holds the rotor even if the power to the stator is removed because the rotor has a permanent magnet.

Variable Reluctance Motor

In this type of motor, the stator is an electromagnet like permanent magnet motor, but the rotor is made of a ferromagnetic material. “Teeth” is formed on the stator and the rotor. When the stator is energized, poles are created on the stator and the rotor teeth align with it. When the stator is energized with a multi-phase alternating signal, a rotating magnetic field is created, causing the rotor to rotate synchronous with the rotating field. Unlike permanent magnet motors, this motor doesn’t have residual torque.

Hybrid Motor

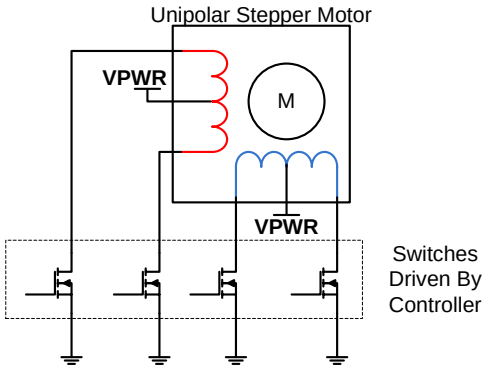
This is the most commonly used stepper motor. It combines the best features of the variable reluctance motor and the permanent magnetic motor. It has a multi-toothed rotor similar to the variable reluctance motor, but made of a permanent magnet. The stator is an electromagnet. This motor provides finer step angle, higher speed, and more torque than permanent magnet motors and variable reluctance motors.

Stator Coil Windings in a 2– Phase Stepper Motor

In a 2-phase motor, there are two types of stator winding arrangements – unipolar and bipolar.

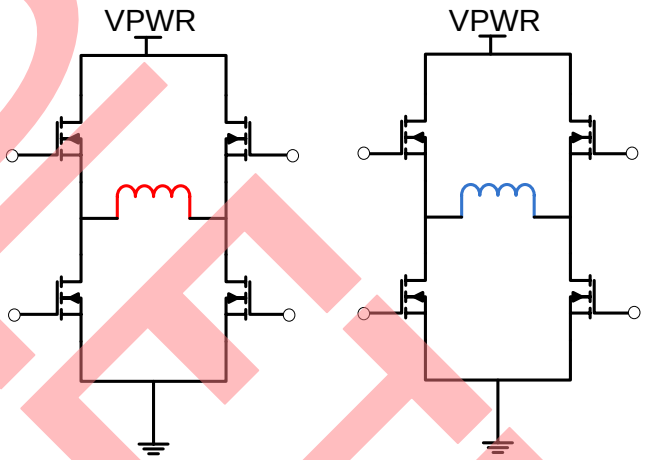
In a unipolar stepper motor, there is one stator winding with a center tap per phase. This means that a unipolar motor has a total of 6 terminals for a 2-phase motor. The drive circuitry for this motor is simple with only four switches required as Figure 1 shows. The center tap is usually tied to the power supply source and the ends of the both phase coils are tied to ground through switches. The current direction in the coil is controlled by turning appropriate switches ON/OFF. Note that at a time only one-half of a coil is utilized. If both switches of a phase coil are turned ON, then the resultant magnetic field becomes zero.

Figure 1. Unipolar Stepper Motor



In a Bipolar stepper motor, there is one winding per phase. The drive circuitry is complex as compared to that of unipolar motor. It requires an H-Bridge circuit for each stator phase coil as Figure 2 shows. The current direction in the coil is controlled by turning the switches in the H-Bridge ON or OFF. Unlike the unipolar motor, the bipolar motor uses the entire length of the phase coil.

Figure 2. Bipolar Stepper Motor



This application note explains in detail about microstepping control using a current chopper PSoC implementation of a bipolar hybrid stepper motor. The methods described in this application note are also applicable for permanent magnet stepper motors.

Stepper Motor Control Method

The operational modes of the stepper motor include full step mode, half step mode, and microstep mode. The full step mode has two driving modes: *one phase on* and *two phases on*. Each operational mode controls the motor with a different method. The full step mode and a half step mode results in jerky movements of the motor, especially at lower speeds. On the other hand, microstepping control achieves increased step resolution and smoother torque between steps. In addition, microstepping control has less noise and resonance problems. Microstepping control works on the

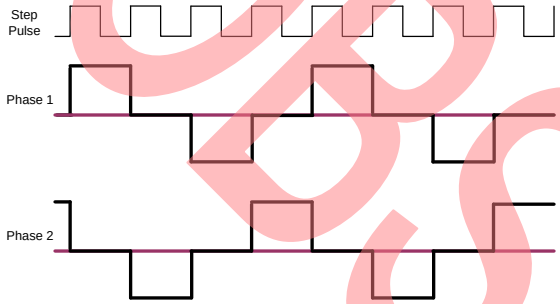
principle of gradually transferring current from one phase to another.

The following sections describe the one phase on full step mode, half step mode, and microstep control.

Full Step (One Phase On)

The current waveform of the one phase on full step is shown in Figure 3. During each step, only one winding is powered. In the next step, the current moves to the other winding. In this mode, the torque varies sinusoidally because the magnetic flux jumps from one winding to the next. Torque variations can cause problems to the mechanical stability of the system.

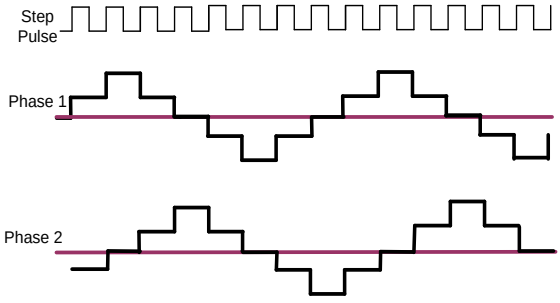
Figure 3. Full Step Current Waveform



Half Step (One and Two Phase On)

The half step mode is also called the “one and two phase on” mode. In this mode, the motor’s step size is one half of a full step mode. One phase is turned on during even steps and two phases are turned on during odd steps. The half step mode provides more consistent torque than full step mode. The current waveform of the half step mode is shown in Figure 4.

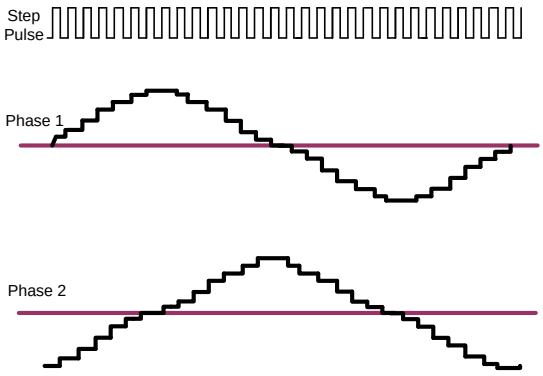
Figure 4. Half Step Current Waveform



Microstep

Microstepping extends the smoothing effect of half stepping. The waveform of eight microsteps is shown in Figure 5. By adding several current levels, the motor current is smoothly transferred from one phase to the other phase, as shown in the following figure. With a sufficient number of current levels, the phase current of the motor changes in a sinusoidal fashion. Thus, the torque of the motor keeps a nearly-constant value with minimal torque fluctuation. Microstepping also provides increased angular resolution beyond the standard 200 steps.

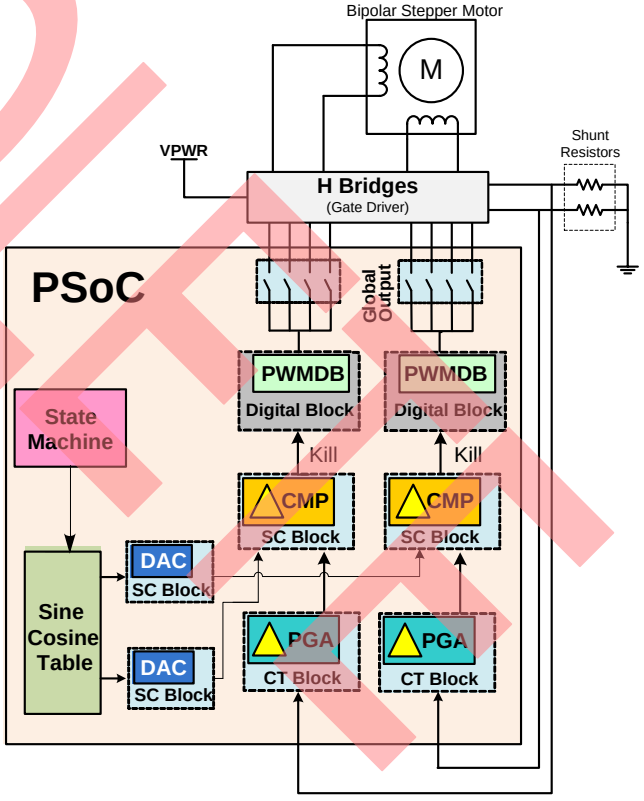
Figure 5. Eight Microstep Current Waveform



PSoC-Based Implementation

The control diagram of the PSoC-based stepper motor driver is shown in Figure 6.

Figure 6. Control Diagram



This solution has lower system costs compared to many existing products because of PSoC’s internal flexible digital and analog user modules. As seen in Figure 6, the PSoC-based stepper motor driver includes four main parts: step state machine, sin and cosine voltage generator, kill-signal generator, and PWM driving signals.

When booting up, the code detects the test board configuration such as the rotation direction, current level, and step pace. The system provides four current options and six step paces. The system then waits for the incoming step pulses from an external pulse generator. If no pulse comes within a predefined time, the system reduces the current to half of the normal step current to reduce motor heating and save energy. When halted, a stepper motor at half the current typically has the same holding torque as the motor running at full current.

A built-in sine table is stored in PSoC's internal flash. A Digital-to-Analog Converter (DAC) is used to set the winding current in the microstep mode. Precise positions are achieved in microstep mode. The voltage output of the DAC is the winding current reference and is fed into a comparator input. The other input into the comparator is the sampled winding current. The winding current is sampled by a shunt resistor, which is placed between the system ground and the winding as shown in Figure 6. The voltage on the shunt resistor is proportional to the current flowing through the windings.

The comparator output is HIGH if the sampled winding current is higher than the DAC output reference current; otherwise the comparator output is LOW. The comparator output is routed into the PWM Dead Band generator (PWMDB) kill input. An active HIGH kill signal pulls the PWMDB outputs LOW, thereby reducing the current through the motor winding. PWMDB outputs are routed to the output pins through the Global Output Bus. The Dead Band generator is only used for its kill feature and is not used for dead band generation in this application.

The Dead Band outputs drive the HIGH side FETs of the H-Bridge. Digital Buffer User Modules are used to invert the outputs of the dead band generators to drive the LOW side FETs of the H-Bridge.

The PSoC device internals are shown in the Appendix. The following user modules are used in the application:

1. Two 16-bit PWMDBs
2. Two SC blocks for two DACs
3. Two SC blocks for two comparators
4. Two PGA for on-chip adjustable current level
5. One 8-bit timer block for half-current mode detection
6. Two DigBufs for internal PWMDB output signal routing

Stepper Motor Driver

The test driver board with motor is shown in Appendix 1. It is an industrial controller with configurable current, rotation direction, and number of microsteps. It also has an input interface for step pulses. The test board used for this application note is not a kit and is unavailable for purchase. Gerber files are provided with the application note which you can use for board fabrication.

The stepper motor driver has the following features:

- Bipolar stepper motor
- PWM current regulator
- Pulse command receiver interface
- Individual power switches
- Two H-Bridge circuits
- Automatic half-current when halted
- Configurable microstep number
- Selectable dynamic motor phase current
- Ability to rotate clockwise or counterclockwise

You can use the eight switches (SW1 to SW8) to select the rotate direction, current level, and the number of microsteps.

Table 1 lists the current configuration. The current selection depends on the load.

Table 1. Dynamic Current Configuration

SW7	SW8	Peak Current
On	On	0.6 A
Off	On	1.0 A
On	Off	1.6 A
Off	Off	3.0 A

Table 2 lists the selection of the number of microsteps.

Table 2. Microstep Configuration

SW1	SW2	SW3	Microstep	Step/Revolution
On	On	Off	Full step	200
On	Off	On	Half step	400
Off	Off	On	4	800
Off	On	Off	8	1600
On	Off	Off	16	3200
Off	Off	Off	32	6400

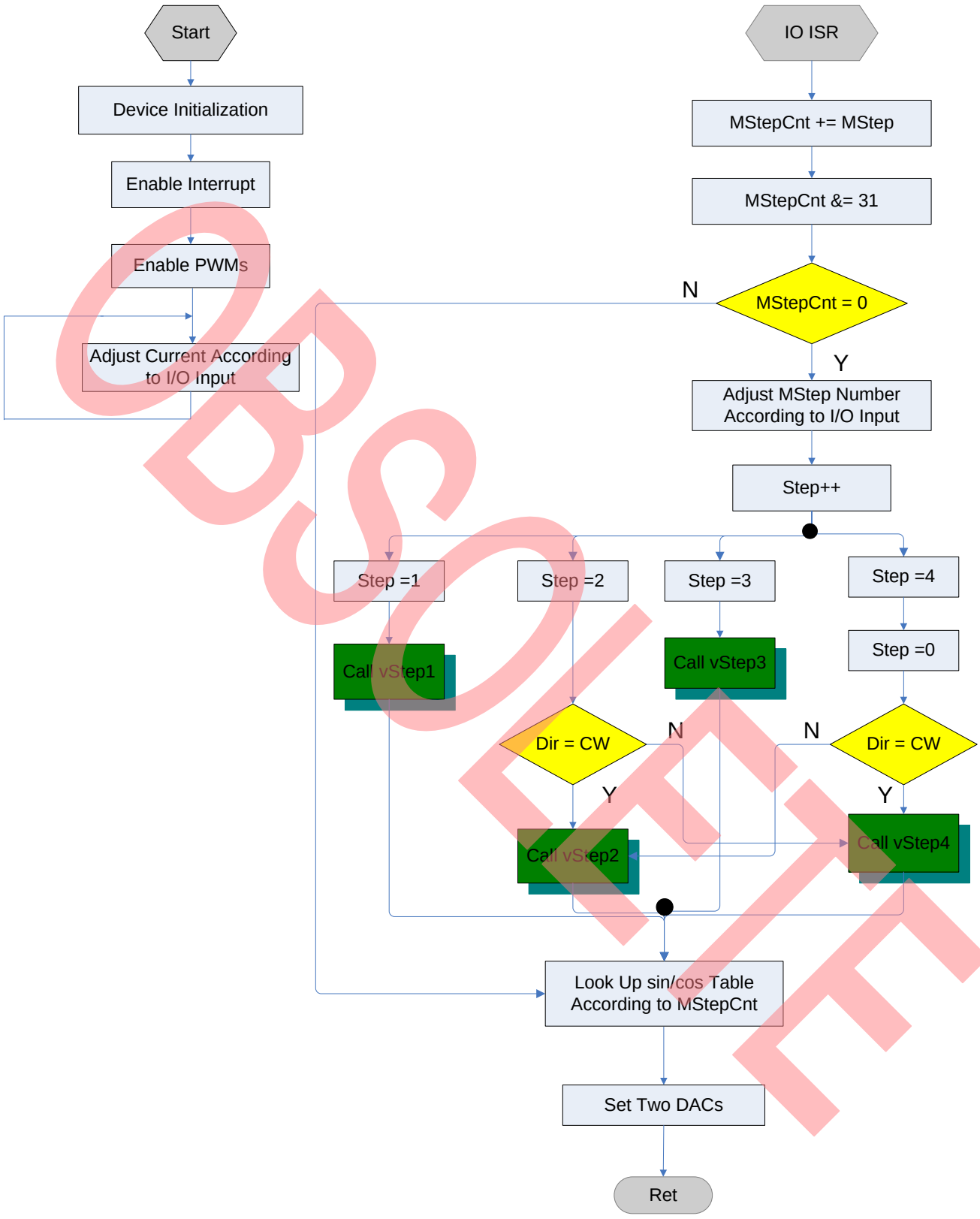
Keeping SW4 on selects clockwise rotation; off selects counterclockwise. SW5 and SW6 are not used.

The step command input (+5 V pulse) is fed into the stepper motor driver. The higher the frequency of the pulse command, the faster the motor spins. Thus, both speed and position of the stepper motor can be precisely adjusted by an external controller.

The J2 header allows isolated signals to be used for input as typically found in industrial environments. J2 is not used in this application note.

The Software

Figure 7. Firmware Flowchart



In the main loop, PSoC monitors the dynamic current settings and inputs, and adjusts the drive current accordingly.

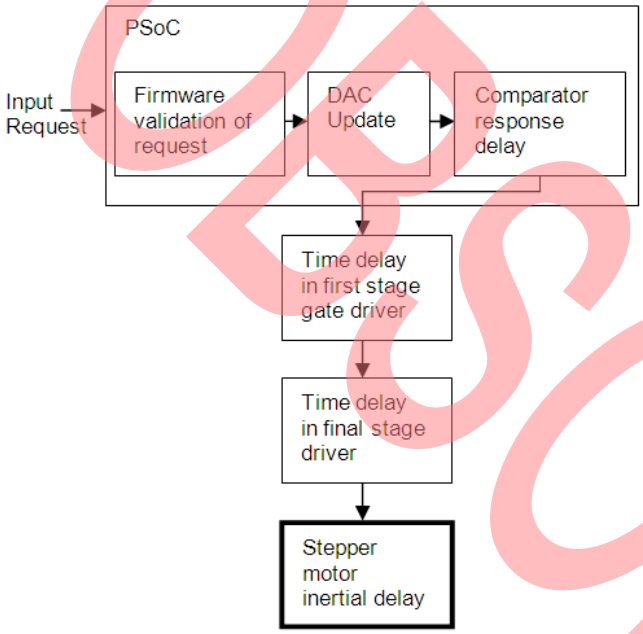
When an external pulse command comes in, an I/O interrupt is triggered. As a result, *MstepCnt*, which is the count of microstep numbers, increases by *MStep*. The

lookup sin/cos table function uses *MStepCnt* as a pointer to generate the sin or cosine current reference value.

When *MStepCnt* loops to zero, the software enters the step switching code. In this code, the patterns of the power switches are rearranged according to the internal state machine. The direction of the stepper motor can be changed by inverting the step loop sequence.

Response Time of the System

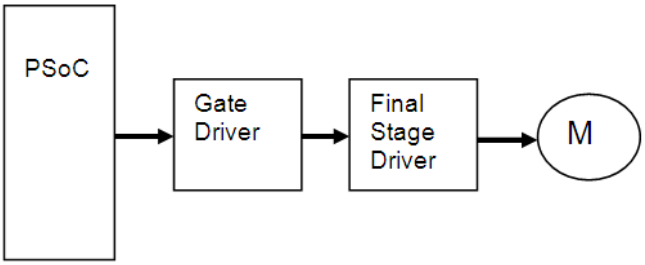
There are multiple levels where delay is introduced in the control signal flow and actuation.



The block diagram shows the typical path the system takes from request to actually positioning (moving) the stepper motor. The delays associated with the firmware to the motor driver is typically very small and can be ignored; however, the delay associated with the stepper motor is significant and should be considered while designing the open-loop drive system. The response time of the motor is composed of two factors: one is the electrical time constant and other is the mechanical time constant (inertial component). These two components are proportional to the size of the motor; normally these two parameters are provided in the manufacturers datasheet. The motor drive control loop should be designed after considering these response delays.

External Component Selection Guidelines

When controlling from a microcontroller, the stepper motor driver involves a 2-stage drive system. PSoC provides a PWM signal to the MOSFET Gate driver, which then drives the final stage MOSFET driver. It is important to select the components in these stages properly, according to the stepper motor and operating specifications.



Gate Driver

This stage drives the MOSFETs controlling the stepper motor. The following points are important while selecting the Gate driver:

- Place small RC low-pass filter with the time constant equal or little higher than the tank frequency created due to parasitic and gate capacitances on the board at the output. This will eliminate the signal ringing around rise and fall edges and also controls the rise and fall times; this in turn reduces the radiated emission.
- Place bypass capacitors close to the Gate driver IC supply pins.
- Ensure that the logic levels for the PWM input of the Gate Driver match the PSoC logic output levels.

Final Stage Driver

This stage drives the stepper motor. In this stage, MOSFETs are arranged in an H-Bridge style to have control over the direction of the current through the coil.

The following MOSFET parameters should be reviewed during selection for your application:

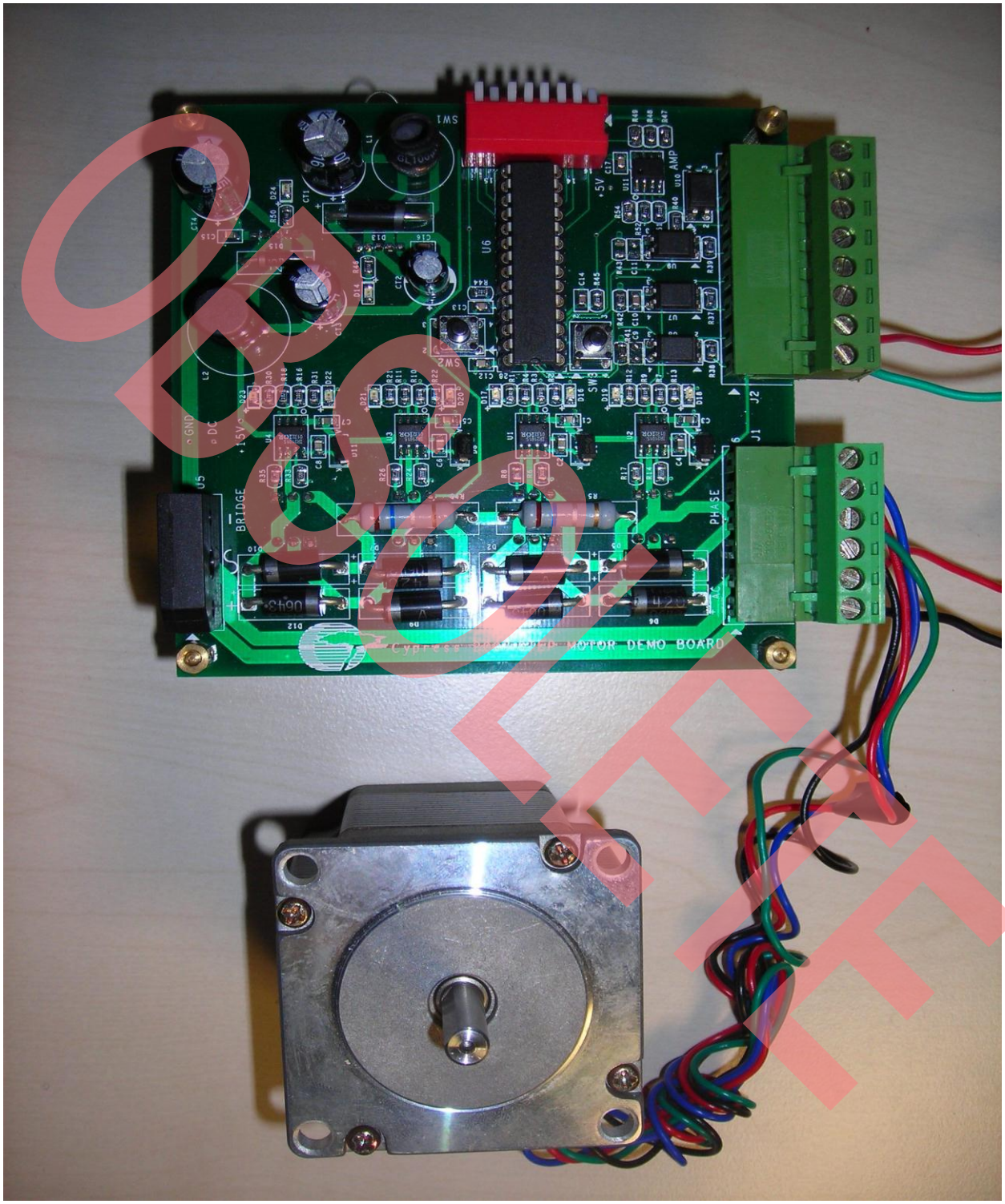
- Continuous current: This should be at least 1.5 times the average full-load motor current rating.
- Drain-to-Source voltage of MOSFETs: This voltage rating should be at least twice the supply voltage.
- Rds_{ON}- channel ON state resistance: This should be low at high-load conditions to avoid high power consumption and to reduce the size of the heat sink required.
- Use low-ESR bulk capacitors across the MOSFET bridge for high-load conditions.

Summary

This application note describes a stepper motor controller based on PSoC. With the assistance of a PSoC device, the stepper motor driver implements microstepping control, and allows the user to easily configure parameters.

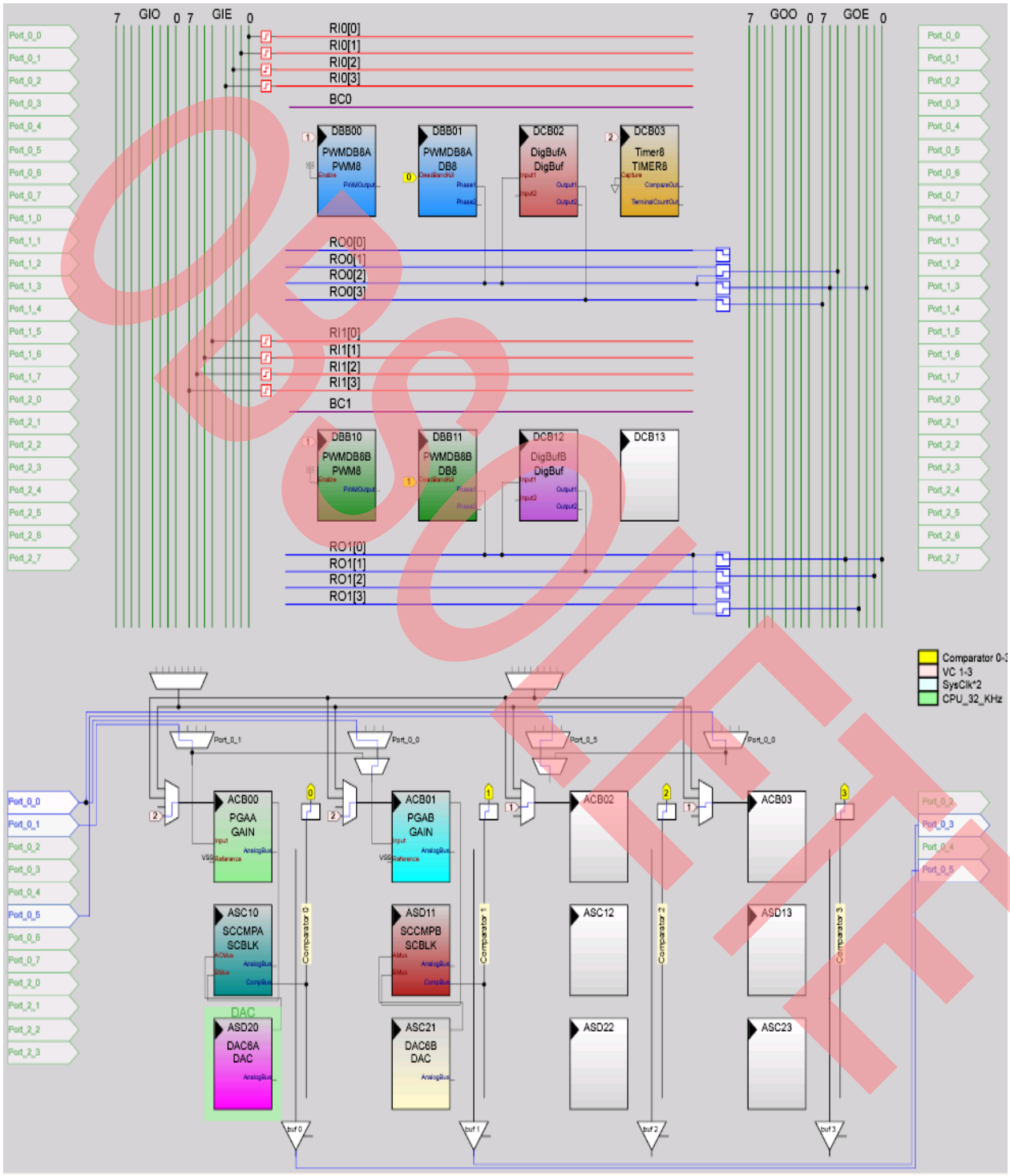
Appendix 1

Figure 8. Stepper Motor Test Driver Board



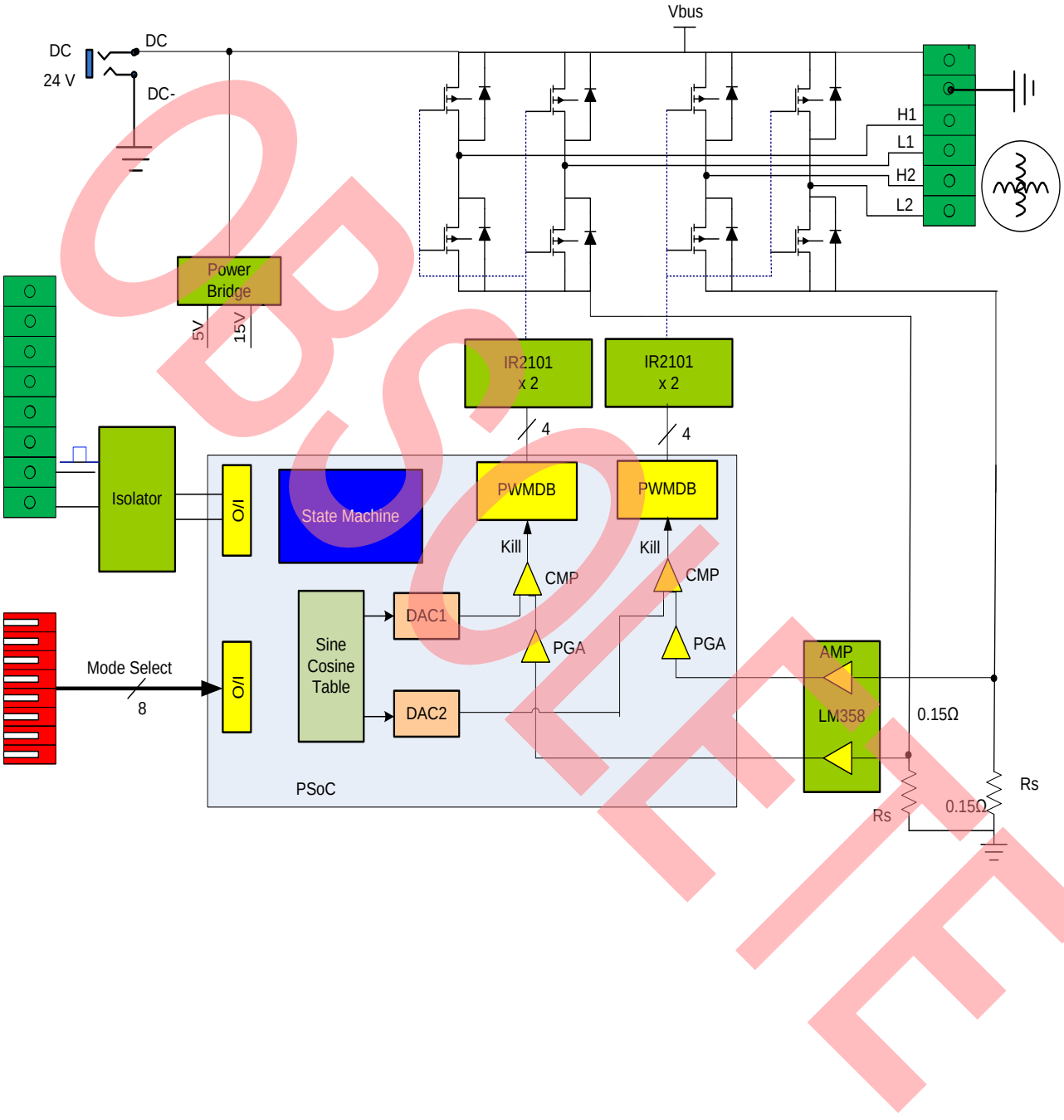
Appendix 2

Figure 9. User Module Placement in PSoC Designer



Appendix 3

Figure 10. Board Control Diagram



Appendix 4

Figure10. Schematic (Control Circuit)

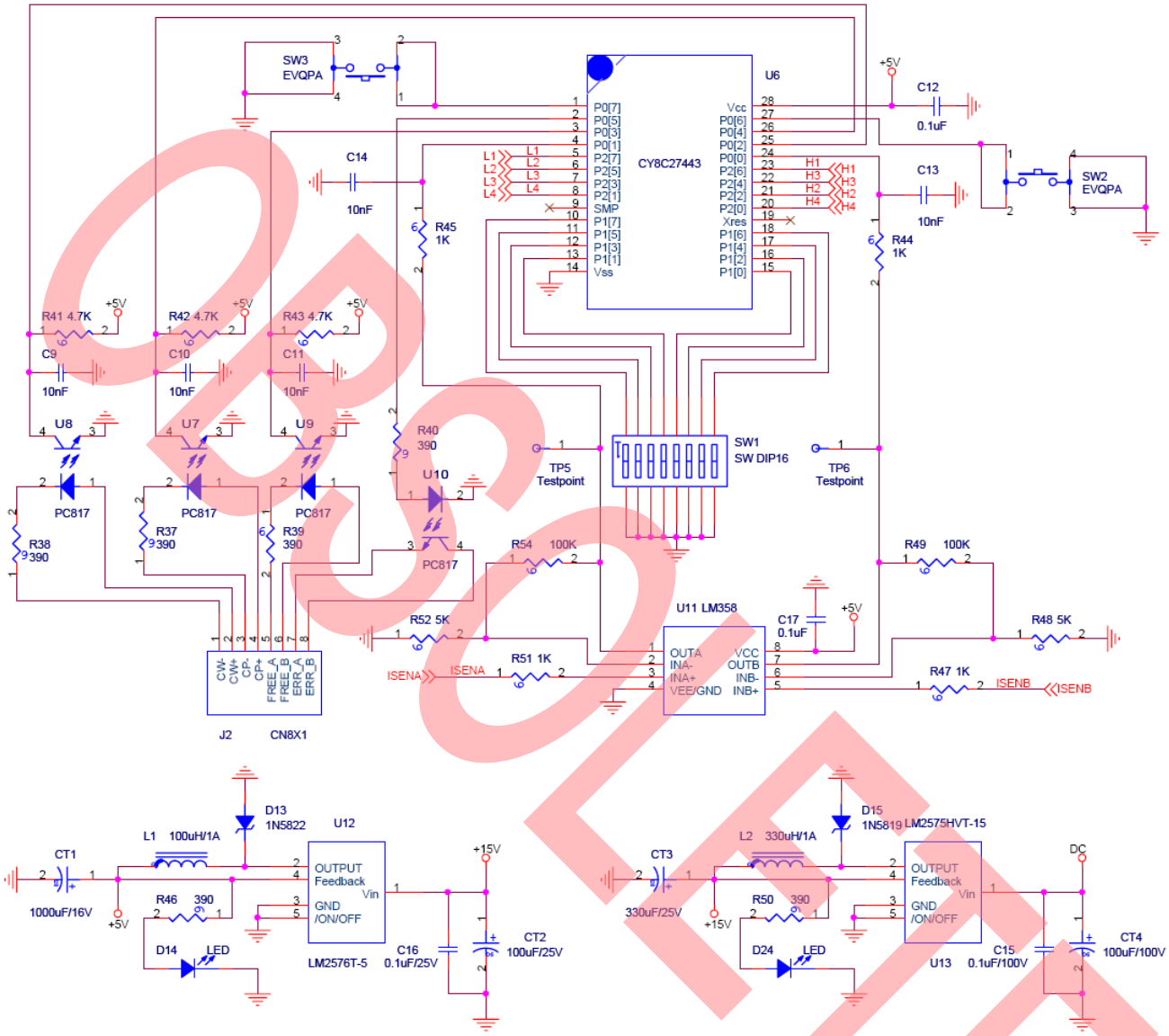
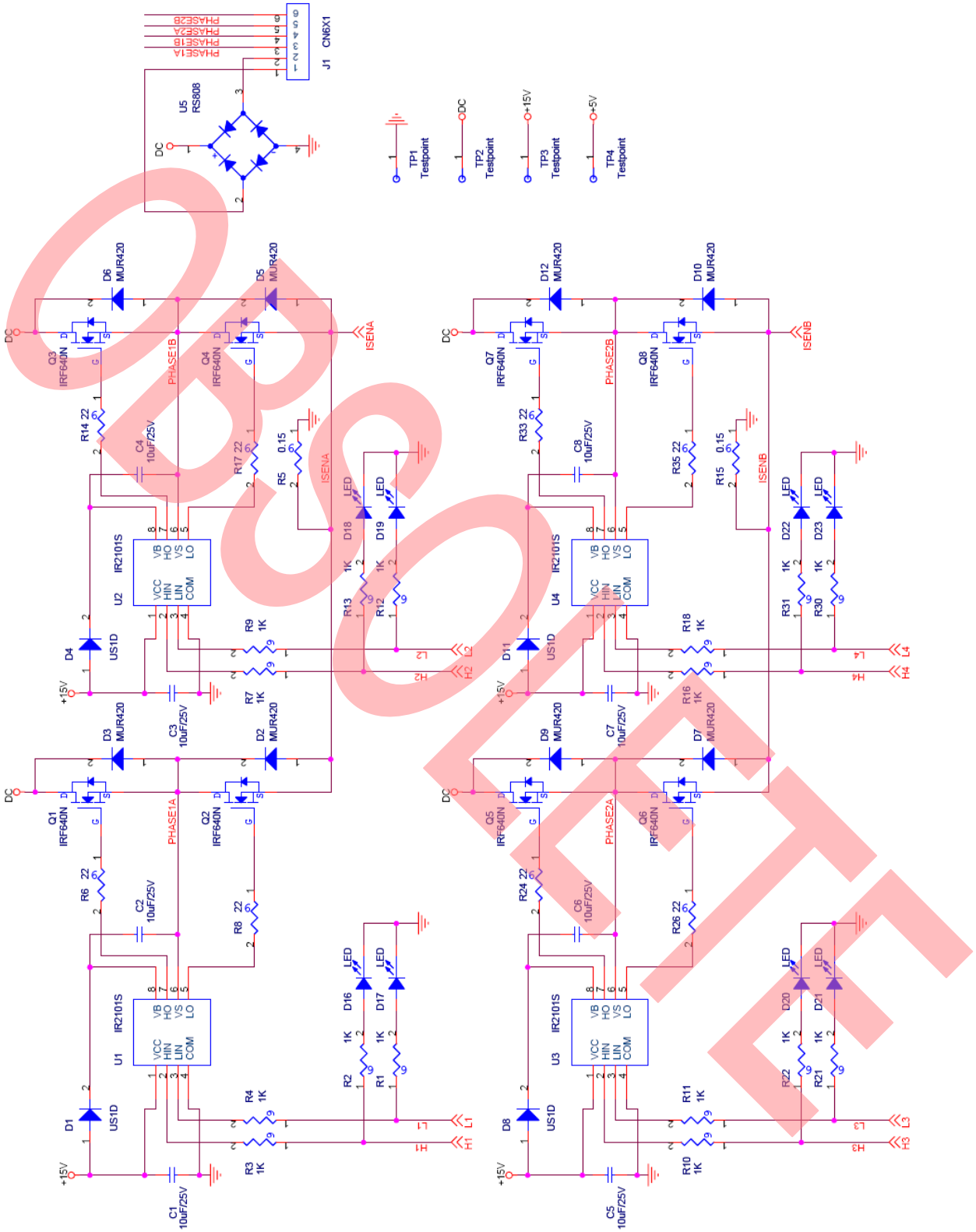


Figure 11. Schematic (Drive Circuit)



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Document History

Document Title: PSoC® 1 Industrial Stepper Motor Controller - AN43679
Document Number: 001-43679

Revision	ECN	Orig. of Change	Submission Date	Description of Change
**	1860806	GJV	12/19/2007	New Application Note. Associated Project zipped with source file.
*A	3118478	GJV	12/22/2010	Updated title to read “PSoC 1 Industrial Stepper Motor Controller”. Updated Stepper Motor Control Method. Updated PSoC-Based Implementation. Updated Stepper Motor Driver.
*B	3189578	RJVB	03/07/2011	Added sections – Response Time of the system and External component selection Replaced with better resolution schematics PCB Gerber Files provided
*C	4247785	RJVB	01/15/2014	Added details on types of motor, unipolar and bipolar. Updated PSoC 1 solution block diagram
*D	4821786	RLIU	07/03/2015	Obsolete as per SHAS#128.

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