Application Report
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MSP430 Stepper Motor Controller

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ABSTRACT

This application report shows how to implement a controller for a stepper motor having bipolar windings using the MSP430F123 along with a pair of UC3717A Stepper Motor Drive ICs. Source code, schematic, bill of material, and board layout files are provided.

1 Stepper Motors

Stepper motors operate by sequentially energizing coils located in the stator. Depending upon the stepper motor’s type; variable reluctance, permanent magnet, or hybrid, the rotor contains a toothed soft-iron core, permanent magnets, or both. What sets a stepper motor apart from other motor types is the ability to step (or turn) its rotor in small, precise increments and lock it in place.

Three configurations are typically found for wiring a stepper motor’s windings; variable reluctance, unipolar, and bipolar. Each configuration requires different drive circuitry and its associated method of control. This application report focuses on controlling stepper motors with bipolar windings. Bipolar stepper motors are driven using an H-bridge circuit since current flow is bi-directional through the windings.

Based on its internal winding resistance, stepper motors are rated for maximum current at a particular voltage. Maximum torque is developed when maximum current is flowing through the windings. Operating at this voltage, however, is inefficient due to the ramp-up time it takes for current flow to overcome the winding's inherent inductance. Applying a voltage much higher than it's rated for to a stepper motor reduces this ramp-up time. To do this without overheating and destroying the motor, however, the winding current must still be limited to its maximum rated value. This is done by using a *chopper circuit* which controls the ratio of winding current *on* time to *off* time once the maximum current level is reached.

2 Implementation

2.1 Hardware

Figure 1 shows a block diagram of the MSP430 Stepper Motor Controller board. Although any MSP430 variant could have been used to implement a basic stepper motor controller using Timer A, the MSP430F123 was chosen since it contains a hardware UART for serial communications with a PC. Two UC3717A integrated circuits (ICs) provide the motor drive circuitry. Each UC3717A IC contains one H-bridge circuit for driving a single winding in a bipolar stepper motor. The UC3717A also contains a *chopper circuit* limiting the maximum current flowing through a motor's winding. To reduce external component count, the protection diodes required to clamp the inductive voltage spikes generated when switching current through a motor are also contained within the UC3717A.

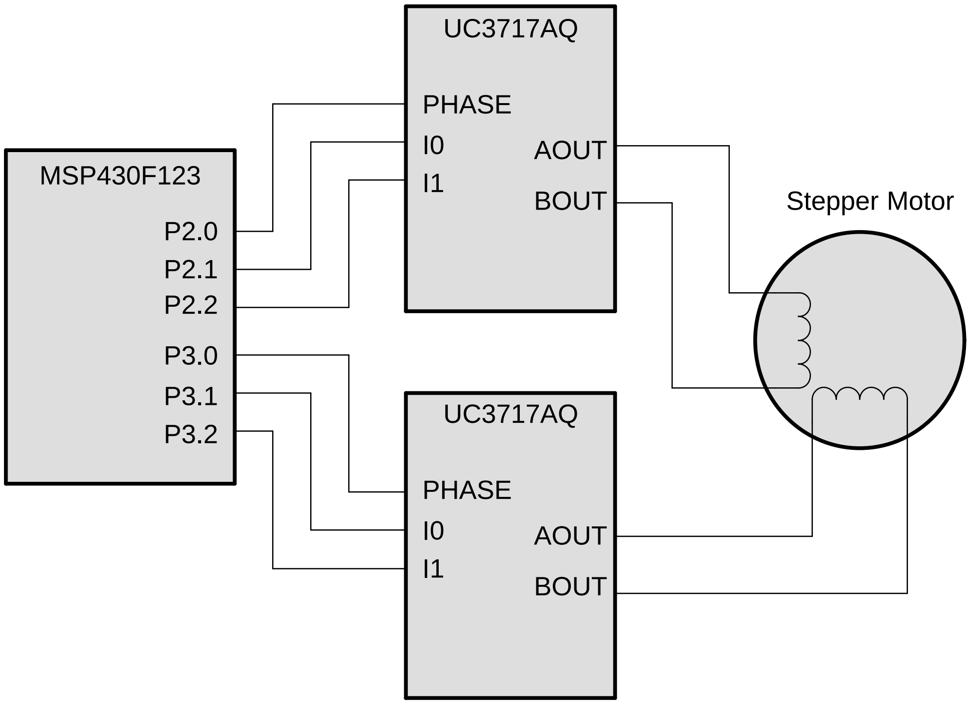

Figure 1. Block Diagram

Figure 2 shows a picture of the MSP430 Stepper Motor Controller board. Figure 4 shows the schematic. Port pins P2.0–P2.2 and P3.0–P3.2 on the MSP430 (U6) provide the control signals for the two UC3717A ICs (U1 and U5). Switches S1–S4 provide the inputs to the MSP430 to control the stepper motor. As an alternative, the stepper motor can also be controlled using a PC. A serial cable can be connected between connector J3 and a PC's serial port. U3 provides the RS-232 line driver/receiver required for level-shifting the RX and TX signals. The 32 kHz watch crystal, X1, provides the clock source for the MSP430's hardware UART. Connector J4 provides a convenient way to connect to a stepper motor. Connector J1 provides the JTAG connection for the MSP430 Flash Emulation Tool. DC power jack J2 enables the board to be powered by a +12V, 1.5A AD/DC adaptor. Battery holder B1 provides the option of powering the board with a +9V battery. Linear regulators U6 and U2 provide +5VDC and +3.3VDC respectively. Jumpers JP3 and JP4 provide an easy way to measure system current and motor current if desired. Jumper JP1 provides an easy way to monitor the UC3717A control signals with a scope. LEDs D1 and D2 are used to display operating modes.

A few external components are required by the UC3717A Stepper Motor Driver ICs. Components C10 and R4 for U1 and C9 and R8 for U5 set the *off* time for the UC3717A's chopper circuit. Components R3 and C8 for U1 and R7 and C12 for U5 form a low-pass filter to reduce switching transients appearing at the input to the UC3717A's *current sensor* section. Parallel resistors R1 and R2 for U1 and R5 and R6 for U5 provide a 1 ohm resistor for sensing current flowing through a stepper motor's windings. For a more detailed explanation, consult the UC3717A's data sheet [1].

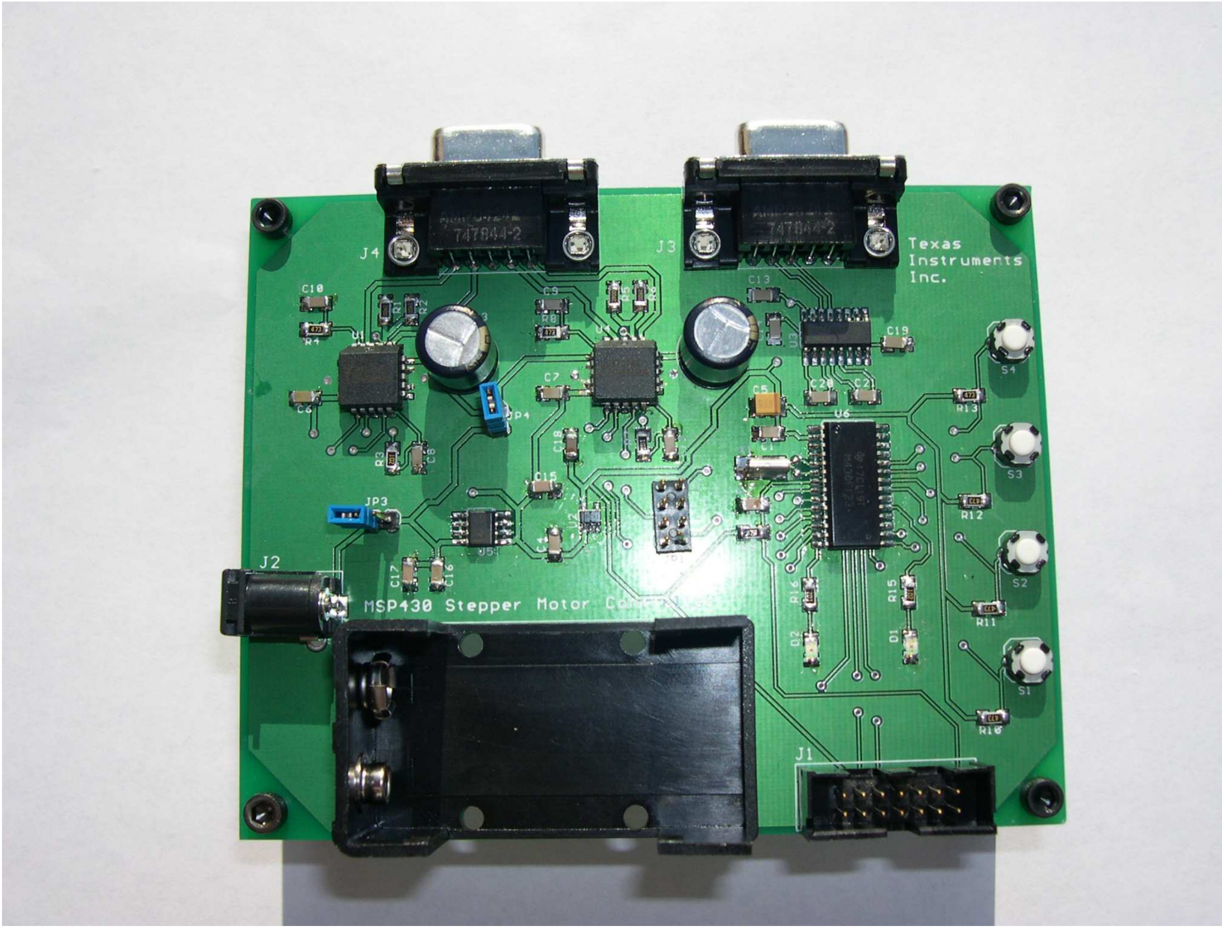

Figure 2. MSP430 Stepper Motor Controller Board

2.2 Software

Since most of the complexity with driving stepper motors involves limiting the winding current through the motor and the U3717A IC contains hardware to do this, the software implementation is relatively straight forward. For continuous mode operation, the MSP430's 16-bit Timer A is configured to generate an interrupt at the same rate as the motor is stepped. This is done by configuring Timer A for Up-mode and setting the maximum count in register TACCR0. Detailed information on Timer A operation can be found in [3]. Changing the value stored in TACCR0 changes the stepping rate. Stepping period equals 1/SMCLK frequency times the value stored in TACCR0. During the Timer A0 interrupt service routine (ISR) a state table lookup is performed to retrieve the next output state for the 6 port pins controlling the two UC3717A devices. The port pins are then updated and the state table index is incremented. Different state tables are used depending upon the direction the motor is stepped as well as the mode of operation; fullstepping or half-stepping. Figure 3 shows the stepping sequences for the various stepping modes and directions. During full-stepping I0 and I1 are held at a constant logic *0* state.

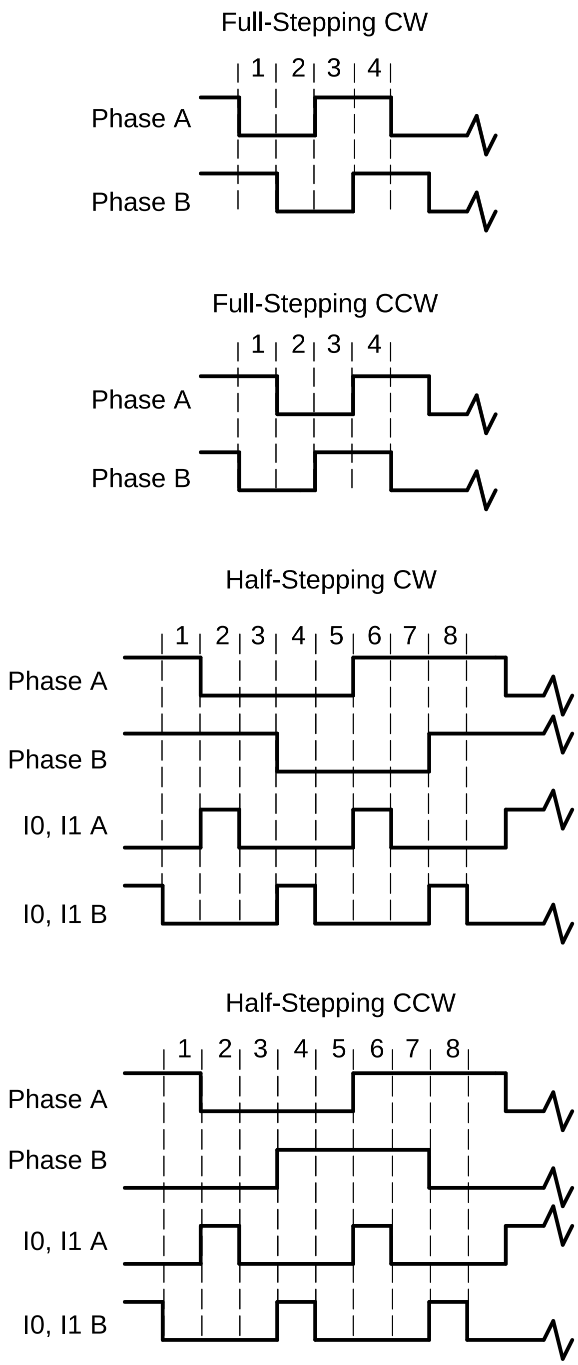

Figure 3. Stepping Sequences

Switches S1 through S4 are used to control stepper motor operation. Whenever any of the switches are pressed, the port 1 interrupt service routine (ISR) executes. The port 1 ISR disables port 1 interrupts and enables watchdog timer (WDT) interrupts. When enabled, the WDT ISR executes about once every 2 milliseconds. Each time the WDT ISR executes it checks the state of the switches. If switch S1, S3, or S4 is held in the *on* state for a *debounce count* of 5 consecutive interrupts or 10 milliseconds, then the operation associated with the particular switch is executed. Switch S2 works a little differently. If S2 is held in the *on* state for more than 10 milliseconds and less than 1 second, then the stepper motor toggles between continuous mode and step mode. Holding S2 *on* for more than 1 second toggles between fullstepping and half-stepping modes. For as long as S2 is held in the *on* state it will continue to toggle between stepping modes every second. Once all the switches are in the off state, the WDT ISR disables itself and re-enables the port 1 ISR.

The serial port on a PC can also be used to operate the stepper motor controller board. Each time the MSP430 receives a character, the UART RX ISR executes. If a *matching* character is received, then the operation associated with the character is executed. At the end of the UART RX ISR, it transmits back to the PC the character it received. This provides feedback to the PC user that the MSP430 received the character sent to it by the PC.

2.3 Operation

Four switches, S1 through S4, control how the Stepper Motor Controller board operates. S1 controls direction. Each time S1 is pressed the motor changes its direction of rotation. S2 controls how the motor is stepped. Each time S2 is pressed for less than 1 second, the motor toggles between continuous mode and single step mode. Holding S2 down for more than 1 second toggles the stepping sequence between full-stepping and half-stepping. LED D2 is illuminated while operating in half-stepping mode. Otherwise, D2 is off. LED D1 is illuminated while in single step mode. Otherwise, D1 is off. While operating in continuous mode, pressing S3 increases the motor's stepping rate, S4 decreases it. For single step mode, the motor steps as long as S3 is pressed. S4 advances the motor one step each time it is pressed.

When using a serial cable to control the board, Table 1 shows the operation performed when a character is received by the MSP430. LED operation does not change. D1 is illuminated while in single-step mode and D2 is illuminated while in half-stepping mode.

Table 1. Serial Port Operation

CHARACTER	OPERATION
D or d	Toggles motor's direction
C or c	Toggles between continuous mode and step mode
M or m	Toggles between full-stepping and half-stepping mode
F or f	Increases motor's speed (continuous mode) / single steps motor (step mode)
S or s	Decreases motor's speed (continuous mode) / single steps motor (step mode)

3 Schematics

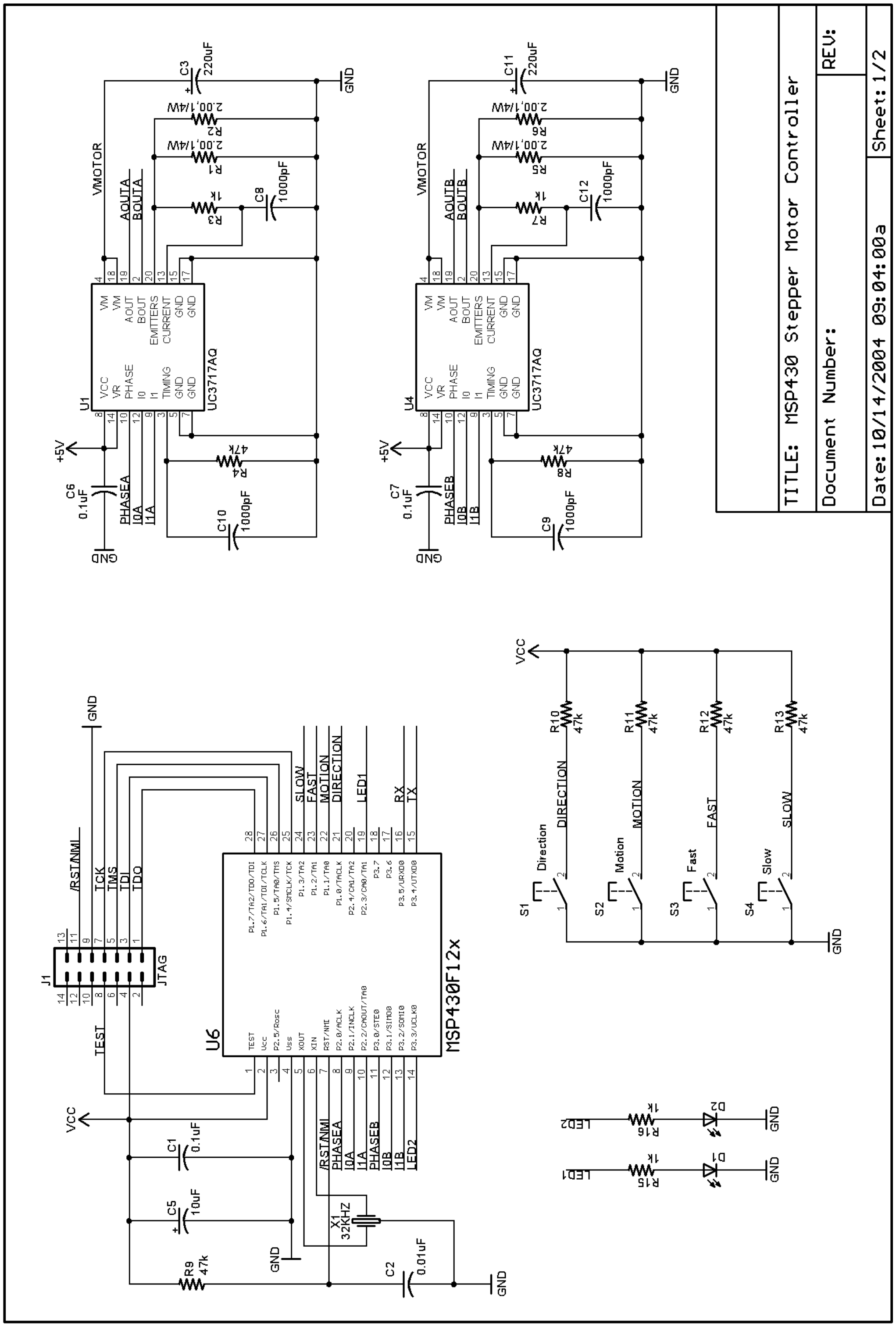

Figure 4. MSP430 Stepper Motor Schematic (1/2)

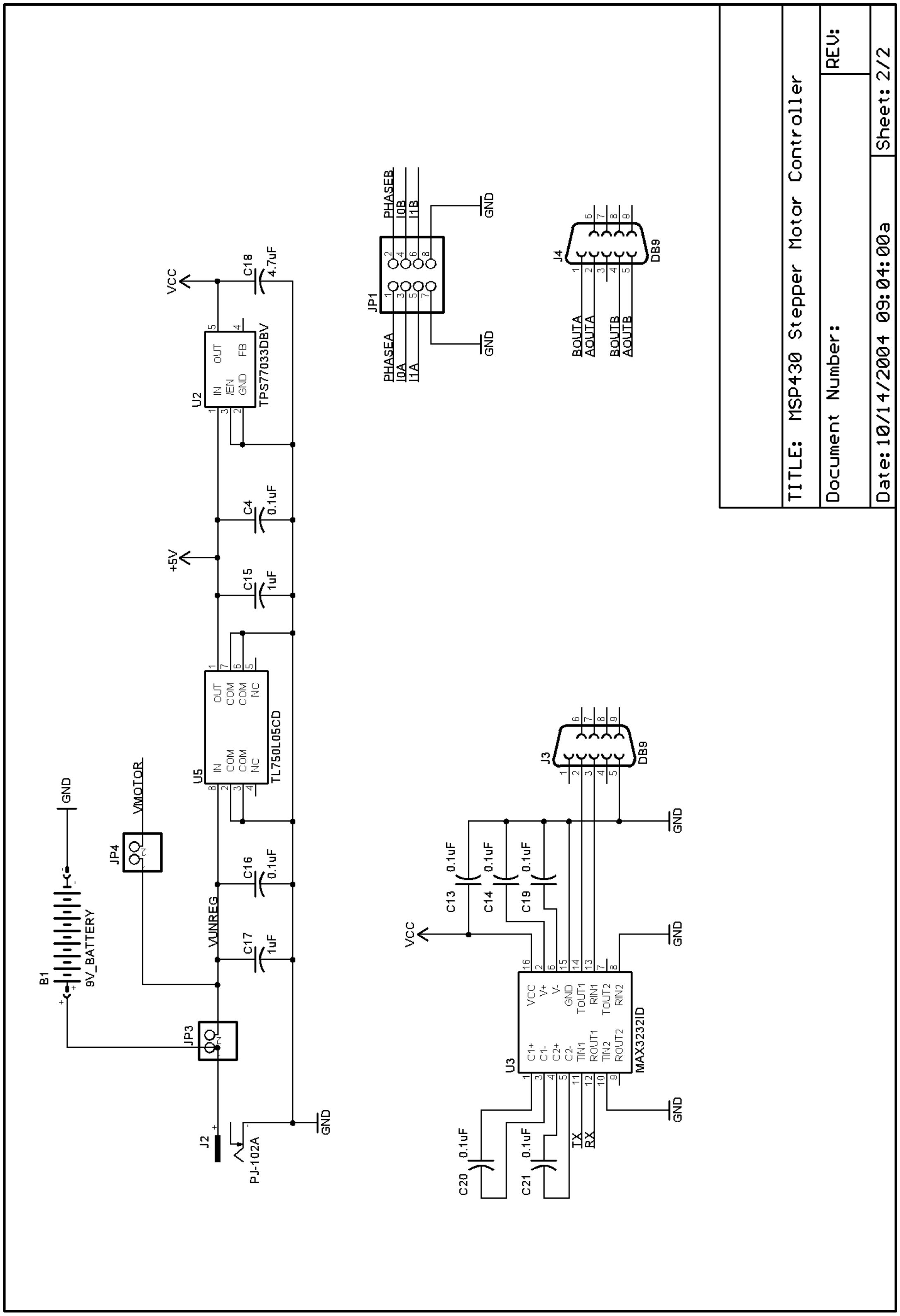

Figure 5. MSP430 Stepper Motor Schematic (2/2)

4 Bill of Materials

REFERENCE DESIG-NATOR	QTY	DESCRIPTION	MFG	MFG PART NUMBER
U1,U4	2	Stepper Motor Drive Circuit	TI	UC3717AQ
U2	1	3.3 V, 50 mA low-dropout linear regulator	TI	TPS77033DBV
U3	1	RS-232 Line Driver/Receiver	TI	MAX3232ID
U5	1	5.0 V, 150 mA low-dropout voltage regulator	TI	TL750L05CD
U6	1	MSP430F123	TI	MSP430F123IDW
S1,S2,S3,S4	4	Momentary push button switch	Panasonic	EVQ11A04M
J1	1	JTAG Connector	AMP	103308-2
J2	1	DC Power Jack	CUI	PJ-102A
J3,J4	2	Right-angle DB9 Connector	AMP	747844-2
B1	1	9 V Battery Holder	Keystone	1294
JP1	1	8-pin 0.100 Header	AMP	87227-4
JP3,JP4	2	2-pin 0.100 Header	AMP	87227-1
X1	1	32.768 kHz Crystal Oscillator	Epson	C-002RX32.7680K-A
R4,R8,R9,R10,R11, R12,R13	7	47K Ohm Resistor	Rohm	MCR18EZHJ473
R3,R7,R15,R16	4	1.0 kΩ Resistor	Rohm	MCR18EZHJ102
R1,R2,R5,R6	4	2.00 Ω Resistor 1/4W	Rohm	MCR18EZHFL2R00
C3,C11	2	220 µF, 35 V Capacitor	Panasonic	EEU-FC1V221
C1,C4,C6,C7,C13, C14,C16,C19,C20,C21	10	0.1 µF, 50 V Capacitor	Yageo America	12062R104K9B20DF
C5	1	10 µF, 16 V Capacitor	Kemet	T491B106K016AS
C15,C17	2	1 µF, 25 V Capacitor	Panasonic	ECJ-3YB1E105K
C18	1	4.7 µF, 25 V Capacitor	Panasonic	ECJ-3FF1E475Z
C2	1	0.01 µF, 50 V Capacitor	Kemet	C1206C103K5RACTU
C8,C9,C10,C12	4	1000 pF, 50 V Capacitor	Yageo America	1206CG102J9B200
D1,D2	2	LED, Red 1206 SMD	Lite-On	LTST-C150KRKT

5 References

1. *Unitrode UC3717A Stepper Motor Drive Circuit Data Sheet* (uc3717a.pdf)
2. *MSP430x12x Mixed Signal Controller Data Sheet* (SLAS312)
3. *MSP430x1xx Family User's Guide* (SLAU049)

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