World's Smallest Micro-stepping Motor Controller

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1 Introduction

Stepper motors are asynchronous motors, where in the magnetic field is switched electronically to rotate the armature magnet. A stepper motor can be operated and controlled very simply with the help of a suitable step sequencer and an appropriate coil current driver.

Typically, a stepper motor achieves a resolution of 1.8 degrees (200 steps per rotation) called the full-step mode, which is quite sufficient for many applications. More resolution can be attained by operating the motor in a so called half-step mode to get 0.9 degrees of angular resolution (400 steps per rotation).

For applications that require increased positional resolution, more than what half-step mode offers, a method called micro-stepping can be utilized.

Micro-stepping mode of operation serves two purposes: it allows the stepper motor to stop and hold a position between the full or half-step positions and it largely eliminates jerky character of low speed stepper motor operation and the noise and intermediate speeds as well as reducing problems of resonance.

Micro-stepping mode of operation allows hundreds of intermediate positions between steps.

The micro-stepping mode of operation requires that the current through the coil windings be sinusoidal with quadrature phase relationship. Digitally, this can be achieved easily with the help of a microcontroller driving a pair of DACs to generate the sinusoidal quadrature phase, followed by suitable coil drivers. The step resolution of the sinusoidal waveform would determine the micro-steps per step. Since each step motion on the stepper motor requires four clock sequences, each sinusoidal waveform translates to a single step. The sinusoidal waveform can be thought of being composed of four phases represented by four quadrants of the sine wave. Thus if an 8-bit resolution

DAC is employed to generate the sine wave, it would result in 64 micro-steps per step.

Figure 1 illustrates the block diagram of a Microcontroller based micro-stepping motor controller. Such a Micro-stepping motor controller, based on AVR AT90S8515 is described in the following documentation:

http://www.circuitcellar.com/avr2004/DA3829.html

The linear amplifiers required to drive the motor coils are based on popular audio power amplifiers, such as the TDA2020.

The problem with this approach is the sizeable circuit components required to implement the quadrature waveforms, as well as the power lost in driving the linear amplifiers, resulting in quite an inefficient operation.

Instead of using a microcontroller based approach outlined above, there are quite a few dedicated micro-stepping motor driver ICs from Allegro (IC 3395 and UDN2916B), Unitrode (UC3770) as well as National Semiconductor (LMD18245). For a complete solution these ICs would certainly require a microcontroller for sequencing and final operation.

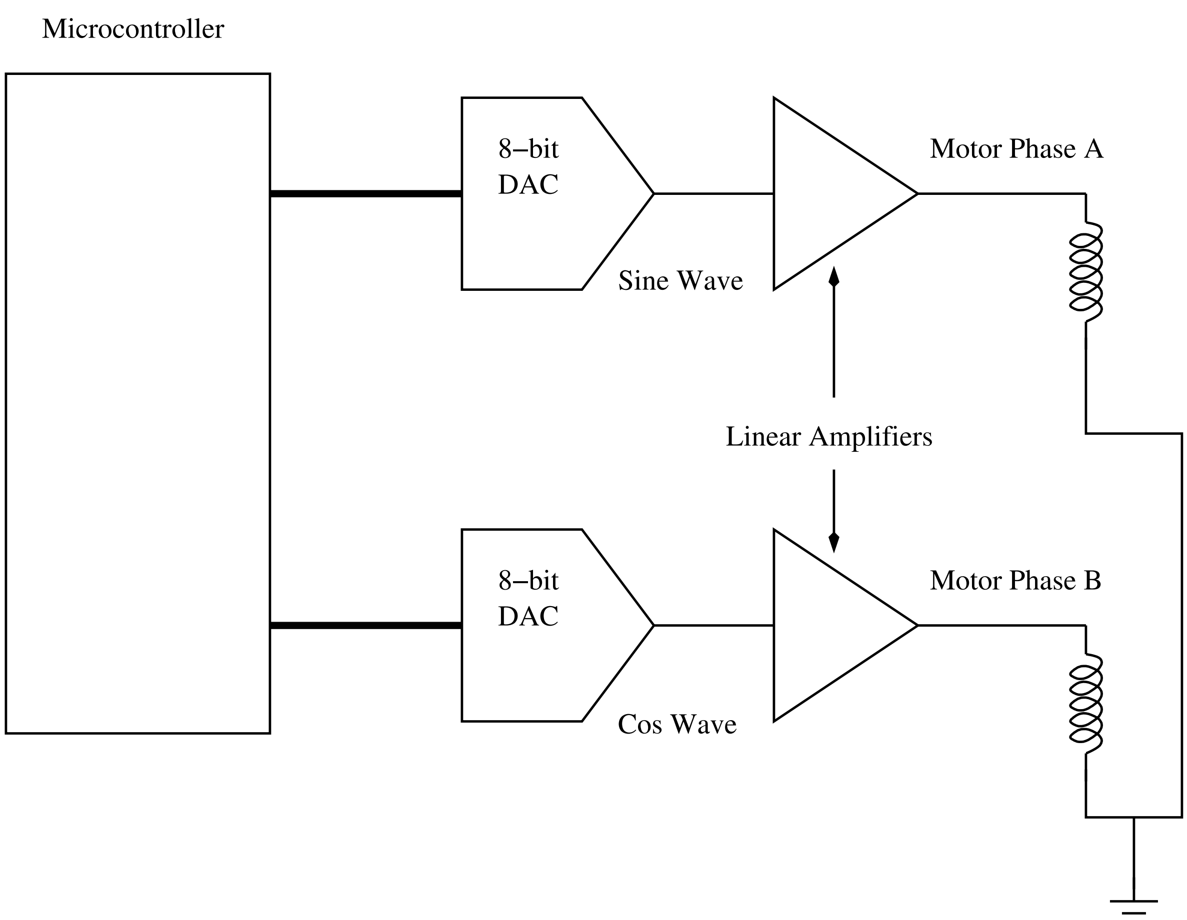

Figure 1: Micro-stepping Motor Controller

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While the above mentioned microcontroller + DAC based solution for achieving micro-stepping operation is interesting, it suffers from being an inefficient design, in terms of wasted power as well as requiring quite a handful of components. It turns out that a more efficient, single chip solution can be realized by generating the quadrature waveforms through high speed PWMs now commonly available on almost all the microcontrollers from the AVR family. Even the Tiny series of 8-pin microcontrollers (Tiny13, Tiny25/45/85, Tiny24/44/84) offer dual PWM channels.

Since the quadrature waveform is realized using a PWM signal, which is a digital signal. The PWM signal can be directly applied to the motor coils through an appropriate voltage translator switch, such as the ULN2003.

Figure 2 illustrates this approach. The Tiny45 microcontroller generates the sine and cosine waveforms through PWM channels. ULN2003 driver is used to drive the motor coils. For stepper motors requiring more current, suitable drivers (BJTs or MOSFETs) can be employed. The Tiny45 receives motion commands through a serial port, implemented using bit-banging type of software driven UART, since Tiny microcontrollers dont have an on-board hardware UART.

Tiny45 offers 8-bit PWM channels and we have used those to generate sine and cosine waveforms. This allows us to operate the stepper motor in 64 micro-steps per step. Currently, the commands that the Tiny45 motion controller offers are:

1. Forward Motion with Major and Minor steps
2. Reverse Motion with Major and Minor steps
3. Two Home positions
4. Speed Control with 9 speed settings

Further options include previous command abortion as well as status checking of previous command.

3 Testing

Preliminary tests for the World's smallest micro-stepping motor controller as described above, have been performed, with the help of a laser pointer mounted on top of the stepper motor for experimental verification of positional accuracy, repeatability and backlash errors. These tests have proved our claims of positional resolution of one part in 12800 parts in one rotation (i.e. 64 micro-steps per step) as well as less than a micro-step of backlash error. The motion is also very repeatable.

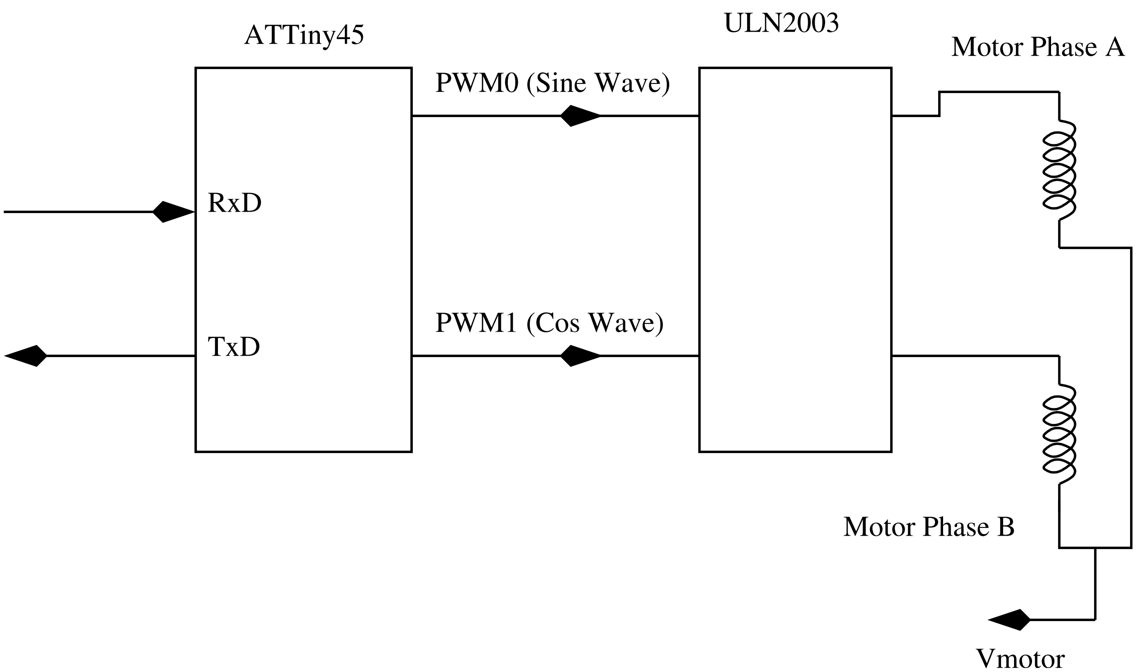

Figure 2: World's smallest Micro-stepping Motor Controller