Stepper Drive for an Equatorial Mount

1. Introduction

The drive box described here controls an equatorially-mounted telescope with worm drives on the RA and Declination axes. Each worm drive is fitted with a 1.7 amp 200 step NEMA-17 bipolar stepper motor with a planetary gearbox having a reduction ratio of 57:11. The current version of the box was developed from an earlier version which controlled a variable frequency RA drive using a synchronous motor. Along with the 2-axis drive function, the box also reads a pair of 5000 pulse-per-revolution incremental encoders, using a protocol similar to that of the original Microguider of David Lane (www.nova-astro.com).

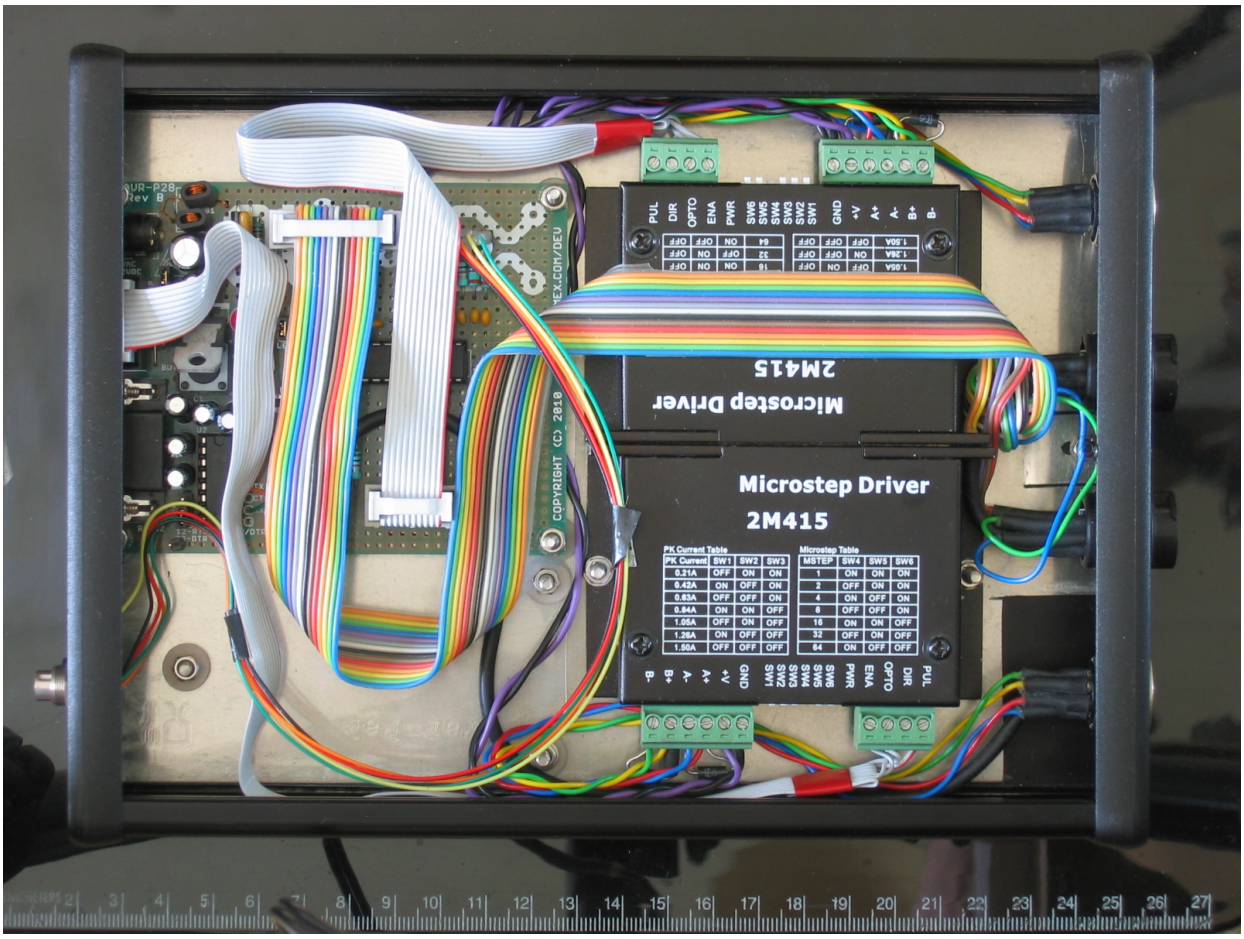
The box is controlled via the serial port of a PC. The program which controls the box (drive.cpp) is written in C++. The program is installed on a headless PC at the telescope running linux (Lubuntu 14.04). An Ethernet connection to an indoor router allows access in principle from anywhere on the internet via ssh. A hand controller is also supported.

The box is built around an Atmel AVR ATMEGA168 microcontroller running at 16MHz. This produces the pulses required by two 2M415 1.5A stepper drivers. These drivers are based on the A3392 chip and are small enough to be included in the enclosure. In the absence of commands from the PC, the box runs the RA stepper motor at sidereal rate plus a fixed periodic error correction (PEC) stored in the flash memory.

2. Hardware

The ATMEGA168 is plugged into a 28-pin DIL socket on an Olimex AVR-P28 development boarrd (now obsolete). The board includes power conditioning, a MAX232 RS232 interface chip, a DB9 serial interface socket and two 10-pin headers, one of which is also used for ICSP. Ribbon cables connect the headers to the 2M415 motor drivers, with the switches set for 64 microsteps. Another ribbon cable carries the encoder inputs to the AVR. External connection to the motors and encoders is made via Binder series 680 7-pin sockets on the box. Three of the pins on the RA connector take wires to a Hall-effect sensor, which gives a reference pulse once per rotation of the worm for PEC.

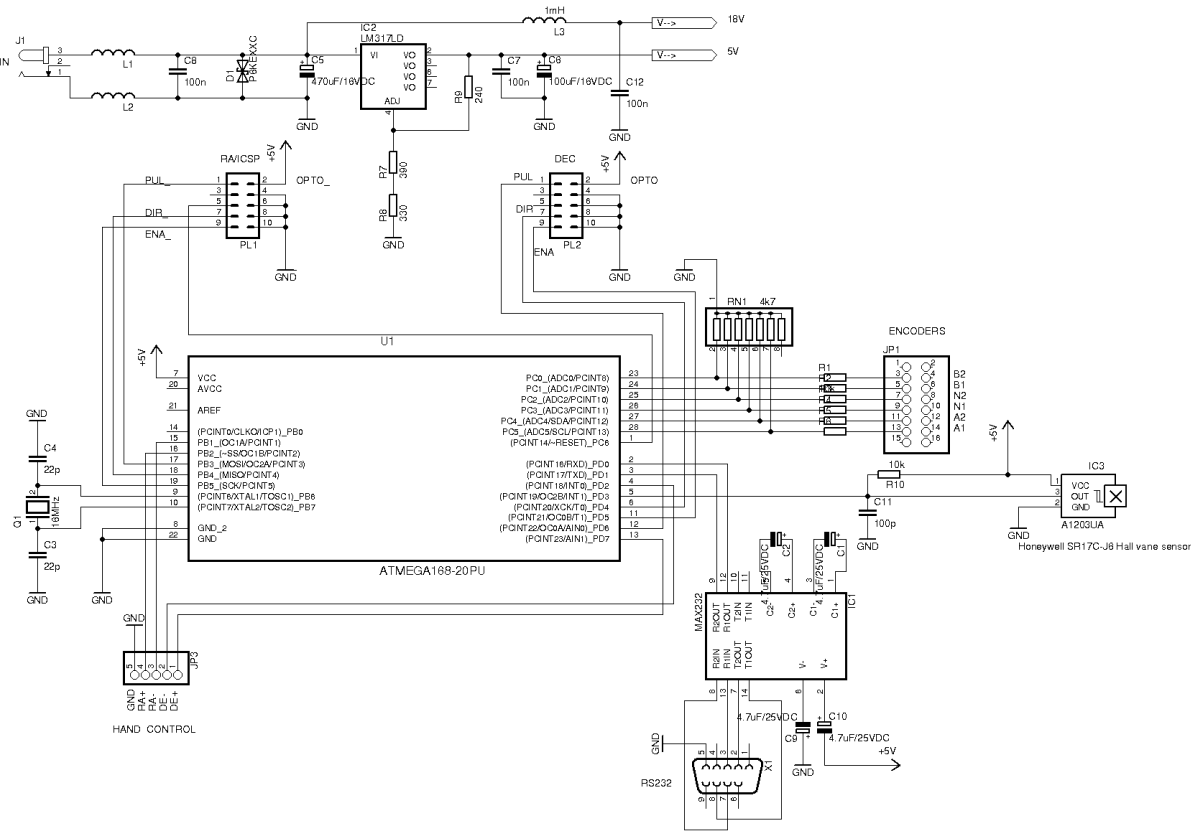
DC power is derived from an unregulated external supply giving approx 18V at 1.5A. To reduce the vulnerability of the 2M415 drivers to transient spikes, additional filtering and transient suppression has been added, at both the power supply input and the motor outputs. Nonetheless, disconnection of the motors while the power is on should be avoided.



View of drive box with top removed

3. Schematic

A schematic diagram of the drive box circuit is given below.



4. Encoders

Hengstler RI58-D/5000EF.47KF-F0 incremental encoders are attached to the RA and Dec axes. The firmware reads the two incremental encoders in an endless loop and the motor-driving functions are implemented using interrupts. The RA and Dec encoders are read roughly every 3µsec. The command ‘Q’ is used to query the encoder counts, which are returned in the Microguider format. This is also readable by the planetarium software Cartes du Ciel. Currently, the encoder reading and driving functions are independent and telescope position is estimated by counting motor microsteps and assuming no missing steps.

5. Firmware

The firmware is written in C and assembler and compiled with AVR-GCC (avrdude). The Makefile builds and programs the AVR though the ICSP header using a parallel port dongle. The size of the program is 5.3 kilobytes. The files are:

Makefile
encoder.h
encoder.S
Keys.S
stepper.c

The bulk of the assembly code is contained in encoder.S.

6. Timers

The following table shows how the drive frequency which gives the default sidereal rate is calculated.

Frequency required for RA drive

microsteps	64	-
motor full steps/rotation	200	-
planetary gear ratio	57/11	= 5.1818…
µsteps/degree	64*200*57/11	= 66327.2727…
RA drive frequency	66327.2727… / 240 / 0.99726966	= **277.120269 Hz**

6.1 TIMER0

TIMER0 generates a 125kHz clock which is divided by OCR0A to produce the driving frequency on the Dec axis. For slewing, the prescaler is set at 256 for the low frequency range and 64 for upper frequency range. The corresponding TIMER0 frequencies are 62.5kHz and 250kHz. The output pulse rate is determined by a divisor taken from the Slew Table (see later).

6.2 TIMER1

TIMER1 produces pulses every 0.461888 seconds. The main function of the timer is to increment a pointer into the PEC table. If guiding is implemented the drive rate can be raised or lowered by a fixed amount for a number of TIMER1 pulses, as determined by the guiding program. A counter is decremented and guiding is terminated when the counter returns to zero.

Xtal frequency = 16MHz
TIMER1 prescaler = 1024
TIMER1 frequency = 15.625kHz
TIMER1 interval = 64μs
OCR1A = 28*256 + 48 = 7216 (=2830h)
TIMER1 interrupts occur at 15625/(1+OCR1A) = 15625/7217 = 2.165027 Hz.
(7217*64μs = 0.461888 sec.)

6.3 TIMER2

Timer 2 generates a 125kHz clock which is divided by OCR2A to produce the driving frequency on the RA axis. For slewing, the prescaler is set at 128 for the low frequency range and 32 for upper frequency range. The output pulse rate is determined by the current divisor taken from the Slew Table.

TIMER2 prescalers = 128, 32
TIMER2 frequencies = 125kHz, 500kHz
OCR2A = 225 (default in absence of PEC)
Default tracking rate: TIMER2 interrupts occur at 125000/(1+OCR2A) = 125000/226 = 553.097345Hz.
OC2A is toggled, so stepper default drive frequency = 553.097345/2 = 276.548672Hz.
(Error = -0.2% with respect to the ideal sidereal rate.)

7. PEC

Program memory includes a table of OCR2A divisors for periodic error correction. This has been obtained by driving the telescope at sidereal rate and measuring the displacement of a star in RA during several rotations of the RA worm driven at 4 minutes per rotation. Obviously PEC must be calculated for each individual telescope mount.

A Honeywell Hall-effect sensor (SR17C-J6) provides an indexing pulse on every rotation of the worm. This resets the pointer to the PEC Table to the number stored in PEC_zero. The pointer then increments on every TIMER1 interrupt. In the absence of an indexing pulse, the pointer is reset when it reaches 518.

8. Slewing

The divisors required for slewing the mount in each axis are read from a 1k table (the Slew Table) stored in Program Memory. When movement of the telescope is commanded, the requested number of microsteps in RA(Dec) are stored in RA(DEC)_step_max and a 32-bit up/down step counter is zeroed. During a slew, the step counter is incremented until the maximum step count is reached, and is then decremented until it reaches zero. Thus the number of microsteps travelled is twice the value in RA(DEC)_step_max.

A pointer into the Slew Table is also zeroed when a slew is initiated and is incremented at each successive microstep. The divisors for OCR2 and OCR0 (RA and Dec, respectively) are taken from the byte pointed to.

To cover the full range of speeds during acceleration/deceleration there are two ‘gears’. The 1 kilobyte slew table is read twice during a slew, once for the low speed range and again with the prescaler changed to give 4x the frequency for the high speed range. The step count is divided by 16 to produce the pointer on the second pass. The pointer thus runs from 64 to 1024 on the second pass. If the pointer reaches the end of the Slew Table on its second pass (step count 16384) maximum speed is maintained until the step count falls below 16384, when deceleration is started. The speed profile is thus symmetrical from start point to finish point.

The table has been calculated for a constant acceleration and therefore the output frequency is proportional to the square root of the distance, i.e. to the square root of the value of the index into the table. For a constant acceleration a, the speed v is given by

$$v^2 = 2\,a\,s$$

where s is the step number. The duration of a step, and therefore the value of the divisor, is inversely proportional to v. The small program slew.c may be used to create the slew table.

The TIMER2 and TIMER0 prescalers for ‘low gear’ are 128 and 256, giving clock rates of 125kHz and 62.5kHz. These are changed to 32 and 64 for ‘high gear’, giving 500kHz and 250kHz. The smallest divisor in the Slew Table is 15, which gives a maximum pulse frequency of ~16kHz for RA and ~8kHz for Dec. A frequency of 16kHz is the highest the RA stepper motor can take without missing microsteps when the 2M415 driver is set to 64 microsteps. The difference between RA and Dec is due to the fact that for the particular mount being used the declination gear has a 2-start worm.

9. Serial Interface Protocol

Serial commands are strings of ASCII characters sent to the box from a COM port at 9600 baud, 8 data bits, 1 stop bit, no parity. The current list of commands is given below.

Command	*Returned bytes*	*Function*
B [byte0] [byte1]	-	Set PEC bin (0 - 518) [byte0] = LSB, [byte1] = MSB
C	-	Set drive correction flags bit0 = encoder, bit1 = RA guiding, bit2 = PEC, bit 4 = Dec guiding
D	-	Perform one step in Dec
E	-	Move East 5 arcmin
N	-	Move North 5 arcmin
n	-	Move North 5 arcmin at 1/4 rate
M [byte0] [byte1] [byte2] [byte3] [byte4]	-	Move specified no. of μsteps in RA or Dec [byte 0...3] is no. of μsteps

		(32-bit unsigned, LSB first) [byte 4] is sign/axis byte bit 1 = 0 for RA bit 1 = 1 for Dec bit 7 is sign bit
P	+00123<tab>+00456<cr>	Return current PEC bin and PEC zero +00123 is PEC bin (always 6 chars including sign) +00456 is PEC zero (always 6 chars including sign)
Q	+00123<tab>+00456<cr>	Read encoders. Result is in format: +00123 is the azimuth (always 6 chars including sign) +00456 is the altitude (always 6 chars including sign) <tab> is the tab character (#9) <cr> is the carriage return character (#13)
S	-	Move South 5 arcmin
s	-	Move South 5 arcmin at 1/4 rate
W	-	Move West 5 arcmin
Z [LSB] [MSB]	-	Set PEC zero (0 - 518)
+ [byte]	-	Increase RA rate by 1.8% [byte] gives no. of TIMER1 interrupts for which increase operates
- [byte]	-	Decrease RA rate by 1.8% [byte] gives no. of TIMER1 interrupts for which increase operates
< [byte]	-	Move [byte] microsteps S
> [byte]	-	Move [byte] microsteps N

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