Alcor – A Microcontroller-Based Control Circuit for Conventional AC Telescope Drives

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Abstract

Many telescopes still use 50- or 60-Hz AC motors controlled by variable-frequency AC power sources. This paper describes a programmed microcontroller that can be used as the oscillating element in such drive controllers, providing efficient two-phase drive, smooth frequency changes, and precise sidereal and lunar rates.

1 Introduction

Many telescope drives using conventional 50- and 60-Hz AC motors are still in use and are controlled with variable-frequency AC power sources. This paper describes a programmed microcontroller that can be used as the oscillating element in a drive controller for such a motor. Its advantages include low cost, low component count, quartz frequency stability, support of 2-phase drive for greater efficiency, and elimination of abrupt frequency changes that could cause the motor to lose sync.

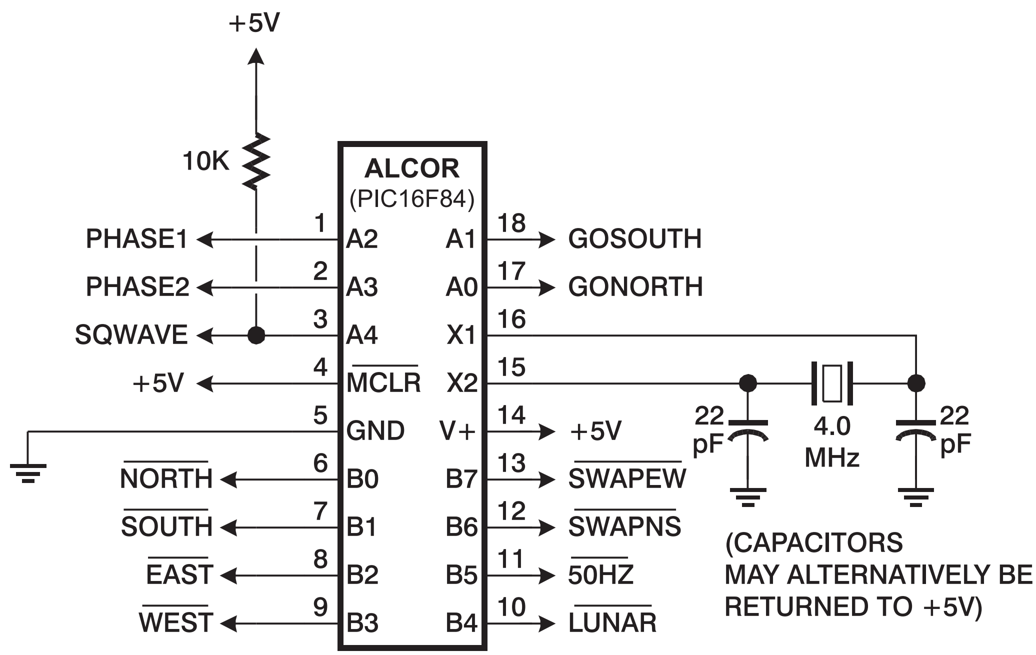

Figure 1: Programmed PIC16F84 with support components; inputs and outputs labeled. The 10k resistor is unnecessary if the SQWAVE output is not used.

This version of the program does not perform periodic error correction (PEC), but a future version may do so.

2 Processor

Named "Alcor" (after ζ Ursae Majoris B), the program described here is designed for the Microchip PIC16F84 microcontroller, but can also be ported to other low-end PICs with 13 (not 12) i/o pins. Suitable chips cost less than £3 each, unprogrammed, in small quantities. Arrangements are being made for programmed Alcor chips to be made available to experimenters. Program code is available at `http://www.ai.uga.edu/~mc/alcor.html`.

EDITOR: Contact me for updates before publication.

As Figure 1 shows, the only support components required by the processor are a crystal, three capacitors, and, of course, a source of 5 volts. A 10-kilohm pull-up resistor is also needed if the SQWAVE output is used. Inputs are TTL-compatible; outputs are 5-volt CMOS and can directly drive TTL gates as well as logic-level switching FETs such as the IRL530.

Alcor uses a 4-MHz microprocessor crystal. For the utmost in accuracy, the crystal frequency can be trimmed by making one of the capacitors variable. This is, however, seldom necessary; without it, the drive frequency will be accurate to at least 0.1%, or one arc-minute per hour. Accuracy is limited by the precision of the crystal and the fact that the oscillator period has to be a multiple of the CPU clock rate. By contrast, the RC oscillators commonly used in drive controllers are accurate to no better than 1% or 2%.

The current version of Alcor is 1.2. Version 1.0 ran on a Philips P87C750; version 1.1 was the first PIC port; and version 1.2 changed from geocentric to topocentric (parallax-corrected) lunar rate.

3 Inputs and outputs

The inputs are all active low. They are:

EDITOR: If you cannot print a line above a word, print a minus sign or slash in front.

- $\overline{\text{NORTH}}$ (B0) – Move telescope north; move image down. Ground this pin to raise the GONORTH output controlling a declination motor.

- $\overline{\text{SOUTH}}$ (B1) – Move telescope south; move image up. Ground this pin to raise the GOSOUTH output controlling a declination motor.

- $\overline{\text{EAST}}$ (B2) – Move telescope east; move image left. Ground this pin to slow down the drive.

- $\overline{\text{WEST}}$ (B3) – Move telescope west; move image right. Ground this pin to speed up the drive.

- $\overline{\text{LUNAR}}$ (B4) – Ground this pin to track at lunar instead of sidereal rate.

- $\overline{\text{50HZ}}$ (B5) – Ground this pin to drive a 50-Hz rather than 60-Hz motor (see Table 1).

- $\overline{\text{SWAPNS}}$ (B6) – Ground this pin (e.g., with a jumper) to interchange the effect of the $\overline{\text{NORTH}}$ and $\overline{\text{SOUTH}}$ pins. Thus, a single jumper or switch can compensate for the addition of a star diagonal or other configuration change.

Table 1: Frequencies output by Alcor version 1.2.

	60-Hz mode	50-Hz mode
Sidereal rate	60.164 Hz	50.137 Hz
Lunar rate (avg. topocentric)	58.696 Hz	48.912 Hz
East slewing (4$''$ per second)	44.164 Hz	36.804 Hz
West slewing (4$''$ per second)	76.164 Hz	63.470 Hz

- $\overline{\text{SWAPEW}}$ (B7) – Ground this pin (e.g., with a jumper) to interchange the effect of the $\overline{\text{EAST}}$ and $\overline{\text{WEST}}$ pins. This input has never been used and may be given a different function in a future version.

All inputs have weak pull-up resistors on the chip. External 10-kΩ pull-up resistors should be used whenever inputs are connected to cables or buttons more than a few centimeters from the chip. Better yet, use 1-kΩ pull-ups on switches that are used frequently; the higher current (5 mA) helps keep the contacts clean.

The outputs are all positive logic (active high). They are:

- GONORTH (A0) – Goes high when user is pressing the NORTH button or its logical equivalent.
- GOSOUTH (A1) – Goes high when user is pressing the SOUTH button or its logical equivalent.
- PHASE1 (A2), PHASE2 (A3) – Two-phase-drive outputs (see next section).
- SQWAVE (A4) – Square wave AC output. Unlike the others, this output requires a pull-up resistor.

Button conflicts are eliminated by the CPU, i.e., GONORTH and GOSOUTH will never both be positive, nor will the telescope try to go east and west at the same time. (In a future version, simultaneous button closures may be used to initiate PEC training.)

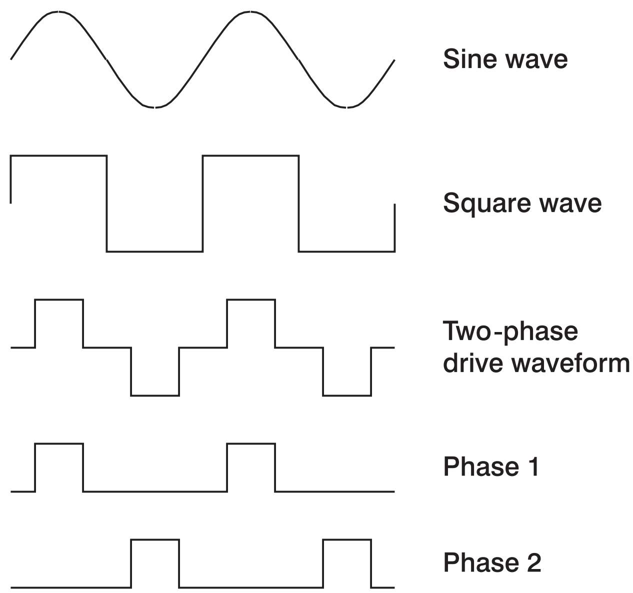

Figure 2: Two-phase drive saves power and provides a better simulation of a sine wave.

4 Two-phase drive

Most drive controllers produce square waves, but there are advantages to using the two-phase or staircase drive waveform shown in Figure 2 (see also Covington, *Astrophotography for the Amateur*, Cambridge, 1999).

With two-phase drive, the positive pulses are not long enough to saturate the transformer; thus, power is saved and heating is prevented.

Further, the pulses are constant in length and only the separation between them is varied, so the RMS voltage is proportional to frequency, exactly as required by an AC motor. Thus the motor does not lose torque at high speeds or waste electricity through saturation at low speeds.

Finally, like a square wave but unlike a sine wave, the two-phase waveform is produced by switching, not by linear amplification, and can therefore be generated efficiently without high-power transistors or heat sinks.

Figure 3 shows a simple two-phase-drive output circuit. The transistors are

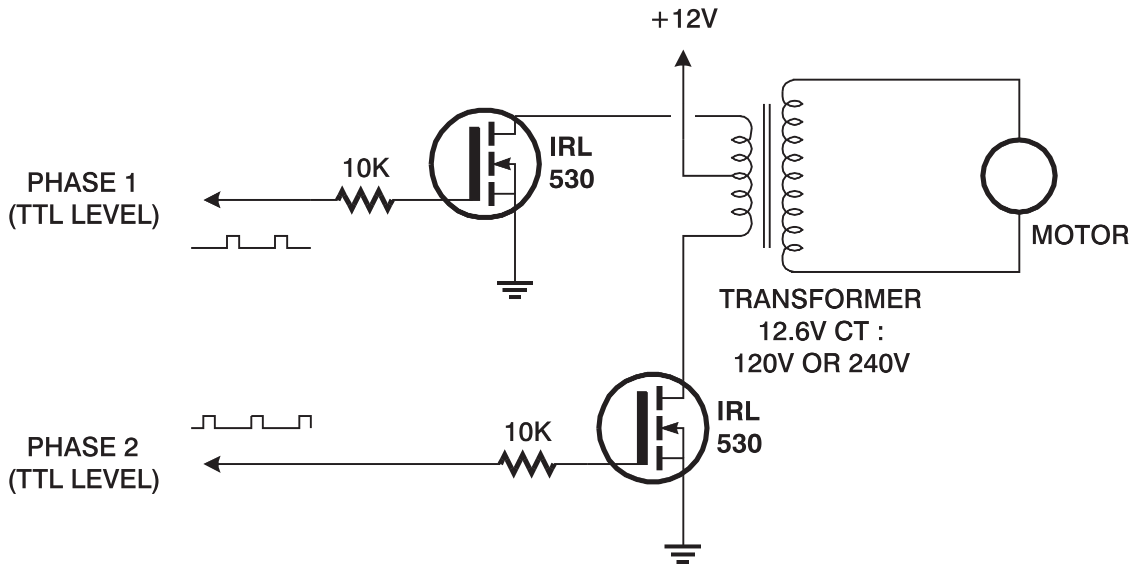

Figure 3: Two-phase drive circuit is extremely simple. IRL530 FETs take logic-level inputs and contain their own protective avalanche diodes. Resistors protect microcontroller from capacitively coupled pulses.

IRL530 logic-level MOSFETs. The more common IRF530 or IRF510 is not satisfactory because the 5-volt signal from the microcontroller is not enough to drive them into full conduction. Instead, they conduct only partially and get hot. The IRL530s begin to turn on at 2 volts and are fully conductive at 5 volts; they are so efficient that, driving a pair of 4-watt motors, they do not require heat sinks and in fact barely get warm.

Note that even though the circuit is driving an inductive load, there are no protective diodes across the transformer windings. There are two reasons for this. First, the IRL530s have built-in avalanche diodes to limit their drain–source voltage. Second, consider what happens when one of the FETs begins to conduct: its drain goes to 0 volts and the drain of the other FET goes to +24 volts by normal autotransformer action (not inductive kickback). A protective diode across the winding would conduct and waste energy.

In field-testing this circuit I discovered the need for the protective 10K resis-

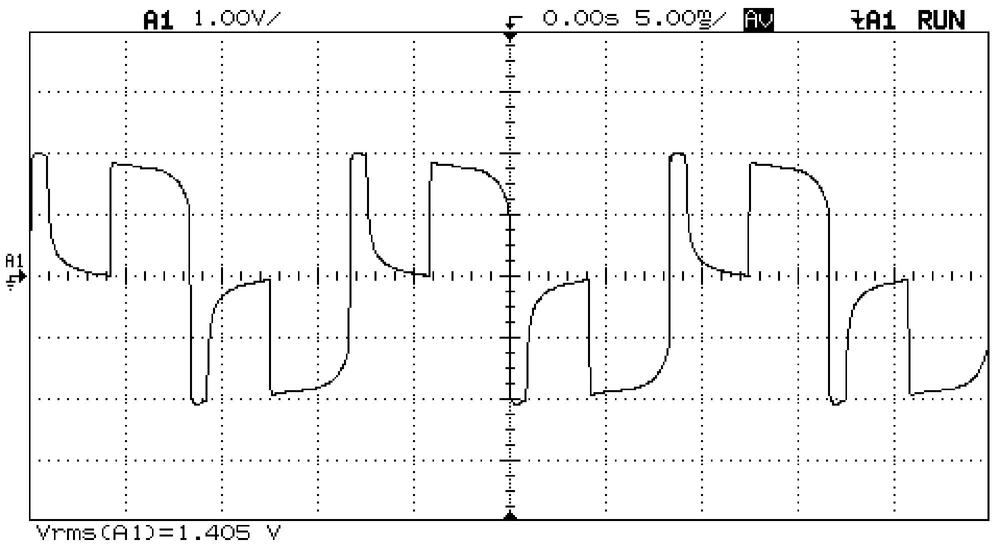

Figure 4: Actual waveform across motor (100 V/div), showing inductive kick-back.

tors shown in Fig. 3. They limit the current that flows when an inductive spike is coupled capacitively back to the FET gate. These spikes, about -3V and about 1 microsecond in duration, are capable of driving the microcontroller's output stage into SCR latchup unless a resistor is interposed to limit the current.

If logic-level MOSFETs are not available, NPN Darlington power transistors such as the TIP121 can be substituted (leaving the 10K resistors in place). Heat sinks should be used because the minimum voltage across a Darlington is about 0.6V and there is therefore some heating.

The measured RMS output voltage with a 120-volt transformer is almost exactly 120 volts into a resistive load. Across the motor, there are some inductive spikes (Fig. 4) and the measured RMS voltage is higher, but part of the voltage comes from energy flowing out of the motor rather than into it.

Unlike an RC oscillator, Alcor never changes frequency abruptly, nor does it truncate a cycle. Frequency changes are always made gradually over several cycles (Fig. 5). Thus, the motor is not asked to change speed with impossible abruptness, and it will never lose sync when changing frequency – as often hap-

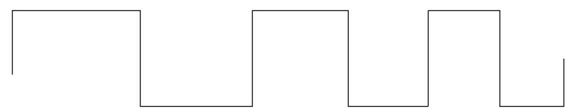

Figure 5: Alcor's frequency changes are gradual.

pens with conventional RC drives, especially when operating at minimum voltage.

5 Replacement for Meade LX3 hand box

Figure 6 shows an Alcor-based replacement for the hand controller box of a Meade LX3 series telescope (vintage 1987). The immediate motive for this design was that the switches in the original hand box were worn out. In addition, the original box could not easily be connected to an autoguider since its switches are not all returned to circuit common (ground).

Two-phase drive is not used here, but the gradual frequency changes give improved performance compared to the original Meade circuit, which would often skip one or two cycles when switching from normal to fast speed, causing the motor to hesitate.

Meade's original hand box contained an RC oscillator synchronized to a sidereal-rate signal generated in the telescope base. The Alcor version ignores the signal coming from the telescope.

The Meade power amplifier expects a waveform with a 45% duty cycle to match the MM5369AA/N oscillator used internally; a resistor in series with one of the power transistors compensates for the asymmetry. Accordingly, a special version of the Alcor software, called Alcor-LX3, was written and installed; the result was slightly quieter operation and lower power consumption than with the original Alcor.

The declination motor is controlled by the GONORTH and GOSOUTH signals through a Texas Instruments SN754410 half-H-bridge driver, a chip designed

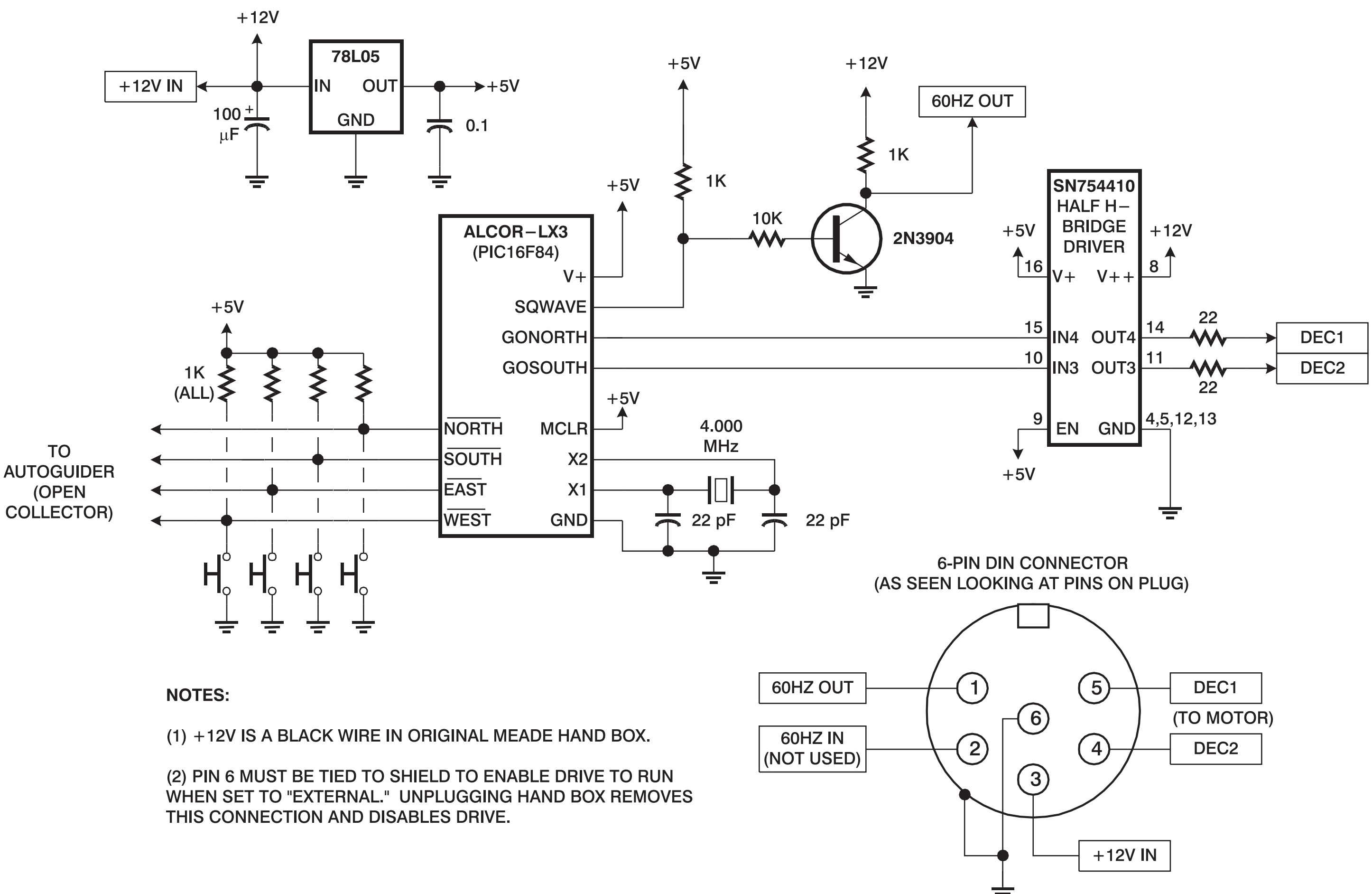

Figure 6: Replacement for Meade LX3 hand box, as built. Sidereal-rate signal from telescope is not used.

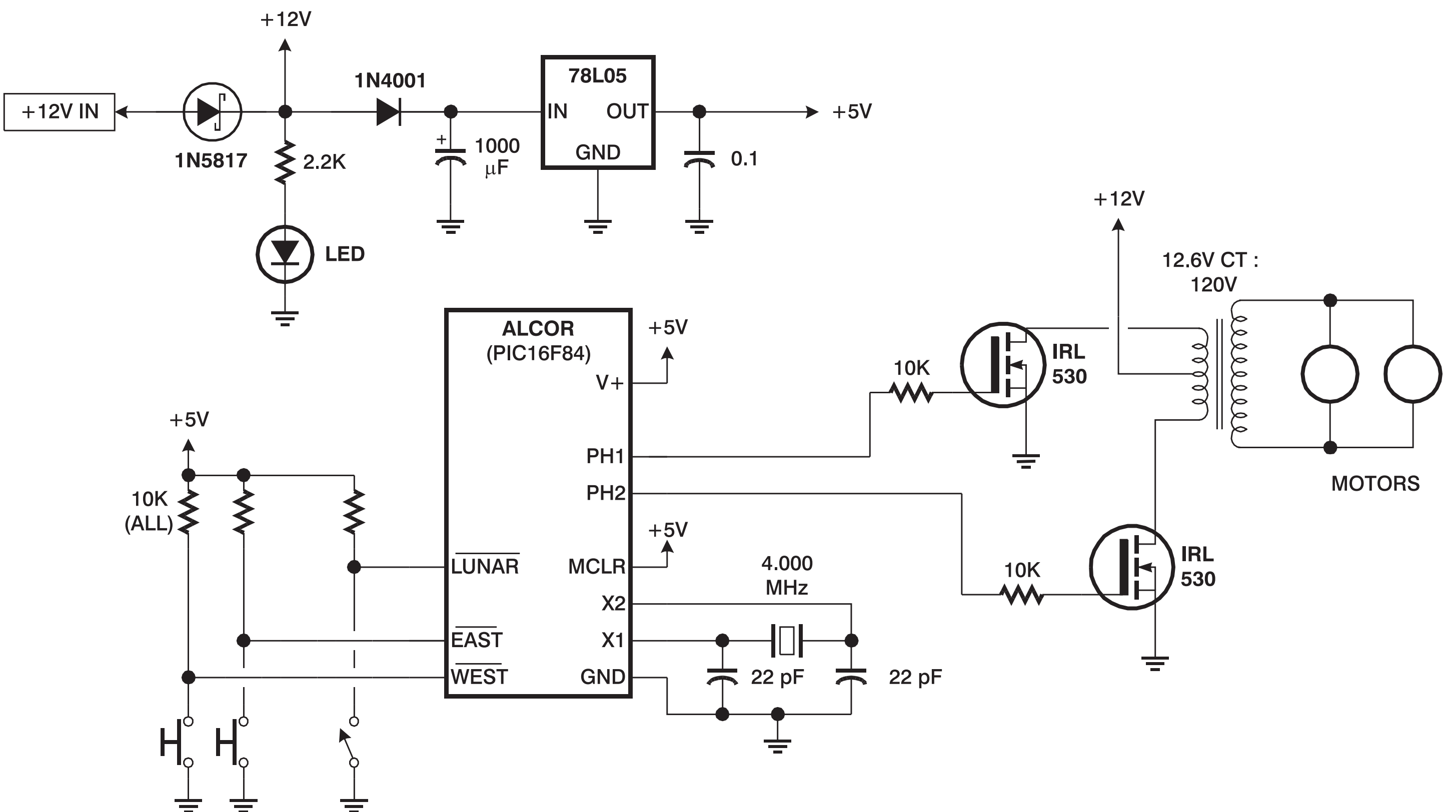

Figure 7: Complete drive controller for vintage orange-tube Celestron 5. Declination-motor support can be added as in Fig. 6.

for bidirectional DC motor control.

6 Drive controller for a Celestron 5

Figure 7 shows a complete drive controller that was built into a sturdy wooden box attached to the drive base of a Celestron 5 (Figs. 8, 9). A 1N5817 Schottky diode provides reverse-polarity protection with minimal voltage drop. Then the 5-volt supply is isolated from the 12-volt supply by a second diode and a 1000-

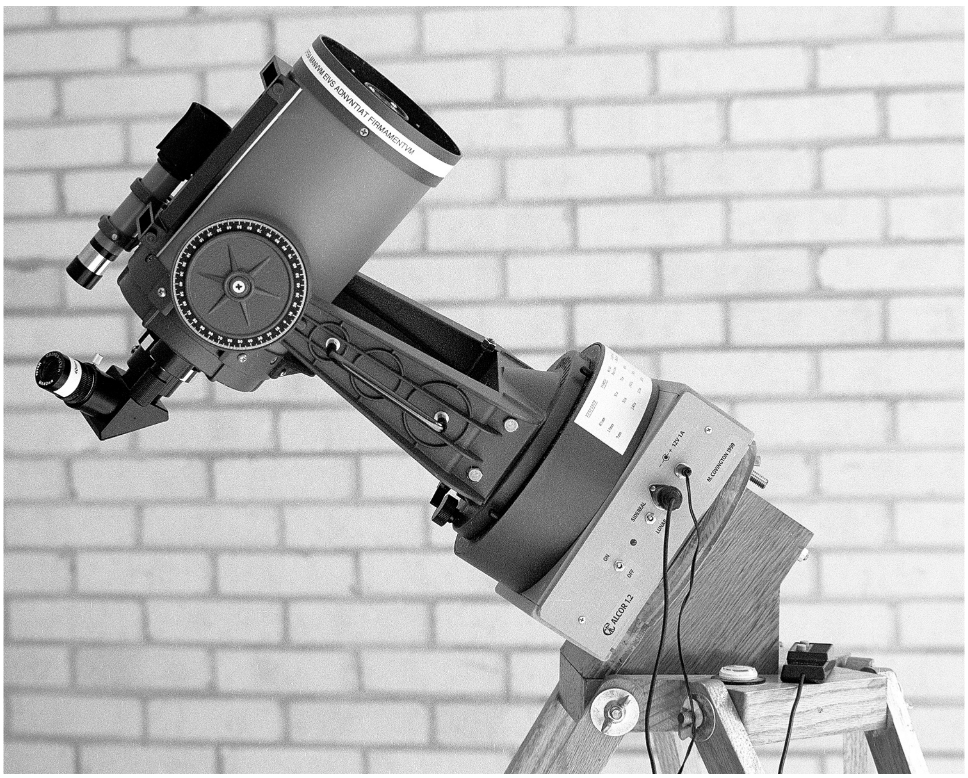

Figure 8: Circuit from Fig. 7 is built into a box permanently attached beneath the drive base.

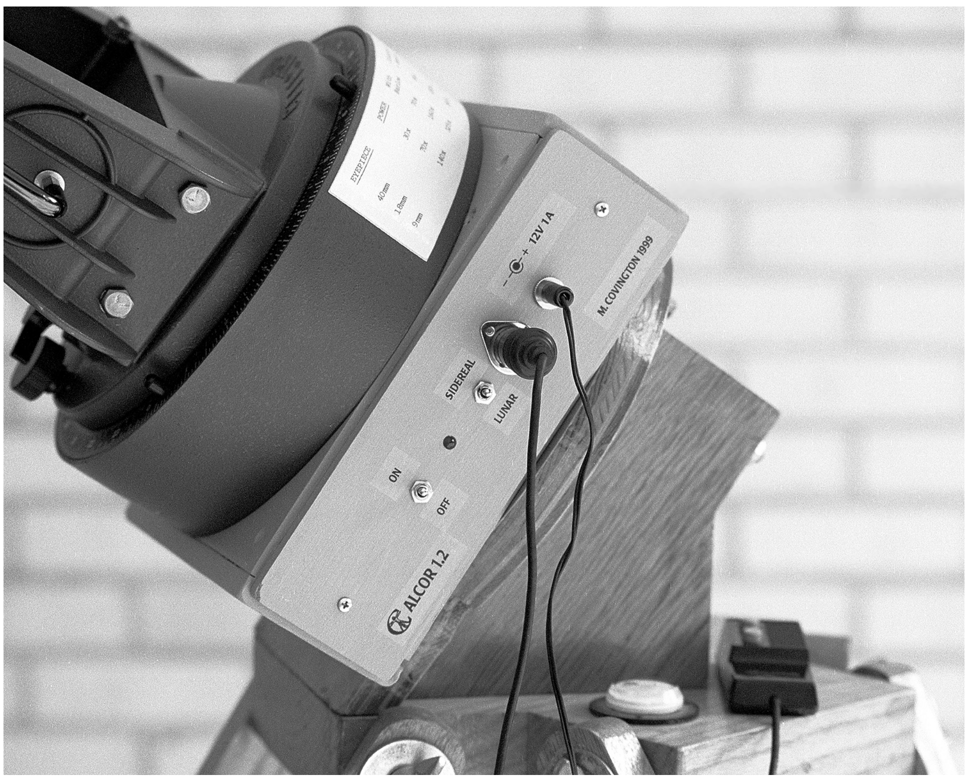

Figure 9: Close-up of Fig. 8.

μF capacitor so that transients and momentary loose connections do not reset the processor.

The hand box, with two buttons tied together on one side, is actually the controller from an old Kodak Carousel slide projector. This and other Carousel parts are abundant on the secondhand market as schools and other institutions switch from slides to video.

In use, this circuit draws 0.7 ampere at 12 volts when powering two 4-watt motors at 60 Hz. That makes it over 90% efficient, assuming the motors are performing as rated (their actual dissipation has not been measured). The telescope does not presently have a declination motor, but if one is added, it can be supported with additional circuitry as in Fig. 6 and a four-button hand box.

7 The fruit of my labour

Figure 10 shows a six-minute piggy-back exposure of M16 and M17 that was guided with the Alcor hand box on my Meade 2080-LX3 telescope. Stars are visible to at least magnitude 12.5. Much of the credit is due to Kodak Elite Chrome 200 (E200) slide film, which has remarkably little reciprocity failure, less than the Spectroscopic films that were specially made for astrophotography in the 1960s.

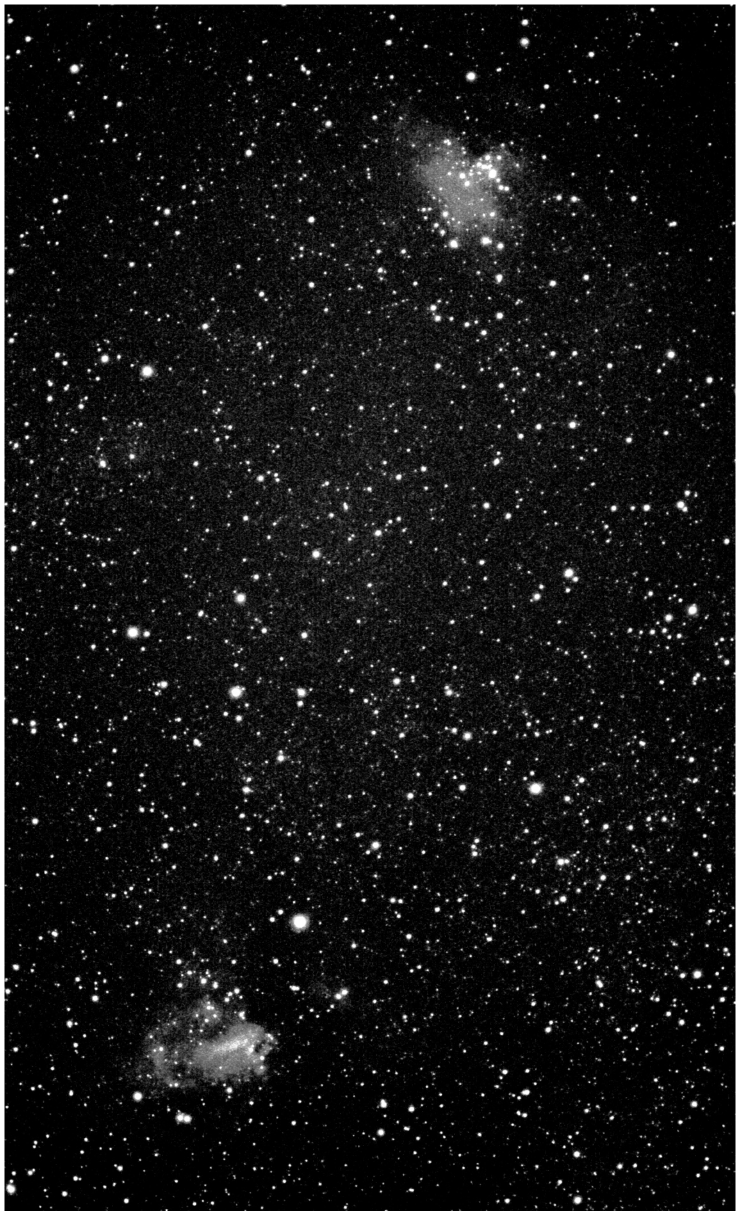

Figure 10: Six-minute exposure of M16 and M17. Olympus 300-mm f/4.5 lens wide open, Elite Chrome 200 film, piggy-backed on Meade telescope with Alcor hand box. Digitally processed image.