Note: Fast, small, accurate 90° rotator for a polarizer

David P. Shelton, William M. O'Donnell, and James L. Norton
Department of Physics and Astronomy, University of Nevada, Las Vegas, Nevada 89154-4002, USA

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A permanent magnet stepper motor is modified to hold a dichroic polarizer inside the motor. Rotation of the polarizer by 90° ± 0.04° is accomplished within 80 ms. This device is used for measurements of the intensity ratio for two orthogonal linear polarized components of a light beam. The two selected polarizations can be rapidly alternated to allow for signal drift compensation, and the two selected polarizations are accurately orthogonal. © *2011 American Institute of Physics*. [doi:10.1063/1.3564911]

Experiments to measure the nonlinear optical properties of materials by hyper-Rayleigh and hyper-Raman light scattering (HRS)[1–7] often require analysis of the polarization state of the scattered light.[2–7] Although more general scattered polarizations have been considered,[4] it is usually just two orthogonal linear polarized components that are measured.[2,3,6,7] Most often these components are measured by rotating a polarizer to select one and then the other component. HRS signals are typically weak and require long integration times, so the accuracy of the measured intensity ratios is often limited by drifts in laser beam power, pointing or mode.[2,7] The effect of these drifts can be compensated by switching the polarization multiple times and averaging the measurements for each polarization. The device described below is designed to facilitate this polarization switching and signal averaging protocol.

The rotator has a 1 cm clear aperture and was developed to improve existing hyper-Rayleigh scattering apparatus, replacing the previous fixed polarizing beam splitter coupled to a pair of optical fibers and a fiber switch.[7] The collimated beam transmitted through the rotating polarizer is focused into a single optical fiber carrying the light to the spectral analysis instruments and detector. The single common path increases calibration accuracy and stability. In a typical experiment using this device there is a sequence of several hundred successive orthogonal polarization measurements, each measurement having a few seconds duration while the dead time between measurements is a fraction of a second (the time for 90° rotation of the polarizer). This rotator is most useful for experiments where one needs a simple, compact device to select and measure only two orthogonal polarizations of the light and does not want to waste measurement time at the intermediate angles. Although many manual and motorized rotation stages are available, very few can execute a rapid and precise 90° rotation.

The rotator is constructed from a permanent magnet stepper motor (Anaheim Automation TSM42-075-17-5V-059A-LW4)[8] by replacing the rotor axle by an internally threaded lens tube for the optics (Thorlabs SM05M10),[9] as shown in Fig. 1. The motor is disassembled by carefully drilling out the two welds holding the halves of the case together. The rotor is removed, the steel shaft is pushed out of the aluminium hub of the rotor, and the hub is rebored to make a snug slip fit on the lens tube, taking care not to damage the thin 24 pole ceramic magnet shell. The outer surface of the anodized lens tube is polished with 3 μm alumina suspension, and after the lens tube is positioned correctly in the hub, it is fixed with a small amount of cyanoacrylate adhesive (e.g., Loctite 401). This new rotor assembly (parts 1, 2, and 3 in Fig. 1) is supported by a pair of plain bearings (parts 6 in Fig. 1) machined from polyethylene terephthalate (Ertalyte) and coated with DuPont Teflon Silicone lubricant. The original bronze bearing insets are discarded and the holes in the end plates of the motor body halves (parts 5 in Fig. 1) are rebored to accept the new larger bearing inserts (it is convenient to

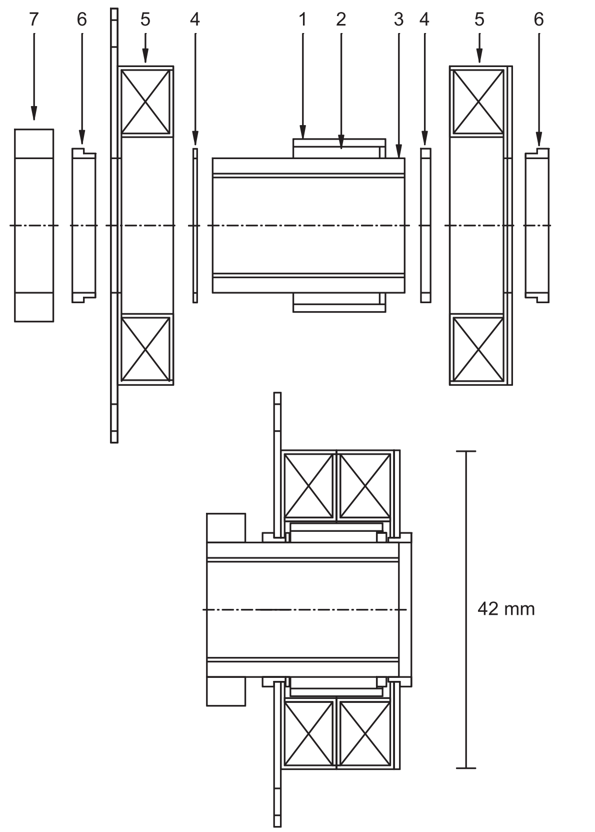

FIG. 1. Exploded and assembled cross section views of the (cylindrically symmetric) motor, showing the (1) 24-pole permanent magnet rotor shell, (2) rotor hub, (3) lens tube rotor axle, (4) spacer ring, (5) 24-pole stator, coil, and case, (6) bearing, and (7) fiducial ring. The main body of the assembled motor is 42 mm diameter × 15 mm long.

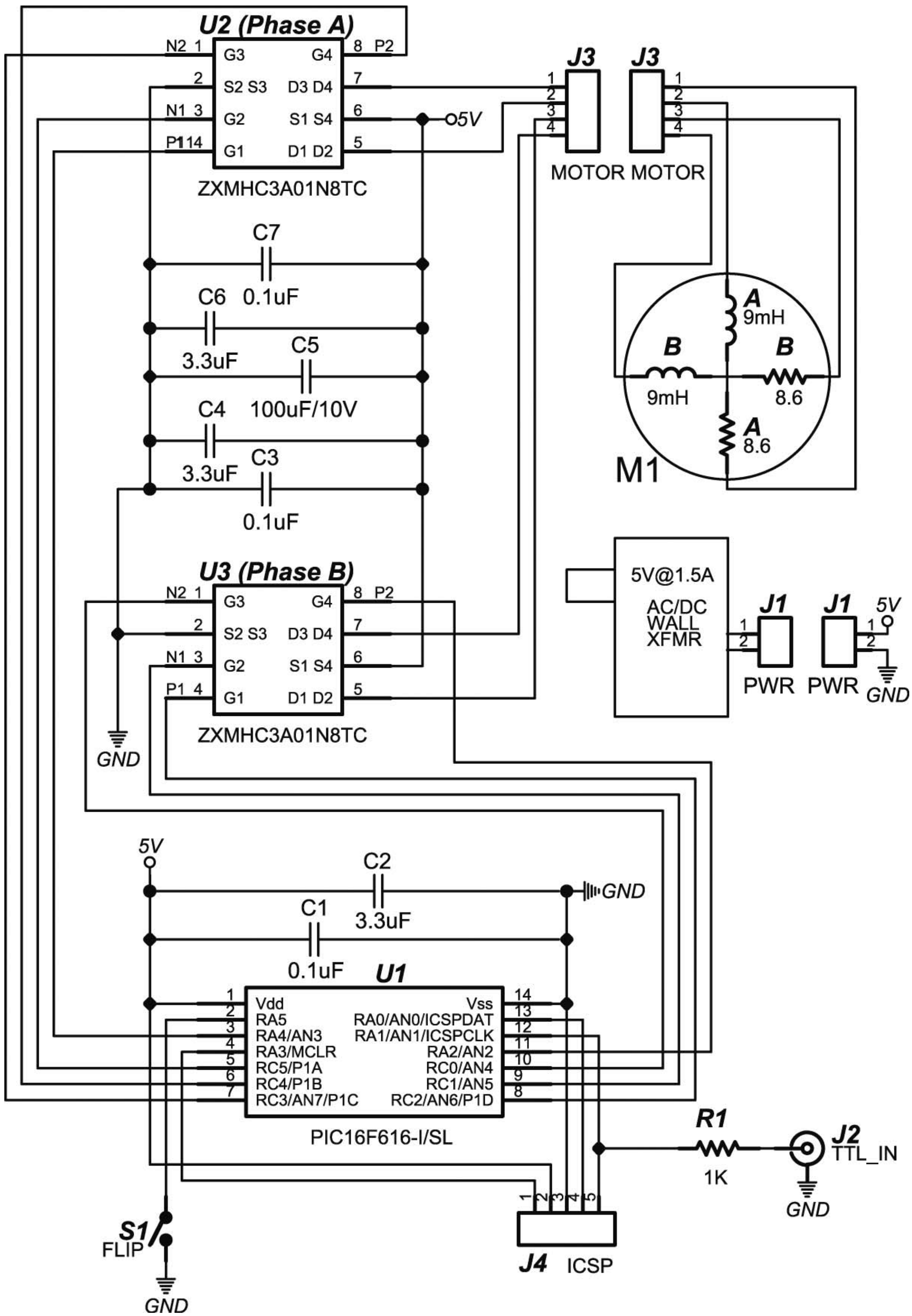

FIG. 2. Circuit diagram of the motor controller. The microcontroller U1 (Microchip PIC16F616-I/SL) (Ref. 10) controls the MOSFET H-bridges U2 and U3 (Zetex ZXMHC3A01N8) (Ref. 11) which connect the motor coils A and B to the 5V power supply with positive or negative polarity. Compiled microcontroller program code in Ref. 12 is loaded using J4, and the controller is operated using S1 or J2. The complete controller fits on a 35 mm × 45 mm circuit board.

temporarily remove the 12-pole stator inserts and coils from the motor body halves). The end play of the assembled motor is adjusted using thin Teflon rings in the gaps between the rotor hub and the bearings. The magnetic field inside the lens tube is <20 G.

The microprocessor controlled H-bridge driver circuit for the motor is shown in Fig 2. Energizing the motor coils in the sequence $3 \times (AB, A\overline{B}, \overline{AB}, \overline{A}B)$ steps the motor 90° in one direction, and the reverse 12 step sequence is used for 90° rotation in opposite direction. A 12 step sequence is initiated at each level change at input terminal J2 ($L \rightarrow H$, forward; $H \rightarrow L$, reverse), while switch closure of the push button S1 toggles the motor alternately forward or backward. The step duration is 5 ms for the first 11 steps, 50 ms for step 12, and then the motor current is off until the next step sequence (this essentially eliminates motor heating). The successive equilibrium positions for the rotor are the same with current on and current off (for this full step sequence), so the motor does not move when the current is turned off after the last step.

The polarizer is mounted in the lens tube between retaining rings. The dichroic polarizer disc is cemented to one threaded retaining ring, screwed into the lens tube, and clamped against a second threaded retaining ring (with or without an O-ring). Precise alignment of the polarizer with respect to the motor may be achieved using a collimated laser beam directed through the polarizer and a second reference polarizer. The polarization axis can be set within 0.2° by observing extinction of the beam transmitted through the reference polarizer, and the tilt between the polarizer normal and the motor rotation axis can be set <0.02° by clamping the polarizer in the lens tube while observing the reflected beam from the polarizer as the motor rotates the lens tube. The rotation axis itself is stable to <0.01°. The polarizer face is aligned perpendicular to the rotation axis to avoid systematic errors due to varying deviation of the beam.

Precise, repeatable 90° rotation of the polarizer is achieved simply without micro stepping despite the coarse 7.5° step size, and the entire motor is rotated to make a coarse or fine angular adjustment to the polarizer axis without affecting the 90° rotation. The performance of the rotator was tested in two ways. The actual motor rotation angle was measured using the reference polarizer and depends on the starting position for the 12 step sequence (for closed cycles there are 12 possible rotor starting positions 30° apart). The measured rotation angle is 90.00° ± 0.04° for the chosen starting point, but the difference from 90° is as large as 0.2° for some other starting positions. The chosen starting position is conveniently indicated using fiducial marks on a light ring affixed to the lens tube with nylon tip set screws. The time to complete the rotation and the repeatability of the final polarizer angle were measured with the reference polarizer rotated 45° from the extinction angle. Figure 3 shows the transmitted intensity versus time following a 90° rotation command to the controller (which initiates a 12 step sequence). The motor accelerates to 1.5° /ms within the first step, then rotates at nearly constant velocity, overshoots 1° on the last step, and has settled to its final position within 80 ms. The final position is repeatable to better than 0.04°. In operation there is little vibration, and no motor wear is evident after 10^5 rotations. This rotator for small optics is constructed from inexpensive components, it is simple to operate, fast, and surprisingly accurate.

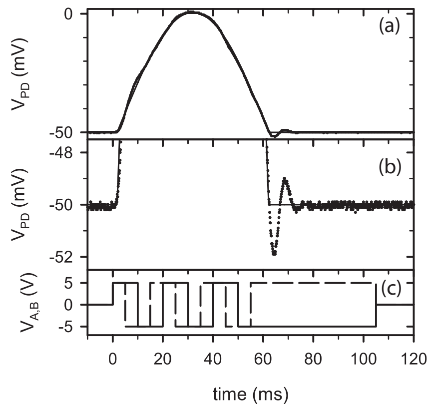

FIG. 3. Light intensity transmitted through the reference and rotating polarizers is measured by a photodiode as the motor executes a 90° rotation, moving from $\theta = -45°$ to $+45°$ with respect to the extinction angle ($I \propto \sin^2 \theta$). The photodiode signal is shown by the data points in (a) and with an expanded scale in (b), while (c) shows the drive voltage on coils A (solid line) and B (dashed line) of the motor. The solid curve in (a) and (b) is calculated assuming rotation through 90° at constant angular velocity of 1.5°/ms, beginning after a 2 ms delay. The signal in (b) shows that the motor overshoots 1.0°, has settled within 0.04° by 80 ms, and does not shift at 105 ms when the motor drive goes off.

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[8] See www.anaheimautomation.com for stepper motor data sheets.
[9] See www.thorlabs.com for lens tube opto-mechanical components.
[10] See www.microchip.com for microcontroller data sheets.
[11] See www.diodes.com for H-bridge data sheets.
[12] See supplementary material at http://dx.doi.org/10.1063/1.3564911 for microcontroller program code (both C-language and compiled machine language code).