SHUTTERS WITH EMBEDDED MICROPROCESSORS

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ABSTRACT

Shutters are used to periodically provide a non-uniformity correction (NUC) calibration surface to micro bolometers. Many bolometer applications, such as TWS and DVE, require compact, power efficient actuators. Actuators in these applications, such as bistable solenoids and stepper motors, benefit from complex drive schemes. Consumer electronics products have generated compact, low-cost drive components that can be used to embed complex drives into these shutters. Shutter drives using these components maintain compactness and power efficiency while simplifying interfaces at minimal cost. Recently, several commercially available shutter systems have been created that incorporate embedded microprocessors into shutters usable for NUC correction of micro bolometers.

Keywords: Thermal, Imaging, Calibration, Shutters, Microprocessor, Embedded

1. BISTABLE ROTARY ACTUATORS FOR LWIR IMAGING

Requirements for shutters used in Infrared Thermal Weapon Sight (TWS) systems, Driver Vision Enhancement (DVE) and other thermal imaging systems are becoming increasingly more demanding. Low cost, uncooled night vision systems were initially developed for military systems, particularly for weapons and transportation applications. Military system shutters require high reliability, shock resistance, low power, small size and light weight. The service condition of operation was between -40 and 65 C. In portable applications, the imager had to be light and power efficient to reduce battery weight. Another design requirement is that the shutter system contribute minimal heat loading the imaging area, which suggests that the actuators should be deactivated when not moving the blade. In life-critical applications, subsystems were required to be highly reliable and have long life.

One actuator system [1] that is used in such system is a bistable rotary actuator shown in Figure 1. The bistable rotary actuator has an internal rotor with a permanent magnet that locks the blade into into either the open or closed positon when unpowered. The drive coil on the rotor is driven bi-directionally to move the shutter between the two positions.

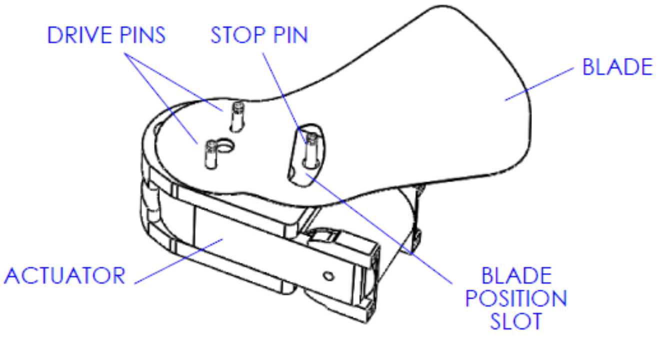


Figure 1. Rotary Drive Actuator.

The blade used in these applications can be polymeric coated spring steel or anodized aluminum. The blade has significant rotary inertia and is operated on by the actuator to move between open and closed positions. Typically, the actuator continuously drives blade to accelerate the blade across the clear aperture. The rotary drive shutter in Figure 1 includes a alastomer-mounted stop pin that engages a slot in the blade to provide two accurately defined stop positions.

At the end of blade travel, the blade has considerable velocity and energy that must be dissipated to bring the blade to a full stop. The energy stored in the blade after continuous actuator torque causes the blade to impact a stopping surface with considerable force. The energy is not fully dissipated on the first impact and the blade bounces several times while power is continuously applied to clamp the blade into position. The final settling time of the blade depends on the damping factor at the impact surface the actuator drive force and the blade inertia. Certain bistable shutters use elastomeric stops to reduce blade impact and minimizes bounce. One consequence of the high-force impacts is to create wear at the impact surface an in polymeric damping systems which reduces the life and reliability of such shutters.

2. ROTARY DRIVE SHUTTERS WITH EMBEDDED MICROPROCESSORS

Standard rotary drive shutters (RDS) from Melles Griot incorporate a circuit board to wire actuators together and/or to support a connector. An earlier paper [2] disclosed drive circuitry on the board and suggested the possibility of embedded microprocessor control of the shutter. The paper discussed the RDi132 shutter which carries a driver and electrical pulse forming circuitry on the board. The RDi132 board has significant amounts of digital logic circuitry and used two digital lines, one each to open and close the shutter. A smaller sigmle-bladed shutter, the RDi131 carried an H-bridge driver chip with two TTL data lines to open and close the shutter. An external controller operating the RDi231 needed to pulse one of the two lines for a specific period of time.

Consumer electronics has driven down the size and cost of microprocessors while increasing functionality of the chips. The microcontrollers can be found as 6 and 8 pin package sizes with areas below 4 square millimeters. The pricing of the microprocessors in volume is well under one dollar. Recently, Melles Griot introduced a second generation of integrated shutters with embedded microprocessors, the RDi231 and RDi232. The onboard microprocessor chips take little board space and reduce cost by eliminating significant amount of logic components in the case of the RDi132.

The two integrated shutters are shown in Fig. 2. On the left is the RDi231, a single blade shutter and on the right is a RDi232 two blade shutter. They share a common, three-component electrical architecture. The microprocessor (uP) and driver (D) share the power line and a capacitor (C) provides stabilized voltage at the shutter. Both integrated shutters include a blade position output. Sensors (S) share the power line and the blade position output is independent of the drive electronics. For optimal safety, the output line is high only when the aperture is fully closed to positively indicate the safe, closed position. In the case of the two blade-sensor RDi232 shutter, a single closed-state indicator is created using input voltage, a pull-up resistor input voltage and two magnetic sensors with open collectors to create a NOR gate.

A single command line is sensed by the microprocessor. When the line is grounded, the microprocessor applies a pulse to the open control line on the driver. When the control line is released, the microprocessor applies a pulse to the close line on the driver. The design creates a simplified interface that offloads processing functions to the shutter. The electronic components on the board creates a simple, low-cost, compact drive system embedded in the shutter.

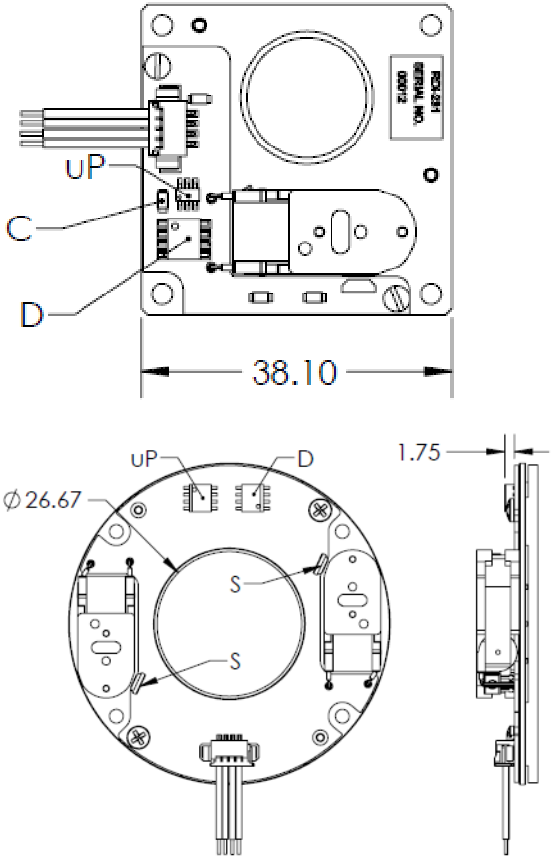


Figure 2. Integrated Rotary Drive Shutters.

The addition of a microprocessor to a shutter has multiple advantages. The controller can integrate logic and control functions into a single chip. That integration permits simplification of the digital interface. Shutters with an integrate microprocessor can use a simple three wire interface: power, ground and control signal lines. Instead of two digital lines that must be sequenced, operation of the shutter is controlled by a single line that pulses the driver chip to open the the shutter when the control line is grounded and pulses the driver chip to close the shutter when the control line returns to the high state. The control line can be digitally filtered by the microprocessor, eliminating the need for external passive filtering components.

3. DYNAMIC CONTROL USING EMBEDDED MICROPROCESSOR

Figure 3 is a plot of blade motion, as defined by open an closed positons, in response to two different electrical drives. A first drive scheme, represented by dashed lines, is a conventional drive that applies drive voltage continuously to move a blade from an open to a closed position. When voltage is initially applied, there is a time delay in blade motion due to the development of the field in the actuator coil and slow initial motion due to blade inertia. At the end of motion, the blade impacts a stop and bounces several times at a constant frequency and decreasing magnitude as blade energy is dissipated through the stop.

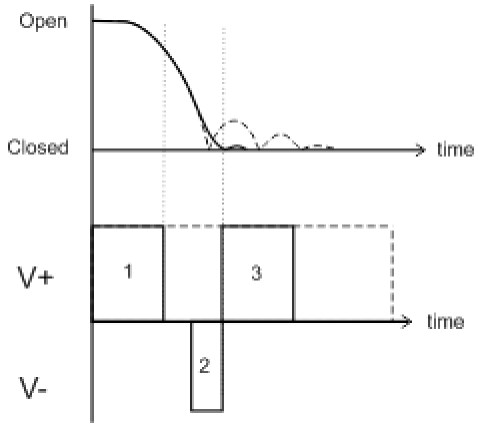


Figure 3. Rotary blade motion dynamic drive method.

The solid curves represent a dynamic drive scheme used by Melles Griot to control blade motion. In phase 1, power is applied for a period of time corresponding to the time for the blade to store enough energy to move to the second position and a safety factor of power to overcome gravity effects and actuator variability. The blade is allowed to coast through mid-motion without applied power which reduces maximum energy in the system. In phase 2, a reverse pulse is applied at end of motion to slow the blade to near-zero velocity as the blade reaches the stop. Phase 3 applies a clamping voltage to dissipate the minor amounts of energy remaining in the blade. Development of the dynamic drive found that each shutter design has unique timing for phases 1, 2 and 3 and for the open and close motions of the shutter blade. The dynamic drive scheme reduces blade impact, reduces blade motion time and reduces total energy required to move the blade. These improvements create shutters that are quieter, last longer and have shorter open and close times.

Applying the dynamic drive to rotary drive requires that the electro mechanics be constant across manufacturing lots, over time, temperature and under shock and vibration. The dynamic drive scheme requires rapid switching of the magnetic field in the coil, and the coil is designed to minimize coil inductance to permit rapid switching of drive fields. Melles Griot rotary drive actuators have been found suitable for dynamic drive due to materials and design that maintains constant, stable drive properties under all operating conditions. Dynamic drive can be implemented in embedded microprocessors without additional cost. The existing microprocessor memory stores the timing and polarity parameters for the open and close processes.

4. LARGE APERTURE MAGNETIC RETURN SHUTTER

Bistable rotary shutter can be configured to have a magnetic blade close on power-down. US Patent 8,851,768 [3] discloses a bias magnet on the stator arm of a bistable actuator that provides a magnetic closing force on a normally bistable shutter across the range of blade motion. In Figure 4, taken from the patent, the dashed line represents the net torque on the rotor from closed to open in blade positions from closed through open when a an external magnet, M, is attached to the side of the stator arm. The drive coil on the actuator can provide varying degrees of torque across the blade motion range depending on drive duty cycle. The shutter mechanics are arranged so that a high force exists when the blade is closed and the rotational closing force drops to a significantly lower value when open. The design requires a high drive torque to open the shutter and a low torque force to hold the shutter open. If power ceases through any cause, the net continuous closing magnetic force closes the shutter.

The oscilloscope traces in Figure 5 show light transmission during opening and closing respectively. The left trace shows an initial continuous application of power for 20 milliseconds, followed by a 20% duty cycle to hold the blade open. The curve on the right shows that removal of the 20% hold voltage and the closing of the blade. A single switching element applies power in a single direction as opposed to the bidirectional H-drive of a bistable rotary drive actuator.

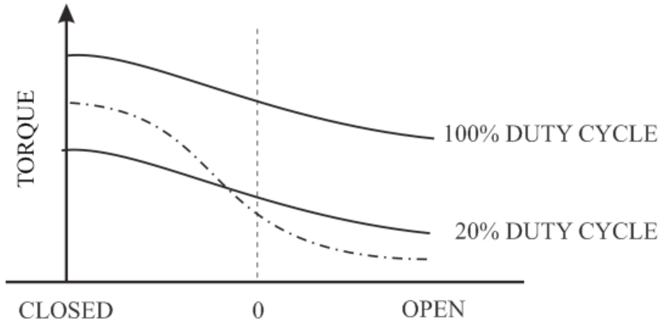


Figure 4. Magnetic return rotary drive.

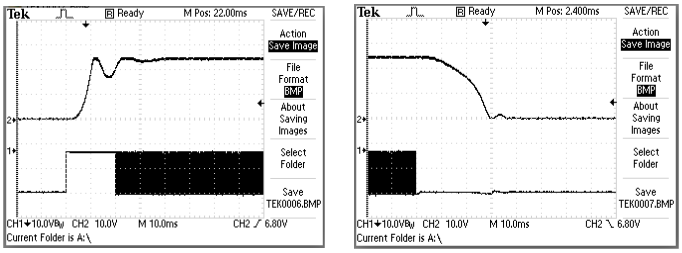


Figure 5. LAMR open and close curves

The Large Aperture Magnetic Return (LAMR) system has been implemented in the Melles Griot LSC002 shutter, shown in Figure 6. A magnet, M, is attached to the side of a rotary drive actuator to provide continuous closing magnetic force throughout positon of the blade. A microprocessor, uP, is mounted on a circuit board on the shutter and is connected to an open-collector driver, D. In this application, the drive voltage is greater than the microprocessor drive voltage, and a voltage regulator, VR, is required. The microprocessor senses the logic state of a control line as in the case of RDi2xx shutters. When the control line is grounded, the embedded microprocessor provides a 20 millisecond continuous voltage to the driver. After the 20 millisecond pulse, the microprocessor modulates the drive voltage at a 20% duty cycle. When the control line is ungrounded, the microprocessor releases the modulated drive voltage and the magnetic bias force closes the shutter. There are six components in the drive that take up a very small area on the board, permitting a microprocessor to be embedded in the shutter. The components can be sourced in at one piece volume for less than five dollars.

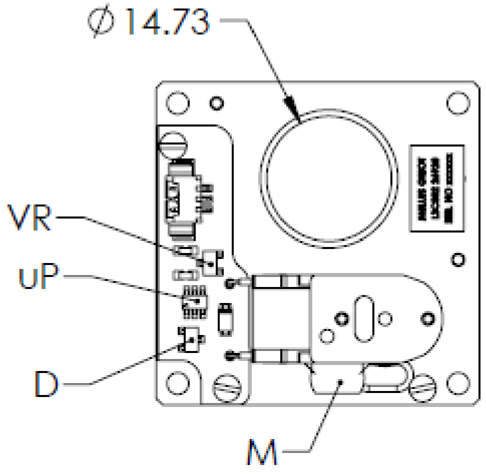


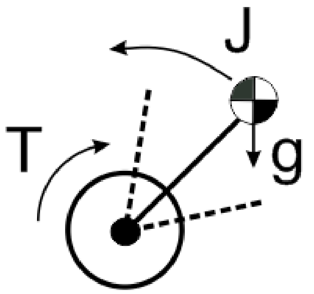
Figure 6. LAMR shutter with embedded microprocessor.

5. STEPPER MOTOR SHUTTERS

Stepper motor shutters are discussed by Durfee in reference [4]. Shutters with stepper motor drive have started to be used for applications that require extremely compact mechanisms. Stepper motors consist of two coils that operate on poles of a rotor in phased sequence. Two bipolar H-Bridges are driven in a pattern of of polarities in the two coils to rotate the stepper motor.

Figure 7 is a drawing of the kinematics and the basic equation for defining blade motion. The stepper motor has a given torque which operates against a blade with a fixed inertia. There can be secondary discontinuous or non-linear loads such as gravitational effect on the blade and magnetic holding mechanisms for retaining the blade in an open or closed position. Optimally the blade is accelerated for the first half of the motion, α/2, and de-accelerated for the second half of motion so that blades velocity is near zero at end of travel. The half angle, α/2, in equation 5 can be expressed as steps and the time difference between step number equals the drive time for any state. The blade rotary inertia and motor torque capacity, T/J define a maximum acceleration and the time for the blade to transition between positions. These equations and values are used to find initial dynamic drive parameters and speed for switching of the stepper motor coils.

When gravity and locking loads are added the resulting drive pattern becomes highly non-linear and discontinuous. The best solution is found empirically by experimentation to create effective blade motion. The bar chart on the right is a set of times for a stepper motor moving through 24 steps. The initial step takes a long time to begin to move the blade from a magnetic retention force. As blade velocity increases, the step time decreases to match blade motion. At mid-motion, the step rate slows to brake the blade motion to stop the blade on the last step in the fastest time possible.



1. $\ddot{\alpha} = T/J$
2. $\dot{\alpha} = T/J\ t$
3. $\alpha = T/J2\ t\text{^}2$
4. $t = (2J/T\alpha)\text{^}.5$
5. $t/2 = (J/T\alpha/2)\text{^}.5$

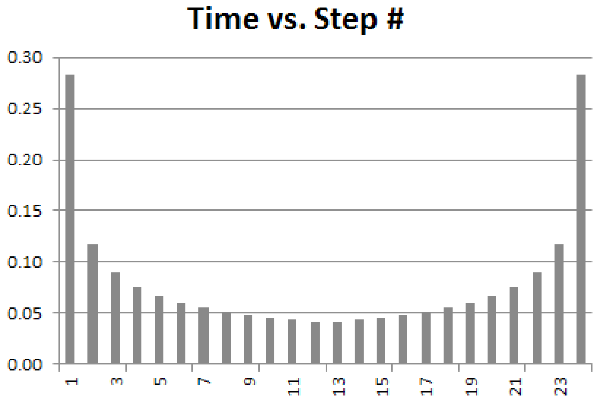


Figure 7. Stepper motor shutter drive.

6. STEPPER MOTOR SHUTTERS WITH CONTROLLER

Melles Griot has recently introduced a line of stepper motor shutters with embedded microprocessor controllers. Figure 8 show front and back views of the SMD001 shutter. The shutter uses a magnetic detent to hold the blade in a power-free state [5].The drive shaft of the stepper motor protrudes from the front of the shutter and has a detent block, Dtnt, that responds to magnet, M. The detent block has two arms that correspond to the open and closed positions that magnetically lock the shutter blade into the open or closed position. The state timing for the stepper motor in Figure 7 is adjusted to compensate for the additional magnetic torque at the beginning and end of travel.

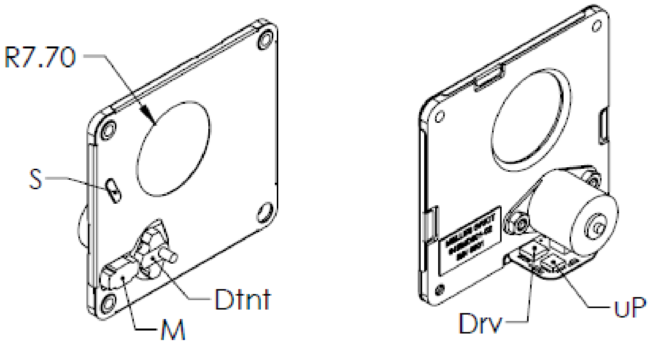


Figure 8. Stepper motor shutter with embedded microprocessor.

That data is stored in a microprocessor, uP, that is embedded in the shutter. The integrated drive system includes a drive chip, Drv, that is used to drive the stepper motor. Two current sensing resistors are used by the drive chip to compensate for variation in coil resistance over a broad operating temperature range. In operation, the shutter moves the blade between open and close positions with no mechanical impact. The blade is held in each of the two positions only by the magnetic detent. A hard stop, S, is used to set blade position when the drive circuit initializes. The absence of mechanical stopping renders the shutter virtually silent during operation. In addition, absence of hard mechanical impacts significantly increases life of the shutter as compared to the rotary drive shutters with hard stops.

The embedded microprocessor has 8 pins. Tow pins are for power and ground and four pins interface the microprocessor to the stepper motor drive chip. On power-up, the microprocessor sequences the stepper motor to close the shutter. If the blade is not in the open position, the blade will be stopped by stop S. When the power-up sequence is completed, the stepper motor is de-energized and the detent system moves the blade to the closed position. The seventh pin on the microprocessor is used to control the shutter. The control line is pulled up to power voltage by the microprocessor. If the control line is grounded by external TTL logic, the microprocessor steps the motor through a timed sequence to move the blade to the open position. When the line is released or rises to logic-high, the stepper motor reverses the stepping sequence to close the shutter. The embedded processor has the simplest possible interface the frees higher logic from the duties of storing drive parameters and driving the shutter.

Very small stepper motor shutters can include embedded microprocessor control without compromising envelope size. Figure 9 shows two of these geared stepper motor shutters [4] that have had embedded microprocessor added, the SMSi001 and SMSi002. The stepper motor drive board has the same schematic and electrical architecture of the SMD001. The board and components have been configured to lie well outside the aperture area but within the perimeter of shutter. These shutters with embedded microprocessor do not interfere with thermal core dimensional envelope, provide the advantages of programmed motion for the shutter and include the data processing and drive.

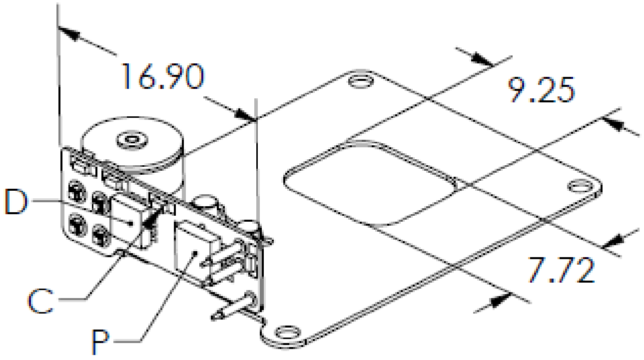


Figure 9. Geared stepper motor shutter with embedded microprocessor.

7. SUMMARY AND FORECAST

The emergence of low-cost, compact embedded microprocessor control with a simplified interface has been well received by the market. The microprocessors have embedded code that permit dynamic blade control that improves shutter performance. The microprocessors replace high-part-count, high-cost digital logic and distributes processing load onto the shutter subsystem. The next steps may be to include more intelligence at the interface so that ice using simple serial communication protocols such as SPI or I2C.

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