TND6073/D

Motor Control and Diagnostics for Automotive Adaptive Front-Lighting System (AFS)

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TECHNICAL NOTE

Abstract

Adaptive front lighting, or AFS, is a new smart automotive application gaining acceptance among car buyers, legislators and road-safety groups. By using stepper motors to adjust the headlamp position for pitch and also horizontally as the driver steers, AFS can ensure optimum night-time vision for drivers while also enhancing comfort and safety for other road users.

Controlling headlamp movement in response to inputs from various sensors around the vehicle requires motor drivers that are not only fast and accurate but also reliable and fault tolerant. Adaptive stall detection is an important diagnostic function that cannot be supported by all stepper-motor driver ICs. A driver that is capable of sensing and communicating the motor back EMF to the host controller provides the information the software needs to prevent lost steps and maintain consistent control over the headlamp position.

Introduction: Smart Technology for Safety and Comfort

Automotive Adaptive Front Lighting Systems (AFS) can help to enhance the driving experience for car owners, while improving safety for all road users including pedestrians and drivers of other cars. AFS encompasses several advanced features that augment the functionality of mandatory front lighting on today's vehicles. These include the ability for the lamps to turn with the steering, thereby improving visibility of the road ahead when cornering. In addition, the lamp position may be adjustable in the vertical plane to correct for changes in the vehicle pitch during braking or over uneven terrain, or to dip headlamps automatically when an oncoming vehicle is detected.

Such advanced capabilities are attractive both to car buyers and to legislators, and initially provide a further opportunity for vehicle manufacturers to differentiate their products from those of competitors. Over time, AFS is expected to be adopted widely; by 2015, Frost & Sullivan expects the combined market for AFS and automotive night-vision systems to exceed €900 million.

Challenges for Lighting Designers

The arrival of an important new technology such as AFS also brings opportunities for new suppliers to enter the market, and certainly demands additional technical competencies outside those normally associated with traditional lighting design. For example, additional sensors and software may be required for detection of oncoming vehicles. Moreover, motion control is an obvious technical requirement, to manage the left/right and up/down adjustment of each lamp.

In the AFS fitted to current cars, a stepper motor is used for lamp positioning. This is the preferred solution for achieving smooth and progressive movement, with suitable response time and high accuracy. If a small steering input is detected, the stepper motor can be instructed to rotate by a small number of steps to align the lamps with the direction of the vehicle. If the steering sensor indicates a large change, the motor can be instructed to move a larger number of steps as appropriate.

Figure 1 shows the typical architecture of a stepper motor controller. Application software hosted on the microcontroller generates instructions for moving the lamps, in response to information from various sensors such as steering position, speed, pitch and oncoming vehicle. The driver IC is responsible for translating the microcontroller output into the PWM waveforms needed to drive the stepper motor to the desired position. A variety of controllers are available, offering micro-stepping accuracy and containing an integrated power stage capable of generating peak current in the region of 1 A or more.

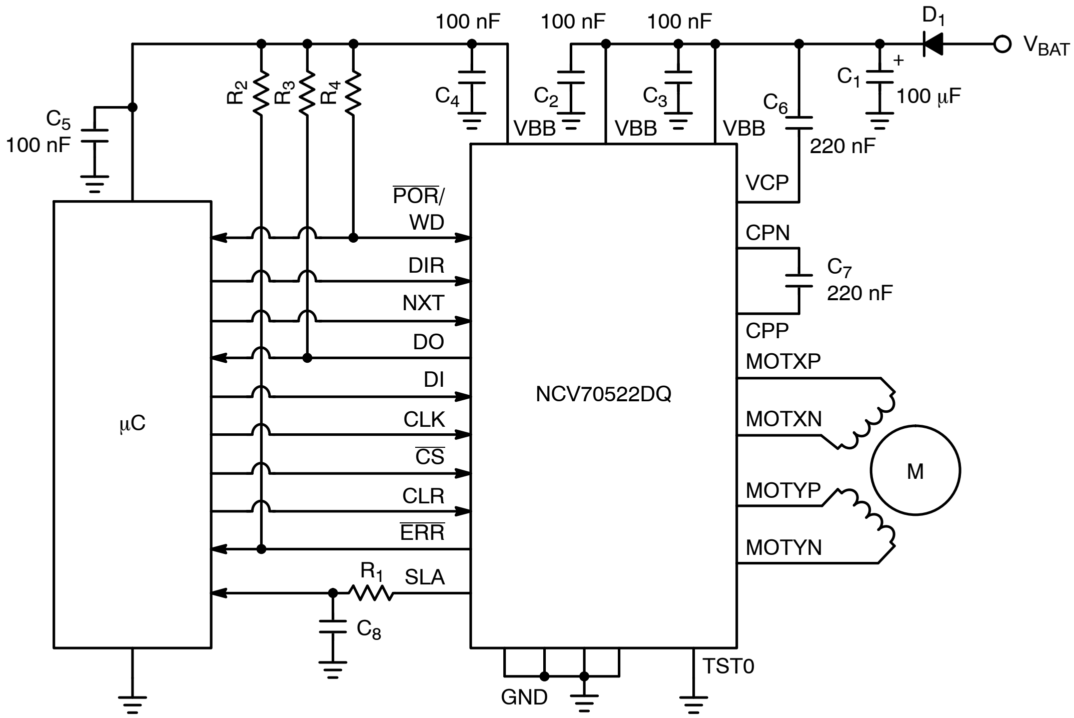

Figure 1. Typical Architecture of Stepper Motor Controller

In addition to ensuring correct behaviour of the motor under normal operating conditions, an important control challenge facing AFS designers is to deal with the possibility that the motor may become stalled if the movement of the lamp becomes restricted for any reason. In such an event, the motor controller cannot be allowed to 'lose steps', as this will subsequently prevent accurate lamp positioning causing uncomfortable and potentially unsafe driving conditions.

Stall detection is a familiar feature of stepper motor drivers. It prevents the controller from losing steps, by detecting the onset of a stall condition and quickly cutting the drive signal to the motor. From this point the controller can attempt to restart the motor and drive it to the desired position. The capabilities required of a suitable stall-detection system for AFS applications can be assessed by first analyzing the principles of stall detection.

The negative electromotive force (EMF), or back EMF (BEMF), generated by the movement of the rotor through the motor's magnetic field is a function of the number of rotor windings, the magnetic flux of the field, and the rotor speed. Because the number of windings and the magnetic flux are constant for a given motor, the BEMF is a good indication of the rotor speed. If the motor becomes obstructed, its speed decreases resulting in a corresponding fall in the BEMF. Hence sensing the BEMF provides information needed to detect if the motor has stalled or not, noting that the effects of motor load and supply voltage must also be taken into consideration.

Stepper Motor Drivers for AFS

Typical general-purpose drivers with built-in stall detection do not provide a BEMF output. The designer can configure the stall-detection parameters only by setting the thresholds in an internal register. This requires all settings to be predefined 'offline' before the system is operated under real road conditions, and hence takes away the ability to adapt and fine-tune the system for its intended application. For example, since the BEMF is dependent on load, which can change at higher speeds due to increased wind resistance, the system must be able to vary parameters in order to allow the AFS to maintain consistent stall-detection accuracy as operating conditions change. Hence a general-purpose driver is not necessarily suited to use in AFS applications.

A driver such as the ON Semiconductor NCV70522 provides an indication of the motor back EMF at an external output called the Speed and Load-Angle (SLA) pin. The analogue signal at this pin provides information enabling the application to perform stall detection in real-time and to adapt the detection levels according to changes in driving conditions. The application is also able to adjust the motor torque and speed based on the motor BEMF.

The NCV70522 is a micro-stepping driver that contains two full H-bridge outputs for driving X and Y coils of a bipolar stepper motor. It is suited to use in automotive, industrial, medical and marine applications, and is fully compatible with automotive voltage and temperature requirements.

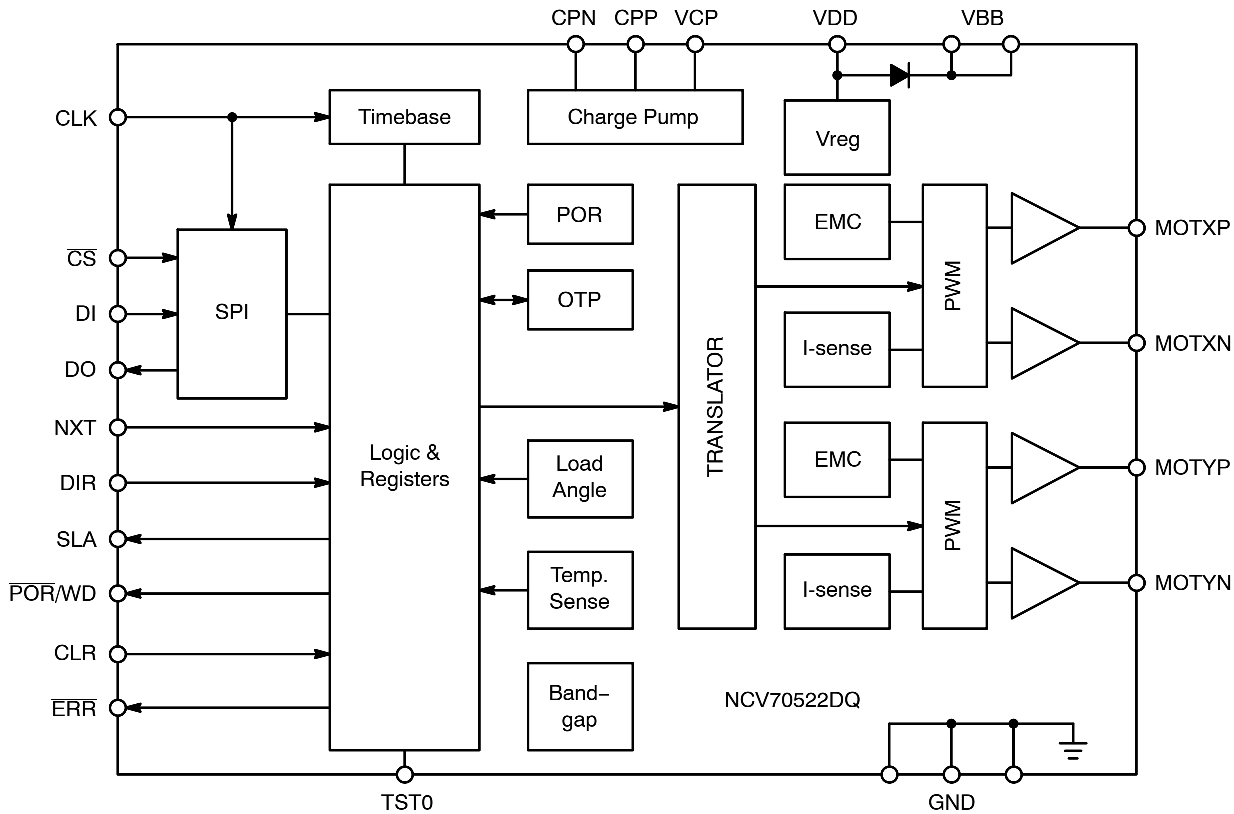

Figure 2. Block Diagram of NCV70522

Figure 2 shows the functional blocks of the driver, which is fabricated using the I2T100 process technology, enabling both high-voltage analogue circuitry and digital functionality on the same chip. The IC is connected to an external microcontroller using the I/O pins and SPI interface shown in the diagram. It provides seven step modes from full-step up to 32 micro-steps as directed by settings in the SPI CR0 register. The motor-drive voltages are generated with reference to an internal current-translation table, causing the motor to take the next micro-step depending on the clock signal on the "NXT" input pin and the status of the direction register [DIRCTRL] or the IC's DIR input pin.

The moment the system is powered on, the microcontroller is initialized and the NCV70522 driver is reset. Next, the coil current and stepping mode are set and the motor driver is enabled. The NXT pulse will be sent to turn the motor. Rotation speed of the motor equals NXT pulse frequency multiplied by value of the stepping mode. Figure 3 illustrates a flow chart for a stepper motor controller for an AFS implemented using this device.

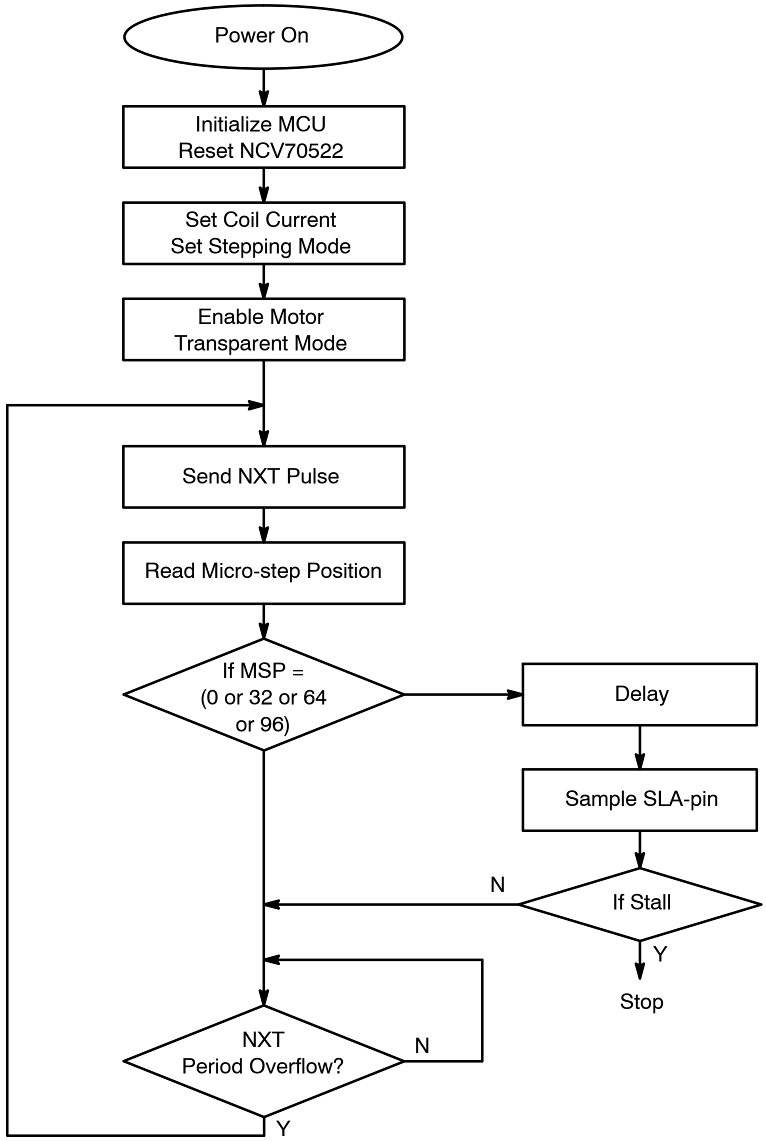

Figure 3. Flow Chart for Stepper Motor Driving

Stall Detection in Detail

As can be seen from Figure 3, the driver has a user-selectable "transparent" mode, which is selected or disabled after power-up and before beginning to generate motor-driving signals. Setting the SLAT bit to 1, in SPI control register CR2, puts the controller into transparent mode, which provides full visibility of the BEMF voltage at the SLA pin. However, this can result in a relatively complex BEMF signal at the SLA pin since the relatively high re-circulation current in the coil during current decay produces a transient behaviour in the coil voltage V_{COIL}. A smoother BEMF input, which helps simplify application processing, is achieved by setting the SLAT bit low to select non-transparent mode. In this case, the BEMF is sampled only when no current is flowing through the coils; that is, at the end of each coil current zero crossing.

In order to convert the sampled BEMF to a suitable output voltage in the range 0–5 V, the sampled coil voltage V_{COIL} is divided by two or by four. This divider is set through the SLAG bit of the SPI CR2 register.

Figure 4 illustrates the operation of the SLA pin and the transparency bit, SLAT. "PWMsh" and "Icoil=0" are internal signals. Together with the SLAT bit, these define the sampling and hold moments of the coil voltage.

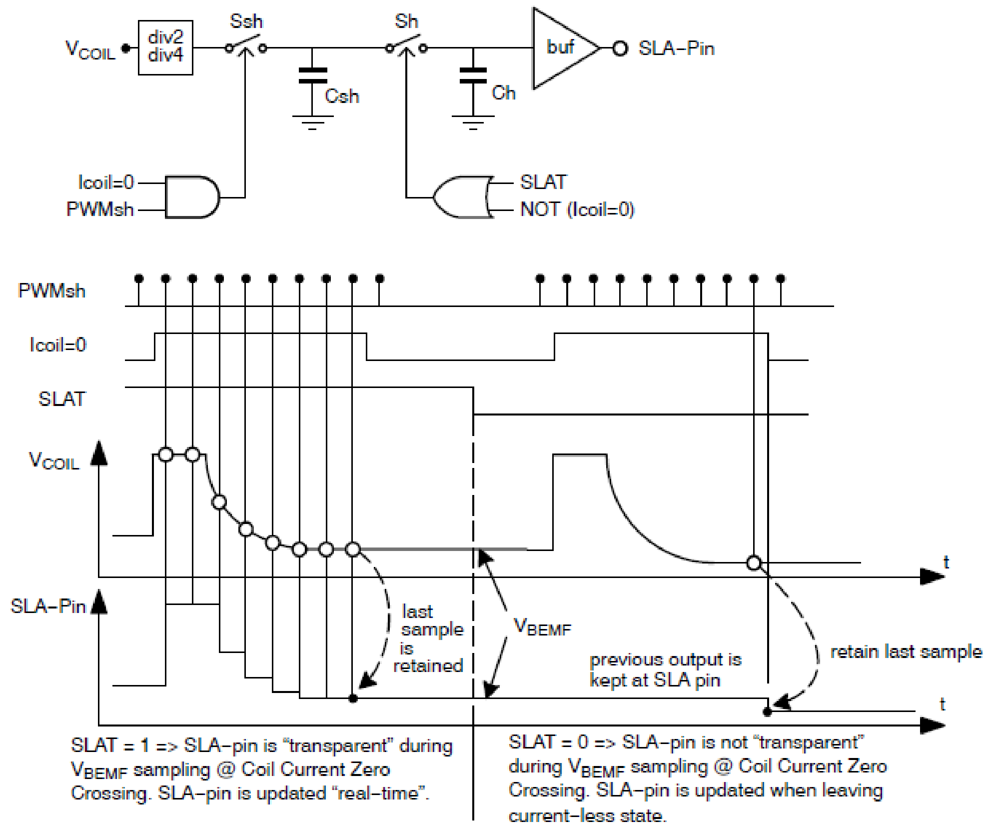

Figure 4. Timing Diagram of SLA-pin

For each coil, two zero-current positions exist per electrical period, yielding a total of four zero-current observation points per electrical period. Hence the BEMF can be measured four times per electrical period. The BEMF voltage will only be sampled by the motor driver if a micro-step position is located on the coil current zero crossing. The micro-step position can be read by SPI. Through software, it is possible to judge whether the motor has become stalled based on the four SLA samples gathered during each electrical period.

Figures 5 and 6 compare the voltage seen at the SLA pin under normal conditions and when the motor is stalled. A stall condition can be identified reliably if the voltage at the SLA pin is below 1.5 V for at least two samples in every four coil-current zero crossings.

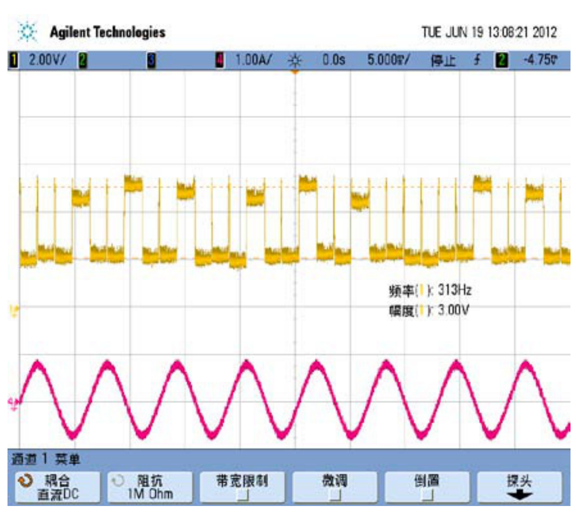

Figure 5. SLA Sampling during Normal Motor Operation

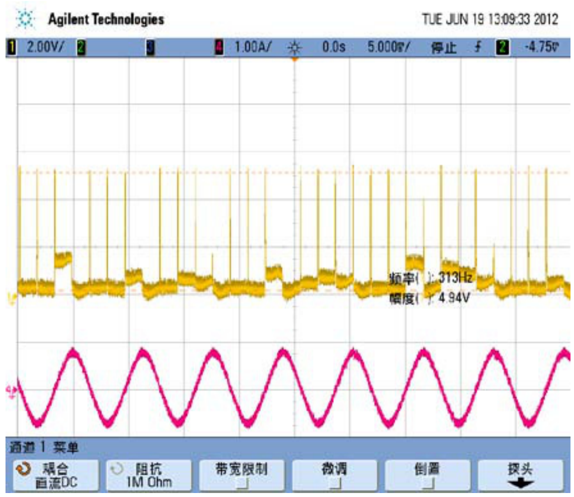

Figure 6. SLA Sampling when Motor is Stalled

Conclusion

Offering the prospect of improved vision during night-time driving, automotive AFS has positive implications for road safety and driver comfort. Customer demand is expected to increase across market sectors, creating opportunities and challenges for established vehicle lighting suppliers and new entrants. Important challenges lie in the need to develop reliable and economical motor drives that are suited to the AFS application, most importantly in the implementation of stall detection for consistent headlamp positioning. This requirement for robust stall detection, capable of self adjustment to maintain accuracy over wide-ranging operating conditions, calls for the use of stepper motor drivers that are capable of feeding back the motor BEMF voltage to a self-learning stall-detection algorithm contained in the application software.

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