Operating an Engine-Grille Shutter Motor With DRV8872-Q1

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ABSTRACT

The addition of an active grille shutter is a key aerodynamic improvement in recent model-year vehicles. Depending on the ambient temperature of the environment, the shutters behind the engine grille can open and close to increase the engine efficiency and reduce turbulent air from entering the engine, thereby reducing drag. The shutters can be operated by a brushed DC (BDC) motor. A suitable device for such an application is Texas Instruments' DRV8872-Q1 BDC motor driver. This application report provides a detailed overview of how the DRV8872-Q1 device can be used to design a circuit to operate an engine-grille shutter motor.

Contents

1 Grille Shutter System Overview 2
2 Internal Current Regulation With DRV8872-Q1 3
3 Circuit Design for Grille-Shutter Application 3
4 Grille Shutter Motor-Current Profile 5
Appendix A Glossary 7

List of Figures

1 Air Flow With Grille Shutter Open and Closed 2
2 Active Grille Shutter Operation 2
3 Internal Current-Chopping Timing Diagram 3
4 Typical Stall-Detection Circuit 4
5 Motor Phase-Voltage Profile 4
6 Motor-Current Profile 5
7 Forward Direction Motor Stalling 5
8 Reverse Direction Motor Stalling 6

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1 Grille Shutter System Overview

When the engine-grille shutters open, air is allowed to flow through the radiator and into the engine compartment for faster cooling of the engine. But when that cooling air is not needed, the shutters close, as determined by the engine control unit (ECU), which reroutes air around the vehicle creating less turbulence than what would otherwise exist if the air was to flow through the vehicle. The reduced turbulence lessens the aerodynamic drag by up to 6%, increasing fuel economy and reducing carbon-dioxide emissions by up to 2%.

Figure 1. Air Flow With Grille Shutter Open and Closed

As an added advantage, the closed shutters also reduce engine warm-up time in cold weather by stopping air from entering the engine on cold days. This advantage allows the engine to run more efficiently, heating to the optimal operating temperature faster, and warming up the interior of car quicker. Figure 2 shows an active grille shutter typically found in most modern vehicles.

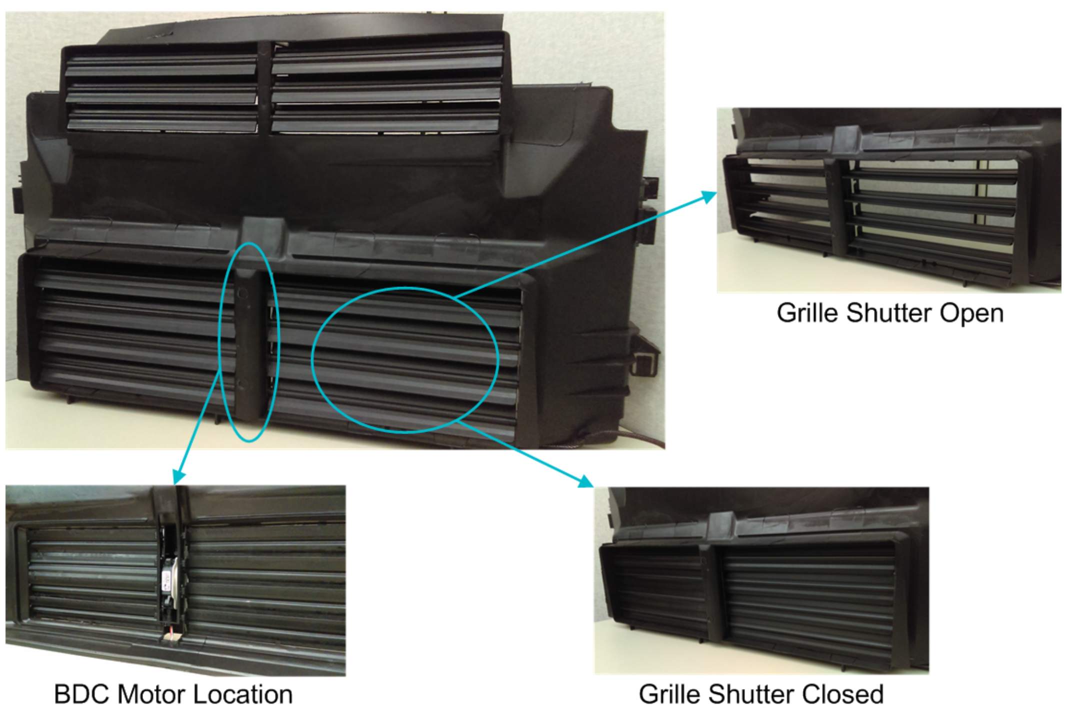

Figure 2. Active Grille Shutter Operation

The brushed DC motor used to operate the shutters would have a peak current rating of approximately 1 A. The DRV8872-Q1 motor driver is a suitable device support this requirement. The device can be used to regulate motor current around 1 A by following the process described in Section 2.

2 Internal Current Regulation With DRV8872-Q1

The DRV8872-Q1 device features current regulation that restricts the motor current to a preset maximum. This restriction is achieved by appropriately sizing an external sense resistor (R_{SENSE}) on the ISEN pin. Use Equation 1 to calculate the current trip level (I_{TRIP}).

$$I_{TRIP}\ (A) = \frac{V_{trip}}{R_{SENSE}} \quad (1)$$

The voltage trip level (V_{trip}) for the device is internally set to 0.35 V (nominal). Select the current-chopping limit of 900 mA which is close to what a grille-shutter BDC motor would receive for peak current.

$$R_{SENSE} = \frac{V_{trip}}{I_{TRIP}} = \frac{0.35\ V}{0.9\ A} = 0.388\ \Omega \quad (2)$$

Use Equation 3 to calculate the power dissipation (P_D) for the R_{SENSE} resistor.

$$P_D\ (R_{SENSE}) = I^2R = (0.9)^2 \times 0.388 = 0.315\ W \quad (3)$$

Therefore, a resistor with these specifications should be appropriate for regulating current in this application. An industry-standard part could be a 0.39-Ω, ½ W resistor in a1206 or larger package.

When the I_{TRIP} threshold is reached the device stops driving the motor and enforce slow decay through the low-side MOSFETs. The motor will be in slow decay for typically 25 µs (t_{OFF} time) and, after t_{OFF} has expired, the outputs will be re-enabled to operate the motor for a drive time ($t_{(DRIVE)}$) until the I_{TRIP} threshold is reached. Figure 3 shows the timing diagram for this operation.

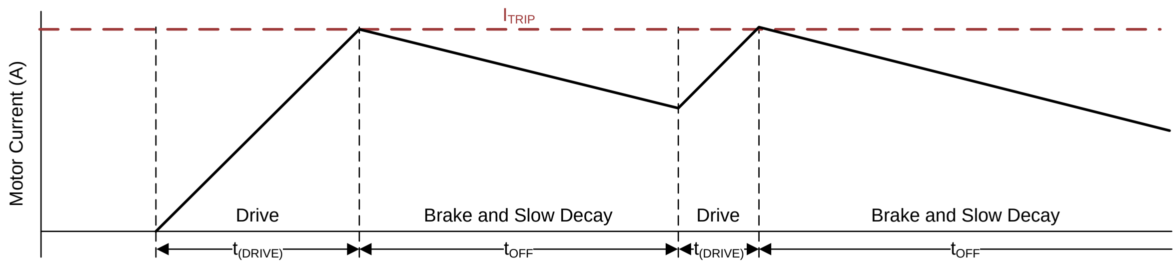

Figure 3. Internal Current-Chopping Timing Diagram

The drive time of the motor ($t_{(DRIVE)}$) primarily depends on the supply voltage, motor inductance, and the back-EMF generated by the motor. For more details about the device, refer to *DRV8872-Q1 Automotive 3.6-A Brushed DC Motor Driver With Fault Reporting* (SLIS175).

3 Circuit Design for Grille-Shutter Application

The block diagram in Figure 4 shows a basic circuit that can be implemented to operate the grille shutters. The DRV8872-Q1 device receives command from the microcontroller unit (MCU) through the IN1 and IN2 lines and drives the BDC motor. The value of the R_{SENSE} resistor, connected to the ISEN pin, is selected based on the calculations in Section 2. The Zener diode is optional but recommended to clamp the node to 3.6 V.

If the source of the power supply is the vehicle battery, instances of load dump could occur for which the Zener diode will be required, especially if the MCU has 3.3-V rated digital I/O pins. Without the Zener diode, the MCU I/O pin can receive a higher voltage that can potentially damage the MCU.

NOTE: The resistor values for R1 through R4, in Figure 4, have been selected for a regulated power supply (VBATT) of 13.5 V.

The phase voltages of the motor will be approximately 0 V and battery voltage depending on which direction the motor is rotating. The R2 resistor is in parallel with the R3 and R4 resistors so the voltage between at the node between R1 and R2 becomes 4.5 V. This voltage gets further scaled down by the resistor divider network of R3 and R4 to bring the nSTALL node voltage to 3.15 V, as shown by Equation 4.

$$V_{nSTALL} = \left(\frac{R2 \,||\, [R3 + R4]}{\left[R1 + \left(R2 \,||\, [R3 + R4]\right)\right]} \right) \times 13.5\text{ V} \times \left(\frac{R3}{R3 + R4} \right) = 3.15\text{ V} \tag{4}$$

If the power supply is significantly higher than 12 V, for example 24 V (which is within the operating supply range of the device), the voltage at the nSTALL node, without the Zener diode, becomes 5.6 V. Such a high voltage can damage the MCU and, therefore, the resistors, R1–R4, should be sized appropriately to meet the maximum allowable voltage at the I/O pin of the MCU, in addition to placing the Zener diode.

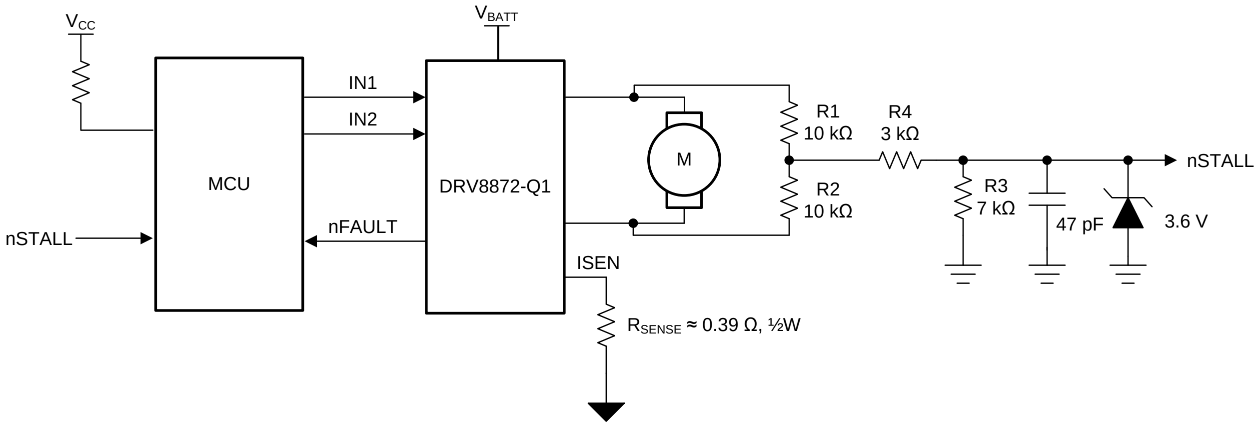

Figure 4. Typical Stall-Detection Circuit

When the motor is running, the voltage at each motor phase is monitored by the MCU, after some signal conditioning, for a motor stall condition. The voltage profile at the nSTALL node will be similar to the profile in Figure 5.

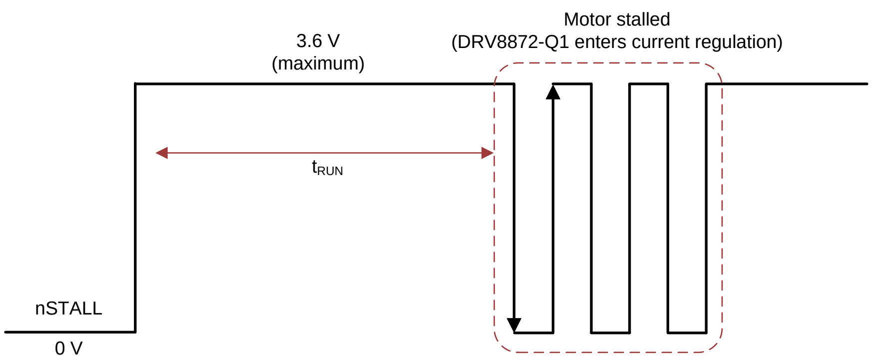

Figure 5. Motor Phase-Voltage Profile

When the MCU identifies the voltage profile at the nSTALL node to be similar to the highlighted portion in Figure 5, the motor has stalled. One way to identify the voltage profile is to trigger an interrupt in the MCU at the first falling edge of the nSTALL node after the motor has been running for the t_{RUN} time. The MCU can then measure the time interval between the first falling edge to the next rising edge and compare it to the t_{OFF} time of the device. If this time interval is less than t_{OFF} equal to 25 µs (with about 10% tolerance), it can be concluded that the motor has stalled. At this point, the MCU must shut off or change the rotational direction of the motor.

The current profile of the motor moving in a given direction (for example, in reverse drive) during this process will look similar to profile in Figure 6. For motor rotation in the opposite direction (for example, forward drive) the profile is inverted. Section 4 includes application graphs for motor motion in both clockwise and counter-clockwise directions.

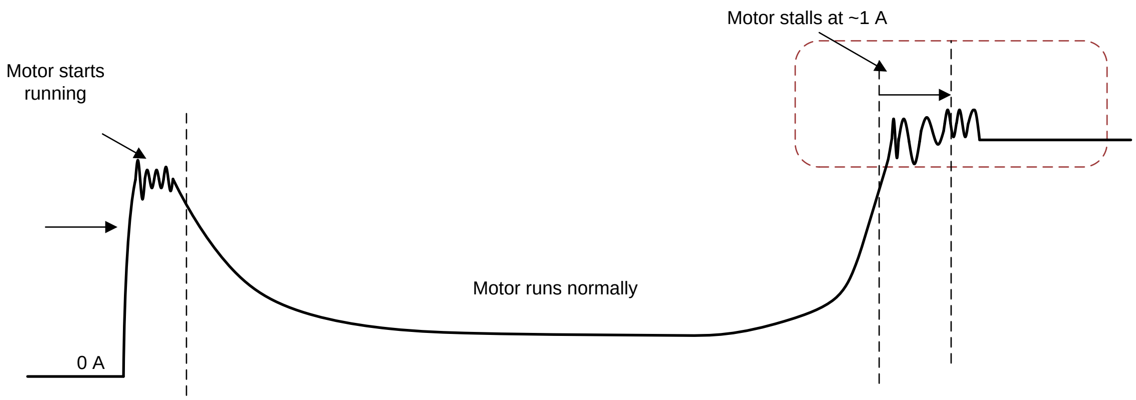

Figure 6. Motor-Current Profile

An inrush of current occurs initially to start the motor. Following that inrush, the current flowing through the motor windings decays to an rms value while the grille shutter is in motion. When the shutters are completely open or closed, the motor stalls at a peak current of approximately 1 A.

4 Grille Shutter Motor-Current Profile

Figure 7 shows current flowing through the motor in forward drive, and the voltage profile at the nSTALL node. The steady-state DC current is approximately 375 mA. As the current flowing through the motor increases above 800 mA, the device starts to perform current regulation. The stall-detection circuit toggles between logic levels 0 and 1 at the nSTALL node, indicating to the MCU that the motor has stalled. The zoomed-in plots show the motor-current profile during start-up and stall.

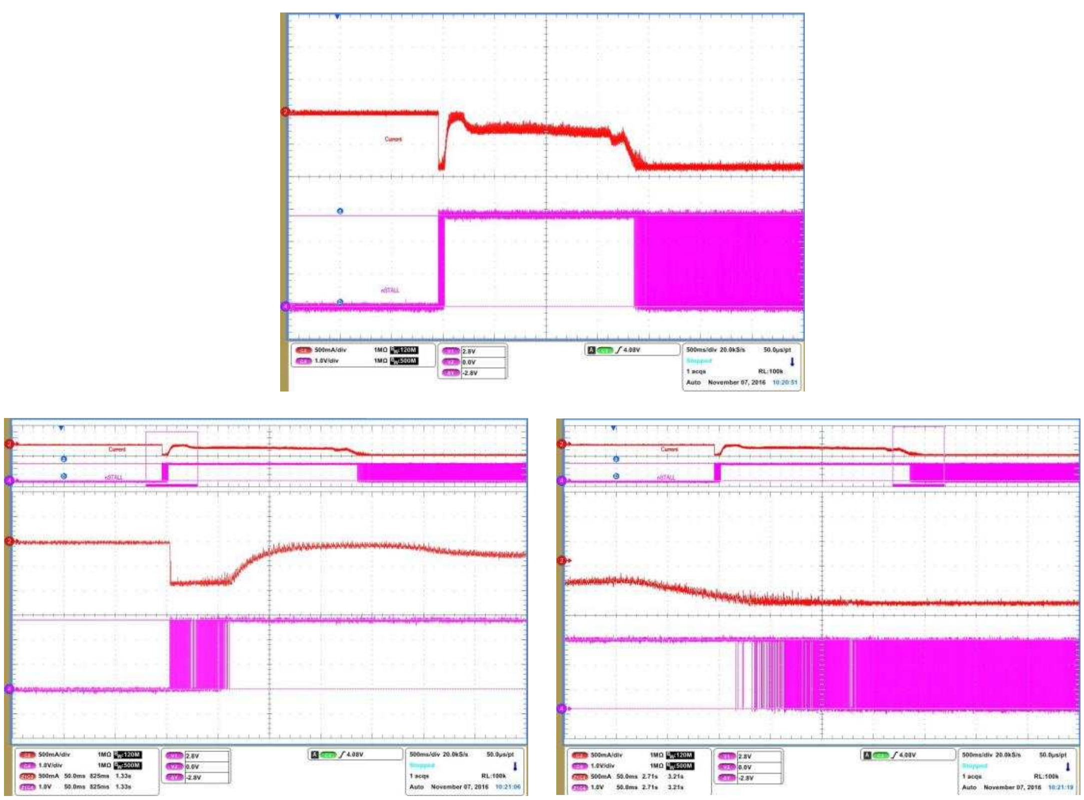

Figure 7. Forward Direction Motor Stalling

Figure 8 shows current flowing through the motor in reverse drive, and the voltage profile at the nSTALL node. The peak current is limited by the R_{SENSE} resistor to approximately 800 mA.

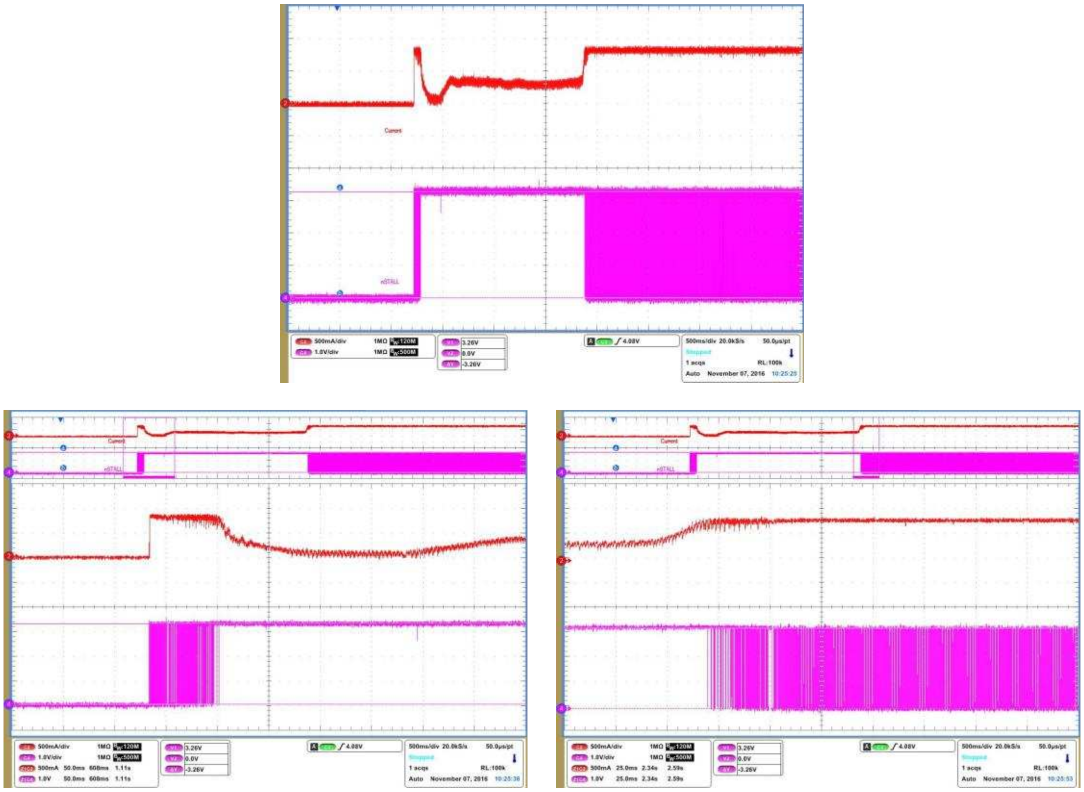

Figure 8. Reverse Direction Motor Stalling

Based on these plots, the DRV8872-Q1 device is concluded to be able to drive the BDC motor for an engine-grille shutter. The stall-detection circuit (Figure 4) also provides accurate information to the host MCU regarding motor stall which prevents the device from over driving the motor.

Glossary

A.1 Nomenclature Used in this Document

The following acronyms and initialisms are used in ths document:

BDC — Brushed DC

ECU — Engine control unit

IC — Integrated circuit

MCU — Microcontroller unit

MOSFET — Metal-oxide semiconductor field-effect transistor

OCP — Overcurrent protection

PWM— Pulse width modulation

For a more comprehensive list of terms, acronyms, and definitions, refer to the *TI Glossary* (SLYZ022).

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