Application Information

Fully Integrated Hall Effect Motor Driver for Brushless DC Vibration Motor Applications

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Vibration motors are used in a variety of applications including mobile phone handsets, game joysticks, handheld video games, pagers, toothbrushes, and razors to name just a few. Of particular interest is the mobile handset market, as global production volume is expected to be greater than 1 billion handsets in 2007. The handset market has driven innovation in the design and manufacturing techniques of miniature vibration motors. Smaller handsets demand motors that consume less PCB area, and require a thin motor design. Motor features for caller ID vibration tones, and gaming applications are also being added to handsets. This paper will discuss an advanced Hall-effect technology Allegro® MicroSystems A1442 brushless direct current BLDC motor driver ideally suited to deliver advanced handset vibration motor functionality.

Vibration Motor Designs

Most vibration motors consist of a small electrical motor that drives an unbalanced weight, as shown in figure 1. The motors are direct current (DC) brush or brushless motors, and are configured in two basic varieties: *coin* (or *flat*) and *cylinder* (or *bar*).

Cylinder type motors are simple brush motors with a traditional axial design, as shown in figure 2.

Cylinder motors are employed in a variety of applications but are undesirable in mobile handset applications due to their large size. The cylinder type motor demands the most volume within the handset, and often the largest diameter space of all vibration motors.

All brush motors create sparks at the commutation points, as the brushes switch the current in the motor coils. These sparks are excellent transmitters of broadband radio frequency interference (RFI). Brushes wear out and prove to be the major cause of motor failure.

The need for smaller, thinner designs led to the adaptation of brush motor technology into the coin-type motor, like that shown in figure 3. The commutator points that are in contact with the brushes energize the electrical coils in the rotor.

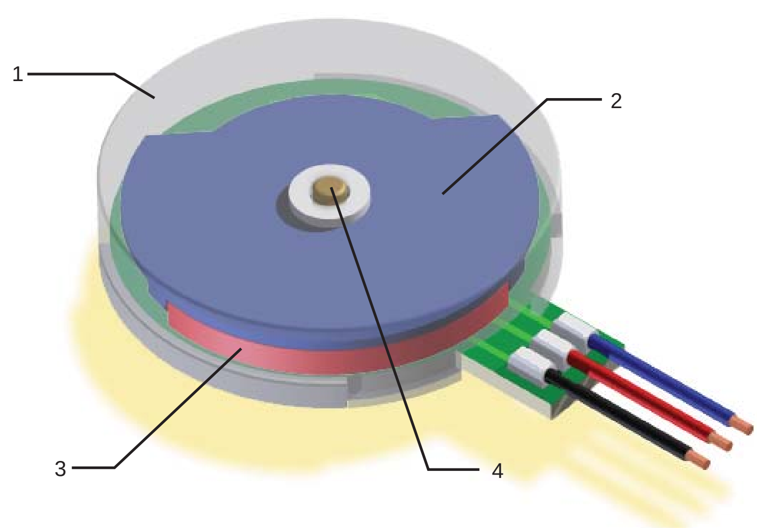

Figure 1. Coin-type vibration motor. A relatively flat eccentric weight spins in a protective enclosure. (1) enclosure, (2) rotor base, (3) weight, (4) shaft.

Energizing the coils establishes a magnetic field strong enough to interact with the ring magnet integrated into the stator, causing rotation.

As shown in figure 3, the commutation points are arranged in alternating polarity pairs, so as the rotor moves, the coils are constantly reversing polarity as they pass over commutation points. In this way the motor continually rotates, and at a speed that is proportional to the applied voltage. The more complex brushes in coin designs are generally less reliable than their equivalent brush cylinder motors.

Brushless Vibration Motors

As discussed, brushless motors bring extended motor life and eliminate RFI by their lack of sparks. BLDC designs are also providing the smallest diameter and thinnest coin-type motors in

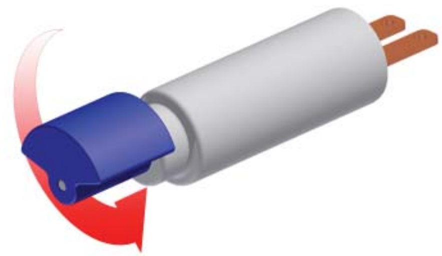

Figure 2. Cylinder (bar) type vibration motor with an external weight spinning perpendicular to the body.

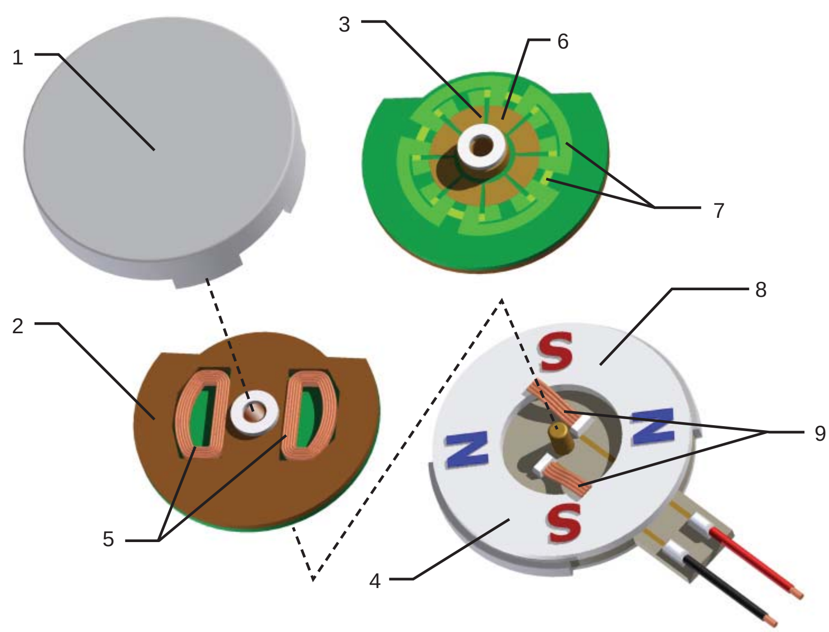

Figure 3. Brush coin-type vibration motor exploded view. (1) enclosure top, (2) rotor (view as mounted), (3) rotor (inverted view), (4) enclosure bottom, (5) coils, (6) commutation points, (7) alternating power supply circuits, (8) ring magnet (showing representative polar zones), (9) power supply brushes.

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the industry. Figure 4 illustrates the basic construction of such a motor.

In this design, the rotor assembly includes the magnet as well as the weight that provides the vibration during rotation. The relatively bulky coils are moved to the stator, where they are connected to the controlling IC.

Digital commutation and linear soft-switching eliminates the sparks and therefore RFI interference. The fully integrated A1442 Hall effect device and precision amplifier are coupled to an internal full bridge output through comparator circuitry that determine the proper commutation points. The third wire shown in the motor of figure 4 is optional, connecting to an enable pin on the A1442 that can be used to control the active braking and sleep functions. This third wire can be eliminated by tying the IC pin to V_{CC} on the PCB.

The A1442 is the only IC necessary to drive the motor. The functional block diagram in figure 5 illustrates the device operation and advanced features. Notice in figures 4 and 5 that the integrated Hall element eliminates the need for an external Hall element, and thereby reduces the motor PCB component count to just the A1442. The only external component required is a standard circuit feature, a 0.1 µF bypass capacitor located on the application motor mount PCB, used to minimize voltage spikes on the supply that are generated when switching an inductive load.

Soft-Switching and Commutation

When the device powers-up, it senses the magnetic field and activates the bridge. The active transistors are set according to the magnetic pole. A south polarity magnetic field activates the output transistors Q1 and Q4, driving current from V_{OUT1} to

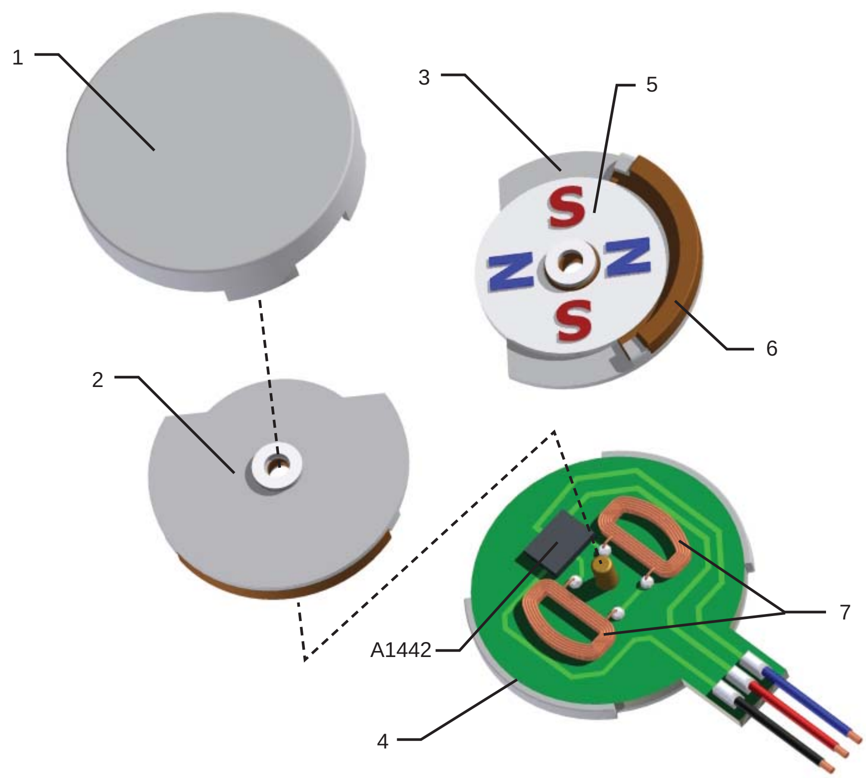

Figure 4. Brushless coin-type vibration motor exploded view. Brushes and commutation contacts are replaced by a Hall effect sensor IC (Allegro MicroSystems A1442 shown), and coils are relocated to the stator. (1) enclosure top, (2) rotor (view as mounted), (3) rotor (inverted view), (4) enclosure bottom, (5) ring magnet (showing representative polar zones), (6) eccentric weight, (7) coils.

V_{OUT2}. As a north polarity magnetic pole approaches (due to rotation), Q1 and Q4 are turned off and Q2 and Q3 are turned on. This drives current from V_{OUT2} to V_{OUT1}, thereby reversing the direction of current flowing in the coils.

Motor designs vary, but maximum rpm ranges from 9000 to 15000 rpm. Most designs employ a 4-pole rotor magnet, with a few designs using 6-pole magnets. Using these parameters, it is easy to calculate the commutation switching frequency (f_{CS}, Hz) using the following formula:

$$f_{CS} = RPM \times PP / 60 \ ,$$

where PP is the quantity of pole-pairs. For a 4-pole magnet at 9000 rpm, f_{CS} is 300 Hz, and for a 6-pole magnet at 15000 rpm, it is 750 Hz. Thus, the commutation signal and coil current switching events occur in the audible frequency range. The soft-switching drive algorithm is optimum for minimizing the audible noise and EMI produced by switching the inductive motor coil load by gradually reducing and then reversing current in the coils. The timing diagram in figure 6 illustrates the switching behavior.

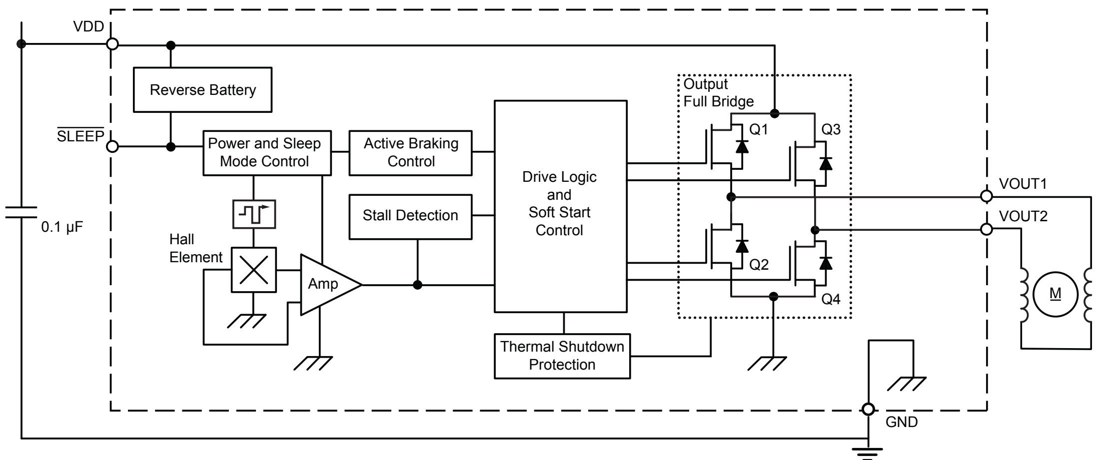

Figure 5. A1442 BLDC vibration motor driver functional block diagram.

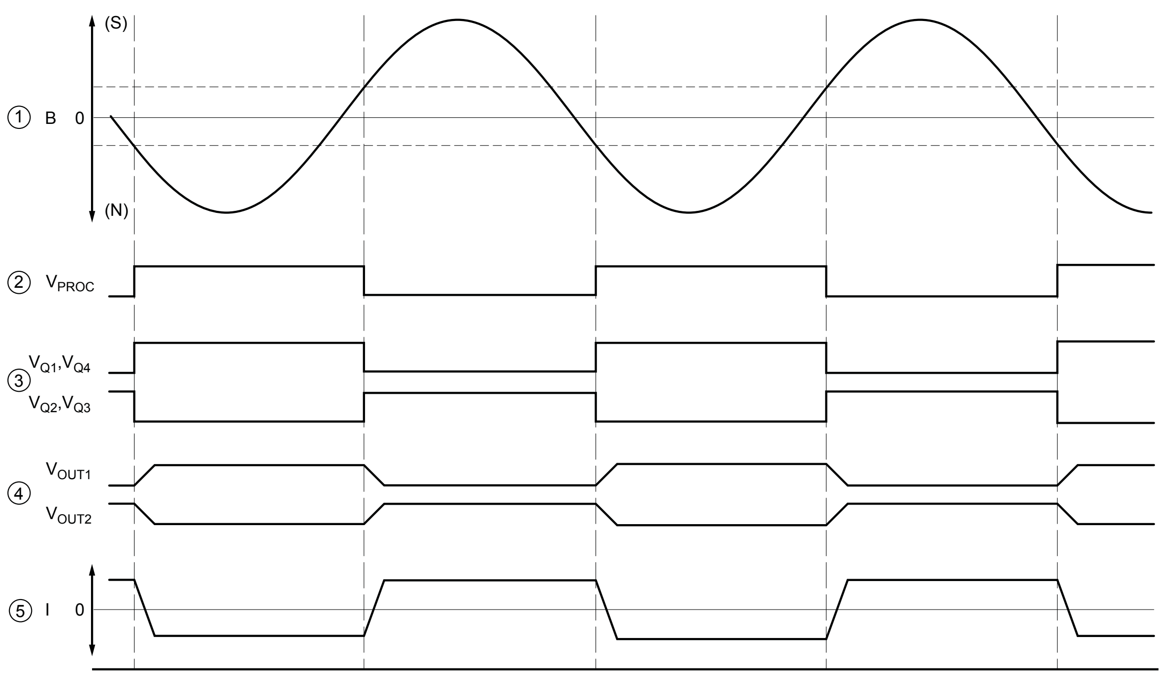

Figure 6. A1442 BLDC vibration motor driver timing diagram. (1) rotor magnet field sensed by A1442, (2) Hall circuitry internal signal for commutation, (3) full bridge activation signals, (4) A1442 output, (5) induced motor coil current.

Active Braking, Sleep Mode, and Anti-Stall

The Allegro A1442 has an integrated active braking function that can be used for fast stop-start cycling. Fast stop-start cycles are useful in mobile handsets for vibration ring tones, caller ID when the phone is in silent mode, and for gaming applications. The braking function is activated using the $\overline{\text{SLEEP}}$ pin, shown in figure 5.

When a low signal is applied to the $\overline{\text{SLEEP}}$ pin, the A1442 initiates the active braking function, by reversing the polarity of the output bridge and thereby the current direction through the motor coils. The effect of reversing the current, and therefore the field, is to apply force to rotate the motor in the reverse direction, which will quickly decelerate the motor. After braking the A1442 enters sleep mode by shutting down the active circuitry of the IC.

During sleep mode, the current consumption of the IC is typically less than 1 μA. The $\overline{\text{SLEEP}}$ pin can eliminate a FET transistor on the customer PCB that would otherwise be necessary to switch power to the motor on and off; as a result, the motor can be permanently connected to the battery.

If the motor stalls, the A1442 will initiate an anti-stall algorithm. When a stall event occurs, the outputs will be continually turned on and off to restart the motor. The on-off cycles generate torque cycles that shake the motor and improve the probability of a start. It also prevents continuous stall current that can damage the motor coils.

Protection and Ultra Thin Packaging

Reverse battery protection is incorporated onto the A1442 to protect the device in case the motor wires are inadvertently soldered backwards on the PCB, making rework possible.

If the outputs of the coil are inadvertently shorted when the device is powered-on, the A1442 has thermal shutdown protection that will disable the outputs as the IC heats up. The reverse battery protection feature and thermal shutdown have proven to be very robust features for assembly plants and for rework at OEM board assembly.

With the advent of very thin designs, such as the Motorola® MOTORAZR™ phone, the thickness of the vibration motor has become an important selling feature. The Allegro A1442 device is available in one of the world's thinnest MLP packages. With present finished motor thickness trending toward 1.5 mm and below, additional design flexibility is obtainable using the Allegro EW package, an MLP (DFN) with an overall package height of 0.4 mm maximum, and length and width dimensions of only 1.5 mm × 2.0 mm. The A1442 EW package is shown in figure 7.

Summary

The A1442 is a full-bridge motor driver designed to drive low-voltage, brushless DC (BLDC) motors. Commutation of the motor is achieved by use of a single Hall element to detect the rotational position of an alternating-pole ring magnet. The device integrates all the necessary electronics. This includes the Hall element circuit used for commutation, the motor control circuitry, and the full output bridge.

This fully integrated single chip solution provides enhanced reliability (including reverse battery protection and output short circuit protection) and eliminates the need for any external support components besides the standard external 0.1 μF bypass capacitor.

The A1442 employs a soft-switching algorithm to minimize audible switching noise, and RFI and EMI interference. An active braking function is available on a third pin that can be used for fast stop-start cycles for caller ID and gaming functions. The third pin also enables a micropower sleep mode to reduce current consumption for battery management in portable electronic devices. The small footprint and low profile EW package enables extremely thin motor designs.

The Allegro A1442 BLDC motor driver is ideally suited to deliver advanced features and packaging in vibration motor applications in portable handsets and other products such as pagers, handheld video game controllers, electronic toothbrushes, and razors.

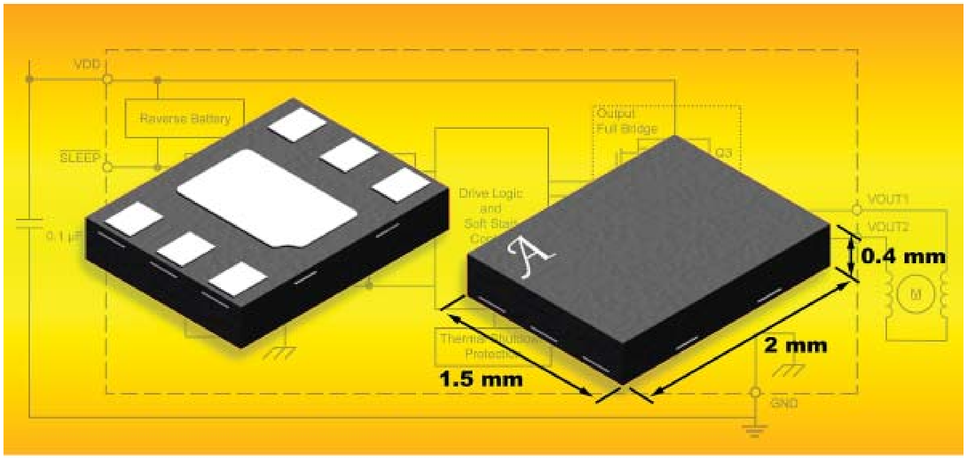

Figure 7. A1442 in EW package.

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