Driver for DC Motors (ERMs) and Linear Vibrators (LRAs) with Ultra-Fast Turn-On

Check for Samples: DRV8601

FEATURES

- **High Current Output: 400 mA**
- **Wide Supply Voltage (2.5 V to 5.5 V) for Direct Battery Operation**
- **Low Quiescent Current: 1.7 mA Typical**
- **Fast Startup Time: 100 µs**
- **Low Shutdown Current: 10 nA**
- **Output Short-Circuit Protection**
- **Thermal Protection**
- **Enable Pin is 1.8 V Compatible**
- **Available in a 2 mm x 2 mm MicroStar Junior™ BGA Package (ZQV)**

APPLICATIONS

- **Mobile Phones**
- **Portable Media Players**
- **PDAs**
- **Gaming Consoles**

DESCRIPTION

The DRV8601 is a general-purpose single-supply driver designed to drive a DC motor (also known as Eccentric Rotating Mass or ERM in haptics terminology) or a linear vibrator (also known as Linear Resonant Actuator or LRA in haptics terminology) using a single-ended PWM input signal. With a fast turn-on time of 100 µs, the DRV8601 is an excellent haptic driver for use in mobile phones and other portable electronic devices.

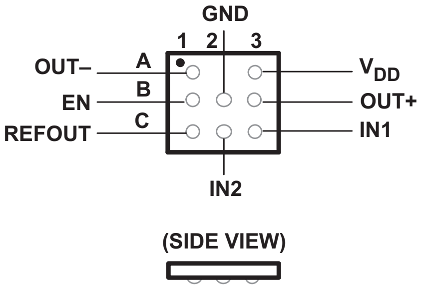
The DRV8601 drives up to 400 mA from a 3.3 V supply. Near rail-to-rail output swing under load ensures sufficient voltage drive for most DC motors. Differential output drive allows the polarity of the voltage across the output to be reversed quickly, thereby, enabling motor speed control in both clockwise and counter-clockwise directions, as well as quick motor stopping.

A wide input voltage range allows precise speed control of both DC motors and linear vibrators.

With a typical quiescent current of 1.7 mA and a shutdown current of 10 nA, the DRV8601 is ideal for portable applications.

The DRV8601 has thermal and output short-circuit protection to prevent the device from being damaged during fault conditions.

MicroStar Junior™ (ZQV) PACKAGE
(TOP VIEW)



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

SELECTED APPLICATION DIAGRAMS

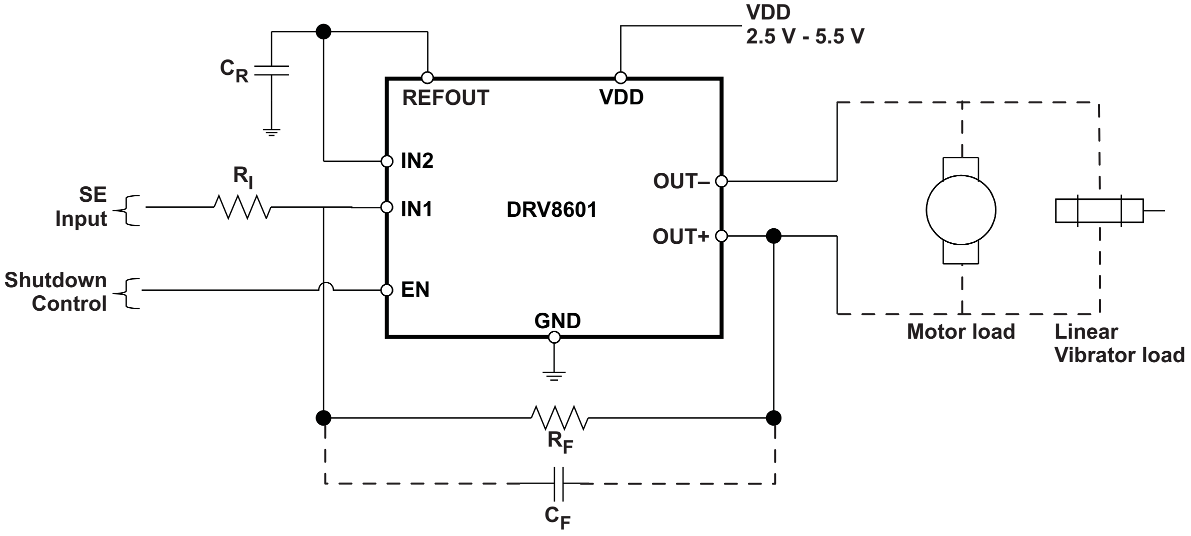


Figure 1. Pseudo-Differential Feedback with Internal Reference

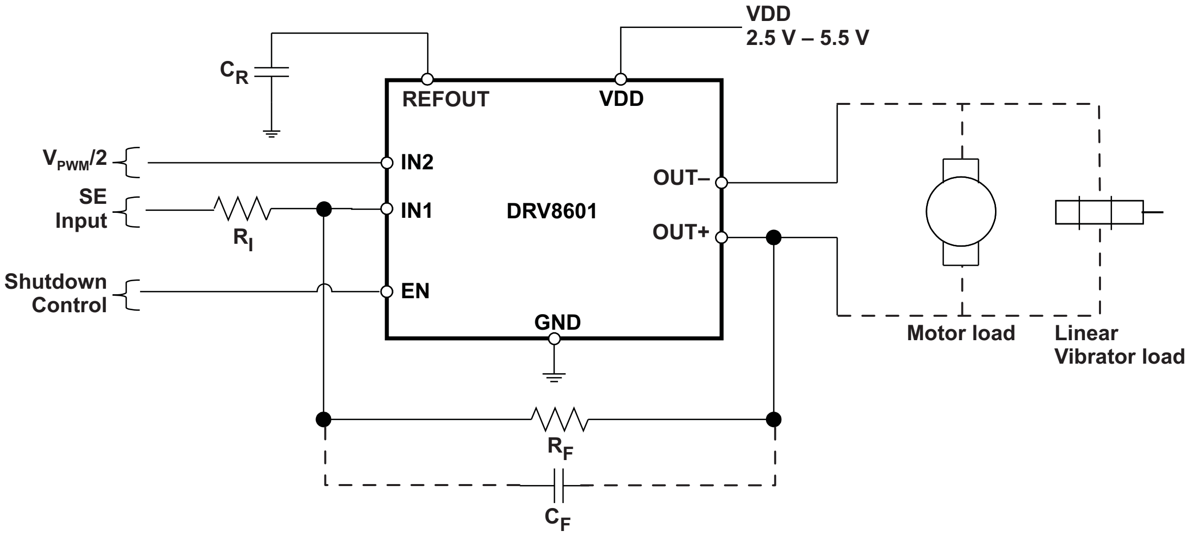


Figure 2. Pseudo-Differential Feedback with External Reference

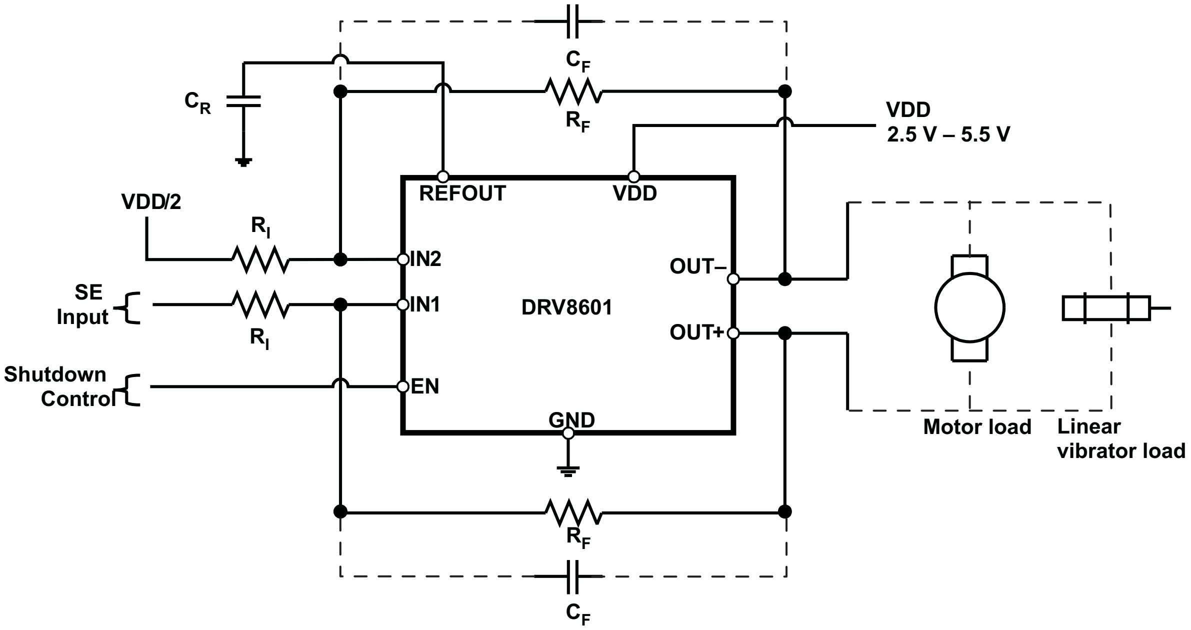


Figure 3. Differential Feedback with External Reference

Pin Functions

PIN		INPUT/OUTPUT/ POWER (I/O/P)	DESCRIPTION
NAME	BALL (ZQV)		
IN1	C3	I	Input to driver
IN2	C2	I	Input to driver
OUT+	B3	O	Positive output
OUT-	A1	O	Negative output
REFOUT	C1	O	Reference voltage output
EN	B1	I	Chip enable
VDD	A3	P	Supply voltage
GND	B2	P	Ground

ORDERING INFORMATION

	MicroStar Junior™ (ZQV)
Device	DRV8601ZQVR(1)(2)
Symbolization	HSMI

(1) The ZQV packages are only available taped and reeled. The suffix R designates taped and reeled parts in quantities of 2500.

(2) For the most current package and ordering information, see the Package Option Addendum at the end of this document or visit the TI website at www.ti.com

ABSOLUTE MAXIMUM RATINGS

over operating free-air temperature range, $T_A \leq 25°C$ unless otherwise noted[1]

			VALUE / UNIT
VDD	Supply voltage		–0.3 V to 6 V
V_I	Input voltage	INx, EN	–0.3 V to V_{DD} + 0.3 V
	Output continuous total power dissipation		See Dissipation Rating Table
T_A	Operating free-air temperature range		–40°C to 85°C
T_J	Operating junction temperature range		–40°C to 150°C
T_{stg}	Storage temperature		–65°C to 150°C

(1) Stresses beyond those listed under *absolute maximum ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *recommended operating conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

THERMAL INFORMATION

THERMAL METRIC[1]		DRV8601	UNITS
		ZQV (8 PINS)	
θ_{JA}	Junction-to-ambient thermal resistance	78	°C/W
θ_{JCtop}	Junction-to-case (top) thermal resistance	155	
θ_{JB}	Junction-to-board thermal resistance	65	
ψ_{JT}	Junction-to-top characterization parameter	5	
ψ_{JB}	Junction-to-board characterization parameter	50	
θ_{JCbot}	Junction-to-case (bottom) thermal resistance	n/a	

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, SPRA953.

RECOMMENDED OPERATING CONDITIONS

			MIN	TYP	MAX	UNIT
V_{DD}	Supply voltage		2.5		5.5	V
V_{IH}	High-level input voltage	EN	1.15			V
V_{IL}	Low-level input voltage	EN			0.5	V
T_A	Operating free-air temperature		–40		85	°C
Z_L	Load impedance		6.4			Ω

ELECTRICAL CHARACTERISTICS

T_A = 25°C, Gain = 2 V/V, R_L= 10 Ω (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
$\|V_{OO}\|$	Output offset voltage (measured differentially)	V_I = 0 V, V_{DD} = 2.5 V to 5.5 V				9	mV
$V_{OD,N}$	Negative differential output voltage (V_{OUT+}-V_{OUT-})	V_{IN+} = V_{DD}, $V_{IN–}$ = 0 V or V_{IN+} = 0 V, $V_{IN–}$ = V_{DD}	V_{DD} = 5.0 V, I_o = 400 mA		-4.55		V
			V_{DD} = 3.3 V, I_o = 300 mA		-2.87		
			V_{DD} = 2.5 V, I_o = 200 mA		-2.15		
$V_{OD,P}$	Positive differential output voltage (V_{OUT+}-V_{OUT-})	V_{IN+} = V_{DD}, $V_{IN–}$ = 0 V or V_{IN+} = 0 V, $V_{IN–}$ = V_{DD}	V_{DD} = 5.0 V, I_o = 400 mA		4.55		V
			V_{DD} = 3.3 V, I_o = 300 mA		2.87		
			V_{DD} = 2.5 V, I_o = 200 mA		2.15		
$\|I_{IH}\|$	High-level EN input current	V_{DD} = 5.5 V, V_I = 5.8 V				1.2	µA
$\|I_{IL}\|$	Low-level EN input current	V_{DD} = 5.5 V, V_I = –0.3 V				1.2	µA
$I_{DD(Q)}$	Supply current	V_{DD} = 2.5 V to 5.5 V, No load, EN = V_{IH}			1.7	2	mA
$I_{DD(SD)}$	Supply current in shutdown mode	EN = V_{IL} , V_{DD} = 2.5 V to 5.5 V, No load			0.01	0.9	µA

OPERATING CHARACTERISTICS

T_A = 25°C, Gain = 2 V/V, R_L = 10 Ω (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
Z_I	Input impedance			2		MΩ
Z_O	Output impedance	Shutdown mode (EN = V_{IL})	>10			kΩ

TYPICAL CHARACTERISTICS

Pseudo-Differential Feedback with Internal Reference, V_{DD} = 3.3 V, R_I = 49.9 kΩ, R_F = 100 kΩ, C_R = 0.001 µF, C_F = None, T_A = 25°C, unless otherwise specified.

Table of Graphs

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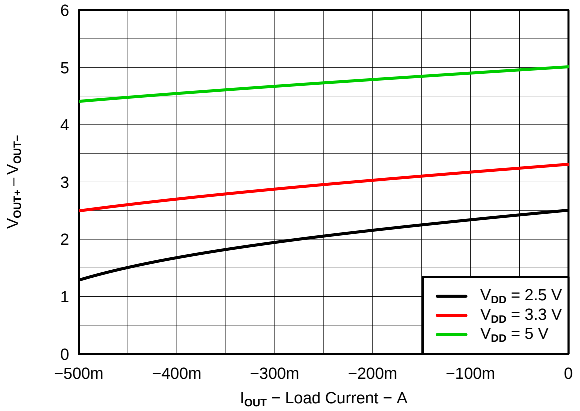
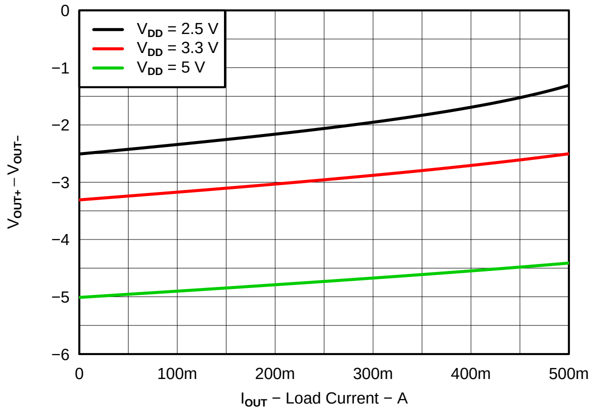
Output voltage (High)	vs Load current	4
Output voltage (Low)	vs Load current	5
Output voltage	vs Input voltage, R_L = 10 Ω	6
Output voltage	vs Input voltage, R_L = 20 Ω	7
Supply current	vs Supply voltage	8
Shutdown supply current	vs Supply voltage	9
Power dissipation	vs Supply voltage	10
Slew rate	vs Supply voltage	11
Output transition	vs Time	12, 13
Startup	vs Time	14
Shutdown	vs Time	15



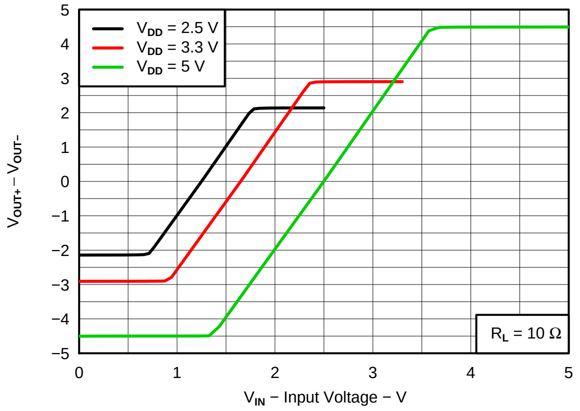
OUTPUT VOLTAGE (HIGH) vs LOAD CURRENT

Figure 4.



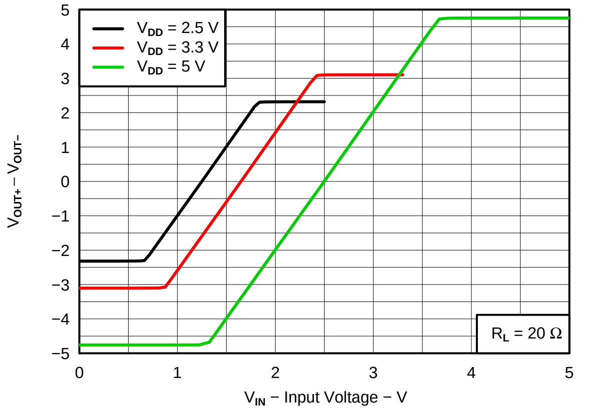
OUTPUT VOLTAGE (LOW) vs LOAD CURRENT

Figure 5.



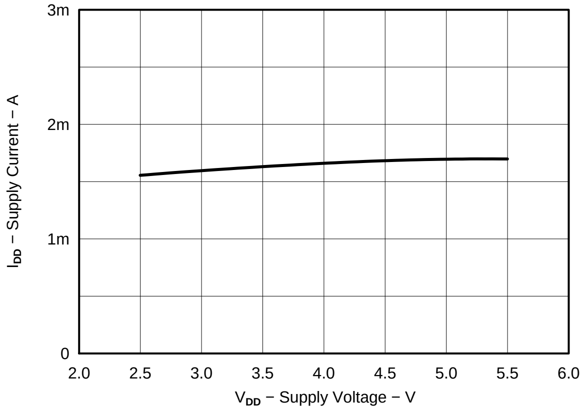
OUTPUT VOLTAGE vs INPUT VOLTAGE

Figure 6.



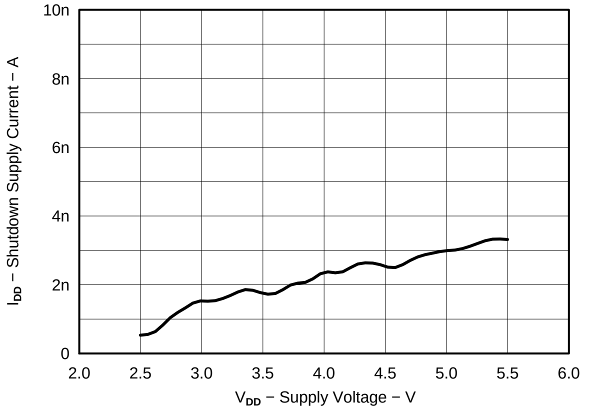
OUTPUT VOLTAGE vs INPUT VOLTAGE

Figure 7.



SUPPLY CURRENT vs SUPPLY VOLTAGE

Figure 8.



SHUTDOWN SUPPLY CURRENT vs SUPPLY VOLTAGE

Figure 9.

POWER DISSIPATION vs
SUPPLY VOLTAGE

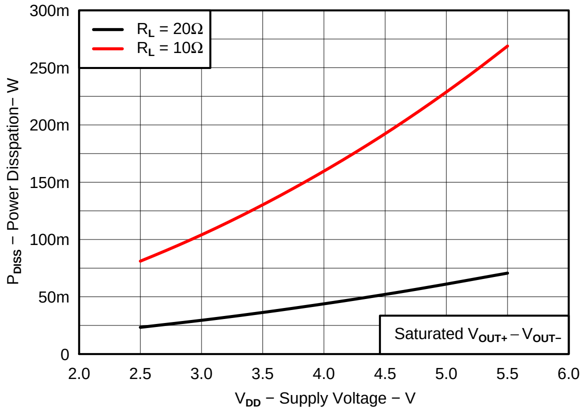


Figure 10.

SLEW RATE vs
SUPPLY VOLTAGE

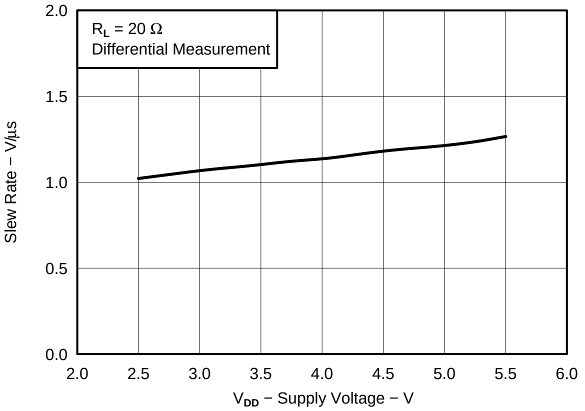


Figure 11.

OUTPUT TRANSITION vs
TIME

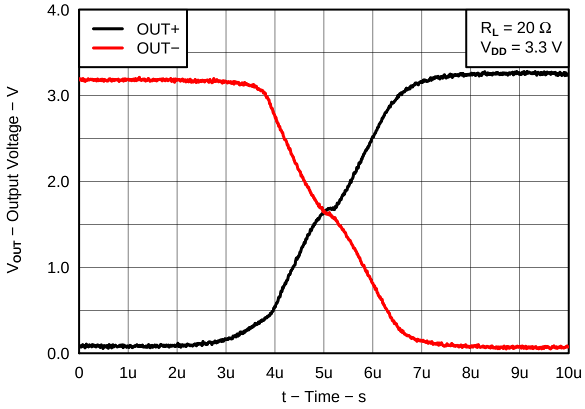


Figure 12.

OUTPUT TRANSITION vs
TIME

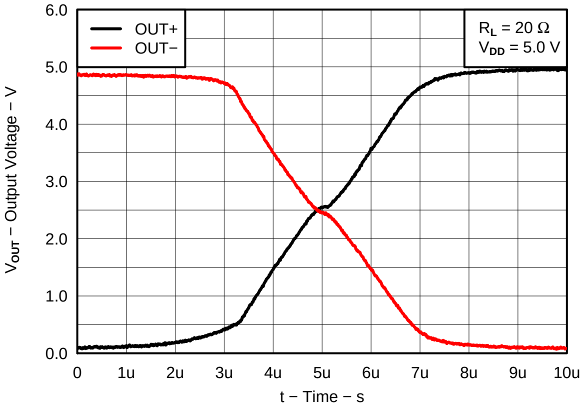


Figure 13.

STARTUP vs
TIME

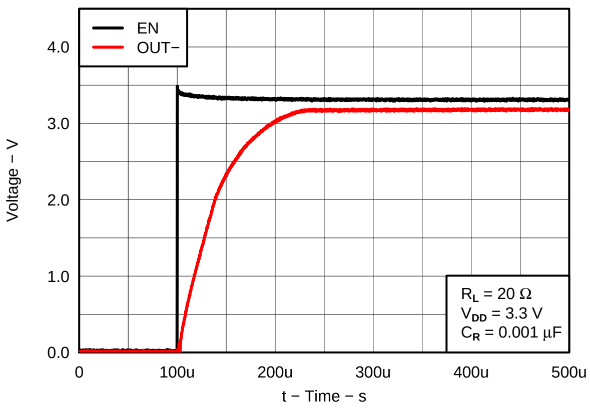


Figure 14.

SHUTDOWN vs
TIME

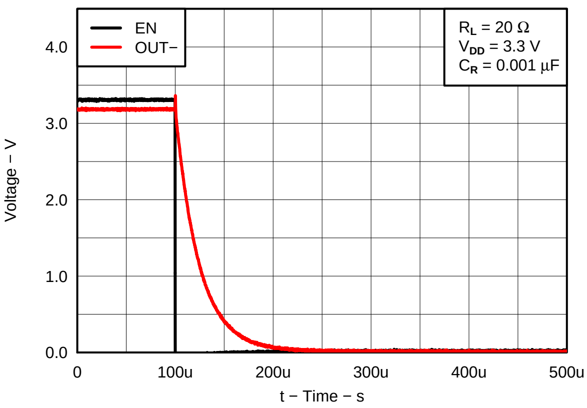


Figure 15.

APPLICATION INFORMATION

DRIVING DC MOTORS USING THE DRV8601

The DRV8601 is designed to drive a DC motor (also known as Eccentric Rotating Mass or ERM in haptics terminology) in both clockwise and counter-clockwise directions, as well as to stop the motor quickly. This is achieved due to the fact that the outputs V_{OUT+} and V_{OUT-}, both source and sink current. This feature helps eliminate long vibration tails which are not desirable in haptic feedback systems.

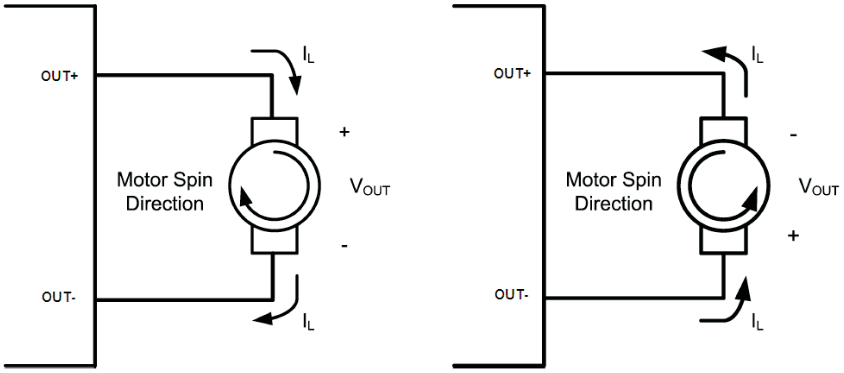


Figure 16. Reversal of Direction of Motor Spin Using DRV8601

Use a single-ended PWM motor control signal frequency < 30 kHz as input to the DRV8601. The PWM signal is typically generated using software, and many different advanced haptic sensations can be produced by inputting different types of PWM signals into the DRV8601.

DRIVING LINEAR VIBRATORS USING THE DRV8601

Linear vibrators (also known as Linear Resonant Actuator or LRA in haptics terminology) vibrate only at their resonant frequency. Usually, linear vibrators have a high-Q frequency response due to which there is almost no vibration at offsets of 3-5 Hz from the resonant frequency. Therefore, while driving a linear vibrator with the DRV8601, ensure that the frequency of the input PWM signal is within the prescribed frequency range for the chosen linear vibrator. Vary the duty cycle of the PWM signal to vary the strength of the vibration. As in the case of DC motors, the PWM signal is typically generated using software, and many different advanced haptic sensations can be produced by inputting different PWM signals into the DRV8601.

PSEUDO-DIFFERENTIAL FEEDBACK WITH INTERNAL REFERENCE

In pseudo-differential feedback (Figure 1), feedback is taken from only one of the output pins, thereby, reducing the number of external components required for the solution. The DRV8601 has an internal reference voltage generator which keeps the REFOUT voltage at VDD/2. In general, the internal reference voltage must be used if and only if the PWM voltage is the same as the supply voltage of the DRV8601 (i.e., if V_{PWM}=VDD, as assumed in this section).

Using VDD/2 as the reference voltage ensures that there is no voltage signal applied to the motor at a PWM duty cycle of 50%. This is a convenient way of temporarily stopping the motor without powering off the DRV8601. Also, this configuration ensures that the direction of rotation of the motor changes when crossing a PWM duty cycle of 50% in both directions. For example, if the motor rotates in the clockwise direction at 20% duty cycle, it will rotate in the counter-clockwise direction at 80% duty cycle at nearly the same speed.

Mathematically, the output voltage is given by Equation 1 (where s is the Laplace Transform variable and V_{IN} is the single-ended input voltage):

$$V_{O,DIFF} = 2 \times \left(V_{IN} - \frac{Vdd}{2} \right) \times \frac{R_F}{R_I} \times \frac{1}{1 + sR_FC_F} \tag{1}$$

The optional feedback capacitor C_F forms a low-pass filter together with the feedback resistor R_F, and therefore, the output differential voltage is a function of the average value of the input PWM signal V_{IN}. When driving a motor, design the cutoff frequency of the low-pass filter to be sufficiently *lower than* the PWM frequency in order to eliminate the PWM frequency and its harmonics from entering the motor. This is desirable when driving motors which do not sufficiently reject the PWM frequency by themselves. When driving a linear vibrator in this configuration, if the feedback capacitor C_F is used, care must be taken to make sure that the low-pass cutoff frequency is *higher than* the resonant frequency of the linear vibrator.

When driving motors which can sufficiently reject the PWM frequency by themselves, or when driving linear vibrators, the feedback capacitor may be eliminated. For this example, the output voltage is given by:

$$V_{O,DIFF} = 2 \times \left(V_{IN} - \frac{Vdd}{2}\right) \times \frac{R_F}{R_I} \tag{2}$$

where the only difference from Equation 1 is that the filtering action of the capacitor is not present.

PSEUDO-DIFFERENTIAL FEEDBACK WITH EXTERNAL REFERENCE

Use this configuration when the PWM voltage (V_{PWM}) and the supply voltage of the DRV8601 (VDD) are different. This configuration (Figure 2) is similar to the previous configuration (Figure 1), with the only difference being the use of an external $V_{PWM}/2$ reference. See the previous section for information on motor speed and direction control, driving a linear vibrator, as well as filtering (remember to factor the change in reference voltage where applicable).

DIFFERENTIAL FEEDBACK WITH EXTERNAL REFERENCE

In this configuration, feedback is taken from both output pins and an external VDD/2 reference voltage is used. Using the internal reference is not recommended for differential feedback. In Figure 3 and the rest of this section, it is assumed that the PWM voltage is the same as the supply voltage of the DRV8601 (if this is not the case, $V_{PWM}/2$ must be used as the reference voltage). Use this configuration to achieve a lower offset voltage (and thereby lower power dissipation at 50% duty-cycle) than the two pseudo-differential configurations.

The output voltage is given by Equation 3 (where s is the Laplace Transform variable and V_{IN} is the single-ended input voltage):

$$V_{O,DIFF} = \left(V_{IN} - \frac{Vdd}{2}\right) \times \frac{R_F}{R_I} \times \frac{1}{1 + sR_FC_F} \tag{3}$$

Note that this differs from Equation 1 for the pseudo-differential configuration by a factor of 2 because of differential feedback.

Using VDD/2 (or $V_{PWM}/2$ if V_{PWM} is different from VDD) as the reference voltage has the same advantages as in the case of the pseudo-differential configurations: motor stoppage at 50% PWM duty cycle and direction reversal when passing through 50% duty cycle.

The optional feedback capacitor C_F forms a low-pass filter together with the feedback resistor R_F, and therefore, the output differential voltage is a function of the average value of the input PWM signal V_{IN}. When driving a motor, design the cutoff frequency of the low-pass filter to be sufficiently *lower than* the PWM frequency in order to eliminate the PWM frequency and its harmonics from entering the motor. This is desirable when driving motors which do not sufficiently reject the PWM frequency by themselves. When driving a linear vibrator in this configuration, if the feedback capacitor C_F is used, care must be taken to make sure that the low-pass cutoff frequency is *higher than* the resonant frequency of the linear vibrator.

When driving motors which can sufficiently reject the PWM frequency by themselves, or when driving linear vibrators, the feedback capacitor may be dropped. For this example, the output voltage is given by:

$$V_{O,DIFF} = \left(V_{IN} - \frac{Vdd}{2}\right) \times \frac{R_F}{R_I} \tag{4}$$

where the only difference from Equation 3 is that the filtering action of the capacitor is not present.

SELECTING COMPONENTS

Resistors R_I and R_f

Choose R_f and R_I in the range 20 kΩ – 100 kΩ for safe operation.

Capacitor C_R

This capacitor filters any noise on the reference voltage generated by the DRV8601 on the REFOUT pin, thereby increasing noise immunity. However, a high value of capacitance results in a large turn-on time. A typical value of 1 nF is recommended for a fast turn-on time. All capacitors should be X5R dielectric or better.

PACKAGING INFORMATION

Orderable Device	Status [(1)]	Package Type	Package Drawing	Pins	Package Qty	Eco Plan [(2)]	Lead/ Ball Finish	MSL Pea
DRV8601ZQVR	ACTIVE	BGA MICROSTAR JUNIOR	ZQV	8	2500	Green (RoHS & no Sb/Br)	SNAGCU	Level-3-260

[(1)] The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

[(2)] Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.
information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all
lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable fo
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package,
the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retard
in homogeneous material)

[(3)] MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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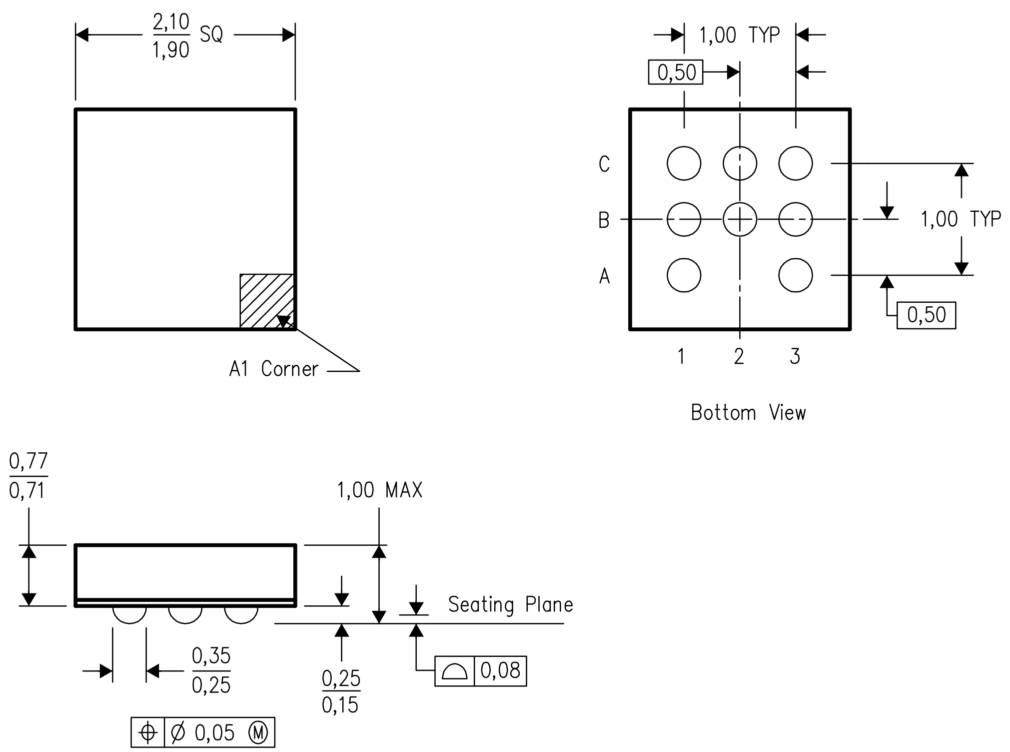
ZQV (S–PBGA–N8) PLASTIC BALL GRID ARRAY



4205131/A 05/03

NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. MicroStar Junior configuration
- D. Falls within JEDEC MO–225
- E. This package is lead–free.

查询"DRV8601"供应商

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Interface	interface.ti.com	Energy	www.ti.com/energy
Logic	logic.ti.com	Industrial	www.ti.com/industrial
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