Haptic Driver with Auto Resonance Tracking for Linear Resonance Actuators (LRA) and Optimized Drive for Eccentric Rotating Mass Actuators (ERM)

Check for Samples: DRV2603

FEATURES

- **Flexible Haptic/Vibra Driver**
  - **LRA (Linear Resonance Actuator)**
  - **ERM (Eccentric Rotating Mass)**
- **Auto Resonance Tracking for LRA**
  - **No Frequency Calibration Required**
  - **Automatic Drive Commutation**
  - **Automatic Braking Algorithm**
  - **Wide Input PWM Frequency Range**
- **Constant Vibration Strength Over Supply**
- **Automatic Input Level Translation**
- **0% to 100% Duty Cycle Control Range**
- **Fast Start Up Time**
- **Differential Drive from Single-Ended Input**
- **Wide Supply Voltage Range of 2.5 V to 5.2 V**
- **1.8 V Compatible, 5 V Tolerant Digital Pins**
- **Available in a 2 mm × 2 mm × 0.75 mm leadless QFN package (RUN)**

APPLICATIONS

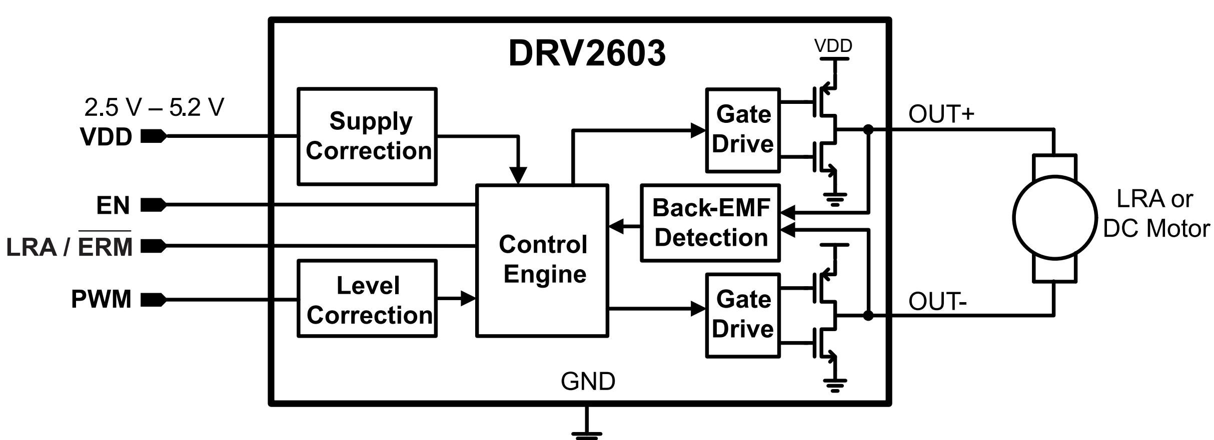
- **Mobile Phones**
- **Tablets**
- **Touch Enabled Devices**

DESCRIPTION

The DRV2603 is a haptic driver designed specifically to solve common obstacles in driving both Linear Resonance Actuator (LRA) and Eccentric Rotating Mass (ERM) haptic elements. The DRV2603 is also designed for low latency, has excellent efficiency, and plenty of drive strength for actuators commonly used in the portable market.

LRA actuators typically have a narrow frequency band over which they have an adequate haptic response. This frequency window is typically ±2.5 Hz wide or less, so driving an LRA actuator presents a challenge. The DRV2603 solves this problem by employing auto resonance tracking, which automatically detects and tracks the optimum commutation frequency. This means that any input PWM frequency within the input range (10 kHz to 250 kHz) will automatically produce the correct resonant output frequency. As an additional benefit, the DRV2603 implements an optimal braking algorithm to stop the LRA from ringing out, leaving the user with a crisp haptic sensation.

For both ERM and LRA actuators, the DRV2603 automatic input level translation solves issues with low voltage PWM sources without adding additional external components, so if the digital I/O levels vary, the output voltage does not change. The DRV2603 also has supply correction that ensures no supply regulation is required for constant vibration strength, allowing an efficient, direct-battery connection.



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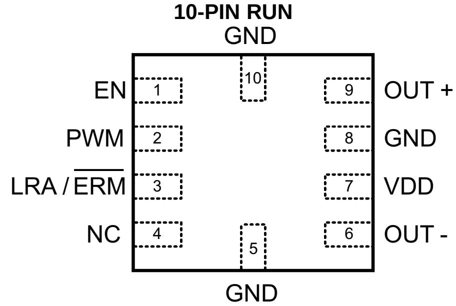
These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

ORDERING INFORMATION

	RUN 2mm × 2 mm × 0.75 mm
Device	DRV2603RUNR
Symbolization	2603

PINOUT INFORMATION

10-PIN RUN



PIN FUNCTIONS

PIN		INPUT/ OUTPUT/ POWER (I/O/P)	DESCRIPTION
NAME	NUMBER		
PWM	2	I	Input signal
EN	1	I	Device enable
LRA/$\overline{\text{ERM}}$	3	I	Mode selection
GND	5, 8, 10	P	Supply ground
NC	4	I	No Connection
OUT–	6	O	Negative haptic driver differential output
OUT+	9	O	Positive haptic driver differential output
VDD	7	P	Supply Input (2.5 V to 5.5 V)

ABSOLUTE MAXIMUM RATINGS(1)

over operating free-air temperature range, T_A = 25°C (unless otherwise noted)

			VALUE	UNIT
	Supply voltage	VDD	–0.3 to 6.0	V
V_I	Input voltage	EN, PWM, LRA/ERM	–0.3 to V_{DD} + 0.3	V
T_A	Operating free-air temperature range		–40 to 85	°C
T_J	Operating junction temperature range		–40 to 150	°C
T_{stg}	Storage temperature range		–65 to 150	°C
	ESD Protection	HBM	2000	V
		CDM	500	V

(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.

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THERMAL INFORMATION

THERMAL METRIC[1]		DRV2603 RUN (10 pins)	UNITS
θ_{JA}	Junction-to-ambient thermal resistance	153.7	°C/W
θ_{JCtop}	Junction-to-case (top) thermal resistance	86	
θ_{JB}	Junction-to-board thermal resistance	70.4	
ψ_{JT}	Junction-to-top characterization parameter	1.3	
ψ_{JB}	Junction-to-board characterization parameter	70.4	
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	VDD	2.5		5.2	V
f_{PWM}	PWM Input frequency		10		250	kHz
R_L	Load Impedance	V_{DD} = 5.2 V	8			Ω
F_0	Supported LRA frequency	Auto resonance tracking range for LRA	140		220	Hz
V_{IL}	Digital input low voltage	EN, PWM, LRA/ERM			0.6	V
V_{IH}	Digital input high voltage	EN, PWM, LRA/ERM	1.2			V
T_A	Operating free-air temperature range		-40		85	°C

ELECTRICAL CHARACTERISTICS

T_A = 25°C, V_{DD} = 3.6 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
$\lvert I_{IL}\rvert$	Digital input low current	EN, PWM, LRA/ERM	V_{DD} = 5.0 V, V_{IN} = 0 V			1	µA
$\lvert I_{IH}\rvert$	Digital input high current	EN	V_{DD} = 5.0 V, V_{IN} = V_{DD}			6	µA
		PWM, LRA/ERM	V_{DD} = 5.0 V, V_{IN} = V_{DD}			3	µA
I_{SD}	Shut down current	V_{EN} = 0 V			0.3	3	µA
I_{DDQ}	Quiescent current	V_{EN} = V_{DD}, ERM Mode, 50% duty cycle input, No load			1.7	2.5	mA
R_{OUT}	Output impedance in shutdown	OUT+ to GND, OUT– to GND			15		kΩ
t_{SU}	Start-up time	Time from EN high to output signal			1.3		ms
f_{SW}	PWM output frequency			19.5	20.3	21.5	kHz
$I_{BAT,AVG}$	Average battery current during operation	Duty Cycle = 100%, LRA Mode, Load = 25 Ω LRA			55		mA
		Duty Cycle = 80%, ERM Mode, R_L = 17 Ω, 2V rated ERM			59		
R_{DS-HS}	Drain to source resistance, high-side				1.05		Ω
R_{DS-LS}	Drain to source resistance, low-side				0.85		Ω
V_{OUT}	Differential output voltage	Duty Cycle = 100%, LRA Mode, Load = 25 Ω LRA			2.2		V_{RMS}
		Duty Cycle = 100%, ERM Mode, R_L = 20 Ω ERM			3.3		V

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TYPICAL CHARACTERISTICS

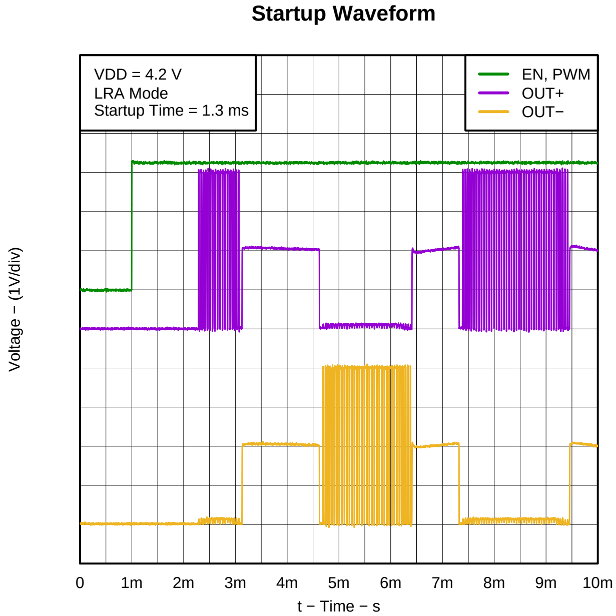

Figure 1.

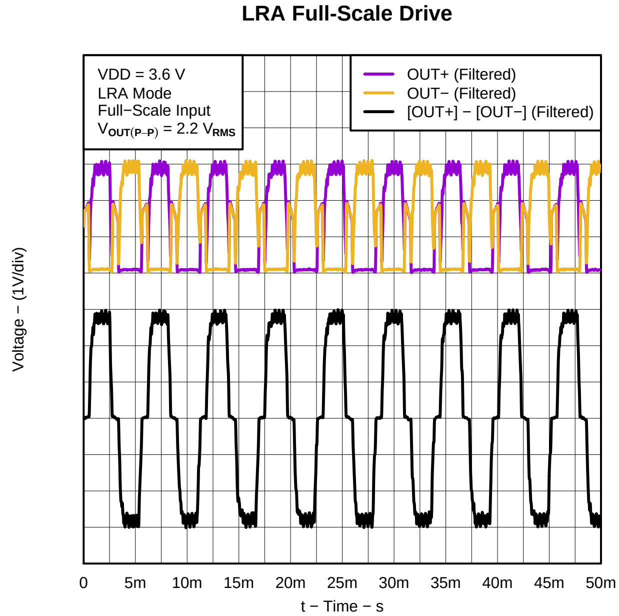

Figure 2.

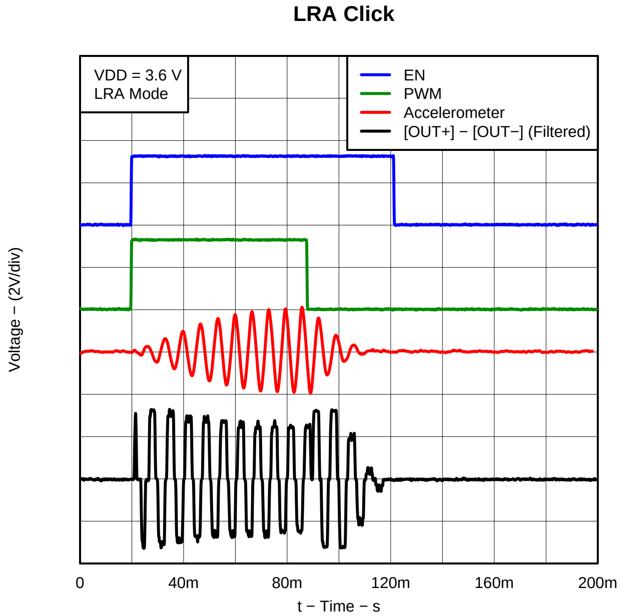

Figure 3.

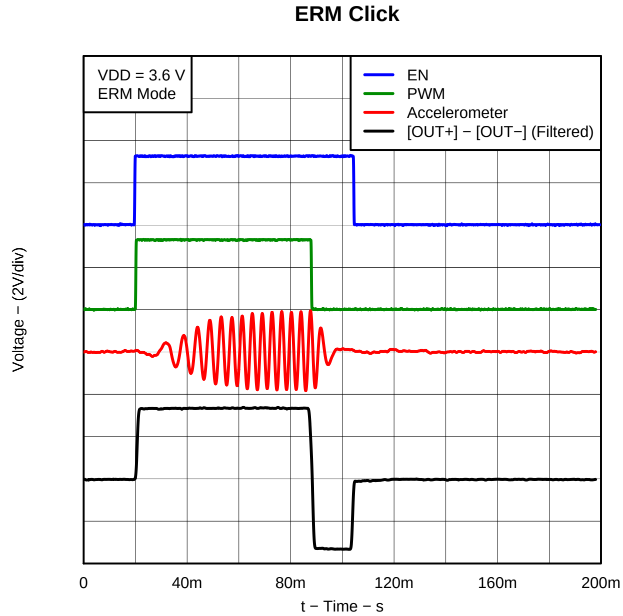

Figure 4.

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TYPICAL CHARACTERISTICS (continued)

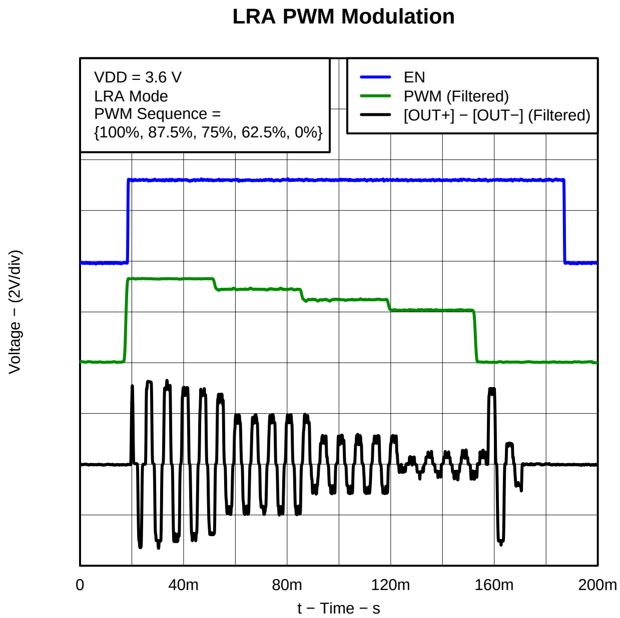

Figure 5.

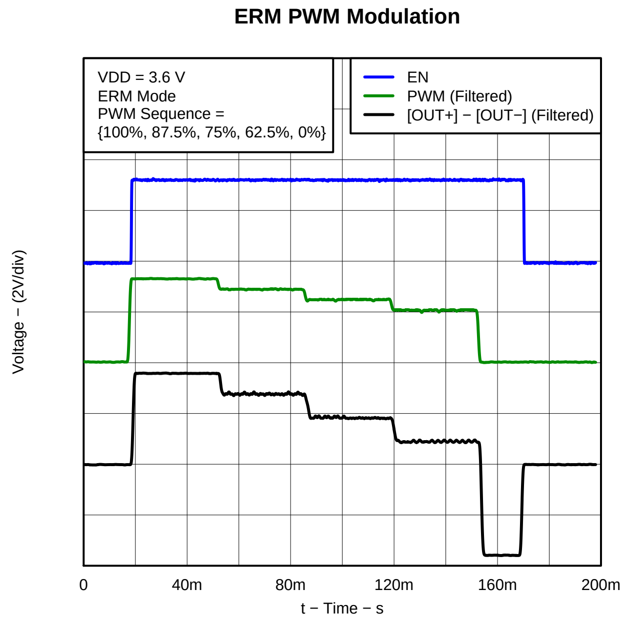

Figure 6.

TEST SETUP FOR GRAPHS

With no output filter, the output waveform from the DRV2603 looks similar to Figure 1. To achieve output filtering for waveform observation, the digital filter function on a digital oscilloscope was utilized in the rest of the Typical Characteristic figures. A 1st order, low-pass filter corner between 1 kHz and 3.5 kHz is recommended.

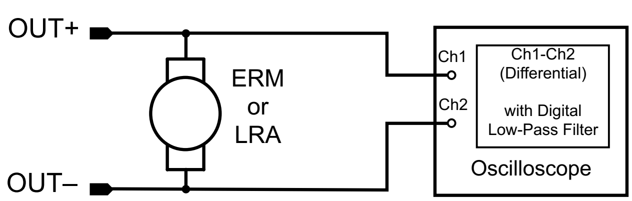

Figure 7. Test Setup for Graphs

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TYPICAL CHARACTERISTICS (continued)

ALTERNATE TEST SETUP

If a digital oscilloscope with digital filtering is not available, a 1st order, low-pass, RC filter network can be used instead. Care must be taken not to use a filter impedance that is too low. This can interfere with the back-EMF behavior of the actuator and corrupt the operation of the auto resonance function. A recommended circuit is shown in Figure 8.

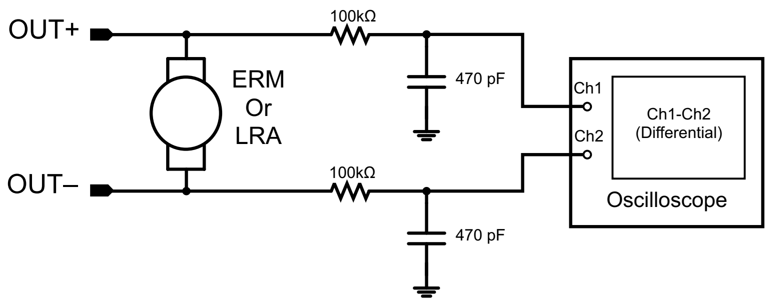

Figure 8. Alternate Test Setup

SYSTEM DIAGRAMS

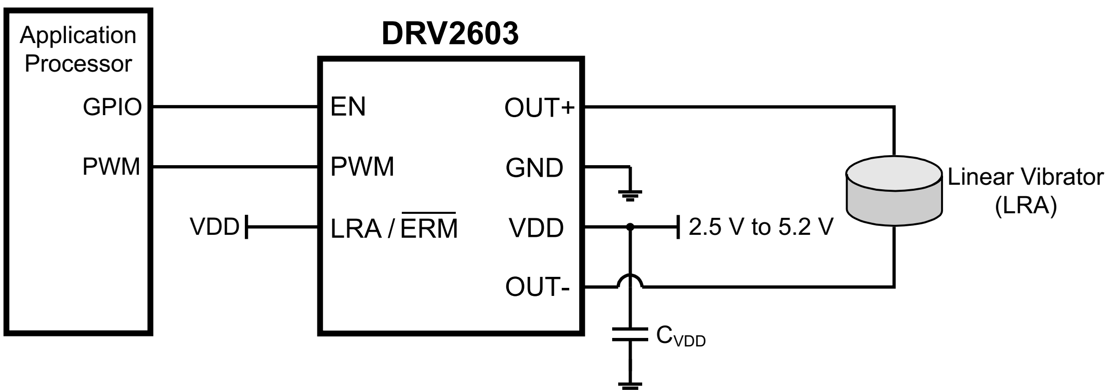

Figure 9. System Diagram for LRA

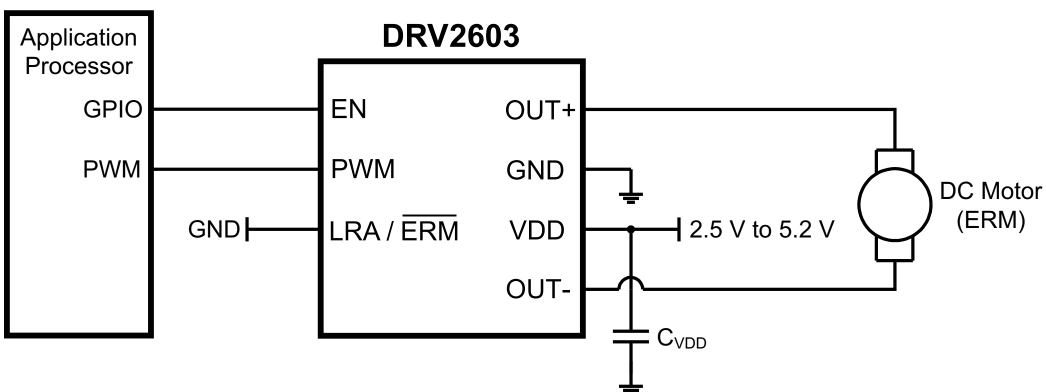

Figure 10. System Diagram for ERM

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APPLICATION INFORMATION

OPERATION

The DRV2603 is a haptic and vibratory driver designed specifically to meet the needs of haptic and vibration applications in the portable market. The DRV2603 has two modes of operation, ERM mode and LRA mode. ERM mode is designed to drive ***Eccentric Rotating Mass*** motors, which are generally DC motors of the bar or coin type. LRA mode is designed to drive ***Linear Resonance Actuators***, also known as linear vibrators, which require an alternating signal that commutates at or very near the natural mechanical resonance frequency of the actuator. These actuators present a unique control challenge that is solved in the DRV2603 by auto resonance tracking.

CONSTANT VIBRATION STRENGTH

The DRV2603 features power supply feedback, so no supply regulation is required, and a direct battery connection may be used. If the supply voltage drifts over time (due to battery discharge, for example), the vibration strength will remain the same so long as there is enough supply voltage to sustain the required output voltage. The DRV2603 PWM input also uses a digital level-shifter, so as long as the input voltage meets the V_{IH} and V_{IL} levels, the vibration strength will remain the same even if the digital levels were to vary. These benefits apply to both ERM mode and LRA mode.

LINEAR RESONANCE ACTUATORS

Linear Resonant Actuators, or LRAs, only vibrate effectively at their resonant frequency. LRAs have a high-Q frequency response due to which there is a rapid drop in vibration performance at offsets of 2 to 3 Hz from the resonant frequency. Many factors also cause a shift or drift in the resonant frequency of the actuator such as temperature, aging, the mass the product to which the LRA is mounted, and in the case of a portable product, the manner in which it is held. Furthermore, as the actuator is driven to its maximum allowed voltage, many LRAs will shift several Hz in frequency due to mechanical compression. All of these factors make a real-time tracking auto-resonant algorithm critical when driving LRA to achieve consistent, optimized performance.

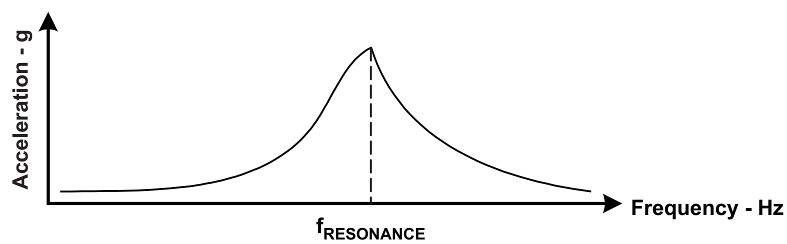

Figure 11. Typical LRA Response

AUTO RESONANCE ENGINE FOR LRA

No frequency calibration or actuator training is required to use the DRV2603. The DRV2603 auto resonance engine tracks the resonant frequency of an LRA in real time. If the resonant frequency shifts in the middle of a waveform for any reason, the engine will track it cycle to cycle. The auto resonance engine accomplishes this by constantly monitoring the back-EMF of the actuator. The DRV2603 tracking range for LRA devices is 140 Hz to 220 Hz.

LRA MODE

When in LRA mode, the DRV2603 employs a simple control scheme that is designed to be compatible with ERM mode signaling. A 100% input duty cycle gives full vibration strength, and a 0% to 50% input duty cycle gives no vibration strength. The auto resonance detection algorithm takes care of the physical layer signaling and commutation required by linear resonance actuators. The DRV2603 implements closed-loop operation comprising a simple feedback loop. If the back-EMF feedback tells the device that the vibration is too low relative to the input duty cycle, the DRV2603 will increase the vibration strength. If the back-EMF feedback tells the device that the vibration is too high relative to the input duty cycle, the DRV2603 automatically enforces a braking algorithm. It follows that a 0% to 50% input duty cycle will always enforce braking until the LRA is no longer moving. This form of signaling is used to preserve the same input format for both ERM and LRA drive; therefore, no software changes are required when switching between ERMs and LRAs with the DRV2603.

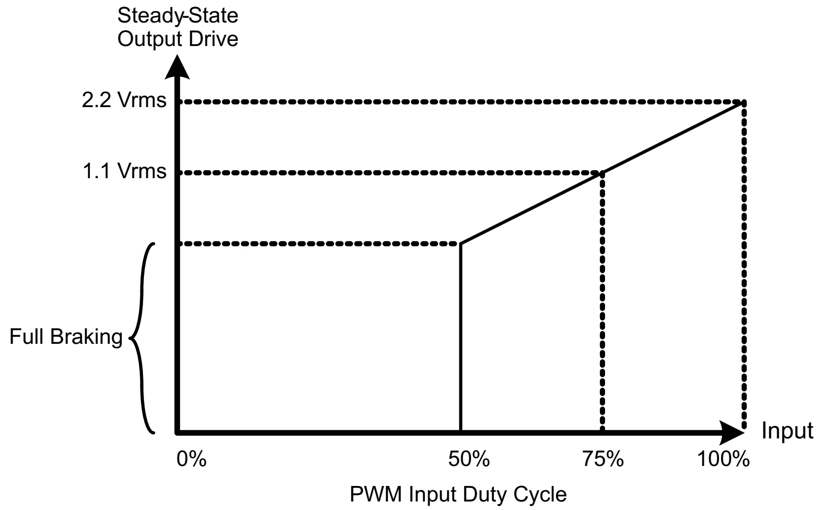

Figure 12. LRA Mode

The exact full-scale output voltage depends on the physical construction of the LRA itself. Some LRA devices give a small amount of back-EMF during full scale vibration, and other LRA devices give a much larger amount. A nominal full-scale output value is 2.2 V_{RMS}, but it can typically vary as much as +/- 10% depending on the actuator's physical design. The output voltage can be approximated by the following equation between 50% and 100% input duty cycle.

$$V_{OUT\ (RMS)} = V_{OUT\ (FULL\text{-}SCALE)} \left[\frac{\text{Input Duty Cycle \%}}{50} - 1 \right] \quad (1)$$

Since the DRV2603 includes constant output drive over supply voltage, the output PWM duty cycle will be adjusted so that the relationship in the above equation will hold true regardless of the supply voltage.

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ECCENTRIC ROTATING MASS MOTORS (ERM)

Eccentric Rotating Mass motors, or ERMs, are typically DC-controlled motors of the bar or coin type. ERMs can be driven in the clockwise direction or counter-clockwise depending on the polarity of voltage across its two terminals. Bi-directional drive is made possible in a single-supply system by differential outputs that are capable of sourcing and sinking current. This feature helps eliminate long vibration tails which are undesirable in haptic feedback systems..

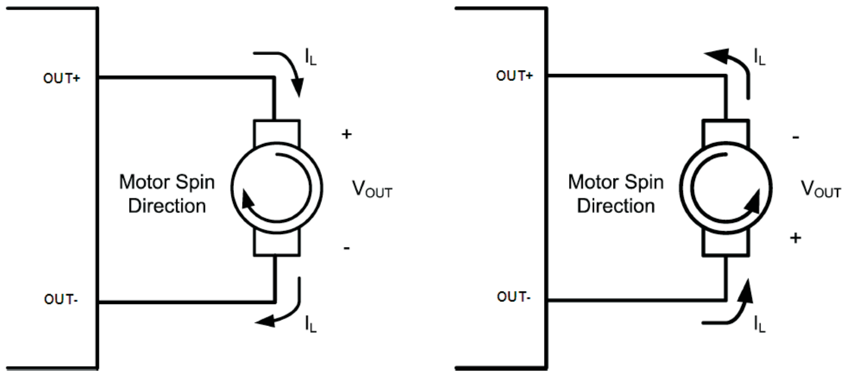

Figure 13. Reversal of Motor Direction

Another common approach to driving DC motors is the concept of overdrive voltage. To overcome the inertia of the motor's mass, they are often *overdriven* for a short amount of time before returning to the motor's rated voltage to sustain the motor's rotation. Negative overdrive is also used to stop (or brake) an ERM quickly by reversing the magnetic field of the driving coil(s).

ERM MODE

The DRV2603 is a compact, cost-effective driver solution for ERM motors. Most competing solutions require external components for biasing or level-shifting, but the DRV2603 requires only one decoupling capacitor giving a total approximate circuit size of 2 mm by 2 mm. This small solution size still comes packed with features such as a level-shifted input, differential outputs for braking, constant drive strength over supply, edge rate control, and a wide input PWM frequency range.

When in ERM mode, the DRV2603 employs a simple control scheme. A 100% input duty cycle gives full-strength forward rotation, a 50% input duty cycle give no rotation strength, and a 0% duty cycle give full-strength reverse rotation. Forcing the motor velocity towards reverse rotation is used to implement motor braking in ERMs. By stringing together various duty cycles over varying amounts of time, a haptic motor control signal will be constructed at the output to precisely drive the motor.

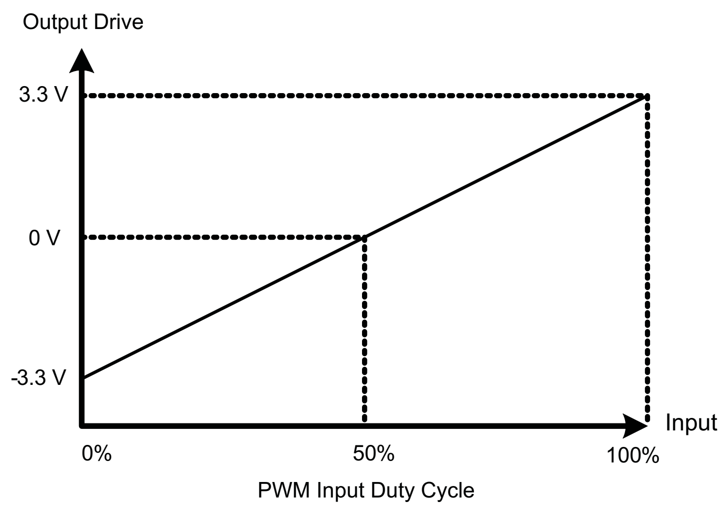

Figure 14. ERM Mode

The full-scale, open-load output voltage of the DRV2603 in ERM mode is 3.6V. The output stage has a total nominal R_{DS} of 1.9 Ω. When driving a 20 Ω ERM at full-scale, the differential voltage seen at the outputs is approximately 3.3 V. When driving a 10 Ω ERM at full-scale, the output voltage is approximately 3.0 V.

The voltage seen at the outputs as a function of input duty cycle is given by this equation.

$$V_{OUT} = V_{OUT\ (FULL\text{-}SCALE)} \left[\frac{\text{Input Duty Cycle \%}}{50} - 1 \right] \tag{2}$$

Since the DRV2603 includes constant output drive over supply voltage, the output PWM duty cycle will be adjusted so that the relationship in the above equation will hold true regardless of the supply voltage. The output duty cycle in ERM mode can be approximated by the following equation.

$$\text{Output Duty Cycle } (\%) = \frac{V_{OUT(FULL\text{-}SCALE)}}{VDD} \left[\frac{\text{Input Duty Cycle \%}}{50} - 1 \right] 100\% \tag{3}$$

EDGE RATE CONTROL

The DRV2603 output driver implements Edge Rate Control (ERC). This ensures that the rise and fall characteristics of the output drivers do not emit levels of radiation that could interfere with other circuitry common in mobile and portable platforms. Because of ERC, no output filter or ferrites are necessary.

DECOUPLING CAPACITOR

The DRV2603 has a switching output stage which pulls transient currents through the VDD pin. A 0.1 µF, low equivalent-series-resistance (ESR) decoupling capacitor of the X5R or X7R type is recommended for smooth operation of the output driver and the digital portion of the device.

SENDING A HAPTIC EFFECT

Sending a haptic effect with the DRV2603 is straightforward. The procedure is the same for both ERM and LRA drive. The ERM/LRA pin should be tied high or low as shown in the system diagrams. Optimum performance is achieved by using the following steps.

1. At or very near the same time, bring the EN pin high and start sourcing PWM waveform. No delays are required. The best startup behavior is usually achieved when momentarily overdriving the actuator for 20 ms to 50 ms. Reference the specifications of the actuator for optimum overdrive characteristics.
2. Change the PWM level as needed to achieve the desired effect.
3. When the effect is complete, set the PWM duty cycle to 0% if braking is desired. The EN pin must remain high to actively brake the actuator. When braking is complete, set the EN pin low, concluding the haptic effect. When braking an ERM, the user should take care not to brake the actuator for too long, or counter-rotation can occur. When braking an LRA, the auto-resonance engine automatically drives the actuator to zero vibration, so no significant reverse-phase vibration will ever occur.

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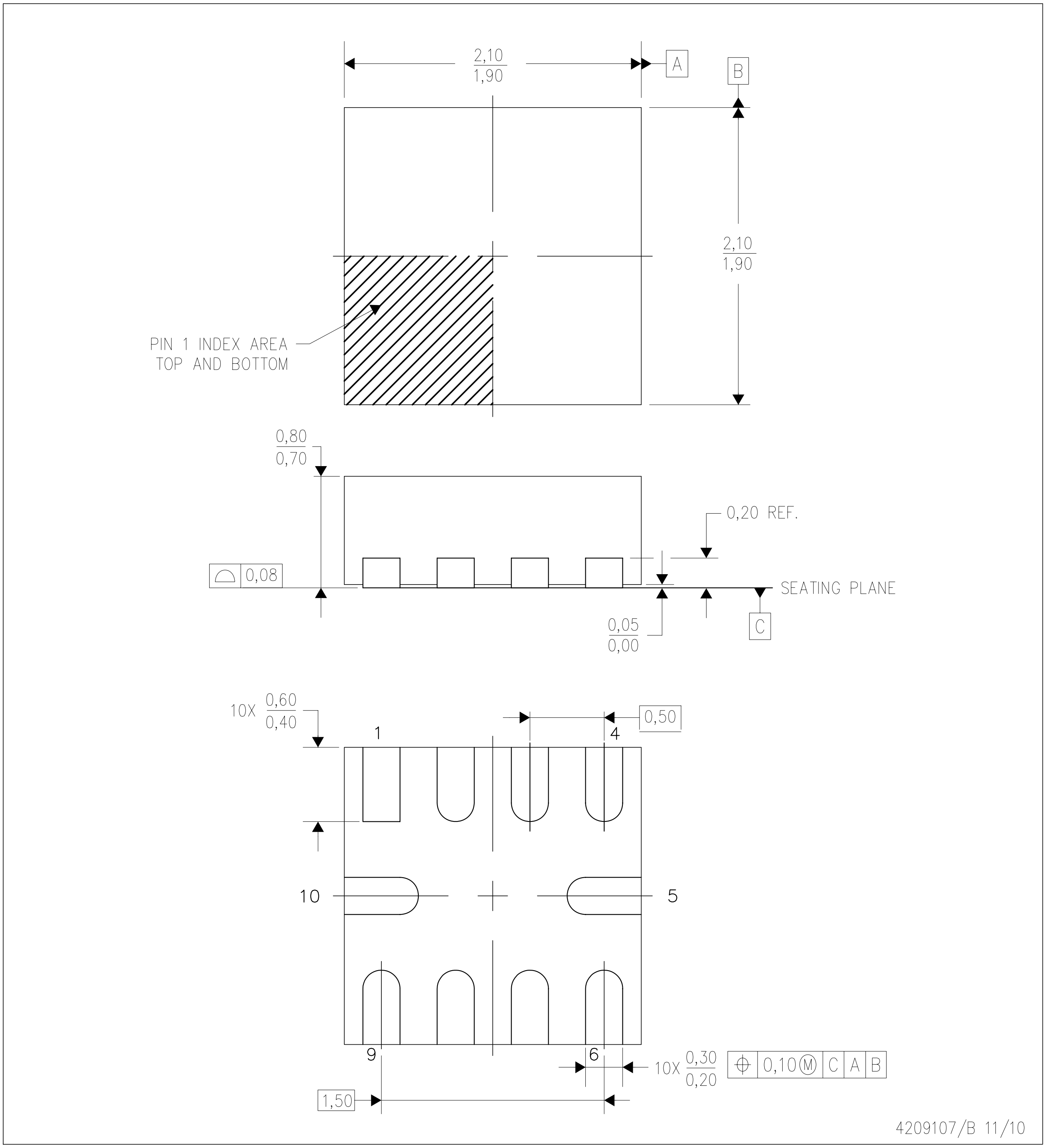
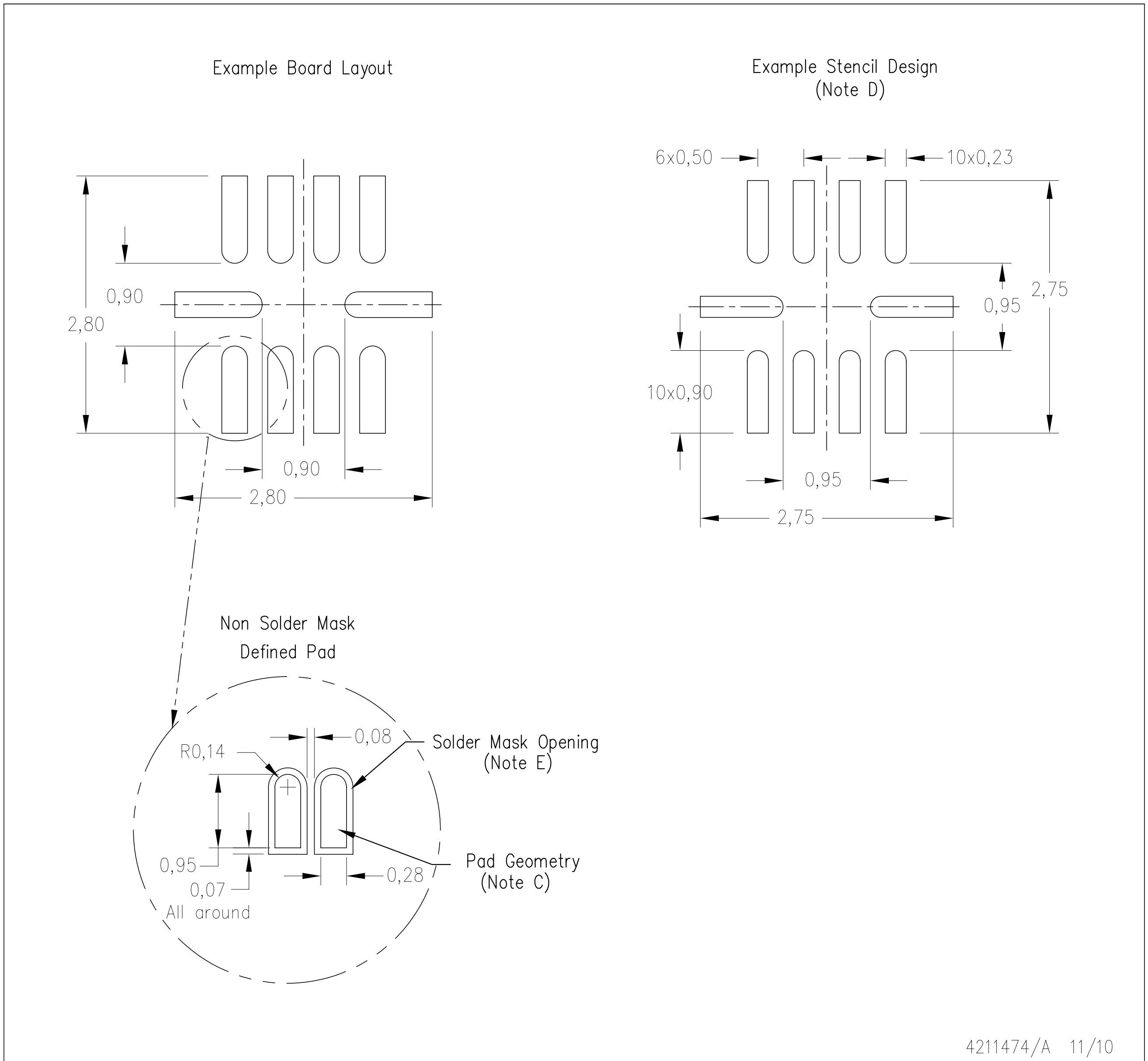
RUN (S-PWQFN-N10) PLASTIC QUAD FLATPACK NO-LEAD



NOTES:
A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M—1994.
B. This drawing is subject to change without notice.
C. Quad Flatpack, No—Leads (QFN) package configuration.

RUN (S-PWQFN-N10) PLASTIC QUAD FLATPACK NO-LEAD



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Publication IPC-7351 is recommended for alternate designs.
D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC 7525 for stencil design considerations.
E. Customers should contact their board fabrication site for minimum solder mask web tolerances between signal pads.

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