TI Designs
Low-Voltage Battery Buck-Boost Haptic Driver

Design Features
• Achieves Constant Vibration Strength Over Battery Voltage
• Buck-Boost Topology Provides Constant Output Voltage for Haptic Feedback
• Haptic Driver With Embedded Waveform Library
• Wide Battery-Operating Range (1.8 V to 5.5 V)
• Supports 2x AA and Lithium Batteries

Featured Applications
• TV Remotes
• PC Accessories
• Mice
• Trackpads
• Portable Electronics
• Battery-Operated Personal Hygiene Products
• Other Accessories

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1 Introduction

Haptics is a new interface that has been adopted in many new portable devices. Many devices use tactile vibrations to communicate with the user. Traditionally, haptic technology is used in many gaming devices and smart phones to immerse the user in the game content or to provide "button feel" to a phone user. Many wearable devices, like TV remotes and mice, are using haptics to provide notifications, tactile feedback, render a virtual scroll wheel, and more. One common feature in all these devices is that they are operated by AA, AAA, or lithium/lithium polymer batteries, where the voltages could range anywhere from 2 V to 4.5 V. This design provides a preconfigured voltage level to the DRV2605L haptic driver by either lowering or boosting the output voltage as required by the system and defined by the hardware. Because the DRV2605L can work anywhere from 2 V to 5.2 V, this design is applicable to systems with battery voltage swings below the drive voltages of the motor.

2 Board Description

The DRV2605L haptic driver is powered by the TPS63030 Buck-Boost DC-DC converter in this design. The input voltage of the TPS63030 ranges from 1.8 V to 5.5 V. The reference design is configured for a default output voltage of 5 V. For different voltage configurations, refer to Equation 1. A buck-boost topology has been chosen to adjust to any higher or lower variations in the battery voltage. The current capability of this DC-DC converter is significantly high to drive powerful motors. Standard 100-mil headers are used to be compatible with breadboards and other external connectors.

3 System Description

3.1 TPS63030 High-Efficiency Single Inductor Buck-Boost Converter

The design uses a TPS63030 Buck-Boost converter with 1-A switches that power the DRV2605LMSOP. The VBAT can be supplied from a battery source (AA, AAA, Lithium, and others). A JST connector is used in this design to be compatible with many battery kits already available on the market. The EN pin is connected to VBAT to have the chip ready to output as soon as a valid VBAT within the operating range is applied.

The PS/SYNC pin can disable or enable the power save feature. This feature may be helpful for loads lighter than 10 mA, like a micro-controller connected to the same rail. The power save is disabled on this board and can be enabled by removing resistor R3 and connecting resistor R5, which pulls the pin high or low. The feedback resistors R4 and R2 provide a steady output voltage of 5 VDC. Based on the maximum overdrive voltage of the motor, the feedback resistors can be configured to obtain a lower voltage. Refer to Equation 1 from the datasheet to get other voltages by changing R2 from the design. The inductor L1 is a 2.2-µH inductor from Coilcraft. Refer to the Design Calculations for Buck-Boost Converters Application Report (SLVA535) for more information on selecting an inductor. The net REG is the output of the TPS63030 and is connected to the DRV2605L.

![Figure 1. TPS63030 Buck Boost (1.8–5 V)](image-url)
3.1.1 Equations

From the datasheet of the device, the following equations are the calculations to configure the output voltage of the TPS63030 (net REG).

\[ R_2 = R_4 \times \left( \frac{V_{\text{out}}}{V_{\text{fb}}} - 1 \right) \]  

If \( R_4 = 100 \, \text{k}\Omega \), \( V_{\text{fb}} = 500 \, \text{mV} \), then

For \( V_{\text{OUT}} = 5 \, \text{V} \),

\[ R_2 = 100 \times \left( \frac{5}{0.5} - 1 \right) \]  

\[ R_2 = 887 \, \text{k}\Omega \]

Similarly for \( V_{\text{OUT}} = 3 \, \text{V} \), \( R_2 \approx 540 \, \text{k}\Omega \).

3.2 DRV2605L Haptic ERM/LRA Driver with Integrated Effect Library and Smart Loop

The DRV2605L is a low-voltage haptic driver with a built-in licensed Immersion TouchSense® 2200 waveform library. The DRV2605L is compatible with ERM and LRA motors and can be controlled over I²C from an external microcontroller. The connections to a motor are on nets OUT+ and OUT–.

![Figure 2. DRV2605L Haptic Driver](image-url)
3.2.1 Motor Voltages

When designing a system for haptic effects, consider these two voltage levels:

- **Rated Voltage**: This is the voltage at which the actuator is driven. The datasheet usually has this parameter.

- **Overdrive**: This is the voltage higher than the rated voltage applied during startup of the actuator to give an initial push to the actuator. During startup and braking phases, overdrive makes the effect very crisp and sharp. During the braking phase, the voltage is on opposite polarity for ERMs and in the same phase as the previous pulse for LRAs. Some datasheets specify the duration and the overdrive voltage, which is usually 1.5× to 2× the rated voltage for approximately under 50 ms. The DRV2605L also calculates the absolute number of overdrive pulses for LRA using the back-emf, which mitigates excessive overdrive or braking scenarios.

![Figure 3. Overdrive and Rated Voltage LRA](image1)

![Figure 4. Overdrive and Rated Voltage ERM](image2)

4 Test Data

4.1 Tools Used

- A DRV2605LEVM-BB AA Battery Buck-Boost reference design board
- A DRV-ACC16-EVM Haptic Accelerometer Measurement Tool
- A DRV-USBCOM-EVM Haptics Communication Board
- A Lecroy AP015 Current Probe
- Silicone Gel Blocks

4.2 Scope Capture Reference

![Figure 5. Sample Scope Capture](image3)
Channel 1 (C1) = OUT+ of DRV2605L
Channel 2 (C2) = OUT– of DRV2605L
Channel 3 (C2) = Acceleration on the dominant motor vibration axis
Channel 4 = Current probe on net VBAT
Math = Difference of OUT+ and OUT– (C1-C2)

The current measurement window is denoted by the two dotted marker lines on the waveform. The size of the window is based on the duration of the effect and will calculate time-based measurements, such as energy per click.

### 4.2.1 Acceleration Conversion

The peak-to-peak value of C3 can calculate the acceleration.

\[
\text{Acceleration} = \frac{\text{Value of } C3_{\text{peak to peak}}}{57} \left(\frac{2}{2}\right)
\]

(3)
4.3 Effects Preview

Different motors were connected to the outputs of the DRV2605LMSOP. Table 1 lists the three motors used in this study:

<table>
<thead>
<tr>
<th>MOTOR</th>
<th>MOTOR TYPE</th>
<th>PROGRAMMED RATED VOLTAGE</th>
<th>PROGRAMMED OVERDRIVE CLAMP</th>
<th>ACCELERATION (G)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEMCO 1030</td>
<td>LRA</td>
<td>1 VRMS</td>
<td>3.3 V</td>
<td>1.5</td>
</tr>
<tr>
<td>NRS2574i</td>
<td>ERM</td>
<td>1.7 V</td>
<td>2 V</td>
<td>1</td>
</tr>
<tr>
<td>Johnson Electric</td>
<td>ERM</td>
<td>4 V</td>
<td>5 V</td>
<td>6.7</td>
</tr>
</tbody>
</table>

List of effects: The following is a list of the effects that were captured.

- Infinite Buzz
- Strong Click
- Sharp Click
- Double Click
- Triple Click
- Buzz 100
- Pulsing

**NOTE:** These effects were captured with the configuration of 5 V applied to the DRV. The resistors R2 and R4 were unchanged.

4.4 SEMCO 1030 Linear Resonant Actuator

![Figure 6. Pulsing Strong](image6)

![Figure 7. Strong Click](image7)
Figure 8. Sharp Click 100

Figure 9. Double Click

Figure 10. Triple Click

Figure 11. Buzz1-100

Figure 12. Infinite Alert
4.5 Johnson Electric

Figure 13. Infinite Alert

Figure 14. Strong Click

Figure 15. Sharp Click 100

Figure 16. Double Click
Figure 20. RTP Buzz

Figure 21. Strong Click

Figure 22. Sharp Click 100

Figure 23. Double Click
4.7 Choice of Output Voltage vs Optimizing for Efficiency

From Equation 1, one can obtain different voltages on the output of the TPS63030, which is powering the DRV2605L. Two different configurations of \( V_{\text{OUT}} \) were obtained with resistor \( R_2 = 887 \) kohm and \( 537 \) kohm, which corresponds to \( V_{\text{OUT}} = 5 \) V and \( 3.3 \) V, respectively.

This voltage is important as it is the maximum to which the overdrive clamp can be set. Table 2 shows that it is optimal to have the difference between the output voltage closer to the overdrive voltage. Based on the application and in an example of a 3-V overdrive on an LRA, a 5-V output configuration for the same acceleration is unnecessary.
4.8 Resistor $R_2 = 887$ kohm ($V_{OUT} = 5$ V)

Figure 27. VBAT = 5 V

Figure 28. VBAT = 4 V

Figure 29. VBAT = 3 V

Figure 30. VBAT = 2 V
4.9 Resistor $R_2 = 530 \, k\Omega$ ($V_{\text{OUT}} \approx 3 \, V$)

<table>
<thead>
<tr>
<th>CONDITION</th>
<th>MEAN CURRENT (mA)</th>
<th>VBAT (V)</th>
<th>REG (V)</th>
<th>DURATION (ms)</th>
<th>ENERGY PER CLICK ($\mu$Ah)</th>
<th>APPROXIMATE NUMBER OF CLICKS FROM A 1500-mAh BATTERY</th>
</tr>
</thead>
<tbody>
<tr>
<td>R2 = 887 k</td>
<td>57.2</td>
<td>5</td>
<td>5</td>
<td>65</td>
<td>1.03</td>
<td>1,452,394</td>
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<tr>
<td>R2 = 887 k</td>
<td>90.8</td>
<td>4</td>
<td>5</td>
<td>65</td>
<td>1.64</td>
<td>914,944</td>
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<tr>
<td>R2 = 887 k</td>
<td>237.1</td>
<td>3</td>
<td>5</td>
<td>65</td>
<td>4.30</td>
<td>350,388</td>
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<tr>
<td>R2 = 887 k</td>
<td>283.7</td>
<td>2</td>
<td>5</td>
<td>65</td>
<td>5.12</td>
<td>292,834</td>
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<tr>
<td>R2 = 530 k</td>
<td>36.6</td>
<td>5</td>
<td>3</td>
<td>65</td>
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<tr>
<td>R2 = 530 k</td>
<td>47.6</td>
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<td>3</td>
<td>65</td>
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<tr>
<td>R2 = 530 k</td>
<td>73.7</td>
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<td>3</td>
<td>65</td>
<td>1.33</td>
<td>1,127,231</td>
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<tr>
<td>R2 = 530 k</td>
<td>153.2</td>
<td>2</td>
<td>3</td>
<td>65</td>
<td>2.77</td>
<td>542,278</td>
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</table>
NOTE: Always configure the output voltage of the Buck-Boost converter to be greater than or equal to the overdrive voltage of the motor.

Table 2 shows that for best results, the output voltage of the Buck-Boost converter must be set as high as the lowest value required for the overdrive clamp voltage of the motor.

5 Design Files

5.1 Schematics

To download the schematics, see the design files at TIDA-00407.
5.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00407.

Table 3. Bill of Materials

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<thead>
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<th>ITEM #</th>
<th>DESIGNATOR</th>
<th>QUANTITY</th>
<th>VALUE</th>
<th>PART NUMBER</th>
<th>MANUFACTURER</th>
<th>DESCRIPTION</th>
<th>PACKAGE REFERENCE</th>
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<td>PCB1</td>
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<td>Any</td>
<td>Printed Circuit Board</td>
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<td>Kemet</td>
<td>CAP, CERM, 10 µF, 6.3 V, ± 20%, X5R, 0603</td>
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<td>3</td>
<td>C4, C5</td>
<td>2</td>
<td>1 µF</td>
<td>C1005X5R C105K050BC</td>
<td>TDK</td>
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<td>4</td>
<td>J3</td>
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<td>5</td>
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<td>5x1 Header</td>
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<td>Inductor, Shielded Drum Core, Ferrite, 2.2 µH, 1.4 A, 0.11 Ω, SMD</td>
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<td>12</td>
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<td>DRV2605LD GS</td>
<td>TI</td>
<td>Haptic Driver for LRA and ERM With Built-In Library and Smart Loop Architecture, DGS0010A</td>
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</table>

5.3 Layer Plots

To download the layer plots, see the design files at TIDA-00407.

Figure 37. Top Overlay

Figure 38. Top Layer
5.4 **Altium Project**
To download the Altium project files, see the design files at TIDA-00407.

5.5 **Layout Guidelines**
To download the layout guidelines, see the design files at TIDA-00407.

5.6 **Gerber Files**
To download the Gerber files, see the design files at TIDA-00407.

6 **References**
1. *Choosing Inductors and Capacitors for DC/DC Converters* (SLVA157)
2. *DRV2605 Setup Guide* (SLOA189)
7 About the Author

GAUTHAM RAMACHANDRAN is an Applications Engineer at TI, where he currently works on Haptic technology. He develops hardware, evaluation modules, and reference designs along with collateral and system-level debug on various consumer electronic platforms. Gautham received his Masters of Electrical Engineering from Texas Tech University researching Micro Electro Mechanical Systems (MEMS). He has also worked on touch-screen controllers and has built automated test setups for touch panels in his previous role at TI.
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