

# DRV2665 Piezo Haptic Driver with Integrated Boost Converter and Digital Front End

## 1 Features

- Integrated Digital Front End
  - Up to 400-kHz I<sup>2</sup>C Bus Control
  - 100-Byte Internal FIFO Interface
  - Immersion TS5000-Compliant
  - Optional Analog Inputs
- High Voltage Piezo-Haptic Driver
  - Drives up to 100 nF at 200 V<sub>PP</sub> and 300 Hz
  - Drives up to 150 nF at 150 V<sub>PP</sub> and 300 Hz
  - Drives up to 330 nF at 100 V<sub>PP</sub> and 300 Hz
  - Drives up to 680 nF at 50 V<sub>PP</sub> and 300 Hz
  - Differential Output
- 105-V Integrated Boost Converter
  - Adjustable Boost Voltage
  - Adjustable Boost Current Limit
  - Integrated Power FET and Diode
  - No Transformer Required
- 2-ms Fast Start Up Time
- 3.3- to 5.5-V Wide Supply Voltage Range
- 1.8-V Compatible, V<sub>DD</sub> Tolerant Digital Pins

## 2 Applications

- Mobile Phones
- Tablets
- Portable Computers
- Keyboards and Mice
- Electronic Gaming
- Touch Enabled Devices

## 3 Description

The DRV2665 device is a piezo haptic driver with integrated 105-V boost switch, integrated power diode, integrated fully-differential amplifier, and integrated digital front end. This versatile device is capable of driving both high-voltage and low-voltage piezo haptic actuators. The input signal can be driven as haptic packets over the I<sup>2</sup>C port or through the analog inputs.

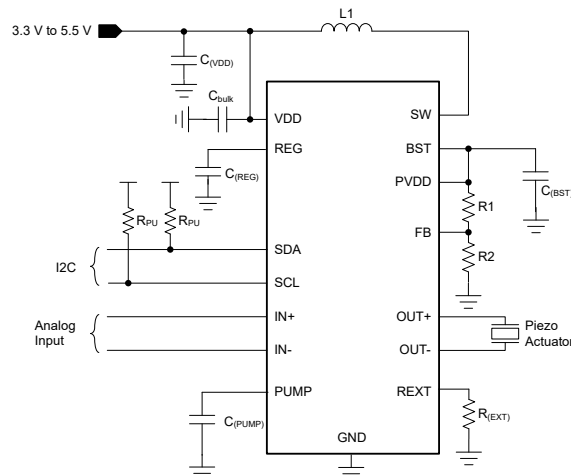
The digital interface of the DRV2665 device is available through an I<sup>2</sup>C compatible bus. A digital interface relieves the costly processor burden of the PWM generation or additional analog channel requirements in the host system. Any writes to the internal first-in, first-out buffer (FIFO) will automatically wake up the device and begin playing the waveform after the 2 ms internal start-up procedure. When the data flow stops or the FIFO under-runs, the DRV2665 device will automatically enter a pop-less shutdown procedure.

The boost voltage is set using two external resistors, and the boost current limit is programmable through the R<sub>EXT</sub> resistor. A typical start-up time of 2 ms makes the DRV2665 device an ideal piezo driver for fast haptic responses. Thermal overload protection prevents the device from being damaged when overdriven.

### Device Information<sup>(1)</sup>

| PART NUMBER | PACKAGE  | BODY SIZE (MAX)   |
|-------------|----------|-------------------|
| DRV2665     | QFN (20) | 4.00 mm × 4.00 mm |

(1) For all available packages, see the orderable addendum at the end of the data sheet.



**Simplified Schematic**



An IMPORTANT NOTICE at the end of this data sheet addresses availability, warranty, changes, use in safety-critical applications, intellectual property matters and other important disclaimers. PRODUCTION DATA.

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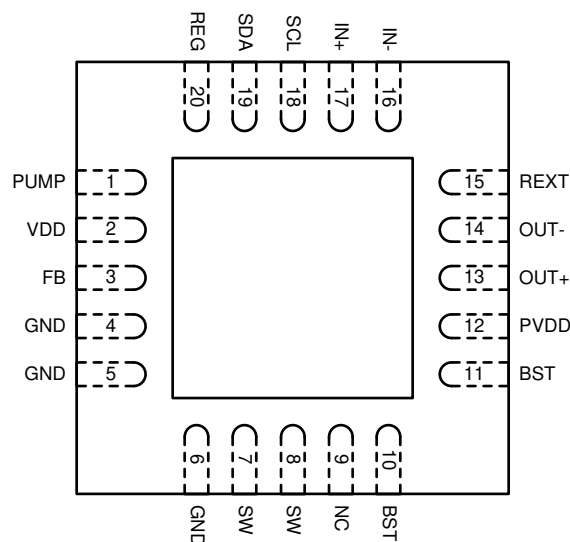
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## 4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

|                                                                                                                                                                                                                                                                                                     |             |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| <b>Changes from Revision B (September 2015) to Revision C (January 2023)</b>                                                                                                                                                                                                                        | <b>Page</b> |
| • Changed $V_{DD}$ MIN spec from 3.0 to 3.3.....                                                                                                                                                                                                                                                    | <b>4</b>    |
| <b>Changes from Revision A (January 2014) to Revision B (September 2015)</b>                                                                                                                                                                                                                        | <b>Page</b> |
| • Added ESD Ratings table, Feature Description section, Device Functional Modes section, Application and Implementation section, Power Supply Recommendations section, Layout section, Device and Documentation Support section, and Mechanical, Packaging, and Orderable Information section. .... | <b>1</b>    |
| • Added Exception description to <a href="#">Section 7.3.11.3</a> section.....                                                                                                                                                                                                                      | <b>12</b>   |
| <b>Changes from Revision * (May 2012) to Revision A (January 2014)</b>                                                                                                                                                                                                                              | <b>Page</b> |
| • Changed from one-page data sheet to full data sheet in product folder.....                                                                                                                                                                                                                        | <b>1</b>    |

## 5 Pin Configuration and Functions



**Figure 5-1. RGP Package 20-Pin QFN With Exposed Thermal Pad Top View**

**Table 5-1. Pin Functions**

| PIN  |                  | TYPE | DESCRIPTION                                                   |
|------|------------------|------|---------------------------------------------------------------|
| NAME | NO. <sup>1</sup> |      |                                                               |
| PUMP | 1                | P    | Internal charge pump voltage                                  |
| VDD  | 2                | P    | 3- to 5.5-V supply input. A 1 $\mu$ F-capacitor is required.  |
| FB   | 3                | I    | Boost feedback                                                |
| GND  | 4, 5, 6          | P    | Supply ground                                                 |
| SW   | 7, 8             | P    | Internal boost switch pin                                     |
| NC   | 9                | —    | No connect                                                    |
| BST  | 10, 11           | P    | Boost output voltage. A 0.1- $\mu$ F capacitor is required.   |
| PVDD | 12               | P    | High-voltage amplifier input voltage                          |
| OUT+ | 13               | O    | Positive haptic driver differential output                    |
| OUT- | 14               | O    | Negative haptic driver differential output                    |
| REXT | 15               | I    | Sets boost current limit. Resistor to ground.                 |
| IN-  | 16               | I    | Negative analog input                                         |
| IN+  | 17               | I    | Positive analog input                                         |
| SCL  | 18               | I    | I <sup>2</sup> C clock                                        |
| SDA  | 19               | I/O  | I <sup>2</sup> C data                                         |
| REG  | 20               | O    | 1.8-V regulator output. A 0.1- $\mu$ F capacitor is required. |

1. I = Input, O = Output, P = Power

## 6 Specifications

### 6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)<sup>(1)</sup>

|                                       |                           | MIN  | MAX            | UNIT |
|---------------------------------------|---------------------------|------|----------------|------|
| Supply Voltage, $V_{DD}$              |                           | -0.3 | 6              | V    |
| Input voltage, $V_I$                  | SDA, SCL, IN+, IN-, FB    | -0.3 | $V_{DD} + 0.3$ | V    |
| Boost voltage                         | BST, SW, OUT+, OUT-, PVDD | -0.3 | 120            | V    |
| Operating free-air temperature, $T_A$ |                           | -40  | 70             | °C   |
| Operating junction temperature, $T_J$ |                           | -40  | 150            | °C   |
| Storage temperature, $T_{stg}$        |                           | -65  | 85             | °C   |

- (1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

### 6.2 ESD Ratings

|                                     |                                                                                | VALUE | UNIT |
|-------------------------------------|--------------------------------------------------------------------------------|-------|------|
| $V_{(ESD)}$ Electrostatic discharge | Human body model (HBM), per ANSI/ESDA/JEDEC JS-001 <sup>(1)</sup>              | ±2500 | V    |
|                                     | Charged device model (CDM), per JEDEC specification JESD22-C101 <sup>(2)</sup> | ±500  |      |

- (1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

- (2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

### 6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

|           |                                | MIN                                                                    | NOM | MAX  | UNIT |
|-----------|--------------------------------|------------------------------------------------------------------------|-----|------|------|
| $V_{DD}$  | Supply voltage                 | 3.3                                                                    |     | 5.5  | V    |
| $V_{BST}$ | Boost voltage                  | 15                                                                     |     | 105  | V    |
| $V_{IN}$  | Differential input voltage     |                                                                        | 1.8 |      | V    |
| $C_L$     | Load capacitance               | $V_{BST} = 105$ V, Frequency = 500 Hz, $V_{OUT} = 200$ V <sub>PP</sub> |     | 50   | nF   |
|           |                                | $V_{BST} = 105$ V, Frequency = 300 Hz, $V_{OUT} = 200$ V <sub>PP</sub> |     | 100  |      |
|           |                                | $V_{BST} = 80$ V, Frequency = 300 Hz, $V_{OUT} = 150$ V <sub>PP</sub>  |     | 150  |      |
|           |                                | $V_{BST} = 55$ V, Frequency = 300 Hz, $V_{OUT} = 100$ V <sub>PP</sub>  |     | 330  |      |
|           |                                | $V_{BST} = 30$ V, Frequency = 300 Hz, $V_{OUT} = 50$ V <sub>PP</sub>   |     | 680  |      |
|           |                                | $V_{BST} = 25$ V, Frequency = 300 Hz, $V_{OUT} = 40$ V <sub>PP</sub>   |     | 1000 |      |
|           |                                | $V_{BST} = 15$ V, Frequency = 300 Hz, $V_{OUT} = 20$ V <sub>PP</sub>   |     | 3000 |      |
| $R_{EXT}$ | Current limit control resistor | 6                                                                      |     | 35   | kΩ   |
| L         | Inductance for boost converter | 3.3                                                                    |     |      | μH   |

### 6.4 Thermal Information

| THERMAL METRIC <sup>(1)</sup> |                                              | DRV2665   | UNIT |
|-------------------------------|----------------------------------------------|-----------|------|
|                               |                                              | RGP (QFN) |      |
|                               |                                              | 20 PINS   |      |
| $R_{\theta JA}$               | Junction-to-ambient thermal resistance       | 32.6      | °C/W |
| $R_{\theta JC(top)}$          | Junction-to-case (top) thermal resistance    | 30.4      | °C/W |
| $R_{\theta JB}$               | Junction-to-board thermal resistance         | 8.2       | °C/W |
| $\Psi_{JT}$                   | Junction-to-top characterization parameter   | 0.4       | °C/W |
| $\Psi_{JB}$                   | Junction-to-board characterization parameter | 8.1       | °C/W |

| THERMAL METRIC <sup>(1)</sup>                                     | UNIT | DRV2665   |
|-------------------------------------------------------------------|------|-----------|
|                                                                   |      | RGP (QFN) |
|                                                                   |      | 20 PINS   |
| $R_{\theta JC(bot)}$ Junction-to-case (bottom) thermal resistance | °C/W | 2.2       |

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

## 6.5 Electrical Characteristics

$T_A = 25\text{ }^{\circ}\text{C}$ ,  $V_{DD} = 3.6\text{ V}$  (unless otherwise noted)

| PARAMETER     |                                          | TEST CONDITIONS                                                                      | MIN   | TYP  | MAX  | UNIT          |
|---------------|------------------------------------------|--------------------------------------------------------------------------------------|-------|------|------|---------------|
| $V_{REG}$     | Voltage at the REG pin                   |                                                                                      | 1.6   | 1.75 | 1.9  | V             |
| $I_{IL}$      | Digital low-level input current          | SDA, SCL<br>$V_{DD} = 3.6\text{ V}$ , $V_I = 0\text{ V}$                             |       |      | 1    | $\mu\text{A}$ |
| $I_{IH}$      | Digital high-level input current         | SDA, SCL<br>$V_{DD} = 3.6\text{ V}$ , $V_I = V_{DD}$                                 |       |      | 1    | $\mu\text{A}$ |
| $V_{IL}$      | Digital low-level input voltage          | SDA, SCL<br>$V_{DD} = 3.6\text{ V}$                                                  |       |      | 0.5  | V             |
| $V_{IH}$      | Digital high-level input voltage         | SDA, SCL<br>$V_{DD} = 3.6\text{ V}$                                                  | 1.4   |      |      | V             |
| $V_{OL}$      | Digital low-level output voltage         | SDA<br>3-mA sink current                                                             |       |      | 0.4  | V             |
| $I_{SD}$      | Shutdown current                         | $V_{DD} = 3.6\text{ V}$ , STANDBY = 1                                                |       | 10   |      | $\mu\text{A}$ |
| $I_Q$         | Quiescent current                        | Digital mode<br>$V_{DD} = 3.6\text{ V}$ , STANDBY = 0                                |       | 130  | 175  | $\mu\text{A}$ |
|               |                                          | Analog mode<br>$V_{DD} = 3.6\text{ V}$ , analog input mode, $V_{BST} = 105\text{ V}$ |       | 24   |      | mA            |
|               | Analog mode                              | $V_{DD} = 3.6\text{ V}$ , analog input mode, $V_{BST} = 80\text{ V}$                 |       | 13   |      |               |
|               |                                          | $V_{DD} = 3.6\text{ V}$ , analog input mode, $V_{BST} = 50\text{ V}$                 |       | 9    |      |               |
|               |                                          | $V_{DD} = 3.6\text{ V}$ , analog input mode, $V_{BST} = 30\text{ V}$                 |       | 5    |      |               |
| $R_{IN}$      | Input impedance                          | IN+, IN–; All gains                                                                  |       | 100  |      | k $\Omega$    |
| $V_{OUT(FS)}$ | Full-scale output voltage (digital mode) | GAIN[1:0] = 00                                                                       | 49    | 50   | 51   | $V_{PP}$      |
|               |                                          | GAIN[1:0] = 01                                                                       | 98    | 100  | 102  |               |
|               |                                          | GAIN[1:0] = 10                                                                       | 147   | 150  | 153  |               |
|               |                                          | GAIN[1:0] = 01                                                                       | 196   | 200  | 204  |               |
| $V_{OUT(OS)}$ | Output offset                            | All gains                                                                            | –0.25 |      | 0.25 | V             |
| BW            | Amplifier bandwidth                      | GAIN[1:0] = 00, $V_{OUT} = 50\text{ V}_{PP}$ , no load                               |       | 20   |      | kHz           |
|               |                                          | GAIN[1:0] = 01, $V_{OUT} = 100\text{ V}_{PP}$ , no load                              |       | 10   |      |               |
|               |                                          | GAIN[1:0] = 10, $V_{OUT} = 150\text{ V}_{PP}$ , no load                              |       | 7.5  |      |               |
|               |                                          | GAIN[1:0] = 11, $V_{OUT} = 200\text{ V}_{PP}$ , no load                              |       | 5    |      |               |

$T_A = 25\text{ }^{\circ}\text{C}$ ,  $V_{DD} = 3.6\text{ V}$  (unless otherwise noted)

| PARAMETER                                              | TEST CONDITIONS                                                                                                          | MIN | TYP | MAX  | UNIT |
|--------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|-----|-----|------|------|
| $I_{BAT,AVG}$ Average battery current during operation | $C_L = 220\text{ nF}$ , $f = 200\text{ Hz}$ , $V_{BST} = 30\text{ V}$ , $GAIN[1:0] = 00$ , $V_{OUT} = 50\text{ V}_{PP}$  |     | 69  |      | mA   |
|                                                        | $C_L = 680\text{ nF}$ , $f = 150\text{ Hz}$ , $V_{BST} = 30\text{ V}$ , $GAIN[1:0] = 00$ , $V_{OUT} = 50\text{ V}_{PP}$  |     | 75  |      |      |
|                                                        | $C_L = 680\text{ nF}$ , $f = 300\text{ Hz}$ , $V_{BST} = 30\text{ V}$ , $GAIN[1:0] = 00$ , $V_{OUT} = 50\text{ V}_{PP}$  |     | 115 |      |      |
|                                                        | $C_L = 22\text{ nF}$ , $f = 200\text{ Hz}$ , $V_{BST} = 80\text{ V}$ , $GAIN[1:0] = 10$ , $V_{OUT} = 150\text{ V}_{PP}$  |     | 67  |      |      |
|                                                        | $C_L = 47\text{ nF}$ , $f = 150\text{ Hz}$ , $V_{BST} = 105\text{ V}$ , $GAIN[1:0] = 11$ , $V_{OUT} = 200\text{ V}_{PP}$ |     | 210 |      |      |
|                                                        | $C_L = 47\text{ nF}$ , $f = 300\text{ Hz}$ , $V_{BST} = 105\text{ V}$ , $GAIN[1:0] = 11$ , $V_{OUT} = 200\text{ V}_{PP}$ |     | 400 |      |      |
| THD+N Total harmonic distortion plus noise             | $f = 300\text{ Hz}$ , $V_{OUT} = 200\text{ V}_{PP}$                                                                      |     | 1%  |      |      |
| $f_S$ Output sample rate                               | Digital playback engine sample rate                                                                                      | 7.8 | 8   | 8.05 | kHz  |

## 6.6 Timing Requirements

 $T_A = 25\text{ }^{\circ}\text{C}$ ,  $V_{DD} = 3.6\text{ V}$  (unless otherwise noted). For timing diagrams, see [Figure 6-1](#) and [Figure 6-2](#).

|                                                          | MIN | NOM | MAX | UNIT          |
|----------------------------------------------------------|-----|-----|-----|---------------|
| $f_{SCL}$ Frequency at the SCL pin with no wait states   |     |     | 400 | kHz           |
| $t_{W(H)}$ Pulse duration, SCL high                      | 0.6 |     |     | $\mu\text{s}$ |
| $t_{W(L)}$ Pulse duration, SCL low                       | 1.3 |     |     | $\mu\text{s}$ |
| $t_{su(1)}$ Setup time, SDA to SCL                       | 100 |     |     | ns            |
| $t_{h(1)}$ Hold time, SCL to SDA                         | 10  |     |     | ns            |
| $t_{BUF}$ Bus free time between stop and start condition | 1.3 |     |     | $\mu\text{s}$ |
| $t_{su(2)}$ Setup time, SCL to start condition           | 0.6 |     |     | $\mu\text{s}$ |
| $t_{h(2)}$ Hold time, start condition to SCL             | 0.6 |     |     | $\mu\text{s}$ |
| $t_{su(3)}$ Setup time, SCL to stop condition            | 0.6 |     |     | $\mu\text{s}$ |

## 6.7 Switching Characteristics

over operating free-air temperature range (unless otherwise noted)

| PARAMETER                 | TEST CONDITIONS                                                              | MIN | TYP | MAX | UNIT |
|---------------------------|------------------------------------------------------------------------------|-----|-----|-----|------|
| $T_{start}$ Start-up time | Time from I <sup>2</sup> C write until boost and amplifier are fully enabled |     | 2   |     | ms   |

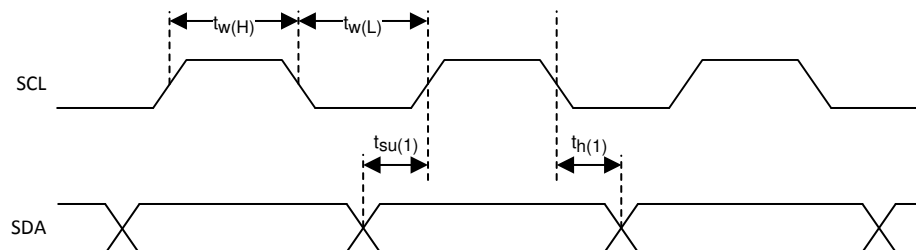
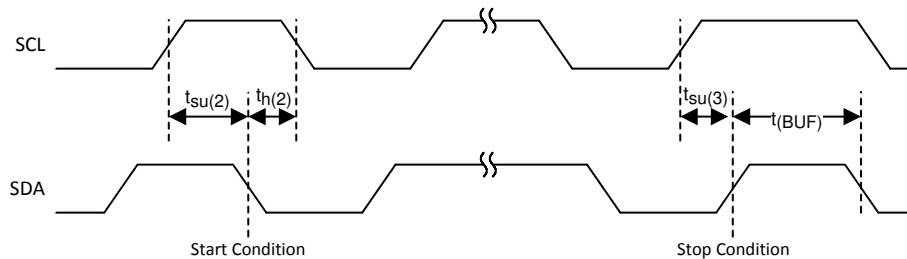
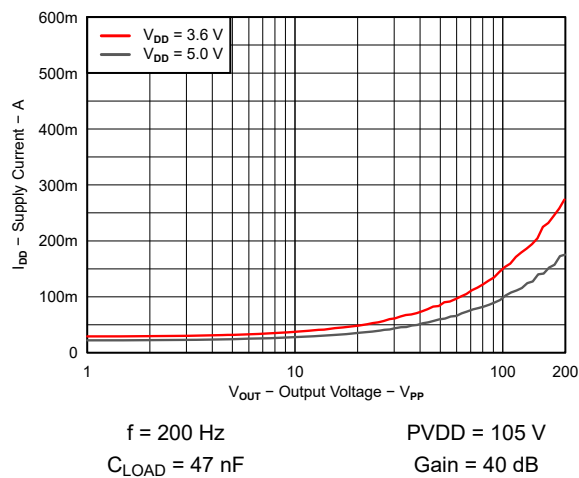


Figure 6-1. SCL and SDA Timing

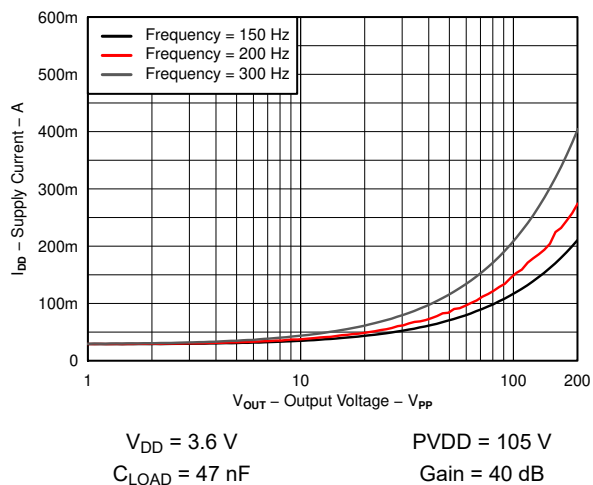


**Figure 6-2. Timing for Start and Stop Conditions**

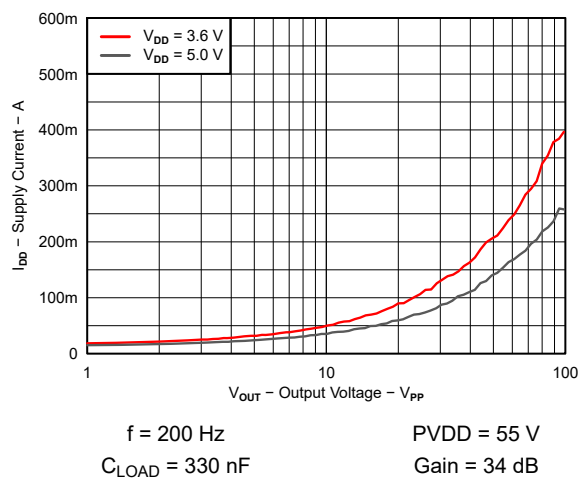
## 6.8 Typical Characteristics



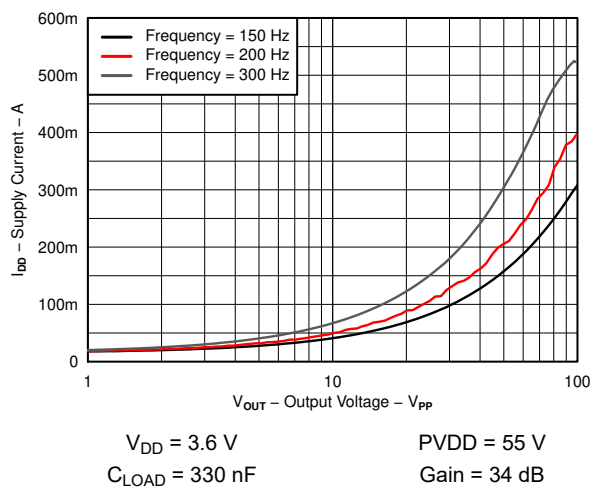
**Figure 6-3. Supply Current vs Output Voltage**



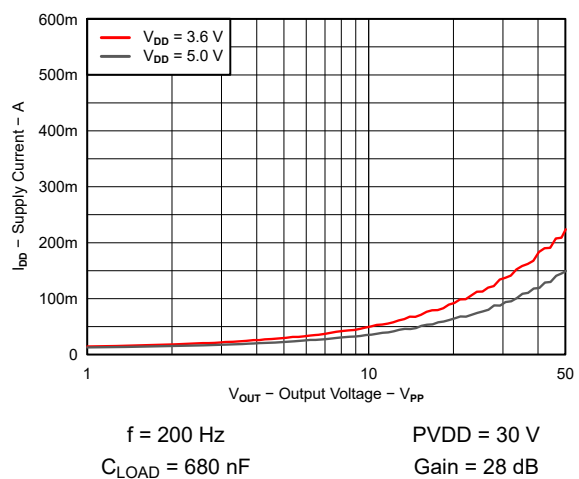
**Figure 6-4. Supply Current vs Output Voltage**



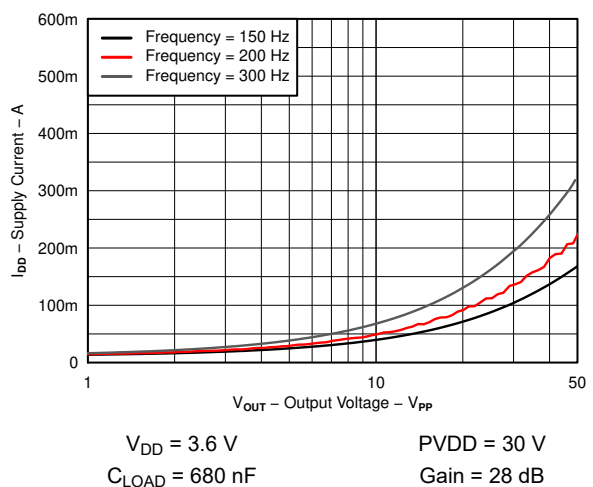
**Figure 6-5. Supply Current vs Output Voltage**



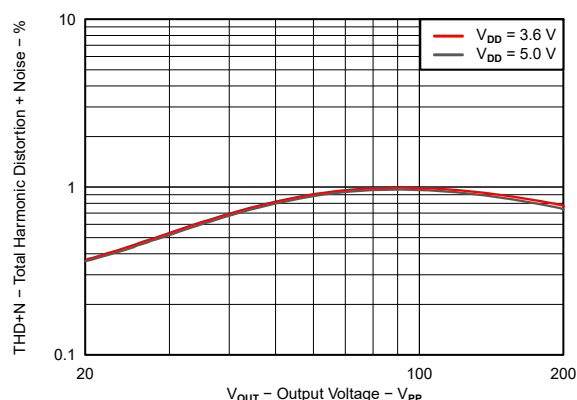
**Figure 6-6. Supply Current vs Output Voltage**



**Figure 6-7. Supply Current vs Output Voltage**

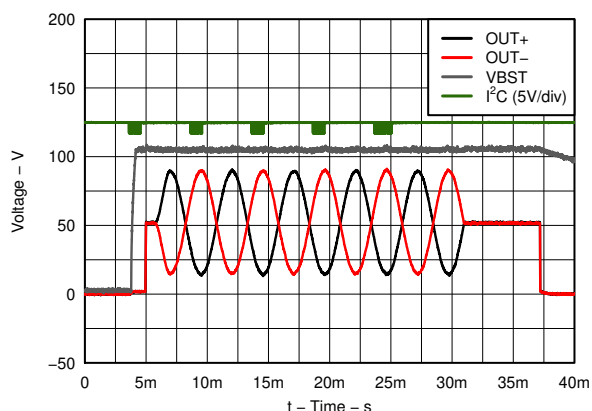


**Figure 6-8. Supply Current vs Output Voltage**



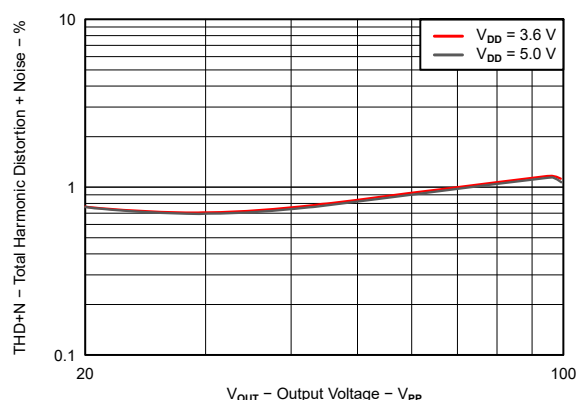
$f = 200 \text{ Hz}$        $PVDD = 105 \text{ V}$   
 $C_{LOAD} = 47 \text{ nF}$        $\text{Gain} = 40 \text{ dB}$

**Figure 6-9. Total Harmonic Distortion + Noise vs Output Voltage**



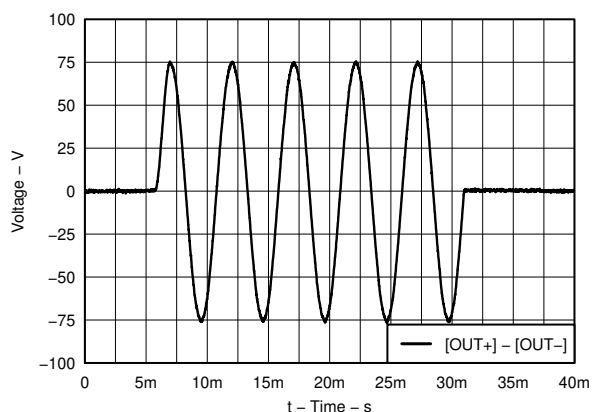
$V_{DD} = 3.6 \text{ V}$        $PVDD = 105 \text{ V}$   
 $C_{LOAD} = 47 \text{ nF}$        $\text{Gain} = 40 \text{ dB}$

**Figure 6-10. Typical Waveform**



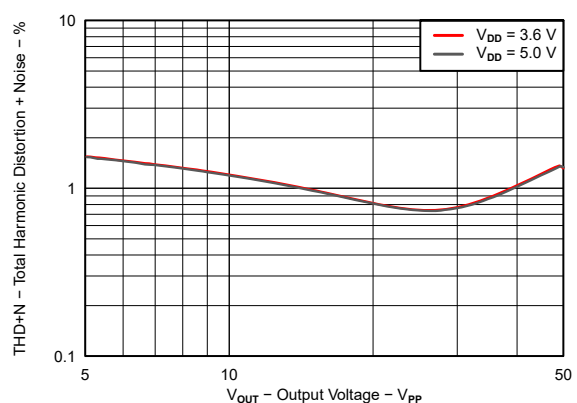
$f = 200 \text{ Hz}$        $PVDD = 55 \text{ V}$   
 $C_{LOAD} = 330 \text{ nF}$        $\text{Gain} = 34 \text{ dB}$

**Figure 6-11. Total Harmonic Distortion + Noise vs Output Voltage**



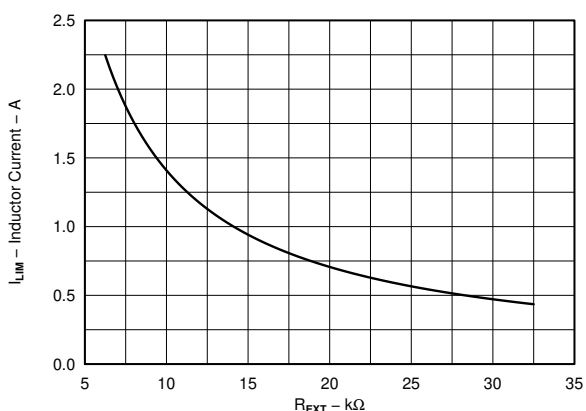
$V_{DD} = 3.6 \text{ V}$        $PVDD = 55 \text{ V}$   
 $C_{LOAD} = 330 \text{ nF}$        $\text{Gain} = 34 \text{ dB}$

**Figure 6-12. Typical Waveform - Differential**



$f = 200 \text{ Hz}$        $PVDD = 30 \text{ V}$   
 $C_{LOAD} = 680 \text{ nF}$        $\text{Gain} = 28 \text{ dB}$

**Figure 6-13. Total Harmonic Distortion + Noise vs Output Voltage**



$V_{DD} = 3.6 \text{ V}$        $PVDD = 30 \text{ V}$   
 $C_{LOAD} = 680 \text{ nF}$        $\text{Gain} = 28 \text{ dB}$

**Figure 6-14.  $I_{LIM}$  vs  $R_{EXT}$**

## 7 Detailed Description

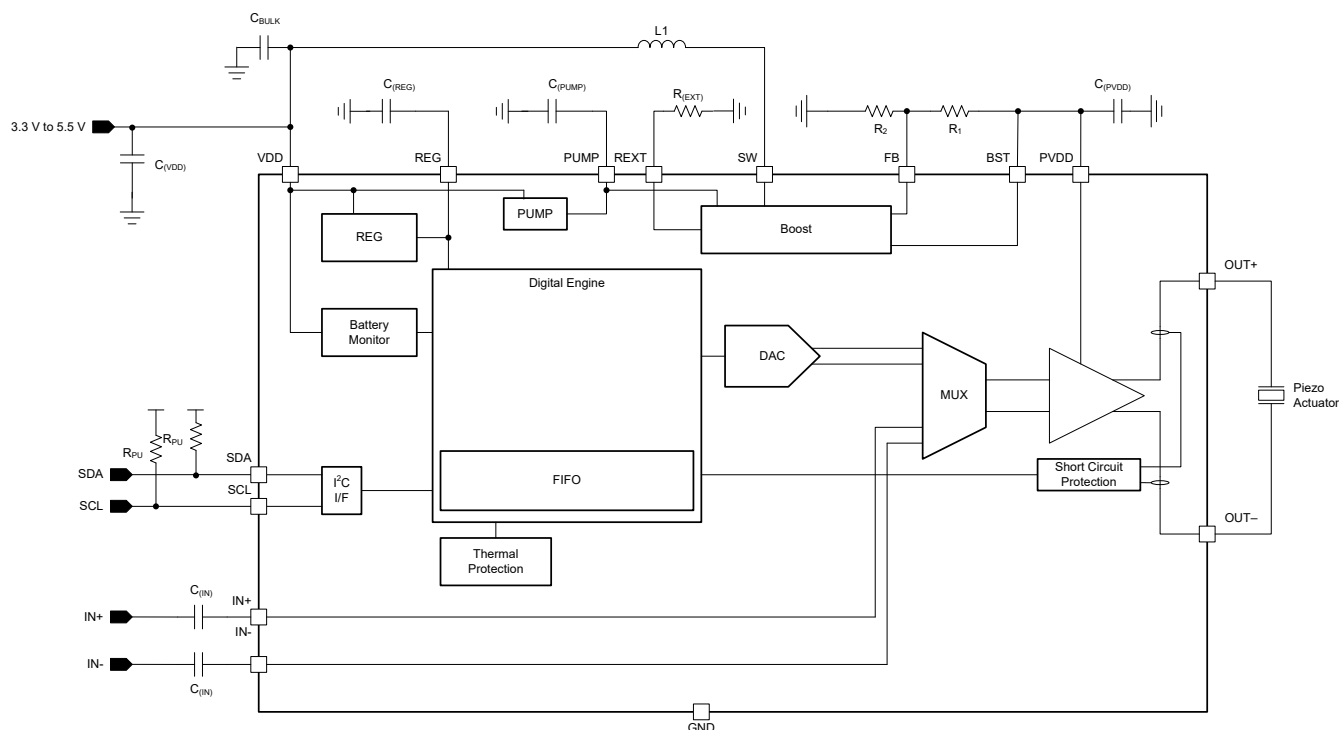
### 7.1 Overview

The DRV2665 device is a piezo haptic driver with integrated boost switch, integrated power diode, integrated fully-differential amplifier, and integrated digital front end. This versatile device is capable of driving both high-voltage and low-voltage piezo haptic actuators. The input signal can be driven over the I<sup>2</sup>C port or the analog inputs.

The digital interface of the DRV2665 device is available through an I<sup>2</sup>C compatible bus. A digital interface relieves the costly processor burden of PWM generation or additional analog channel requirements in the host system. Any writes to the internal FIFO automatically wakes up the device and begin playing the waveform after the 2 ms internal startup procedure. When the data flow stops or the FIFO under runs, the device automatically enters a pop-less shutdown procedure.

The boost voltage is set using two external resistors, and the boost current limit is programmable through the R<sub>EXT</sub> resistor. A typical start-up time of 2 ms makes the DRV2665 an ideal piezo driver for fast haptic responses. Thermal overload protection prevents the device from being damaged when overdriven.

### 7.2 Functional Block Diagram



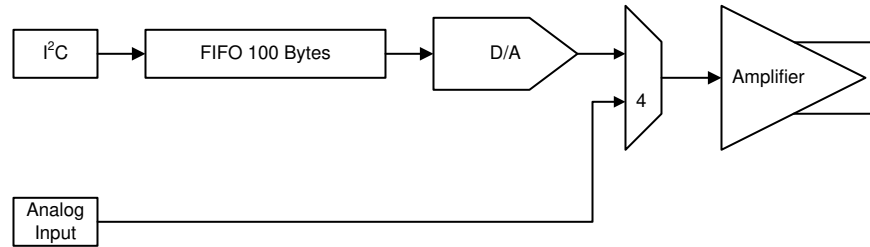
### 7.3 Feature Description

#### 7.3.1 Support for Haptic Piezo Actuators

The DRV2665 device supports haptic piezo actuators of up to 200 V<sub>PP</sub>.

#### 7.3.2 Flexible Front End Interface

The DRV2665 device supports multiple approaches to launch and control haptic effects, that are detailed in [Section 7.4](#).



**Figure 7-1. Front-End Interface**

### 7.3.3 Ramp Down Behavior

If the user leaves the state of the DAC at any level other than mid-scale (0x00), the DAC automatically ramps down at a safe rate after the timeout period has expired. If the DRV2665 device is properly programmed, the ramp down sequence will never be used. This is a failsafe for any unavoidable interruptions to the playback process. Any writes to the FIFO during the ramp down period are discarded.

### 7.3.4 Low Latency Startup

The DRV2665 device features a fast startup time, that is essential for achieving low latency in haptic applications. When the STANDBY bit is transitioned from high to low, the device is ready for operation. The device logic automatically controls the internal boost converter and amplifier enable signals. The boost converter and amplifier are enabled only when needed and otherwise remain in a lower power idle state. When the device received a data byte through the FIFO interface, the boost converter and amplifier wake up and the internal logic sends the first sample through the internal DAC after the wake-up is completed. In the system application, the entire system latency must be kept to less than 30 ms total to be imperceptible to the end user. At a 2-ms wake-up time, the device is a small percentage of the total system latency.

If the EN\_OVERRIDE bit is set, the device immediately enters the startup procedure and the boost converter and amplifier remain enabled, bypassing the internal controls. Subsequent transactions occur immediately with no wake-up overhead, but the boost converter and amplifier draw a quiescent current until the EN\_OVERRIDE bit is cleared by the user.

### 7.3.5 Low Power Standby Mode

The DRV2665 device has a low-power standby mode through the I²C interface that puts the device in its lowest power state. This mode is entered when the standby bit (STANDBY) is set from low to high. When the STANDBY bit is set high, no other mode of operation is enabled. When the STANDBY bit transitions from high to low, the device is readied for operation and may receive data.

### 7.3.6 Device Reset

The DRV2665 device has software-based reset functionality. When the DEV\_RST bit is set, the device immediately stops any transaction in process, resets all of its internal registers to the default values, and enters standby mode.

### 7.3.7 Amplifier Gain

The amplifier gain determines the gain from IN+/IN– to OUT+/OUT– when using the analog playback mode. For digital playback, the gain is optimized for achieving approximately 50 V<sub>PP</sub>, 100 V<sub>PP</sub>, 150 V<sub>PP</sub>, 200 V<sub>PP</sub> without clipping. Note that clipping of the amplifier occurs if the expected peak voltage is greater than the boost converter output voltage (VBST)

The DRV2665 device gain is programmable according to [Table 7-1](#).

**Table 7-1. Amplifier Gain Table**

| GAIN[1] | GAIN[0] | FULL SCALE PEAK VOLTAGE (V) | GAIN (dB) ANALOG MODE |
|---------|---------|-----------------------------|-----------------------|
| 0       | 0       | 25                          | 28.8                  |
| 0       | 1       | 50                          | 34.8                  |

**Table 7-1. Amplifier Gain Table (continued)**

| GAIN[1] | GAIN[0] | FULL SCALE PEAK VOLTAGE (V) | GAIN (dB) ANALOG MODE |
|---------|---------|-----------------------------|-----------------------|
| 1       | 0       | 75                          | 38.4                  |
| 1       | 1       | 100                         | 40.7                  |

### 7.3.8 Adjustable Boost Voltage

The output voltage of the integrated boost converter may be adjusted by a resistive feedback divider between the boost output voltage (VBST) and the feedback pin (FB). The boost voltage must be programmed to a value greater than the maximum peak signal voltage that the user expects to create with the device amplifier. Lower boost voltages achieve better system efficiency when lower amplitude signals are applied, thus the user must take care not to use a higher boost voltage than necessary. The maximum allowed boost voltage is 105 V.

### 7.3.9 Adjustable Current Limit

The current limit of the boost switch can be adjusted through a resistor to ground placed on the REXT pin. To avoid damage to both the inductor and the DRV2665 device, the programmed current limit must be less than the rated saturation limit of the inductor selected by the user. If the combination of the programmed limit and inductor saturation is not high enough, then the output current of the boost converter will not be high enough to regulate the boost output voltage under heavy load conditions. This then causes the boosted rail to sag, possibly causing distortion of the output waveform.

### 7.3.10 Internal Charge Pump

The DRV2665 device has an integrated charge pump to provide adequate gate drive for internal nodes. The output of this charge pump is placed on the PUMP pin. An X5R or X7R storage capacitor of 0.1  $\mu$ F with a voltage rating of 10 V or greater must be placed at this pin.

### 7.3.11 Device Protection

#### 7.3.11.1 Thermal Protection

The DRV2665 device contains an internal temperature sensor that shuts down both the boost converter and the high-voltage amplifier when the temperature threshold is exceeded. When the device temperature falls below the threshold, the device will restart operation automatically. Continuous operation of the device is not recommended. Most haptic use models only operate the device in short bursts. The thermal shutdown function protects the device from damage when overdriven, but usage models which drive the device into thermal shutdown must always be avoided.

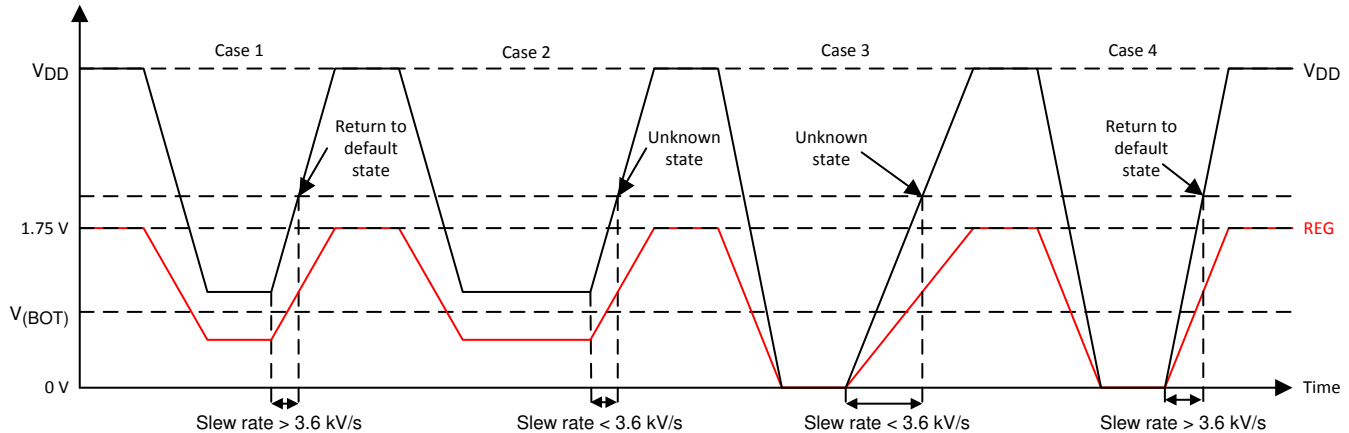
#### 7.3.11.2 Overcurrent Protection

If the load demands more current than what the DRV2665 device can supply, the device automatically clamps the output voltage to avoid damage.

#### 7.3.11.3 Brownout Protection

The DRV2665 device has on-chip brownout protection. When activated, a reset signal is issued that returns the DRV2665 device to the initial default state. If the voltage regulator  $V_{REG}$  goes below the brownout protection threshold ( $V_{BOT}$ ) the DRV2665 device automatically shuts down. When  $V_{REG}$  returns to the typical output voltage (1.75 V), the DRV2665 device returns to the initial device state. The brownout protection threshold,  $V_{BOT}$ , is typically at 0.84 V.

There is one exception to this behavior. The brownout circuit is designed to tolerate fast brownout conditions as shown by Case 1 in [Figure 7-2](#). If the  $V_{DD}$  ramp-up rate is slower than 3.6 kV/s, then the device can fall into an unknown state. In such a situation, to return to the initial default state the device must be power-cycled with a  $V_{DD}$  ramp-up rate that is faster than 3.6 kV/s.



**Figure 7-2. Brownout Behavior**

## 7.4 Device Functional Modes

### 7.4.1 FIFO Mode

The DRV2665 device includes a 100-byte FIFO for real-time haptic waveform playback. The FIFO mode accepts 8-bit digital haptic waveform data over an I<sup>2</sup>C compatible bus and writes it into an on-chip FIFO. The data is read out of the FIFO automatically at an 8-kHz sampling rate and fed into a digital-to-analog converter (DAC). The DAC then drives the high-voltage amplifier. This mode is utilized when the user writes directly to the I<sup>2</sup>C FIFO entry address (0x0B). When the first data byte is written to the FIFO, the device goes through the proper start-up sequence and begins outputting the waveform automatically. An internal timing sequence waits approximately 2 ms before the first data is sent through the DAC and output by the device. It is important that the data values start and end at or near the mid-scale code (0x00) to avoid large steps at the beginning and end of the waveform. When the FIFO is empty, the device waits for the timeout period, and then enters into an idle state.

Because the speed of the serial interface could be faster than the read-out rate of the FIFO, the device does not acknowledge, or NAK, if the FIFO is full during a FIFO write transaction. If at any time the FIFO becomes completely full, the FIFO\_FULL bit is set. When in this condition, the FIFO cannot accept more data without overwriting previous data that has not yet been played. If this occurs, the user must wait until data has had a chance to empty from the FIFO before sending more data. The data must be re-sent starting at the byte that received a NAK.

Any multi-byte I<sup>2</sup>C write to the FIFO register is treated as a continuous write to the FIFO. Multi-byte writes are preferred for optimum performance. The FIFO interprets the incoming data as twos complement. This means the maximum full-scale code is 0x7F, the maximum negative voltage is 0x80, and the mid-scale is 0x00.

### 7.4.2 Analog Playback Mode

In analog playback mode the signal in the IN+/IN– inputs is amplified and played through the high-voltage amplifier. When the INPUT\_MUX bit is set, the DRV2665 device switches the analog inputs (IN+/IN–) to the high-voltage amplifier. While in the analog mode, the gain is still register-selectable. Also, the high-voltage amplifier enable is controlled directly through the EN\_OVERRIDE bit, so the EN\_OVERRIDE bit must be set for the boost and amplifier to be active.

### 7.4.3 Low Voltage Operation Mode

The lowest gain setting is optimized for 50 V<sub>PP</sub> with a boost voltage of 30 V. Some applications may not need 50 V<sub>PP</sub>, so the user may elect to program the boost converter as low as 15 V to improve efficiency. When using boost voltages lower than 30 V, consider the following: First, to reduce boost ripple to an acceptable level, a 50-V rated, 0.22-μF boost capacitor is recommended. Second, the maximum code range of the digital interface is limited. For example, the user may elect to program the boost voltage to 25 V, and plan for a maximum drive signal of 40 V<sub>PP</sub> at the actuator. Any digital code given to the FIFO that is greater than  $20 V_P / 25 V_P \times 127 = \pm 102$  may induce clipping, so the user must only send digital codes between –102 and 102. Use of codes outside this range, for this example, may clip or drive the actuator beyond its rating.

## 7.5 Programming

### 7.5.1 Programming the Boost Voltage

The boost output voltage is programmed through two external resistors as shown in Figure 7-3. The boost output voltage is given by Equation 1.

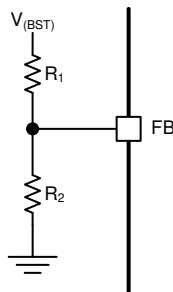


Figure 7-3. FB Network

$$V_{(BST)} = V_{(FB)} \cdot \left( 1 + \frac{R_1}{R_2} \right) \quad (1)$$

where

- $V_{(FB)} = 1.32 \text{ V}$

$V_{(BST)}$  must be programmed to a value of 5.0 V greater than the largest peak voltage expected in the system to allow adequate amplifier headroom. Because the programming range for the boost voltage extends to 105 V, the leakage current through the resistor divider can become significant. It is recommended that the sum of the resistances  $R_1 + R_2$  be greater than 400 kΩ. When resistor values greater than 1 MΩ are used, PCB contamination may cause boost voltage inaccuracy. Exercise caution when soldering large resistances, and clean the area when finished for best results. Table 7-2 shows examples on how to configure the device for different output voltages.

Table 7-2. Boost Voltage Table

| $R_1$  | $R_2$   | GAIN[1:0] | $V_{(BST)}$ | FULL SCALE PEAK VOLTAGE (V) |
|--------|---------|-----------|-------------|-----------------------------|
| 402 kΩ | 18.2 kΩ | 00        | 30          | 25                          |
| 392 kΩ | 9.76 kΩ | 01        | 55          | 50                          |
| 768 kΩ | 13 kΩ   | 10        | 80          | 75                          |
| 768 kΩ | 9.76 kΩ | 11        | 105         | 100                         |

### 7.5.2 Programming the Boost Current Limit

The peak current drawn from the supply through the inductor is set solely by the  $R_{(EXT)}$  resistor. This peak current limit is independent of the inductance value chosen, but the inductor must be capable of handling this programmed limit. The relationship of  $R_{(EXT)}$  and  $I_{LIM}$  is approximated by Equation 2.

$$R_{(EXT)} = \left( K \cdot \frac{V_{REF}}{I_{LIM}} \right) - R_{INT} \quad (2)$$

where

- $K = 10500$ , , and
- $V_{REF} = 1.35 \text{ V}$
- $R_{INT} = 60 \text{ } \Omega$
- $I_{LIM}$  is the desired peak current limit through the inductor.

### 7.5.3 I<sup>2</sup>C Interface

#### 7.5.3.1 General I<sup>2</sup>C Operation

The I<sup>2</sup>C bus employs two signals, SDA (data) and SCL (clock), to communicate between integrated circuits in a system. The bus transfers data serially, one bit at a time. The 8-bit address and data bytes are transferred with the most-significant bit (MSB) first. In addition, each byte transferred on the bus is acknowledged by the receiving device with an acknowledge bit. Each transfer operation begins with the master device driving a start condition on the bus and ends with the master device driving a stop condition on the bus. The bus uses transitions on the data pin (SDA) while the clock is at logic high to indicate start and stop conditions. A high-to-low transition on the SDA signal indicates a start, and a low-to-high transition indicates a stop. Normal data-bit transitions must occur within the low time of the clock period. Figure 7-4 shows a typical sequence. The master device generates the 7-bit slave address and the read-write (R/W) bit to start communication with a slave device. The master device then waits for an acknowledge condition. The slave device holds the SDA signal low during the acknowledge clock period to indicate acknowledgment. When this acknowledgment occurs, the master transmits the next byte of the sequence. Each device is addressed by a unique 7-bit slave address plus a R/W bit (1 byte). All compatible devices share the same signals through a bidirectional bus using a wired-AND connection.

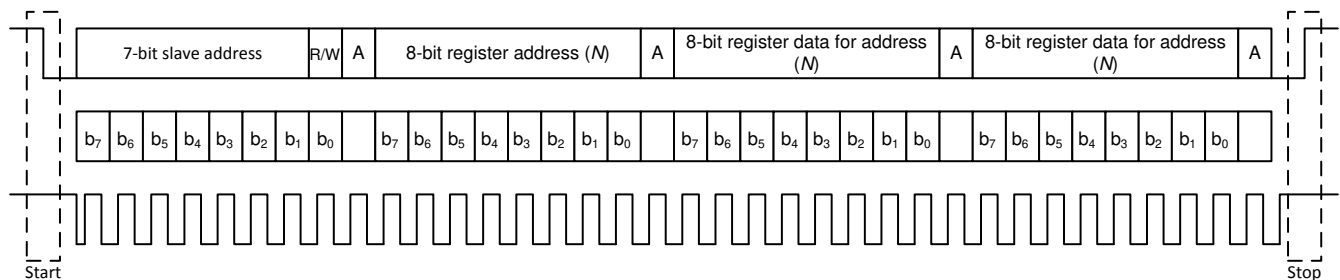
The number of bytes that can be transmitted between start and stop conditions is not limited. When the last word transfers, the master generates a stop condition to release the bus. Figure 7-4 shows a generic data-transfer sequence.

Use external pullup resistors for the SDA and SCL signals to set the logic-high level for the bus. Pullup resistors with values between 660 Ω and 4.7 kΩ are recommended. Do not allow the SDA and SCL voltages to exceed the DRV2665 supply voltage, V<sub>DD</sub>.

The DRV2665 device operates as an I<sup>2</sup>C-slave with 1.8-V logic thresholds, but can operate up to the V<sub>DD</sub> voltage.

#### Note

The slave address for the DRV2665 device is 0x59 (7-bit), or 1011001 in binary, which is equivalent to 0xB2 (8-bit) for writing and 0xB3 (8-bit) for reading.



**Figure 7-4. Typical I<sup>2</sup>C Sequence**

#### 7.5.3.2 Single-Byte and Multiple-Byte Transfers

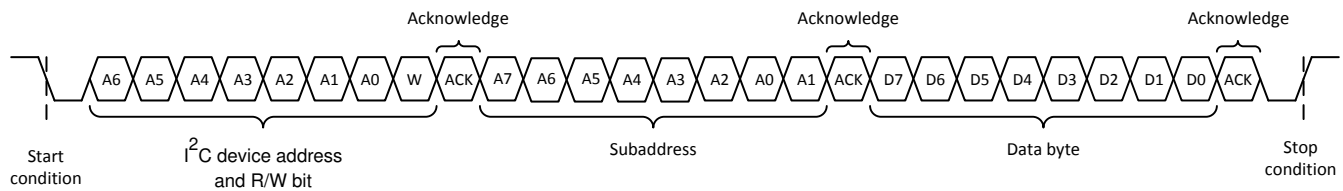
The serial control interface supports both single-byte and multiple-byte read-write operations for all registers.

During multi-byte transactions, the register address provided serves as the starting address. Subsequent data transfers automatically increment the register address accessed until a stop condition is reached.

#### 7.5.3.3 Single-Byte Write

As shown in Figure 7-5, a single-byte data-write transfer begins with the master device transmitting a start condition followed by the I<sup>2</sup>C device address and the read-write bit. The read-write bit determines the direction of the data transfer. For a write-data transfer, the read-write bit must be set to 0. After receiving the correct I<sup>2</sup>C device address and the read-write bit, the DRV2665 device responds with an acknowledge bit. Next, the master transmits the register byte corresponding to the DRV2665 internal-memory address that is accessed.

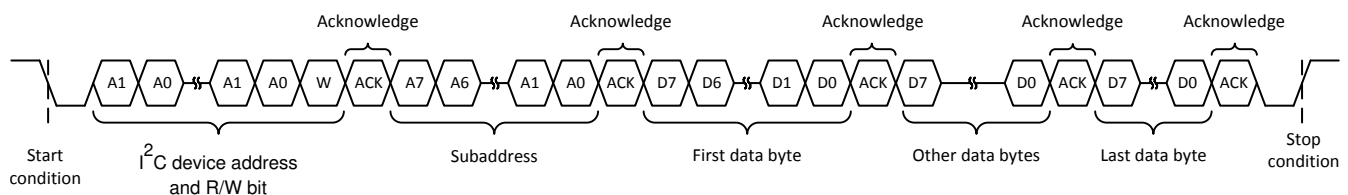
After receiving the register byte, the device responds again with an acknowledge bit. Finally, the master device transmits a stop condition to complete the single-byte data-write transfer.



**Figure 7-5. Single-Byte Write Transfer**

#### 7.5.3.4 Multiple-Byte Write and Incremental Multiple-Byte Write

A multiple-byte data write transfer is identical to a single-byte data write transfer except that multiple data bytes are transmitted by the master device to the DRV2665 device. After receiving each data byte, the DRV2665 device responds with an acknowledge bit as shown in Figure 7-6.

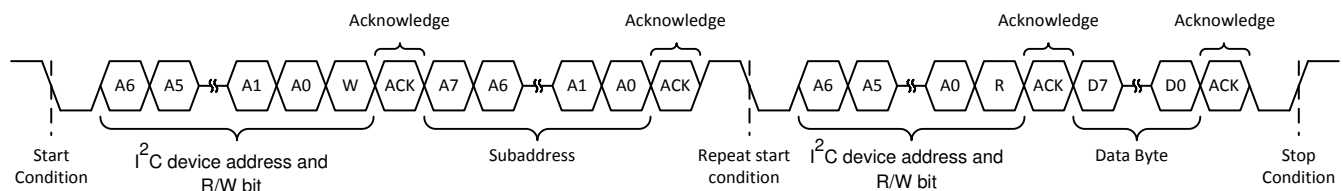


**Figure 7-6. Multiple-Byte Write Transfer**

#### 7.5.3.5 Single-Byte Read

Figure 7-7 shows that a single-byte data-read transfer begins with the master device transmitting a start condition followed by the I<sup>2</sup>C device address and the read-write bit. For the data-read transfer, both a write followed by a read actually occur. Initially, a write occurs to transfer the address byte of the internal memory address to be read. As a result, the read-write bit is set to 0.

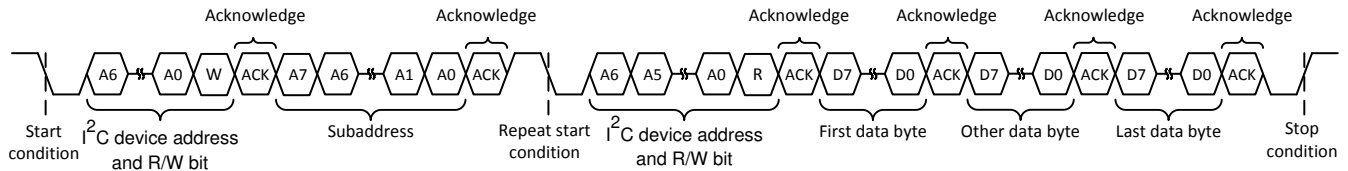
After receiving the DRV2665 address and the read-write bit, the DRV2665 device responds with an acknowledge bit. The master then sends the internal memory address byte, after which the device issues an acknowledge bit. The master device transmits another start condition followed by the DRV2665 address and the read-write bit again. This time, the read-write bit is set to 1, indicating a read transfer. Next, the DRV2665 device transmits the data byte from the memory address that is read. After receiving the data byte, the master device transmits a not-acknowledge followed by a stop condition to complete the single-byte data read transfer. See the note in the Section 7.5.3.1 section for the device address.



**Figure 7-7. Single-Byte Read Transfer**

### 7.5.3.6 Multiple-Byte Read

A multiple-byte data-read transfer is identical to a single-byte data-read transfer except that multiple data bytes are transmitted by the DRV2665 device to the master device as shown in Figure 7-8. With the exception of the last data byte, the master device responds with an acknowledge bit after receiving each data byte.



**Figure 7-8. Multiple-Byte Read Transfer**

## 7.6 Register Map

**Table 7-3. Register Map Overview**

| REG NO. | DEFAULT | BIT 7     | BIT 6       | BIT 5    | BIT 4 | BIT 3        | BIT 2     | BIT 1       | BIT 0     |
|---------|---------|-----------|-------------|----------|-------|--------------|-----------|-------------|-----------|
| 0x00    | 0x02    | Reserved  |             |          |       |              |           | FIFO_EMPTY  | FIFO_FULL |
| 0x01    | 0x28    | Reserved  | CHIPID[3:0] |          |       |              | INPUT_MUX | GAIN[1:0]   |           |
| 0x02    | 0x40    | DEV_RST   | STANDBY     | Reserved |       | TIMEOUT[1:0] |           | EN_OVERRIDE | Reserved  |
| 0x0B    | 0x00    | FIFO[7:0] |             |          |       |              |           |             |           |

## 7.6.1 Address: 0x00

**Figure 7-9. 0x00**

| 7        | 6 | 5 | 4 | 3 | 2 | 1             | 0            |
|----------|---|---|---|---|---|---------------|--------------|
| Reserved |   |   |   |   |   | FIFO_EMPTY[0] | FIFO_FULL[0] |
|          |   |   |   |   |   | RO-1          | RO-0         |

**Table 7-4. Address: 0x00**

| BIT | FIELD      | TYPE | DEFAULT | DESCRIPTION                                                                                                                                                                |
|-----|------------|------|---------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7-2 | Reserved   |      |         |                                                                                                                                                                            |
| 1   | FIFO_EMPTY | RO   | 1       | Indicates that the internal 100-byte FIFO is empty.<br>0 FIFO is not empty.<br>1 FIFO is empty.                                                                            |
| 0   | FIFO_FULL  | RO   | 0       | Indicates that the internal 100-byte FIFO is full and cannot accept data until another byte has played through the internal DAC.<br>0 FIFO is not full.<br>1 FIFO is full. |

## 7.6.2 Address: 0x01

**Figure 7-10. 0x01**

| 7        | 6           | 5    | 4    | 3    | 2            | 1         | 0     |
|----------|-------------|------|------|------|--------------|-----------|-------|
| Reserved | CHIPID[3:0] |      |      |      | INPUT_MUX[0] | GAIN[1:0] |       |
|          | RO-0        | RO-1 | RO-0 | RO-1 | R/W-0        | R/W-0     | R/W-0 |

**Table 7-5. Address: 0x01**

| BIT | FIELD       | TYPE | DEFAULT | DESCRIPTION                                                                                                                                                                                      |
|-----|-------------|------|---------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7   | Reserved    |      |         |                                                                                                                                                                                                  |
| 6-3 | CHIPID[3:0] | RO   | 5       | Identifies the device.<br>0 DRV2660<br>7 DRV2667                                                                                                                                                 |
| 2   | INPUT_MUX   | R/W  | 0       | Selects the source to be played.<br>0 Digital input source<br>1 Analog input source                                                                                                              |
| 1-0 | GAIN[1:0]   | R/W  | 0       | Selects the gain for the amplifier.<br>0 25 V (Digital) - 28.8 dB (Analog)<br>1 50 V (Digital) - 34.8 dB (Analog)<br>2 75 V (Digital) - 38.4 dB (Analog)<br>3 100 V (Digital) - 40.7 dB (Analog) |

### 7.6.3 Address: 0x02

**Figure 7-11. 0x02**

| 7          | 6          | 5        | 4 | 3            | 2     | 1              | 0        |
|------------|------------|----------|---|--------------|-------|----------------|----------|
| DEV_RST[0] | STANDBY[0] | Reserved |   | TIMEOUT[1:0] |       | EN_OVERRIDE[0] | Reserved |
| R/W-0      | R/W-1      |          |   | R/W-0        | R/W-0 | R/W-0          |          |

**Table 7-6. Address: 0x02**

| BIT  | FIELD        | TYPE | DEFAULT | DESCRIPTION                                                                                                                                                                                              |
|------|--------------|------|---------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7    | DEV_RST      | R/W  | 0       | When asserted, the device will immediately stop any transaction in process, reset all of its internal register to their default values, and enters standby mode.<br>0 Normal operation<br>1 Reset device |
| 6    | STANDBY      | R/W  | 1       | Low-power standby<br>0 Device is active and ready to receive a signal.<br>1 Device is in low power standby mode.                                                                                         |
| 5-4  | Reserved     |      |         |                                                                                                                                                                                                          |
| 3-2  | TIMEOUT[1:0] | R/W  | 0       | Time period when the FIFO runs empty and the device goes into idle mode, powering down the boost converter and amplifier.<br>0 5 ms<br>1 10 ms<br>2 15 ms<br>3 20 ms                                     |
| 1    | EN_OVERRIDE  | R/W  | 0       | Override bit for the boost converter and amplifier enables.<br>0 Boost converter and amplifier enables are controlled by device logic.<br>1 Boost converter and amplifier are enabled indefinitely.      |
| 0--1 | Reserved     |      |         |                                                                                                                                                                                                          |

### 7.6.4 Address: 0x0B

**Figure 7-12. 0x0B**

| 7         | 6     | 5     | 4     | 3     | 2     | 1     | 0     |
|-----------|-------|-------|-------|-------|-------|-------|-------|
| FIFO[7:0] |       |       |       |       |       |       |       |
| R/W-0     | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 |

**Table 7-7. Address: 0x0B**

| BIT | FIELD     | TYPE | DEFAULT | DESCRIPTION                                                                                               |
|-----|-----------|------|---------|-----------------------------------------------------------------------------------------------------------|
| 7-0 | FIFO[7:0] | R/W  | 0       | Entry point for FIFO data. The user repeatedly writes this register with continuous haptic waveform data. |

## 8 Application and Implementation

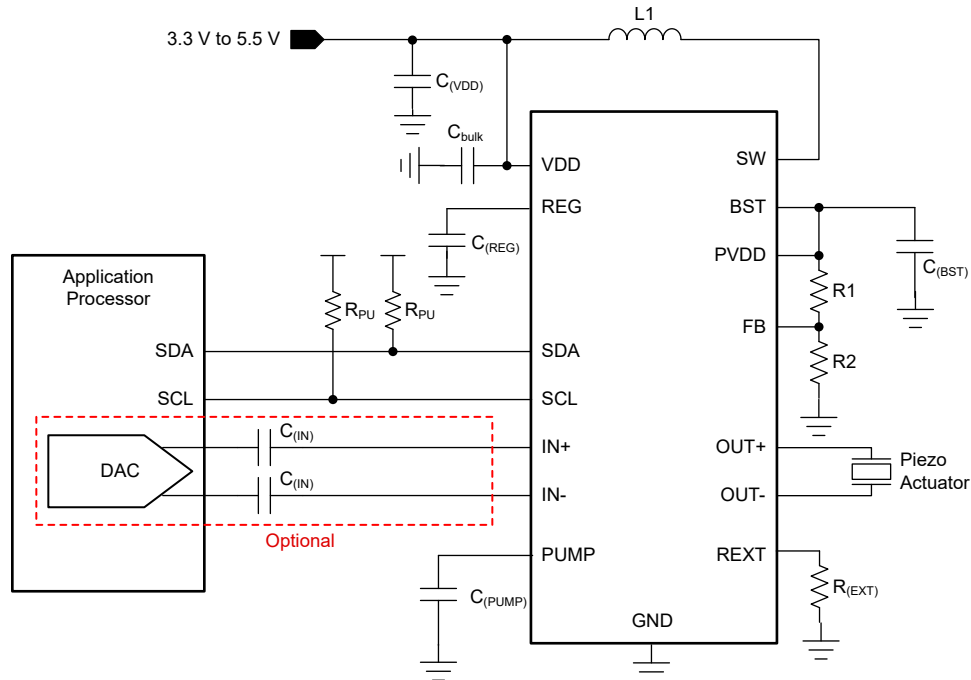
### Note

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers must validate and test their design implementation to confirm system functionality.

### 8.1 Application Information

The typical application for a haptic driver is in a touch-enabled system that already has an application processor that makes the decision on when to execute haptic effects.

The DRV2665 device is configured and can be used fully with I<sup>2</sup>C communication to stream or launch haptic effects. Additionally, the system designer may decide to use the analog input to stream the desired haptic effects.



**Figure 8-1. Typical Application Configuration**

**Table 8-1. Recommended External Components**

| COMPONENT    | DESCRIPTION                                                  | SPECIFICATION | TYPICAL VALUE   |
|--------------|--------------------------------------------------------------|---------------|-----------------|
| $C_{(VDD)}$  | Input capacitor                                              | Capacitance   | 1 $\mu$ F       |
| $C_{(REG)}$  | Regulator capacitor                                          | Capacitance   | 0.1 $\mu$ F     |
| $C_{(BST)}$  | Boost capacitor                                              | Capacitance   | 0.1 $\mu$ F     |
| $C_{BULK}$   | Bulk capacitor                                               | Capacitance   | 10 $\mu$ F      |
| $C_{(PUMP)}$ | Internal charge pump capacitor                               | Capacitance   | 0.1 $\mu$ F     |
| $C_{(IN)}$   | AC coupling capacitor (optional)                             | Capacitance   | 1 $\mu$ F       |
| $R_1$        | Boost feedback resistor (see <a href="#">Section 7.5.1</a> ) | Resistance    | 768 k $\Omega$  |
| $R_2$        | Boost feedback resistor (see <a href="#">Section 7.5.1</a> ) | Resistance    | 9.76 k $\Omega$ |
| $R_2$        | Current limit resistor (see <a href="#">Section 7.5.2</a> )  | Resistance    | 13 k $\Omega$   |

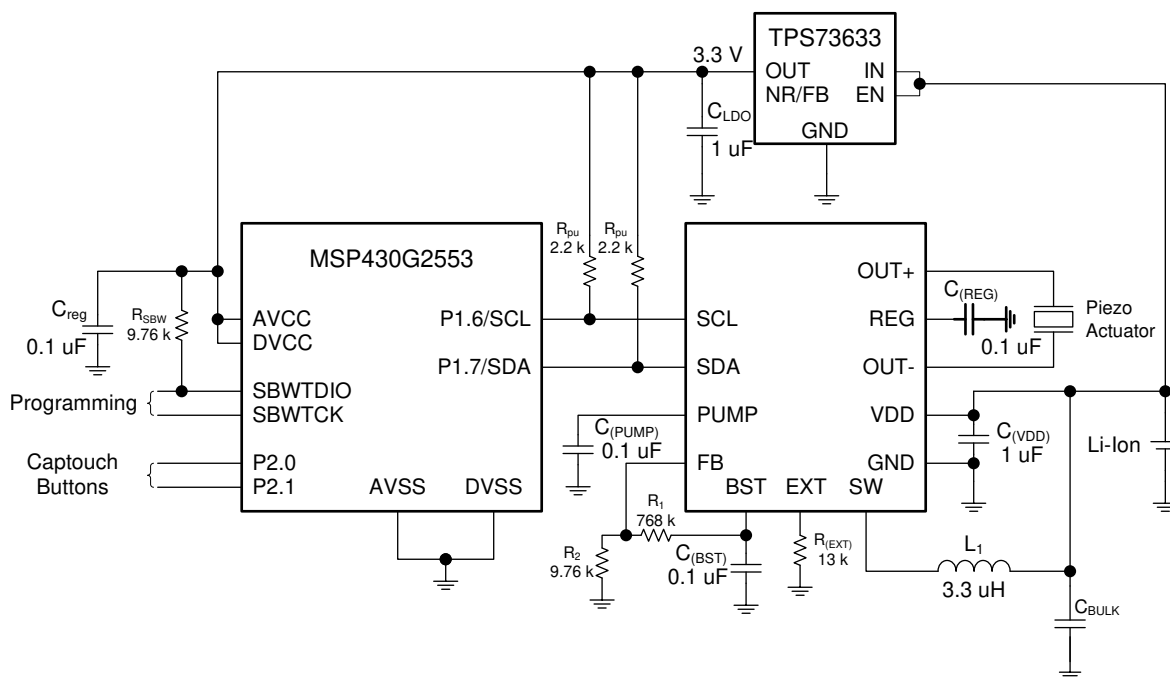
**Table 8-1. Recommended External Components (continued)**

| COMPONENT  | DESCRIPTION     | SPECIFICATION | TYPICAL VALUE  |
|------------|-----------------|---------------|----------------|
| $R_{(PU)}$ | Pullup resistor | Resistance    | 2.2 k $\Omega$ |
| $L_1$      | Boost inductor  | Inductance    | 3.3 $\mu$ H    |

## 8.2 Typical Application

A typical application of the DRV2665 device is in a system that has external buttons which fire different haptic effects when pressed. Figure 8-2 shows a typical schematic of such a system. The buttons can be physical buttons, capacitive-touch buttons, or GPIO signals coming from the touch-screen system.

Effects in this type of system are programmable.

**Figure 8-2. Example Application Schematic**

### 8.2.1 Design Requirements

For this design example, use the values listed in Table 8-2 as the input parameters.

**Table 8-2. Design Parameters**

| DESIGN PARAMETER   | EXAMPLE VALUE       |
|--------------------|---------------------|
| Actuator type      | 120 V <sub>PP</sub> |
| Input power source | Li-ion / Li-polymer |

### 8.2.2 Detailed Design Procedure

#### 8.2.2.1 Inductor Selection

Inductor selection plays a critical role in the performance of the DRV2665 device. The range of recommended inductances is from 3.3  $\mu$ F to 22  $\mu$ F. In general, higher inductances within an inductor series of a given manufacturer have lower saturation current limits, and vice-versa. When a larger inductance is chosen, the device boost converter automatically runs at a lower switching frequency and incurs less switching losses; however, larger values of inductance may have higher equivalent series resistance (ESR), that increases the parasitic inductor losses. Because lower values of inductance generally have higher saturation currents, they are a better choice when attempting to maximize the output current of the boost converter. Ensure that the saturation current of the inductor selected is higher than the programmed current limit for the device.

### 8.2.2.2 Piezo Actuator Selection

There are several key specifications to consider when choosing a piezo actuator for haptics, such as dimensions, blocking force, and displacement. However, the key electrical specifications from the driver perspective are voltage rating and capacitance.

At the maximum frequency of 500 Hz, the device is optimized to drive up to 50 nF at 200 V<sub>PP</sub>, that is the highest voltage swing capability. It drives larger capacitances if the programmed boost voltage is lowered and/or the user limits the input frequency range to lower frequencies (e.g. 300 Hz).

### 8.2.2.3 Boost Capacitor Selection

The boost output voltage may be programmed as high as 105 V. A capacitor with a voltage rating of at least the boost output voltage must be selected. A 250-V rated 100-nF capacitor of the X5R or X7R type is recommended for the 105 V case because ceramic capacitors tend to come in ratings of 100 V or 250 V. The selected boost capacitor must have a minimum working capacitance of at least 50 nF. For boost voltages from 30 V to 80 V, a 100-V rated or 250-V rated, 100-nF capacitor is acceptable. For boost voltages less than 30 V, a 50-V, 0.22-μF capacitor is recommended.

### 8.2.2.4 Bulk Capacitor Selection

The use of a bulk capacitor placed next to the inductor is recommended due to the switch pin current requirements. A ceramic capacitors of the X5R or X7R type with capacitance of at least 1 μF is recommended.

## 8.2.3 Application Curves

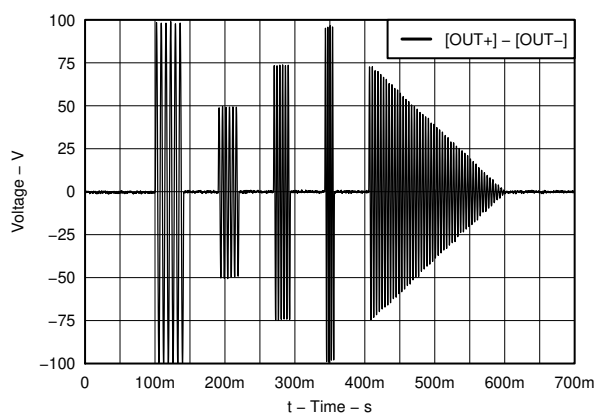


Figure 8-3. Example Waveform – Pinball Effect

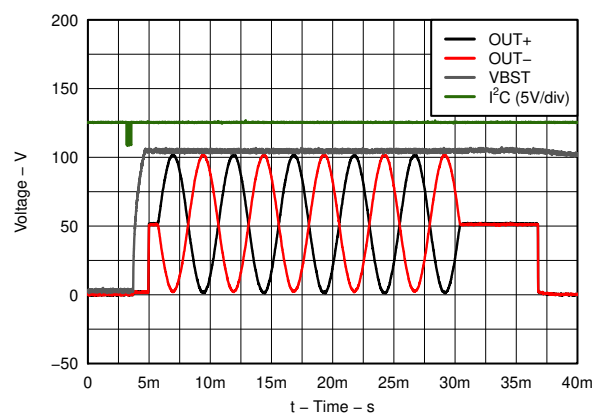


Figure 8-4. Typical Waveform

## 8.3 Initialization Setup

The DRV2665 device features a simple initialization procedure:

### 8.3.1 Initialization Procedure

1. Apply power to the DRV2665 device.
2. Wait for 1 ms for the DRV2665 device to power-up before attempting an I<sup>2</sup>C write.
3. Exit low-power standby mode by clearing the STANDBY bit in register 0x02, bit 6.
4. Choose the interface mode as analog or digital in register 0x01, bit 2.
5. Select the gain setting for your application in register 0x01, bits [1:0].
6. Choose the desired timeout period in register 0x02, bits[3:2].
7. If using the digital interface mode, the device is now ready to receive data. If using the analog input mode, set the EN\_OVERRIDE bit in register 0x02, bit 1 to enable the boost and high-voltage amplifier and begin sourcing the waveform to the analog input.

## 9 Power Supply Recommendations

The DRV2665 device is designed to operate from an input-voltage supply range between 3.3 V and 5.5 V. The decoupling capacitor for the power supply must be placed as close to the device pin as possible.

## 10 Layout

### 10.1 Layout Guidelines

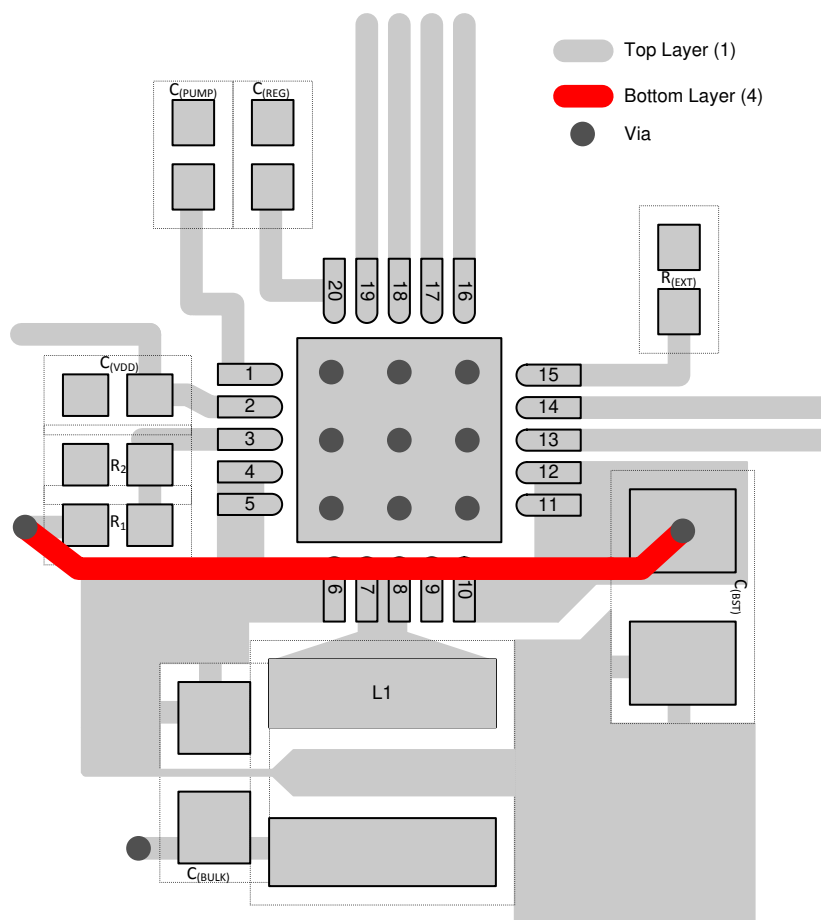
Use the following guidelines for the DRV2665 device layout:

- The decoupling capacitor for the power supply ( $V_{DD}$ ) must be placed close to the device pin.
- The filtering capacitor for the regulator (REG) must be placed close to the device pin.
- The boost inductor must be placed as close as possible to the SW pin.
- The bulk capacitor for the boost must be placed as close as possible to the inductor.
- The charge pump capacitor (PUMP) must be placed close to the device pin.

Use of the thermal footprint outlined by this datasheet is recommended to achieve optimum device performance. See land pattern diagram for exact dimensions.

The DRV2665 device power pad must be soldered directly to the thermal pad on the printed circuit board. The printed circuit board thermal pad must be connected to the ground net and thermal vias to any existing backside/internal copper ground planes. Connection to a ground plane on the top layer near the corners of the device is also recommended. Another key layout consideration is to keep the boost programming resistors ( $R_1$  and  $R_2$ ) as close as possible to the FB pin of the device. Care must be taken to avoid getting the FB trace near the SW trace.

### 10.2 Layout Example



**Figure 10-1. Layout Example with a 4-Layer Board**

## **11 Device and Documentation Support**

### **11.1 Community Resources**

### **11.2 Trademarks**

All trademarks are the property of their respective owners.

## **12 Mechanical, Packaging, and Orderable Information**

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

## PACKAGING INFORMATION

| Orderable part number       | Status<br>(1) | Material type<br>(2) | Package   Pins | Package qty   Carrier | RoHS<br>(3) | Lead finish/<br>Ball material<br>(4) | MSL rating/<br>Peak reflow<br>(5) | Op temp (°C) | Part marking<br>(6) |
|-----------------------------|---------------|----------------------|----------------|-----------------------|-------------|--------------------------------------|-----------------------------------|--------------|---------------------|
| <a href="#">DRV2665RGPR</a> | Active        | Production           | QFN (RGP)   20 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-4-260C-72 HR                | -40 to 70    | 2665                |
| <a href="#">DRV2665RGPT</a> | Active        | Production           | QFN (RGP)   20 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-4-260C-72 HR                | -40 to 70    | 2665                |

<sup>(1)</sup> **Status:** For more details on status, see our [product life cycle](#).

<sup>(2)</sup> **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

<sup>(3)</sup> **RoHS values:** Yes, No, RoHS Exempt. See the [TI RoHS Statement](#) for additional information and value definition.

<sup>(4)</sup> **Lead finish/Ball material:** Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

<sup>(5)</sup> **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

<sup>(6)</sup> **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "-" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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## TAPE AND REEL INFORMATION



\*All dimensions are nominal

| Device      | Package Type | Package Drawing | Pins | SPQ  | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|-------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| DRV2665RGPR | QFN          | RGP             | 20   | 3000 | 330.0              | 12.4               | 4.25    | 4.25    | 1.15    | 8.0     | 12.0   | Q2            |
| DRV2665RGPT | QFN          | RGP             | 20   | 250  | 180.0              | 12.4               | 4.25    | 4.25    | 1.15    | 8.0     | 12.0   | Q2            |

## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

| Device      | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|-------------|--------------|-----------------|------|------|-------------|------------|-------------|
| DRV2665RGPR | QFN          | RGP             | 20   | 3000 | 346.0       | 346.0      | 33.0        |
| DRV2665RGPT | QFN          | RGP             | 20   | 250  | 210.0       | 185.0      | 35.0        |

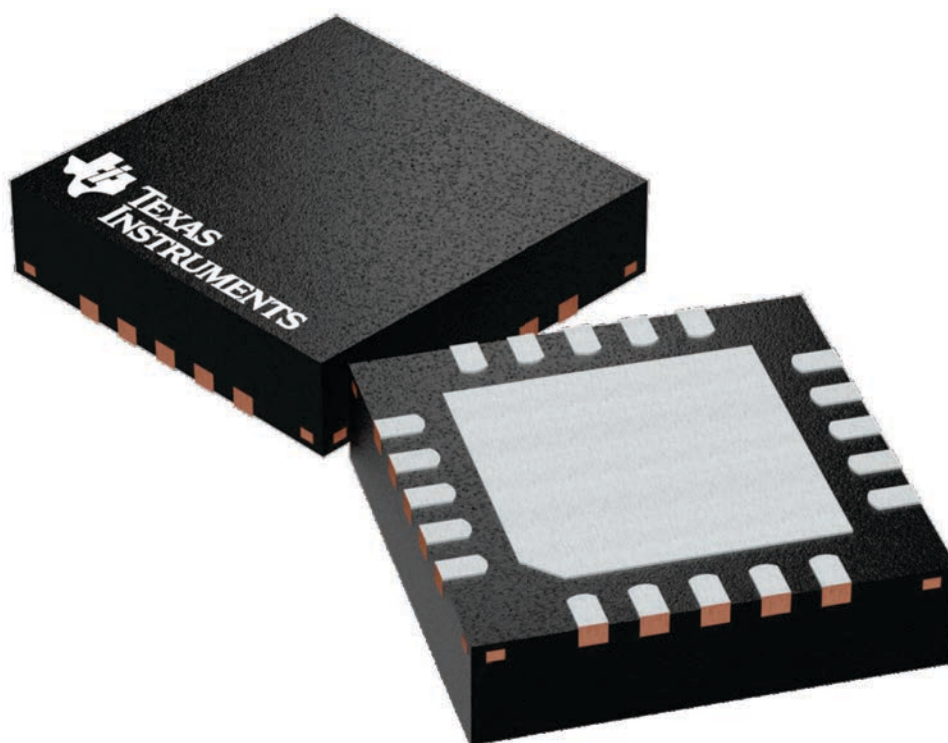
## GENERIC PACKAGE VIEW

**RGP 20**

**VQFN - 1 mm max height**

4 x 4, 0.5 mm pitch

VERY THIN QUAD FLATPACK



Images above are just a representation of the package family, actual package may vary.  
Refer to the product data sheet for package details.

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