Component Selection for BOS1901

1 Introduction

The BOS1901 is a highly integrated low-power piezo actuator driver with integrated digital front end and energy recovery. The driver requires a single low-voltage supply and a few passive components to generate waveforms up to 190 Vpk-pk.

To operate properly in a set of application conditions, these components must be selected appropriately. Component selection is guided by expected performance, but application factors such as available PCB footprint, physical space in the final device, and bill of materials (BOM), must also be considered.

The BOS1901-KIT User Guide provides a general reference design that will work in most situations, but is not optimized for specific actuators and applications.

This document explains how to select components required to operate the BOS1901 properly in any application. Requirements and guidelines are provided on each component. Considerations are taken regarding the power supply used.

2 Reference Documents

This document refers to the following documents.

2.1 Product Datasheet

This is the main reference document for selecting components. The product datasheet contains the required equations to calculate specific component requirements. These equations are copied here for convenience, and they are put in context.

The datasheet also provides guidelines on selecting components, and this information is complemented in the current document.

Please refer to these sections in the datasheet:

- Sections 7.1 to 7.3 for typical configurations and component overview.
- Section 7.5 provides equations and guidance on selecting components.

2.2 Development Kit User Guide

This document focuses on the BOS1901-KIT usage, but also contains the design reference including board schematics, layout view of the board, detailed BOM list used.

This information can serve as an example that will work in most cases, although it is not optimized for all specific cases. It is offered as a starting point, but it should be revisited in the context of any application.

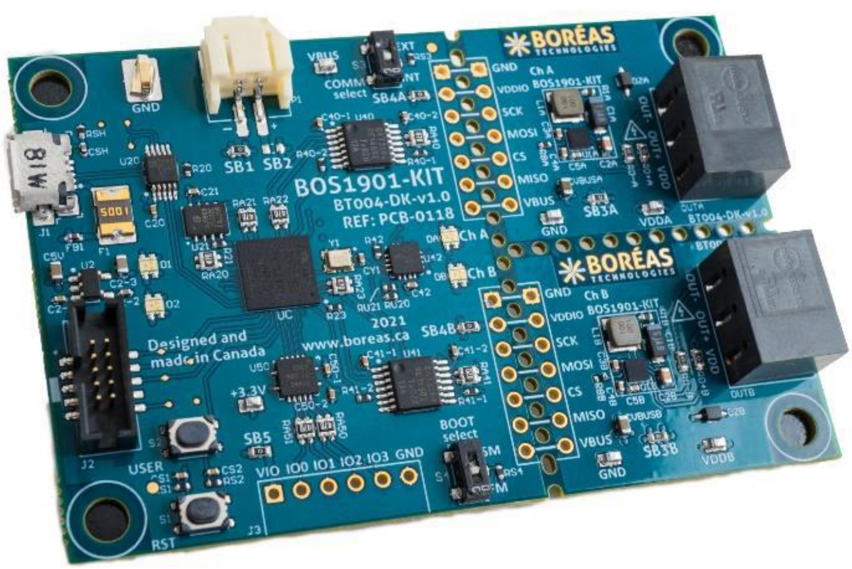


Figure 1: BOS1901-KIT overview

2.3 Online BOM Generator

Boréas Technologies website offers a BOM Generator tool to help calculate component requirements (https://www.boreas.ca/pages/bos1901-bom-calculator). The BOM Generator provides requirements for components given a set of general operating conditions, including supply, actuator used and output waveform.

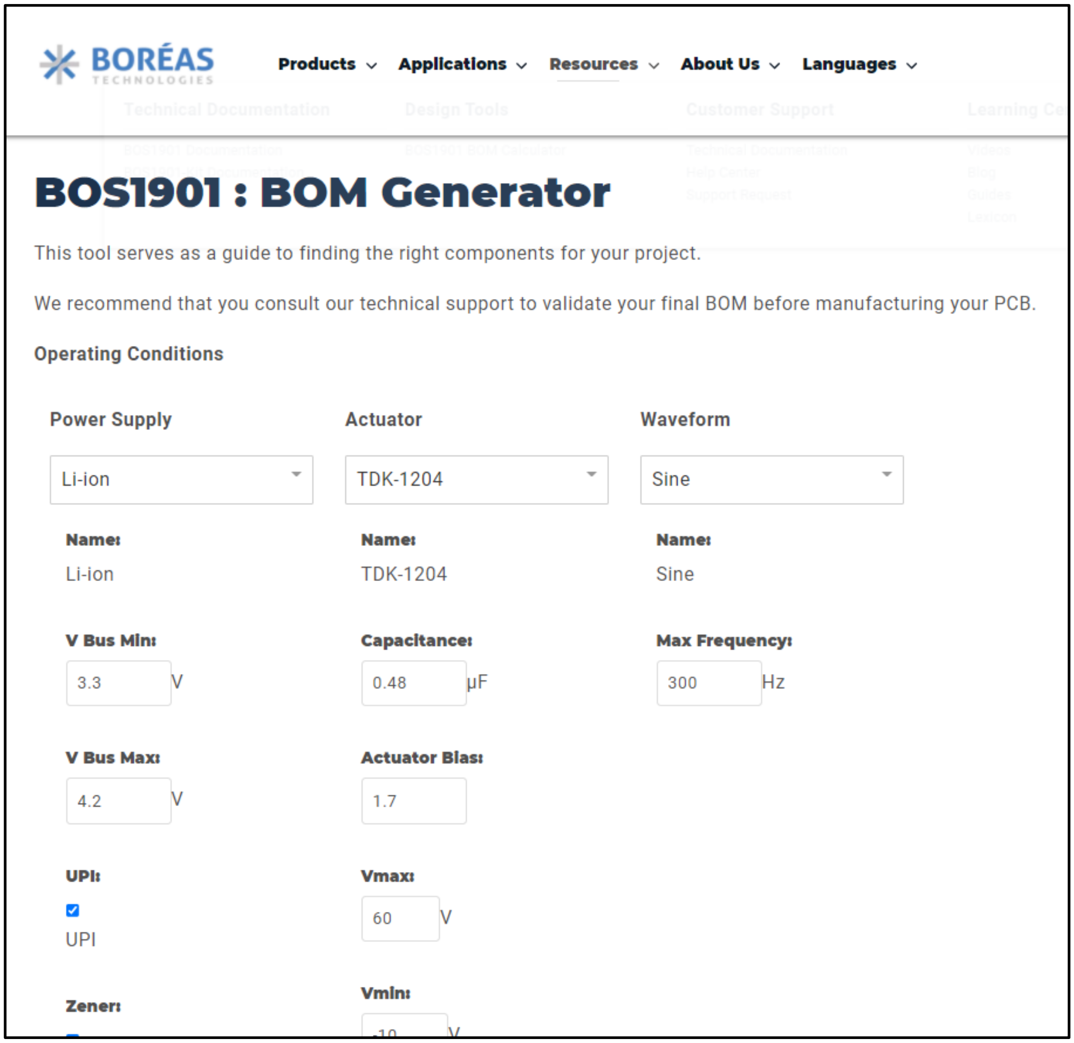


Figure 2: BOS1901 BOM Generator Tool

The user inputs these operating conditions and scrolls down to see the calculated component requirements and provided recommendations. The tool automatically updates the calculations when inputs are changed, allowing for exploration. User can then scroll down and download an XLS file of the analysis and the product datasheet. This BOM analysis is a good starting point to build a prototype, and BOM selection may be refined after test.

It is highly recommended that users contact Boréas to validate the BOM selection and conditions for the application.

3 Factors Impacting Component Selection

Actuator choice and waveform shape have a strong impact on component selection, but other factors will also impact the circuit schematic. This section covers the application input factors to consider.

When application parameters are unknown, consider buying a development kit to experiment with it and uncover those values. The development kit is very flexible. It can be used with various actuators, supplied from an external power source, and wired to an external SPI controller for prototyping. In many cases, it will be possible to replace some of the components on the board to try specific parts in the context of a given application.

3.1 Package Type

Many applications, like mobile, require smaller components and often dictates the use of the BOS1901 in WLCSP chip-scale package. It is smaller than the QFN package version but will require specific PCB and assembly options that are more expensive. When these options are not already used and when the PCB area is not critical, selecting the QFN package is generally appropriate.

Both QFN and WLCSP package types have the same level of performance and both BOMs will have the same requirements.

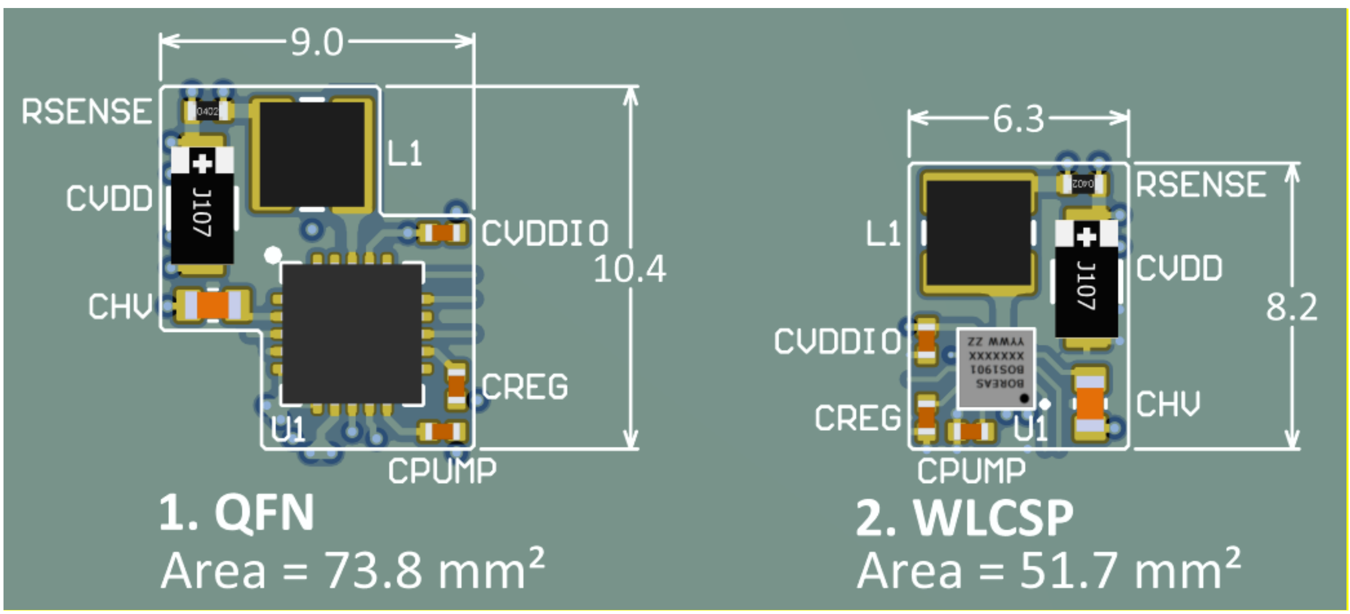


Figure 3 QFN and WLCSP typical PCB footprints

3.2 Piezoelectric Actuator Characteristics

The actuator is the core engine of any haptic application. It is generally determined first before selecting the BOS1901 as a piezoelectric driver. They come in various shapes and sizes, each with detailed specifications.

Although actuators generally have an extensive list of characteristics, only a few are needed to be considered for electrical component selection.

Voltage range is the first characteristic. Some actuators are bipolar and will tolerate symmetrical (e.g. ± 50 V) or asymmetrical waveforms (e.g. – 50 V to + 80 V). Others will only tolerate unipolar output (e.g. 0 V to 60 V). The BOS1901 output differential voltage range is ± 95 V. It can drive most actuators operating within that voltage range.

Actuator capacitance is the second characteristic to consider. Piezoelectric actuators are transducers converting voltage to force and vice-versa. Electrically, they mostly behave as capacitors. Piezoelectric materials datasheet rarely specify capacitance, but piezoelectric actuator products with defined physical dimensions and number of layers should have this parameter specified. This capacitance will be the capacitive load that will be electrically driven by the BOS1901.

Note piezoelectric actuators are subject to a DC bias effect. The capacitance value will increase as voltage is increased on their terminals. The driving circuit will need to compensate for this voltage increase by providing more energy. Calculations using the load capacitance should take this capacitor DC bias into account. This value is not always specified directly. It is sometimes specified as a loading charge given at maximum voltage. Dividing this value by the voltage yields an effective capacitance that can be used to deduce the capacitance bias factor. If not specified, check with the actuator maker for the capacitance DC bias, loading charge or capacitance increase in the range of operation. In absence of this information, presume 50 % capacitance increase at maximum voltage.

3.3 Output Waveform

Piezoelectric actuators can be driven with any waveform shape. It is not limited to sine or square waveforms; it can also be triangular, even custom, such as a heartbeat. It is this capability that makes piezoelectric actuators shine in high-definition haptics.

The shape, frequency, amplitude, and polarity of the waveform to drive on the actuator determines the amount of power that must be driven on the actuator capacitance at any moment. Therefore, it has a major impact on component selection.

If the waveform for the application is not known, consider a sine waveform, at maximum voltage, and at the maximum frequency expected for the application (keep the frequency below 300 Hz for haptic applications since higher frequencies will be mostly heard and not felt by skin receptors).

3.4 Supply Source

Supply source is often overlooked when selecting components and planning the schematic. Source type, voltage range, current drive and impedance will impact circuit schematic, component selection, and can limit the performance depending on the waveform to output.

Type and Voltage Range

The BOS1901 supports 3.0 to 5.5 V supply range. However, the output performance and current consumption will be better at higher supply voltages. Therefore, if the same system has both 5 V and 3.3 V, it might be better to use the 5 V even though the 3.3 V might look more convenient.

Consider the supply source type (rail, battery) and its possible voltage range. Various batteries have different voltage ranges.

For example, rechargeable secondary lithium-ion batteries typically have a voltage range from 4.2-4.3 V when fully charged, down to 2.6-3.0 V at battery cut-off. However, they are mostly used at a voltage higher than 3.3 V since below this voltage the usable charge is minimal. Also, these batteries must be charged using a tightly controlled algorithm. They will not sink any current flowing back. This will have an impact on the supply circuit. See section 5.2 for details on UPI configuration that deals with such situations.

Voltage rails also have an expected voltage range depending on the type and accuracy of the regulator supplying them, and the loads attached to them. Other loads will draw current profiles from the rail, causing voltage variations.

Current Drive

Even though the BOS1901 IC has low power consumption, it will consume higher current at times when playing the waveforms. The supply source must be able to provide the required current otherwise voltage will drop on the rail. Calculations are given in section 5.4.

Supply Rail Capacitance

As the output waveform is driven to increasing voltage, current will be drawn from the supply. As the output waveform is driven to decreasing voltage, the energy stored in the piezo actuator will be recycled to the input. The total capacitance on the supply rail will store this energy. The bigger the capacitance, the higher the capacity to store the energy without affecting other loads on the same supply. The power supply or other loads connected to the supply rail might be affected by this voltage rise. There are mechanisms that can be used to limit the voltage rise. See section 5 for details.

4 Component Selection

This section gets into the details of component selection. For each component, the value calculation is given, and important component parameters are explained. Calculations from the datasheet are reused here for convenience. In case of discrepancy between these equations and those given in the datasheet, the latter will take precedence.

It is recommended to always read the components datasheet carefully and take into account specifications mentioned here, but also any other parameter that might also be relevant.

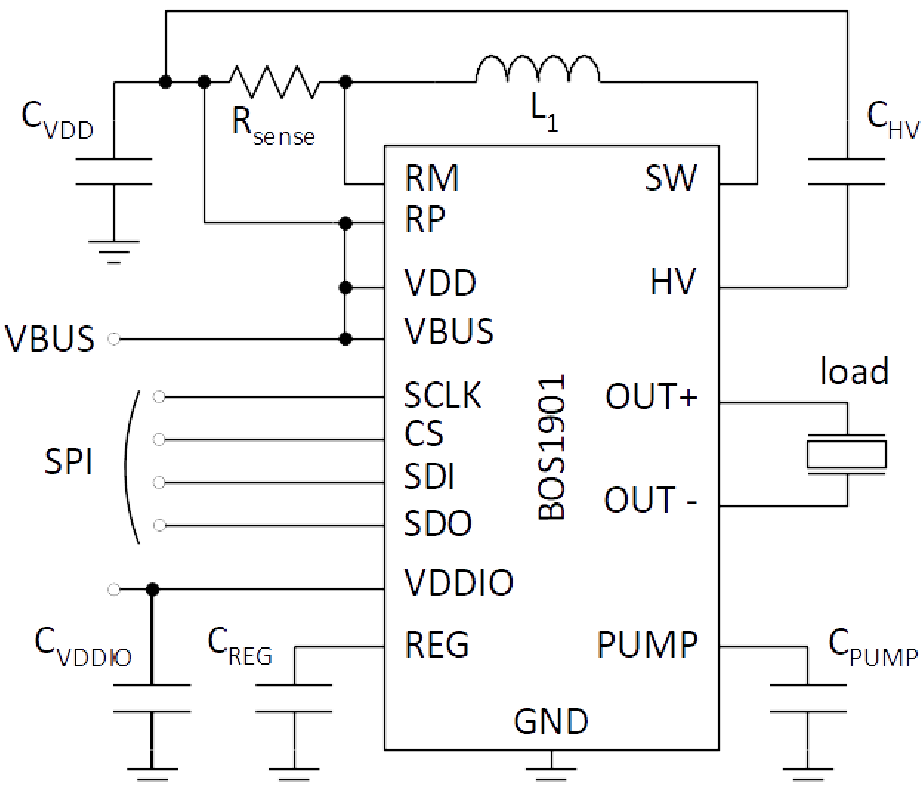


Figure 4 Typical BOS1901 schematic

4.1 Inductor

The inductor is a very important and complex component to select. Follow the procedure below to first select an inductor, and then experimentation can be done to optimize the selected component for a given application if required.

Two sets of equations are given below, one for strictly unipolar waveforms, and another one for symmetrical bipolar waveforms. Both sets are assuming a full sine cycle waveform (360 degrees).

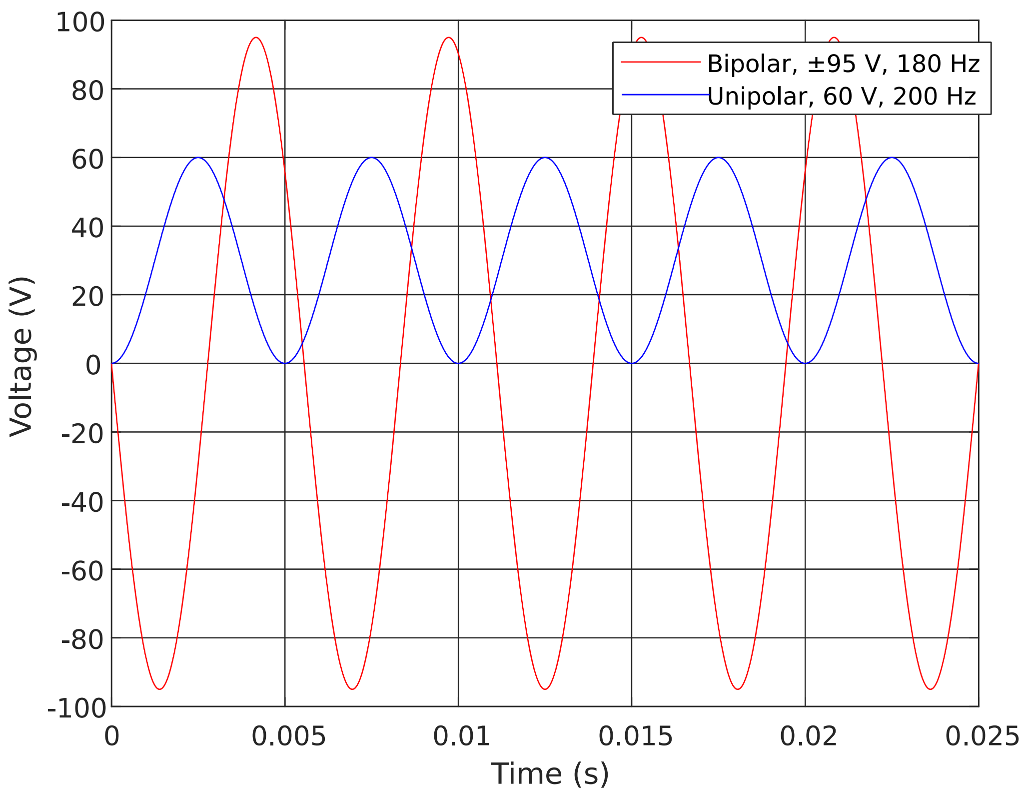


Figure 5 Unipolar (blue) and bipolar (red) waveforms

1. Set the output signal maximum frequency (f_{sig}), e.g. 200 Hz. This frequency is the maximum expected frequency of the output haptic waveform. If the final waveforms are not determined yet, use the maximum expected frequency for experimentation, and then revisit the BOM selection once it is known.
2. Set the maximum amplitude of the waveform (V_{pk}), e.g., 95 V for a bipolar 190 $V_{pk\text{-}pk}$ waveform, or 60 V for a 0 to 60 V unipolar waveform.
3. Set the minimum supply voltage (V_{BUS}) value expected during operation, e.g. 3 V.

4. Calculate the maximum power transfer point:

Bipolar Waveform	Unipolar Waveform	
$V_{out} = V_{pk}\sin(45°) + V_{BUS}$	$V_{out} = \frac{V_{pk}}{2}(1 + \sin(30°)) + V_{BUS}$	(1)
$\overline{I_{out}} = 2\pi f_{sig} C_{Load} V_{pk}\cos(45°)$	$\overline{I_{out}} = \pi f_{sig} C_{Load} V_{pk}\cos(30°)$	(2)

   Note the V_{out} and $\overline{I_{out}}$ expressions can be changed accordingly if the waveform is not a sinewave. V_{out} is the expression of the voltage waveform as seen on either OUT+ or OUT- node, hence the $+V_{BUS}$ term at the end, and $\overline{I_{out}}$ expression is taken from the capacitance equation

$$\overline{I_{out}} = C_{Load}\frac{dV_{out}(t)}{dt} \quad (3)$$

   and evaluated at the maximum transfer point, which is at the instant the power ($P(t) = \overline{I_{out}}(t)\, V_{out}(t)$) is maximum.

5. Calculate the average input current at the maximum transfer point:

$$\overline{I_{IN}} = 1.5\frac{V_{out} * \overline{I_{out}}}{V_{BUS}} \quad (4)$$

   Note the factor 1.5 is considering losses in the power transfer. Omitting this factor may result is distorted output waveform in the considered conditions. $\overline{I_{IN}}$ is used later when considering the supply.

6. Calculate the inductor peak current:

$$I_{pk} = 2\overline{I_{IN}} \quad (5)$$

Note these equations only give approximate values, as the power dissipation will vary with operation conditions and selected components. Consider these a starting point and readjust if needed after prototype testing.

Inductance

Select an inductor with 10 µH inductance. Please contact Boréas technical support if you intend to use any other inductance value.

Saturation Current

Select an inductor with saturation current higher than I_{pk}. Inductor specifications generally provide two current parameters: saturation current and rated current (these names may vary). Saturation current is defined as the current at which the inductance value drops by a certain amount. At this point, the inductor behavior starts to degrade significantly, preventing the expected operation.

Rated Current

Rated current is related to power dissipation and self-heating. It is defined for reliability purposes. Using the BOS1901, the required rated current will always be lower than the peak current. An upper bound for the rated current can be taken as the RMS current at the maximum transfer point:

$$I_{RMS,max} = \frac{I_{pk}}{\sqrt{3}} \tag{6}$$

As the output voltage waveform is played, this current will change, and the effective RMS current will drop. Moreover, in most haptics applications where the effects played are short and the actuator is not driven between these effects, the effective RMS current will drop significantly.

DCR or ESR (Equivalent Serial Resistance)

Select an inductor with a DCR or ESR value as low as possible. Serial resistance reduces the voltage drop on the inductor and therefore decreases the output drive, degrading the output waveform bandwidth. Try not to exceed 400 mV drop at peak current. This value is not a hard requirement, but a high value will lead to decreased power efficiency and reduced output bandwidth. Prototype testing might reveal higher values can be tolerated.

Voltage Rating

This parameter is often not specified. When it is, it will likely be lower than required, even though the inductor can sustain it. Voltage ratings are specified considering years of continuous operation. However, in most haptic applications, the use time will be much lower than the end-product lifetime. Check with the inductor manufacturer and be sure to consider the activity model (the effective time the inductor is stressed).

The following helps determine the activity model. During waveform playback, the inductor is biased by a PWM voltage with the high-level voltage following

$$V_{L,max}(t) = V_{out}(t) - V_{BUS} \tag{7}$$

The duty cycle of the PWM for relative amount of time the inductor is biased at that voltage is given by

$$D_{L,high}(t) = \frac{V_{BUS}}{V_{out}(t)} \tag{8}$$

For example, Figure 6 shows the PWM high-level voltage across the inductor (upper graph) and its duty cycle (lower graph) for a unipolar 60 V, 180 Hz sine waveform, on a typical TDK actuator. One can see the voltage will be close to 60 V across the inductor for a short duration per cycle, and at a duty cycle lower than 10 % during that time.

Furthermore, in haptics applications, the ratio between the time the output waveform is played and the time delay between effects (activity model) drastically reduces the stress on the inductor compared to typical always-on lifetime evaluations, thereby enabling further relaxation of reliability criteria for the inductor used.

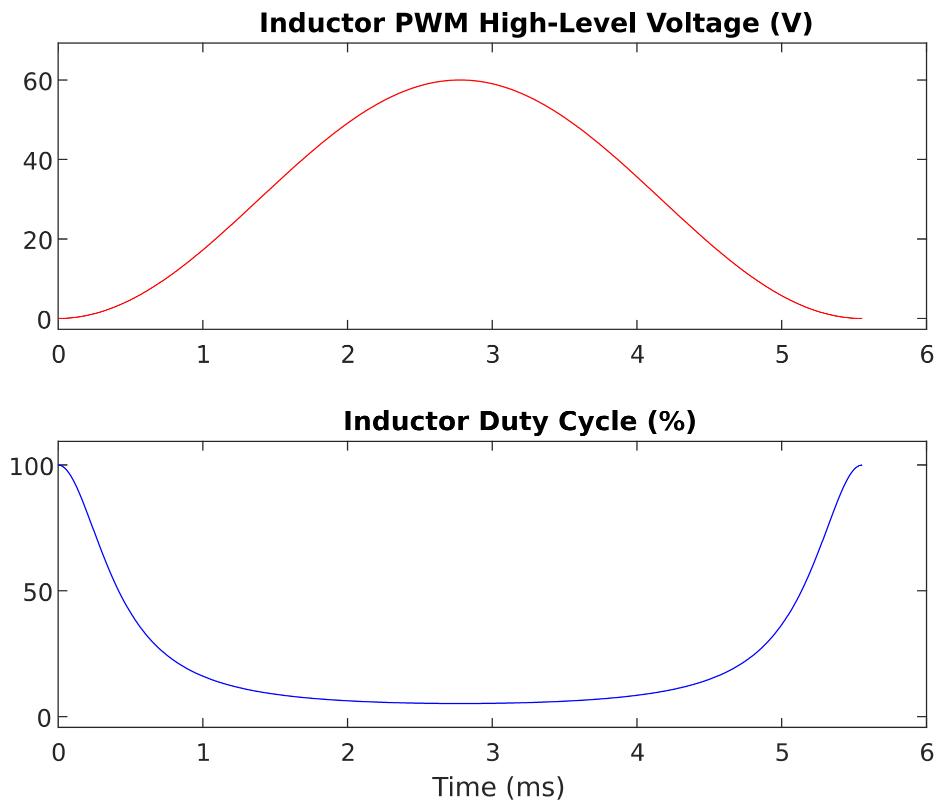


Figure 6 Inductor duty cycle for a 60 V, 180 Hz sine waveform on a TDK 1204H018V060 actuator

4.2 Rsense

Rsense determines the peak current allowed in the inductor. This also limits the maximum input current from the supply ($\overline{I_{IN}}$). However, increasing the Rsense value will also reduce the output drive and thus the maximum output frequency.

Resistance

Rsense resistance value is normally set using this equation and the peak current calculated above, but keep Rsense between 0.2 and 1 Ω as specified in the datasheet.

$$R_{sense} = \frac{0.256\ \mathrm{V}}{\text{current limit}} \quad (9)$$

Note that if Rsense value is lower than 0.32 Ω, bit LMI in register PARCAP (0x6) must be set high.

Power Rating

An upper bound for power dissipation can be taken as

$$P_{Rsense,max} = \frac{R_{sense}\, I_{pk}^2}{3} \tag{10}$$

4.3 C_{HV}

Capacitance

C_{HV} is sized according to load capacitance

$$C_{HV} = 5\%\ C_{Load} \tag{11}$$

An accurate value is not critical but take into account the DC bias characteristics of some capacitor types that would significantly reduce the effective capacitance (see section 4.6). 10 % tolerance is appropriate.

If a resistor is used in series with the actuator to create a low-pass filter, then the C_{HV} capacitance value must be increased. There is no hard rule for the capacitance increase; it must be determined during prototyping to produce an appropriate output waveform.

Voltage Rating

C_{HV} is driven in parallel with the load and will be subject to the same waveform. The voltage rating must be higher than the single-sided peak voltage of the waveform. For unipolar waveforms, take the peak voltage of the waveform. For bipolar waveforms, take the maximum amplitude value between the negative and positive peak voltages. For example,

- for a 0 to 60 V waveform, use 60 V;
- for a ± 90 V waveform, use 90 V;
- for a -10 to 60 V waveform, use 60 V;
- for a -70 to 30 V waveform, use 70 V.

Application conditions such as temperature and capacitor type must be considered to counter applicable derating (see section 4.6).

Capacitor Type

Ceramic capacitors are recommended for their small size and low cost. Adjust the value according to the DC bias characteristic.

4.4 C_{VDD}

This capacitor serves two purposes.

First, it serves as a tank for the reverse charges when recycling the energy from the actuator. When charges are coming back to C_{VDD}, the voltage will rise. C_{VDD} is calculated to prevent the voltage from exceeding the 5.5 V maximum input voltage of the BOS1901 (see below).

Second, it provides charges for the switching inductor and must be located near the inductor.

Often, the power supply or supply rail will be able to sink the reverse current. In such situations, only the switching purpose need to be supported (see section 5.1). When the supply cannot sink or store this current, or when the UPI configuration is used (see section 5.2), the calculated C_{VDD} must be placed on the VDD node.

Capacitance

The capacitance value required to store the reverse current is calculated using

$$C_{VDD} = \frac{C_{load} V_{pk}^2}{V_{DD\_max}^2 - V_{BUS\_max}^2} \quad (12)$$

where V_{DD_max} is the maximum voltage specified on VDD (5.5 V), and the other parameters are the same given in section 4.1.

This value is approximative and not taking into consideration every power loss in operation. This value should provide a secure boundary, but lower values can be used if prototype testing reveals it can be reduced. When using the calculated C_{VDD}, ignore the 10 µF for switching support.

It is preferable to use this capacitance as much as possible to get the best power savings. Sometimes, this value may be impractical, or the supply does not tolerate voltage increase on the reverse current. In such cases, it can be substituted by a 10µF with a Zener diode (see section 5.3). If possible, it is recommended to still use the highest capacitance allowed by the application to maximize its power efficiency.

When selecting the capacitor, make sure to select a capacitor with an effective capacitance close to the calculated value for the operating conditions.

Voltage Rating

The voltage on C_{VDD} should not exceed 5.5 V. Choose a voltage rating according to the application conditions and capacitor type selected (see section 4.6). For example, using a tantalum polymer capacitor, 6.3 V rating is generally enough.

Capacitor Type

When using only 10 µF, a low-ESR ceramic capacitor is sufficient. Note however the 10 µF value is an effective value. Many ceramic capacitors have significant DC bias, and they should be selected accordingly (see section 4.6).

The same goes for the calculated C_{VDD} value; it is an effective value. Therefore it is recommended to use Tantalum Polymer capacitors since they do not suffer from DC bias and will maintain the component to a decent size.

4.5 C_{VREG}, C_{VDDIO}, C_{PUMP}

These three capacitors are used for decoupling and output tank functions. Low-cost, low-ESR ceramic capacitors are sufficient.

Capacitance

100 nF is required for all of them, but accuracy is not critical.

Voltage Rating

Voltage on these capacitors should not exceed 5.5 V. Choose a voltage rating according to the application conditions and capacitor type selected.

Capacitor Type

Low-cost, low-ESR, small-size ceramic capacitors are adequate.

4.6 Capacitor Type

The most common types of capacitors found in mobile devices are either multilayer ceramic capacitors (MLCC) or tantalum. Both have advantages and disadvantages. When selecting capacitors for the BOS1901, one must consider those differences. It is recommended to always consult a component datasheet in detail before using it.

Multilayer Ceramic Capacitors (MLCC)

This capacitor type is the most common due to its low ESR (a few milliohms), low cost and small size. However, for high capacitance values (47 µF and above) they become very large.

The major characteristic often overlooked of an MLCC capacitor is its DC bias. As voltage increases, the capacitance change, and may drop by a very significant amount (e.g. 80 %). This may not be critical in decoupling situations, but for purposes such as filters where the capacitance value is important, this might force the use of a much bigger component to counter the DC bias. The following figure illustrates variations of this effect on various capacitor models.

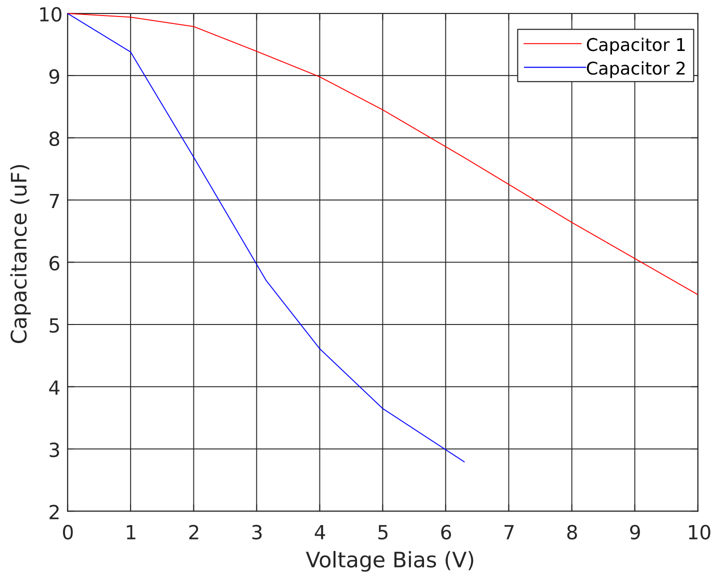


Figure 7 Two typical DC bias characteristics

Tantalum Capacitors

These capacitors offer a better capacitance to volume ratio than MLCC and they do not have a DC bias characteristic like the MLCC. They are therefore more advisable when larger capacitance values are required.

However, the ESR is a bit higher than MLCC, and they require voltage derating. It is important to differentiate between tantalum MnO_2 and tantalum polymer types. Their electrode material is different, the latter having less ESR. Tantalum MnO_2 typically requires 50 % voltage derating (operation up to 50 % of the specified voltage), while the tantalum polymer type typically requires between 80 and 90 % voltage derating depending on nominal rating and temperature range.

Which Capacitor Type to Use?

For C_{VDDIO}, C_{REG}, and C_{PUMP}, it is recommended to use MLCC since they are cheaper, small enough and the capacitance values are not critical. X5R and X7R types are appropriate.

For C_{HV}, MLCC are also recommended, but make sure to adjust the component value to compensate its DC bias characteristic.

For C_{VDD}, tantalum polymer are preferred to keep their size reasonable while ensuring the appropriate capacitance value. Most 6.3V-rated models will allow safe operation up to 5.5 V and 85 C.

Again, always consult the component datasheet before using any component.

4.7 SPI Damping Resistors

It is recommended to use damping resistors on all SPI lines for impedance matching. Resistance value should match the impedance of PCB lines. If line impedance is unknown, use 51 ohms resistors. Locate the resistors close to the driving output. On CS, SCLK and SDI lines, locate the resistors close to the master. On SDO line, locate the resistor close to the slave.

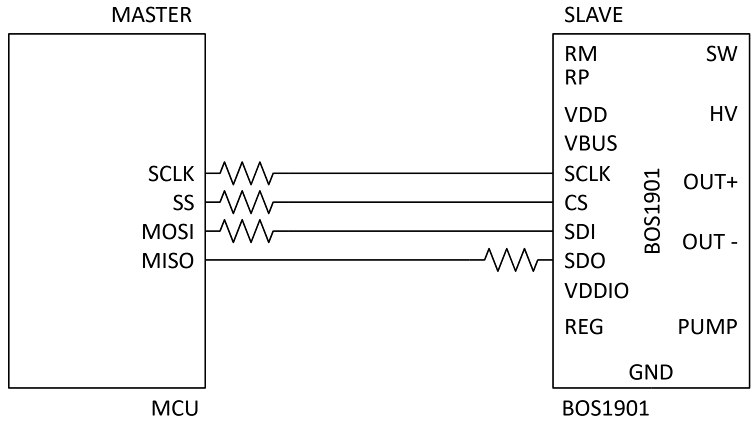


Figure 8 SPI damping resistors

5 Supply Considerations

The power distribution network (PDN) is the set of all components and routing that combines to provide the supply and maintain voltage and current to the load. It includes many elements such as PCB traces, tank and bypass capacitors, filtering beads, etc., but also parasitics (capacitance and inductance from traces, vias, etc). Some components help the supply, others might hinder it.

Haptic technologies are now made low-power thanks to piezo actuators and Boréas drivers. However, it still consumes significant energy at times and its interactions with the power rail or PDN must be considered for a successful integration.

The amount of current drawn from and returned to the PDN can and will make it fluctuate depending on its impedance. If this is not taken into account, some modules may lose performance, others might stop working.

5.1 PDN Contribution to C_{VDD} Requirement

The PDN combines any component impedance shared on the same supply if they are accessible through low impedance. Therefore, other capacitors on the PDN may be considered as part of the tank capacitance on this network.

Not using UPI configuration of the BOS1901 (see next section), this combined capacitance can be used as tank for the BOS1901 operation. The BOS1901 datasheet calculated C_{VDD} can then come mostly from the PDN capacitance, reducing the requirement on C_{VDD} value near the BOS1901.

In the case the PDN capacitance is higher than the calculated C_{VDD} value, then only a 10 uF is required near the VDD pin to provide the inductor switching current. Most PDNs will tolerate this current, but this needs to be checked in the context of the application beforehand.

5.2 UPI Configuration

The BOS1901 recycles energy stored on the actuator by creating a reverse current to the input tank capacitance (see section 4.4). This also implies the return current will increase the voltage on the C_{VDD} equivalent input capacitance (including PDN impedance). Even if the voltage rise is kept below a 5.5 V, it might still rise higher than the admissible range of other modules on the same supply rail.

An example is a 3.3 V rail that does not tolerate voltages higher than 3.63V. Another example is lithium-ion batteries. Such batteries have strict requirements on the charging sequence, forbidding any return current other than the one controlled by the charging circuit.

Also, the BOS1901 may create ripple on the power rail (VBUS) which can be an issue for sensitive modules sharing the same supply.

In such cases, it is recommended to use the BOS1901 UPI configuration. This configuration will allow current to be drawn from the source but will block any reverse current from returning to that source. The reverse current will be stored on the local C_{VDD} capacitor. C_{VDD} is calculated for the voltage increase to stay below the BOS1901 maximum operation voltage (5.5 V) given the application conditions. See section 6.2.10 in the product datasheet for details.

If unsure about which configuration to use, it is possible to add a 0 Ω resistor between VBUS and VDD to test both configurations at the system-level in the prototype.

When using UPI configuration, VDD is not longer part of the PDN and VBUS becomes the main supply for the circuit. Add a 100 nF decoupling capacitor on VBUS and make sure to set PARCAP.UPI bit to 1 in the main register map when programming the IC over SPI.

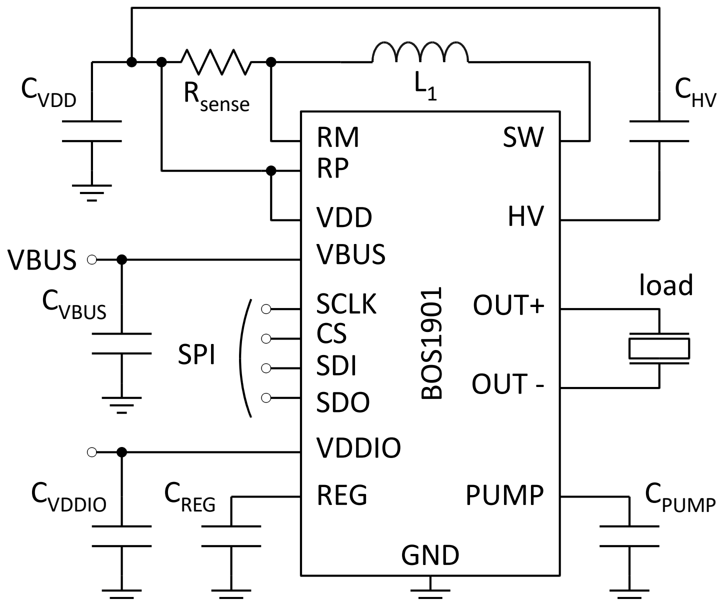


Figure 9 BOS1901 schematic using UPI configuration

5.3 Zener Diode

In many cases, the C_{VDD} required to prevent voltage rise to a safe level may become physically too big for the application, using UPI or not. An example is using a 5 V USB supply (maximum 5.25 V), leaving only 250 mV margin and necessitating an impractically large component. Another one would be using a lithium-ion battery (4.2 V maximum) and a high-capacitance actuator, regardless of the waveform frequency. Yet another example is using a generic 5 V charger going as high as + 10 %, then there is simply no room left for any voltage rise. Even using lower supply voltage, cases may come requiring a capacitor size bigger than the application can tolerate.

In such cases a Zener diode can be used to drain the excess charges and keep the voltage to acceptable levels. Note that using such a diode will slightly increase the average energy consumption. Select a diode with a Zener voltage that suits the application.

The following equation provides an upper bound for the diode power dissipation rating required, assuming the actuator is cycled multiple times and no power losses.

$$P_{Zener,Rating} = \frac{C_{load} V_{pk}^2 f_{sig}}{2} \qquad (13)$$

This value may be refined after prototype testing and once waveforms are determined. When selecting this diode, be mindful of its leakage current.

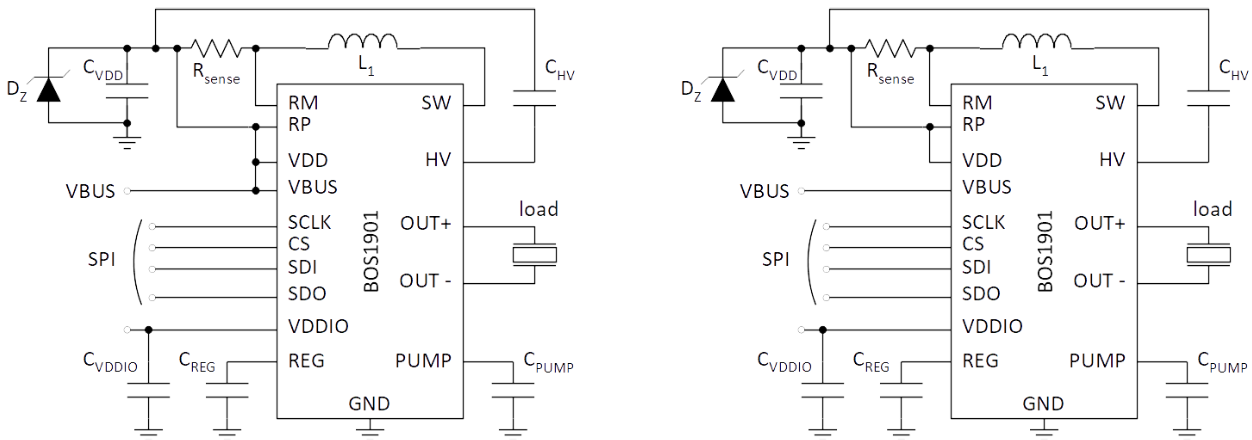


Figure 10 BOS1901 schematics using Zener diode, without UPI (left) and with UPI (right)

5.4 Supply Current Drive

Even though BOS1901 is a low-power piezo electric actuator driver circuit, as a waveform is being driven on the BOS1901 output (shape, amplitude and frequency), the input current drawn will vary. The PMIC, regulator, battery or power source supplying the BOS1901 must be able to provide this varying current during the entire waveform.

Haptics waveforms are generated at low frequencies, being generally below 300 Hz. Changes in current will be seen as low-frequency changes to the power source at every moment of the waveform. If the source cannot supply the current at all times, the voltage rail will significantly drop, causing noise, performance degradation, or function failure.

The maximum instantaneous input current will occur at the maximum power transfer point. This current ($\overline{I_{IN}}$) is calculated with equation (4) in section 4.1. It is possible to reduce the input current requirement by limiting the current of the BOS1901 via an increase in Rsense. However, this also results in reducing the output waveform bandwidth.

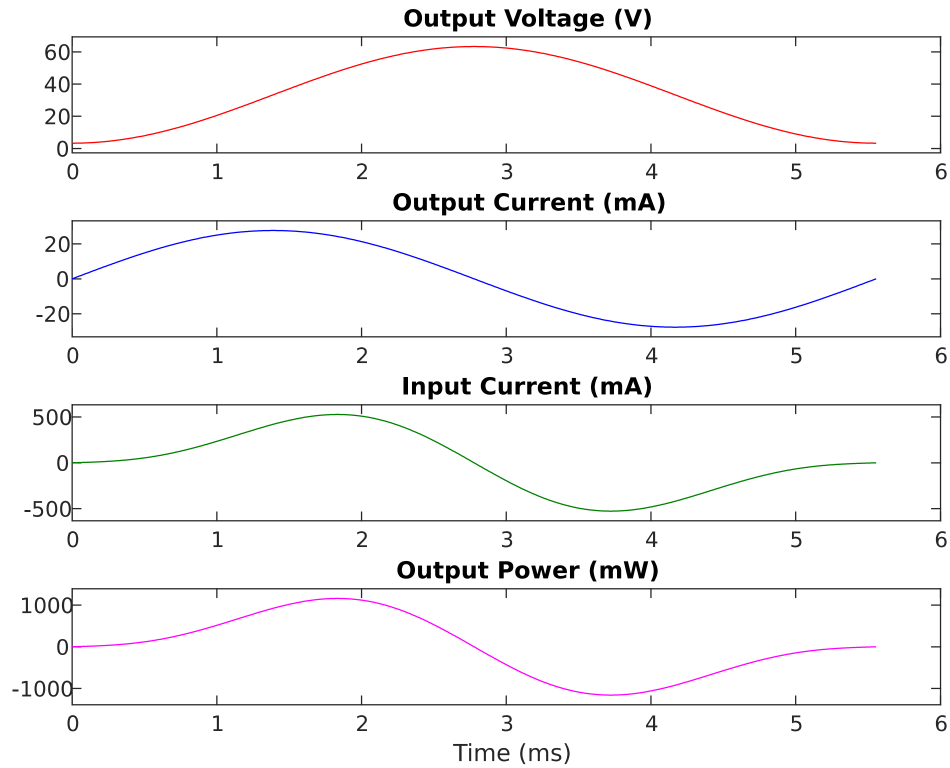


Figure 11 Voltage and current variations during a unipolar sine cycle (60 V sine, 180 Hz, TDK 1204H018V060 actuator)

5.5 Power Rail Noise

As stated previously, while driving a waveform, voltage on the PDN might drop near the maximum power transfer point and rise during the reverse current phase. There are ways to reduce these voltage changes (UPI, Zener, extra capacitance), but the system designer should be aware of these voltage variations and their potential impact and risk on other modules sharing the same supply. In some case, using dedicated supplies, or using a LDO might be required for sensitive circuitry. Avoid operating the BOS1901 on a supply near the 3.0 V minimum operating voltage; as the current drawn risks dropping the supply voltage below 3.0 V and inducing performance degradation or even operation failures.

5.6 Connector and Wiring Ratings

The BOS1901 output voltage can rise to ± 95 V. Use connectors and wires that can support these levels. Use appropriate PCB separation between lines and vias accordingly.

The actuator connected between OUT+ and OUT- output nodes of the BOS1901 will be referenced to VDD. This means that while one actuator terminal is being driven, the other one is maintained at VDD. Make sure connectors and cables are isolated properly and will not cause short-circuits to grounds.

The output RMS current to the actuator is generally small. It can be evaluated using the equations below for the cases of sine waveforms to size PCB traces and select wires that will work reliably. Given the equations in section 4.1:

Bipolar Waveform	Unipolar Waveform	
$I_{out,max} = 2\pi f_{sig} C_{Load} V_{pk}$	$I_{out,max} = \pi f_{sig} C_{Load} V_{pk}$	(14)
$I_{out,RMS} = \frac{I_{out,max}}{\sqrt{2}}$	$I_{out,RMS} = \frac{I_{out,max}}{\sqrt{2}}$	(15)

5.7 VDDIO

VDDIO is the supply of BOS1901 digital interface. SPI signals are in this voltage domain and their high-level must match the VDDIO supply level. VDDIO specified voltage range is 1.62 to 5.5 V. VDDIO can be shared with VDD as long as the SPI signals are also in that domain.

6 Register Parameters

The BOS1901 main register map parameters may be adjusted to fit specific applications, selected components and board layout. Aside from the bits LMI and UPI mentioned earlier, it is recommended to start by using default values, calculate parameters based on selected components (see equations in the datasheet), and then adjust other parameters as needed to achieve the appropriate output waveform shape and power consumption.

7 Prototype Test Guidelines

Haptics applications may be all about the sensation felt, but electrical testing is recommended to ensure the circuit has the correct performance. The following guidelines are provided to help assessing the circuit performance.

- Check SPI signals:
  - Use oscilloscope to check signal voltage levels and transitions:
    - SPI signals should be in the VDDIO domain.
    - Signals should display rather sharp transitions; increase the MCU GPIO output drive if needed.
    - Check if the signals follow the correct protocol.
  - Use a logic analyzer to debug instructions sent to the IC and information returned.
    - Use SDO (MISO) pin even if the application does not require it. This helps debug problematic operation and check for errors at runtime.
    - Make sure the IC returns the CHIP ID by default.
    - Read all registers on SDO (using CONFIG.BC parameter) to verify the data was correctly received.
- Check the output signals:
  - Use an oscilloscope with a separate channel for each of the actuator terminals. It is possible to use a differential probe but checking OUT+ and OUT- separately will provide information on the DC level of the signals. Never connect the probe ground clip to one of the actuator terminals. Figure 12 gives and example of such output for a 95 V bipolar sinewave. The blue line is OUT+, red line is OUT- and the purple line is the math difference between them. Note, both signals are offset by V_{DD}.
  - Consult our application note on oscilloscope measurements on Boréas website for more details on connexions and settings.
  - When playing waveforms, check if the waveform has the same shape as the one programmed.
  - While probing the voltage as the user is pressing the actuator, increase the voltage zoom to check how the voltage reacts. It is then possible to monitor all phases of sensing and feedback in a button emulation sequence for example.
- Check the supply levels, especially while driving waveforms:
  - Check V_{DD} and V_{BUS} voltages. These should display the energy recycling and variation during the waveform. It is normal for V_{DD} to vary significantly over a waveform cycle. An example is given at Figure 13.
  - If V_{DD} rises too much, then C_{VDD} might be too small, or a Zener diode could be used.

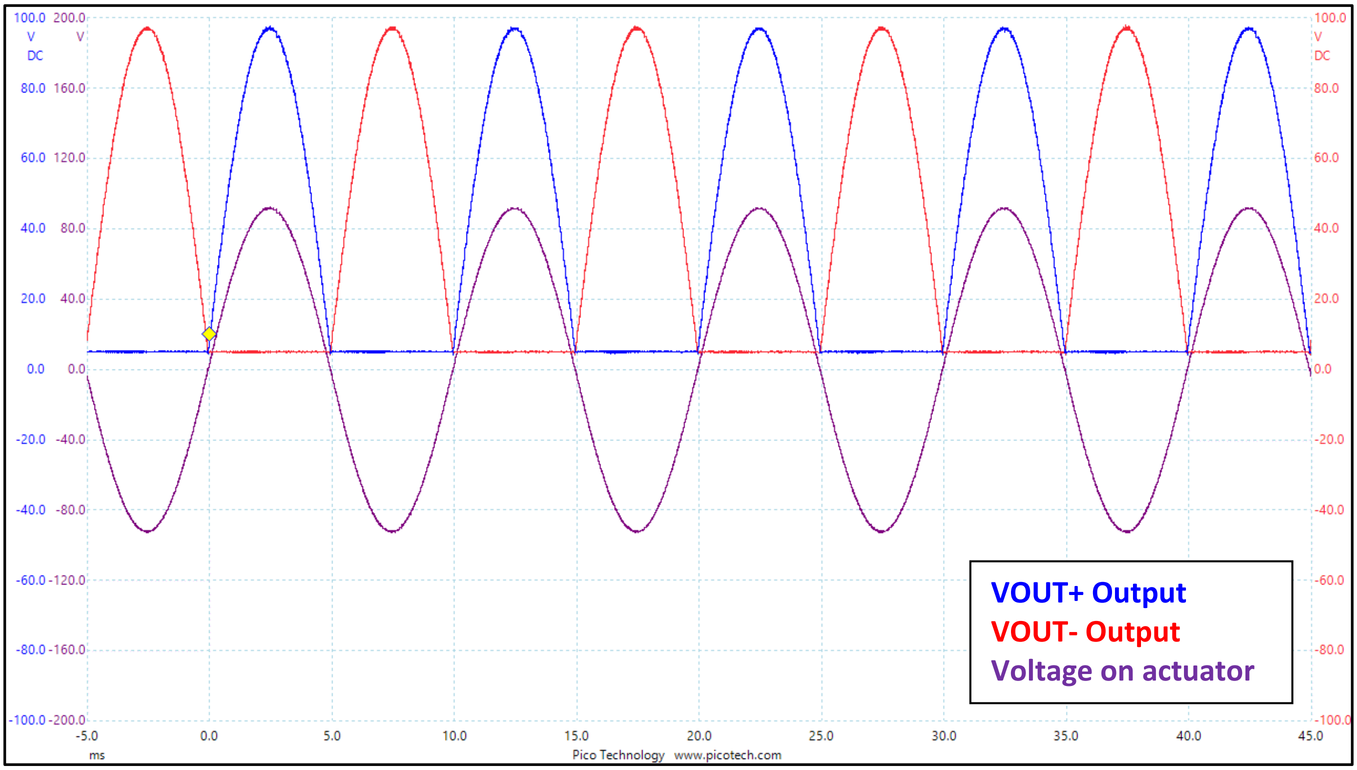


Figure 12 Typical output of a 95V bipolar output waveform measurements on an oscilloscope

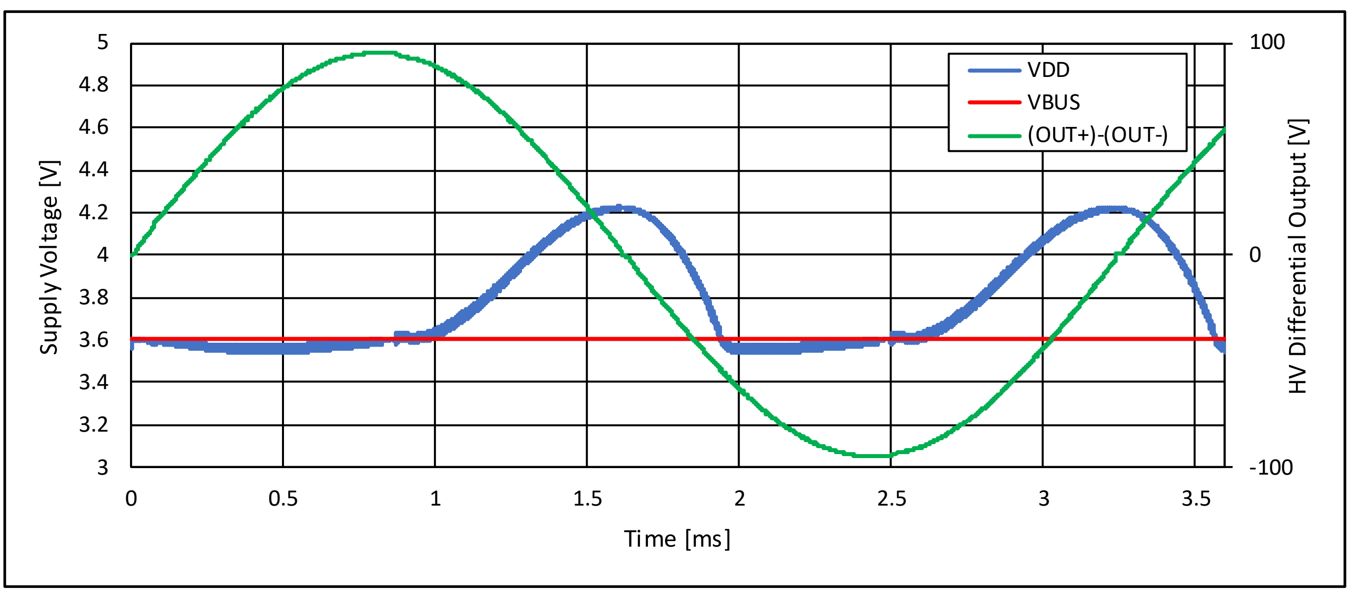


Figure 13: VDD voltage increase during energy recovery when bit UPI = high. C_{VDD} = 100 µF, C_{Load} = 100 nF

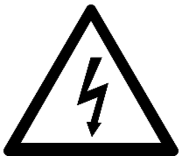
8 Related Parts

	Part Number	Description
1	BOS1901	BOS1901 Piezo Haptic Driver with Digital Front End

9 Document Changes

ISSUE	DATE	Document Number	CHANGES
1	December 2021	BT001DAN05.01	Original document

10 Notice and Warning



Danger High Voltage!

Electric shock possible when connecting board to live wire. Board should be handled with care by a professional. For safety, use of isolated test equipment with overvoltage and/or overcurrent protection is highly recommended.

ESD Caution

This product uses semiconductors that can be damaged by electrostatic discharge (ESD). When handling, care must be taken so that the devices are not damaged. Damage due to inappropriate handling is not covered by the warranty.

The following precautions must be taken:

- Do not open the protective conductive packaging until you have read the following and are at an approved anti-static workstation.
- Use a conductive wrist strap attached to a good earth ground.
- If working on a prototyping board, use a soldering iron or station that is marked as ESD-safe.
- Always disconnect the microcontroller from the prototyping board when it is being worked on.
- Always discharge yourself by touching a grounded bare metal surface or approved anti-static mat before picking up an ESD - sensitive electronic component.
- Use an approved anti-static mat to cover your work surface.

Oscilloscope measurements:

Both OUT+ and OUT- are active outputs. When measuring these signals using an oscilloscope, use a separate probe on each output. Never connect the ground of a probe to one of these outputs. Doing so might damage the BOS1901-KIT and/or your oscilloscope. For more information please consult the *Probing BOS1901 with an Oscilloscope* application note available for download on Boréas website.