![TDK]

Piezo Haptic Actuators - PowerHap

Application note for evaluation kit 60 V

Ordering code:	**Z63000Z2910Z1Z44**
Date:	2019-05-08
Version:	1.6

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1 Introduction

This evaluation kit was developed to support engineers during their first steps designing applications with the PowerHap piezo actuators for haptic feedback.

The design is not qualified regarding manufacturing and operation over the whole operation temperature range or lifetime.

This evaluation kit provided by TDK is intended to be used for functional testing only.

Due to their purpose, evaluation driver kits are not intended to be used by the same procedures regarding returned material analysis (RMA) and process change notification (PCN) as regular products.

The board described is an evaluation driver board dedicated for laboratory environment only. It operates at voltages up to 100V. This board must be operated by qualified and skilled personnel familiar with all applicable safety standards.

1.1 Ordering code

The ordering code for this evaluation kit is Z63000Z2910Z 1Z 44.

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1.2   Features

- Plug and play developer kit to experience piezo haptic feedback/sensation
- Including the BOS1901-KIT for the low-power BOS1901 integrated circuit by Boreas Technologies, a high voltage driver with digital interface
    - Simple power interface for development via USB port
    - Standard USB audio to prototype haptic effects in MATLAB®, Python®, Audacity® and many other software[1]
    - Fully embeddable modular software driver
    - Easy generation of high-voltage waveforms up to 70 Vpp for the PowerHap
    - Two breakable miniature PCBs with BOS1901 drivers
- TDK PowerHap actuators included in the kit (1 pcs each, with wire):
    - 0909H011V060 (previously known as 2.5 G)
    - 0904H014V060 (previously known as Lateral Mini 9 x 3.75)
    - 1204H018V060 (previously known as Lateral Mini 12 x 4)

1.3   Description

The BOS1901-KIT is a development kit to support users who want to get familiarized with the BOS1901 piezo haptic driver IC.

The USB powered kit appears as an USB audio device for the computer, which allows the rapid generation of waveforms using existing audio software like Audacity® for haptic prototyping. Each breakable miniature PCB gives access to all signals allowing the user to experiment with the BOS1901 using a development platform of his/her choice.
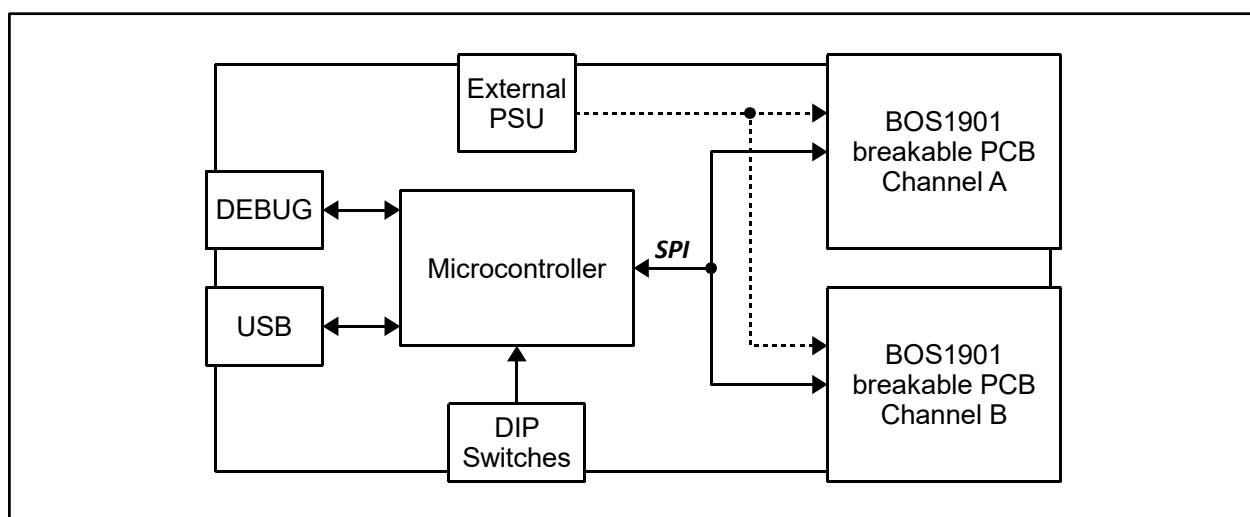
Figure 1: Simplified BOS1901 - KIT diagram.

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[1] MATLAB® is registered trademark of The MathWorks, Inc.
Python® is a registered trademark of the PSF
Audacity® is a registered trademark of Dominic Mazzoni
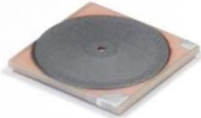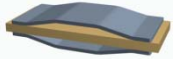
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2 Quick start guide

2.1 What is in the box

Table 1: Development kit content

Item #	Item	Description	Reference
1	Driver board	BOS1901 evaluation PCB	
2	USB cable	Micro USB cable to connect the evaluation PCB to a computer	
3	TDK piezo actuator*	0909H011V060 (previously known as 2.5 G); part number Z63000Z2910Z 1 Z2	
4	TDK piezo actuator*	0904H014V060 (previously known as lateral mini 9 x 3.75); part number Z63000Z2910Z 1Z41	
5	TDK piezo actuator*	1204H018V060 (previously known as lateral mini 12 x 4); part number Z63000Z2910Z 1Z39	

* The actuators are delivered with a black and red wire soldered on the terminals. Please connect the red wire to HV+ and the black wire to HV-.

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2.2   PCB overview
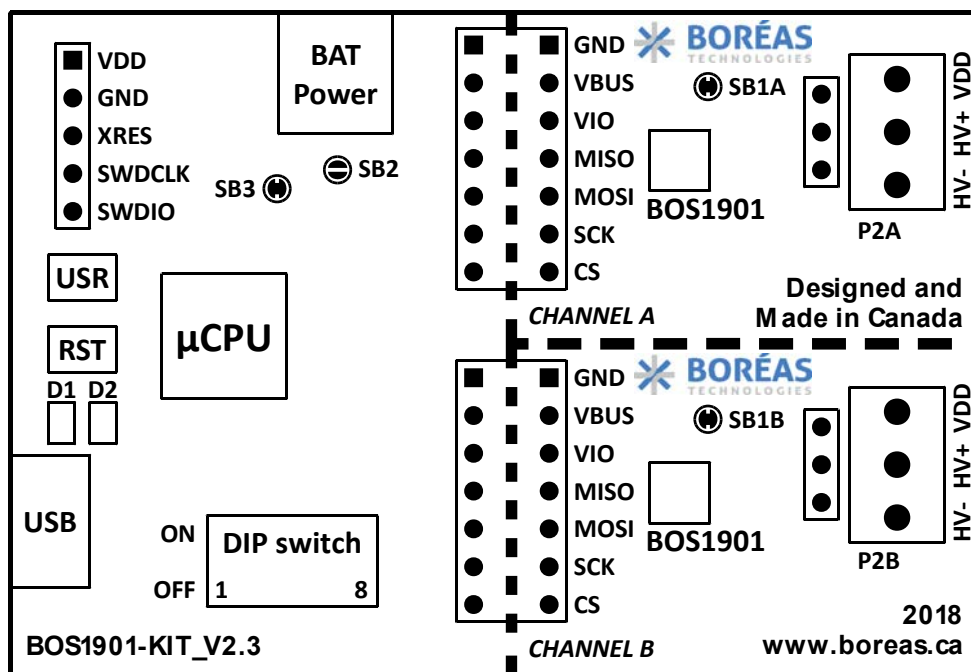
Figure 2: BOS1901-KIT Evaluation PCB overview.

2.3   Quick start procedure

- Refer to section for jumper options and for switch settings to ensure the evaluation PCB is in the intended settings

- Connect the selected actuator to the proper channel on P2A or P2B connector

- Connect the evaluation PCB to a computer using the included USB cable, then wait for LED D1 (green) to light up and LED D2 (red) to turn off after the firmware identification sequence

- Push the sensor with a finger to feel the feedback. Enhance the feedback experience by changing DIP switch settings.

- Using the Audacity® software, select a waveform to play on the actuator

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3   Hardware

3.1   Jumper options

The BOS1901-KIT is provided by default with jumpers SB2, SB3 and SB1X set to operate from USB power, UPI mode off.

Table 2: Jumper options

Function	Shorts		HW
USB Power UPI OFF (default)	SB2		
	SB3		
	SB1x		
USB Power UPI ON*	SB2		
	SB3		
	SB1x		
BAT Power UPI OFF	SB2		
	SB3		
	SB1x		
BAT Power UPI ON*	SB2		
	SB3		
	SB1x		

* Refer to the section of the jumper settings for details and limitations.

3.1.1   Use BAT power (external power supply connection)

From default state:

- Remove power to the evaluation PCB by unplugging the USB cable
- Cut junction of SB3 jumper
- Put a solder joint on SB2
- Optional, solder a capacitor on C19 if additional decoupling is required on VBUS node
- Plug the USB cable to the evaluation PCB for power and communication to the microcontroller section
- Apply an external DC source ranging from 3 V to 5 V on connector P5
- Push and release "RST" button (S2), then wait for LED D1 (green) to light up and LED D2 (red) to turn off

Note: the "USR" button (S1) has reserved usage on the current firmware.

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3.1.2 Use UPI feature

Warning - With UPI enabled, the energy recovery feature of the BOS1901 will accumulate energy in C1A/C1B capacitor, causing COM voltage to increase. The user should make sure that VDD voltage never exceeds the 5.5 V limit otherwise it may permanently damage the BOS1901. For instance, due to its larger capacitance, it is not recommended to use the PowerHap actuators with 5 V supply and UPI feature ON. Please refer to BOS1901 data sheet section 6.2.10 for more details.

From default state:

- Remove power to the evaluation PCB by unplugging the USB cable
- Remove solder joint on one or both SB1X, depending on the choice of UPI configuration
- Plug the USB cable to the evaluation PCB, wait for LED D1 (green) to light up and LED De (red) to turn off

3.2 Piezo actuators

TDK PowerHap piezo actuator specifications:

Type	Cymbal design
Polarity	Red wire on "HV+" terminal
	Black wire on "HV-" terminal
Range	Unipolar -10 V to +60 V, use with switch SW1 at "OFF" position
	(refer to section DIP Switch settings)

It is of utmost importance to not use the TDK PowerHap actuators in full-scale mode as it can get damaged unless the waveform is properly designed to limit the output voltage between -10 V and +60 V. Example waveforms are provided on Boréas website (www.boreas.ca/bos1901-kit.

Refer to section for a special output configuration, in which two TDK actuators can be connected on a single BOS1901 circuit:

- "Load 1" with red wire connected to "HV+" and black wire on "VDD"
- "Load 2" with red wire connected to "HV-" and black wire on "VDD"
- Use of full-scale mode with output voltage limited to +60 V
- Toggle SW2 to single ended mode (ON)

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3.3   DIP switch settings

The evaluation PCB is provided by default with S3 DIP switch set to unipolar operation with only channel A enabled. It is recommended to toggle these switches only when not playing waveforms.

Table 3: DIP switch settings

DEFAULT	SWITCH	OFF	ON
OFF	SW1	Unipolar (-10V/+60V)	Full-scale (-95V/+95V)
OFF	SW2	Differential out config*	Single ended config*
ON	SW3	Only channel A ON	Both channels ON
ON	SW4	Press-release feedback on channel B	Multipress feedback on channel B
ON	SW5	100 Hz feedback	180 Hz feedback
ON	SW6	75% amplitude feedback	100% amplitude feedback
ON	SW7	Low sensitivity feedback	High sensitivity feedback
OFF	SW8	Future use	Future use

* Refer to the according section for more details on output configurations.

SW1   The output ranges listed for SW1 settings are for full amplitude input signal, for example -1 to +1 when using Audacity® software. When using TDK PowerHap 2.5G piezo actuator, set SW1 to OFF.

More precisely, this switch sets the maximum and minimum values allowable for the selected range. It does not affect the gain and offset conversion between the input signal and the output voltage. If the requested voltage is out the range, the firmware will clip the signal to the limits of the range. Therefore, a single conversion equation is used for the same voltage in both ranges. The relation between the input signal value and the output voltage is:

$$Signal = \frac{Voltage}{95\ V}$$

Thus signals of +1, -1 and 0 correspond to 95 V, -95 V and 0 V respectively. To generate a 60 V output, the signal should be 60 V/95 V = 0.631.

SW2   Refer to the according section for configuration details. Sensing is not possible in single-ended configuration.

SW3   SW3 determines how many channels are active. Set SW3 to OFF to activate only channel A. Set SW3 to ON to activate both channels. When a channel is activated it can sense pressure and give feedback, and it can play waveforms.

SW4   When both channels are active (SW3 is ON), set SW4 to OFF to have both channels feedback a single click. Setting SW4 to ON will maintain channel A to feedback single clicks but channel B will give three feedback response levels depending on the exerted pressure. A low-level pressure triggers a single light click, medium pressure triggers a stronger click, and a high pressure triggers a longer feedback.

SW5   SW5 sets the frequency of the feedback response when the actuator is pressed and released.

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SW6   SW6 sets the amplitude level of the feedback response. Setting SW6 to ON will provide a stronger response than setting it to OFF. SW6 has an effect only in press-release mode.

SW7   SW7 sets the sensitivity level for feedback. Setting SW7 to ON will require less pressure to trigger the feedback.

SW8   SW8 is not used in the current firmware. It could be used in firmware created by the user.

Setting SW5, SW6 and SW7 to ON will maximize the feedback response.

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3.4 Output configuration options

With the two-terminal differential output, two outputs configurations are possible to drive a piezo.

3.4.1 Differential output configuration

The typical output configuration is the differential output, refer to the figure below. The piezo element is driven with one terminal connected to "HV+" and the other connected to "HV-". This configuration can achieve a differential output voltage of 190 V_{pp} in full-scale mode. Please limit the range to 60 V for TDK PowerHap actuators with the DIP switches.
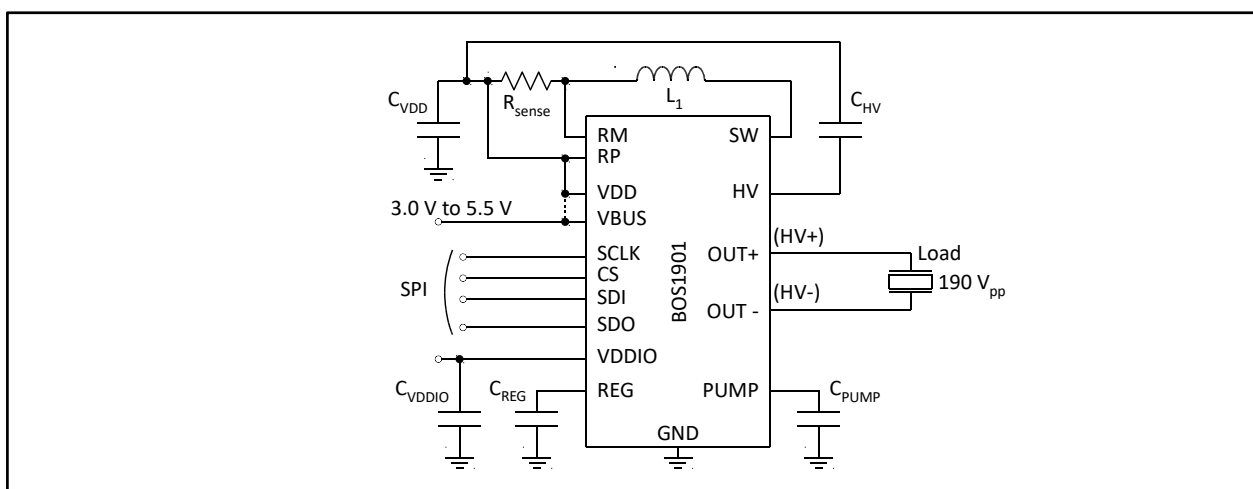

Figure 3: Two-terminal differential output configuration.

3.4.2 Single ended output configuration

The single ended output configuration allows to drive up to two different piezo elements, see Figure 4. A piezo element is driven with one terminal connected to "HV+" or "HV-" and the other connected to "VDD". This configuration can achieve a single ended output voltage of 95 V. Please limit the range to 60 V for TDK PowerHap actuators with the DIP switches.

Only one piezo element can be driven at a time based on signal polarity.

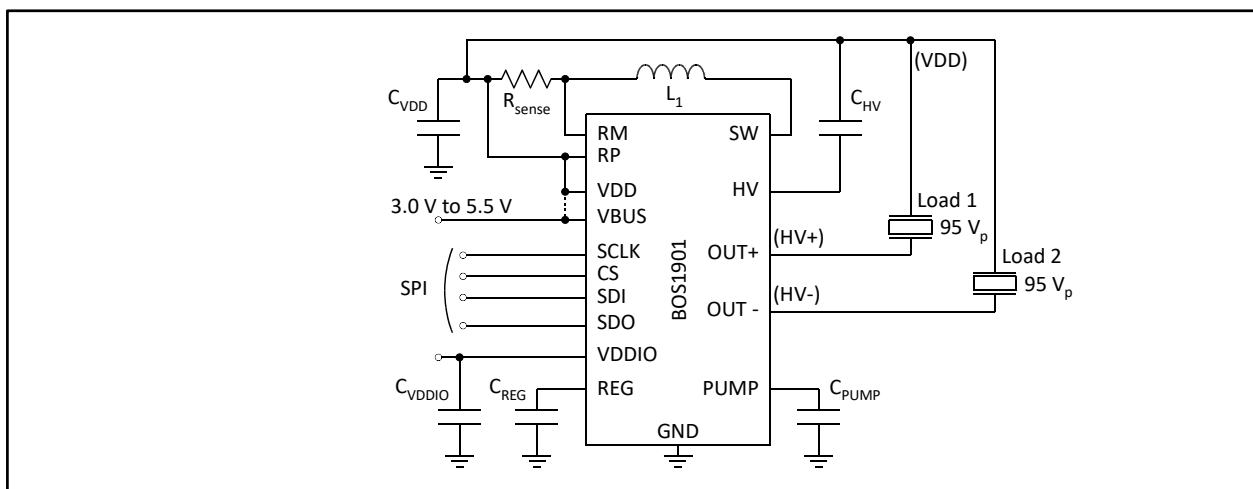Figure 4: Two-terminal single ended output configuration.

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3.5 Breakable units

Each channel is on a breakable PCB unit that can be used alone with a user-preferred development platform. The available signals are:

- GND   0 V reference
- VDD   Main power supply for the BOS1901 (from 3 V to 5 V)
- VIO   Digital IO power supply (set to SPI signals voltage level, between 1.8 V and 5 V)
- MISO   SPI Master In/Slave Out signal
- MOSI   SPI Master Out/Slave In signal
- SCK   SPI Clock signal
- CS   SPI Chip Select signal (active low)

Refer to BOS1901 datasheet for a complete description on how to use and program the circuit.

The use of the breakable units with custom-made firmware is done at the user's own risk of causing damage beyond repair to the BOS1901 circuit.

4 Software

4.1 Software installation procedure

Please follow the Audacity® installation procedure. The software is free of use and can be found at: https://www.audacityteam.org/download/.

Refer to https://www.audacityteam.org/about/license/ for the terms of GNU General Public License (GPL) for Audacity® use.

4.2 Software operation

The evaluation PCB appears as a speaker to the computer. The following operation example is made using Audacity® software, but the use of any other software is also possible. Make sure the USB audio firmware is installed on the evaluation PCB, refer to section for firmware installation/update procedure.

1. Connect the evaluation PCB with the USB cable, wait for green LED to light up and for red LED to turn and stay off, after the firmware identification sequence
2. Start Audacity®, then select "File/Open…" to load "Audacity project - BOS1901-KIT.aup" file available for download on Boréas website.
3. Select the appropriate Audio Host (see below):
   - For Windows: select "Windows Direct Sound"
   - For MAC OS X: select "Audio Core"
   - Fox Linux: select "ALSA"
4. Select "Cypress Digital Audio" as the Playback device (see below)
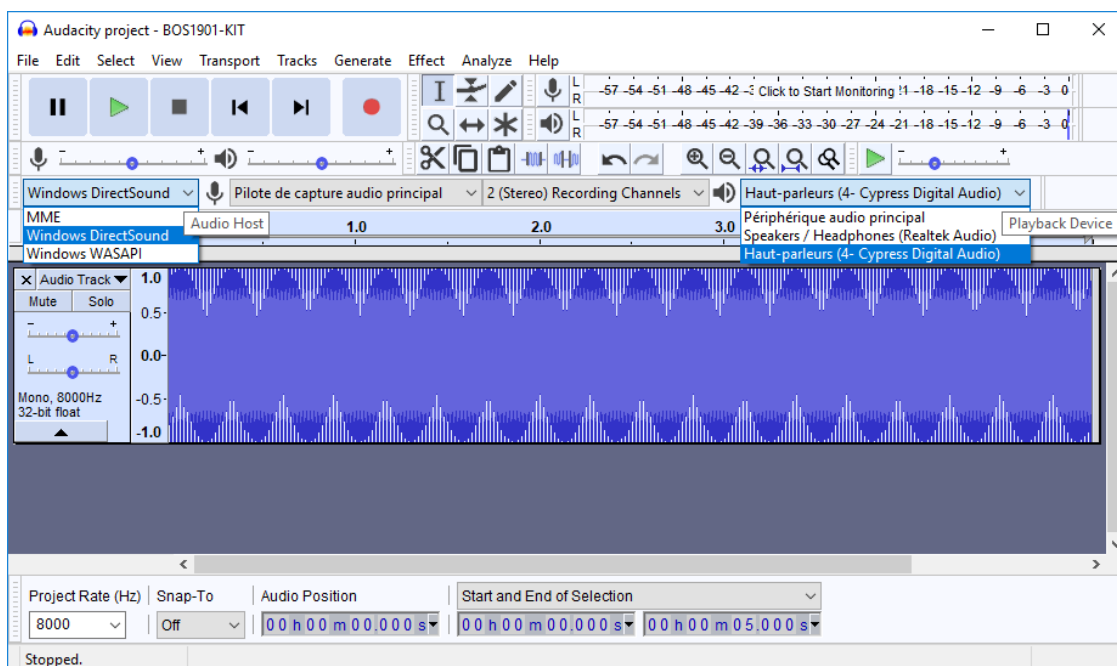5. Press play button to start the default 100 Hz sine waveform, which will play for 5 seconds.

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Figure 5: Audacity® software interface.

6. The balance between channels A and B can be changed using the "L/R" dial in the "Audio Track" field, L corresponding to channel A, R to channel B. The gain can also be changed with "-/+" dial, but beware of positive gains that may cause output clipping.
7. To generate another kind of waveform, change its frequency or amplitude, go to the "Generate/Tone…" menu. For Square and Sawtooth, it is possible the software will calculate points based on an 8 kHz filter, therefore distorting the output waveform.
8. Existing or generated .wav files can be played with Audacity®, loaded with the "File/Open…" dialog.
9. If starting a new project, make sure to use a Project Rate at 8 kHz (lower left corner field).
10. For other Audacity® features, please refer to the software help

5 Firmware

5.1 Identifying the firmware revision number

Since firmware revision 2.2, when powering up the development kit, both LEDs will show the firmware revision number and then the IC revision.

After the 10-second bootload window while both LEDs are on (see next section), the green and red LEDs flash to indicate the firmware revision number. For a firmware revision X.Y with major revision X and minor revision Y, the green LED will flash X times and then the red LED will flash Y times. This sequence is repeated for a beta revision.

Then both LEDs are lit a short while as some initialization is performed, and then ICs are identified. Green LED will flash to indicate channel A BOS1901 IC revision, and red LED will flash to indicate channel B BOS1901 IC revision. For each channel, the LEDs will flash 1, 2 or 3 times to indicate the IC for that channel is of revision A, B or C respectively.

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5.2 Firmware installation / update procedure

The BOS1901-KIT is provided out-of-the box with a firmware for use as an USB Audio device.

This firmware can be changed and/or updated using the USBBootloaderHost.exe application available on Boréas website. The procedure is as following:
1. Load the appropriate *.cyacd file using the "Load File" button.
2. Press and release the "RST" button on the evaluation PCB, LEDs will go through the firmware identification sequence given in the previous section, and end with green LED on and red LED off. If red LED does not turn off, wait a couple of seconds then press and release "RST" again.
3. When the "USB HID State" field reads "Connected", press on "Program" button. Note that the evaluation PCB will stay connected for only 10 seconds; the "Program" button must be pressed within that time. After this delay, red LED turns off, the firmware identification sequence occurs and then the evaluation PCB enters normal operation. If the "USB HID State" field does not read "Connected", press on "RST" button again, it should solve the issue.
4. Wait for installation/update to finish, the "Status Log" field will inform of a successful firmware installation.
5. Press and release the "RST" button, wait for red LED to light up and for red LED to turn and stay off, after the firmware identification sequence.

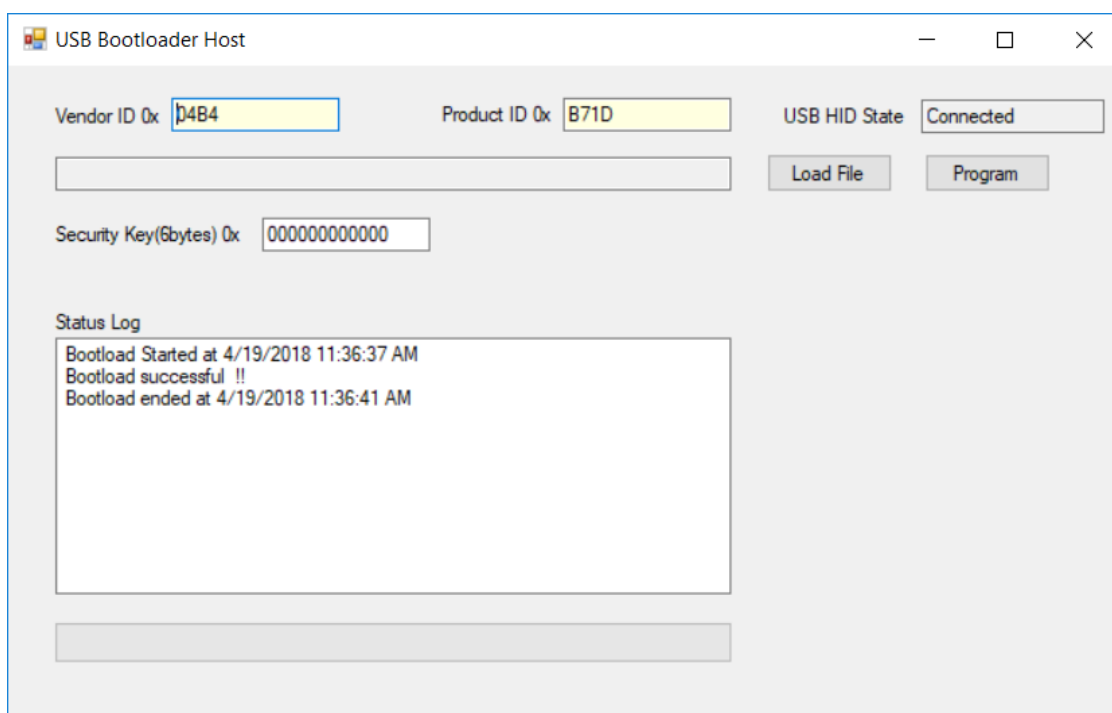Figure 6: BootloaderHost.exe interface for firmware installation/update.

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5.3   Firmware modification – using PSoC® Creator™

Firmware modification by the user will not be supported by Boréas Technologies. It is done at the user's own risk of causing damage beyond repair to the BOS1901. This section only presents a starting point for any user who may want to modify the firmware. A careful read of the BOS1901 datasheet is strongly recommended before doing so.

The firmware source code is available for download on Boréas website. PSoC® Creator™ IDE is available for download at http://www.cypress.com/products/psoc-creator-integrated-design-environment-ide.

The procedure for first firmware compilation is:

1. Start PSoC® Creator™, then go to "File/Open/Project" and select the file "PSoCCreator.cywrk" (make sure to start with the latest project file).
2. In the "Workspace Explorer", right-click on "Project 'USBFS_Bootloader'" then choose "Build USBFS_Bootloader".
3. In the "Workspace Explorer", right-click on "Project 'BOS1901_Test'" then choose "Build BOS1901_Test".
4. The compiled firmware BOS1901_Test.cyacd will be in the folder:
    Project name\BOS9101_Test.cydsn\CortexM3\ARM_GCC_541\Debug\
5. Update the firmware using the procedure presented in section **Fehler! Verweisquelle konnte nicht gefunden werden.**.

After any code modification, repeat steps 3 to 5 to test.

It is highly recommended to use a Cypress MiniProg3 (CY8KIT-002) when modifying the source code. This inexpensive kit allows to program the PSoC® microcontroller directly from PSoC® Creator™ through the SWD connector on the board. It also enables to enter debug mode and save valuable time in producing bug-free code.

Board resources can be used in modified code. DIP switch 8 is not used and can be programmed by the user. Other DIP switches, USR button, and LEDs can all be reprogrammed if the associated code is adjusted accordingly.

Unused PSoC® I/Os can be activated to expand user-specific application code; wires can be soldered on them if necessary. PSoC® internal components such as ADCs and EEPROM memory may also be used.

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5.4   Adjusting sensing feedback parameters

The BOS1901-KIT is provided out-of-the box with a firmware that allows sensing feedback to be experienced (see section quick start procedure). S3 DIP switches SW4 to SW7 can be used to toggle the sensing feedback parameters between preset values (see section DIP switch settings). Finer adjustment of the sensing feedback parameters is done by firmware modification. The following sections explain how to change the settings of each DIP switch state.

5.4.1   Sensing feedback amplitude

Do not put values higher than 1.0 for any of those variables or it will permanently damage the piezo. These variables only have an effect when in TDK mode (SW1 OFF).

1. In PSoCCreator, go to project "BOS1901_Test", then go to folder "Header Files" and open file "sensing_button_data.h".
2. Edit the #define variables values in section "Amplitude variables".
    - LOW_AMP_MULTIPLICATOR changes the high-low amplitude ratio.
    - HIGH_AMP_PRESS_FEEDBACK_TDK_CIRC changes the press feedback intensity.
      - When SW6 is ON, the feedback amplitude is set to HIGH_AMP_PRESS_FEEDBACK_TDK_CIRC.
      - When SW6 is OFF, the feedback amplitude is set to LOW_AMP_MULTIPLICATOR times HIGH_AMP_PRESS_FEEDBACK_TDK_CIRC.
    - HIGH_AMP_RELEASE_FEEDBACK_TDK_CIRC changes the release feedback intensity.
      - When SW6 is ON, the feedback amplitude is set to HIGH_AMP_RELEASE_FEEDBACK_TDK_CIRC.
      - When SW6 is OFF, the feedback amplitude is set to LOW_AMP_MULTIPLICATOR times HIGH_AMP_RELEASE_FEEDBACK_TDK_CIRC.
3. Save the project and upload the new firmware.

[1] PSoC® is a registered trademark of Cypress Semiconductor Corporation.
    PSoC® Creator™ is a trademark of Cypress Semiconductor Corporation.

5.4.2   Sensing feedback frequency

1. In PSoCCreator, go to project "BOS1901_Test", then go to folder "Header Files" and open file "sensing_button_data.h".
2. Edit the #define variables values in section "Frequency variables".
    - SENSING_FEEDBACK_FREQ_DEFAULT_LOW changes the low feedback signal frequency (SW5 is OFF).
    - SENSING_FEEDBACK_FREQ_DEFAULT_HIGH changes the high feedback signal frequency (SW5 is ON).
3. Save the project and upload the new firmware.

Do not put values higher than 300 for any of those variables or it will permanently damage the piezo.

5.4.3   Sensing threshold

1. In PSoCCreator, go to project "BOS1901_Test", then go to folder "Header Files" and open file "sensing_button_data.h"
2. Edit the #define variables values in section "Threshold variables".
    - HS_TRESH_TDK_CIRC changes the high sensitivity threshold (SW7 is OFF).
    - LS_TRESH_TDK_CIRC changes the low sensitivity threshold (SW7 is ON).
3. Save the project and upload the new firmware.

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These variables only have an effect when in TDK mode (SW1 OFF).

5.4.4 Response type

1. In PSoCCreator, go to project "BOS1901_Test", then go to folder "Header Files" and open file "sensing_button_data.h"
2. Edit the #define variables values in section "Response type".
   - RESPONSE_TYPE_CLICK_PRD changes number of sine wave period on single click feedback (press-release feedback on both channels, low pressure of multipress feedback on channel B).
   - RESPONSE_TYPE_SMALL_PRD changes number of sine wave period on small feedback (medium pressure of multipress feedback on channel B).
   - RESPONSE_TYPE_LONG_PRD changes number of sine wave period on long feedback (high pressure of multipress feedback on channel B).
3. Save the project and upload the new firmware.

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6 Design reference

6.1 Schematics
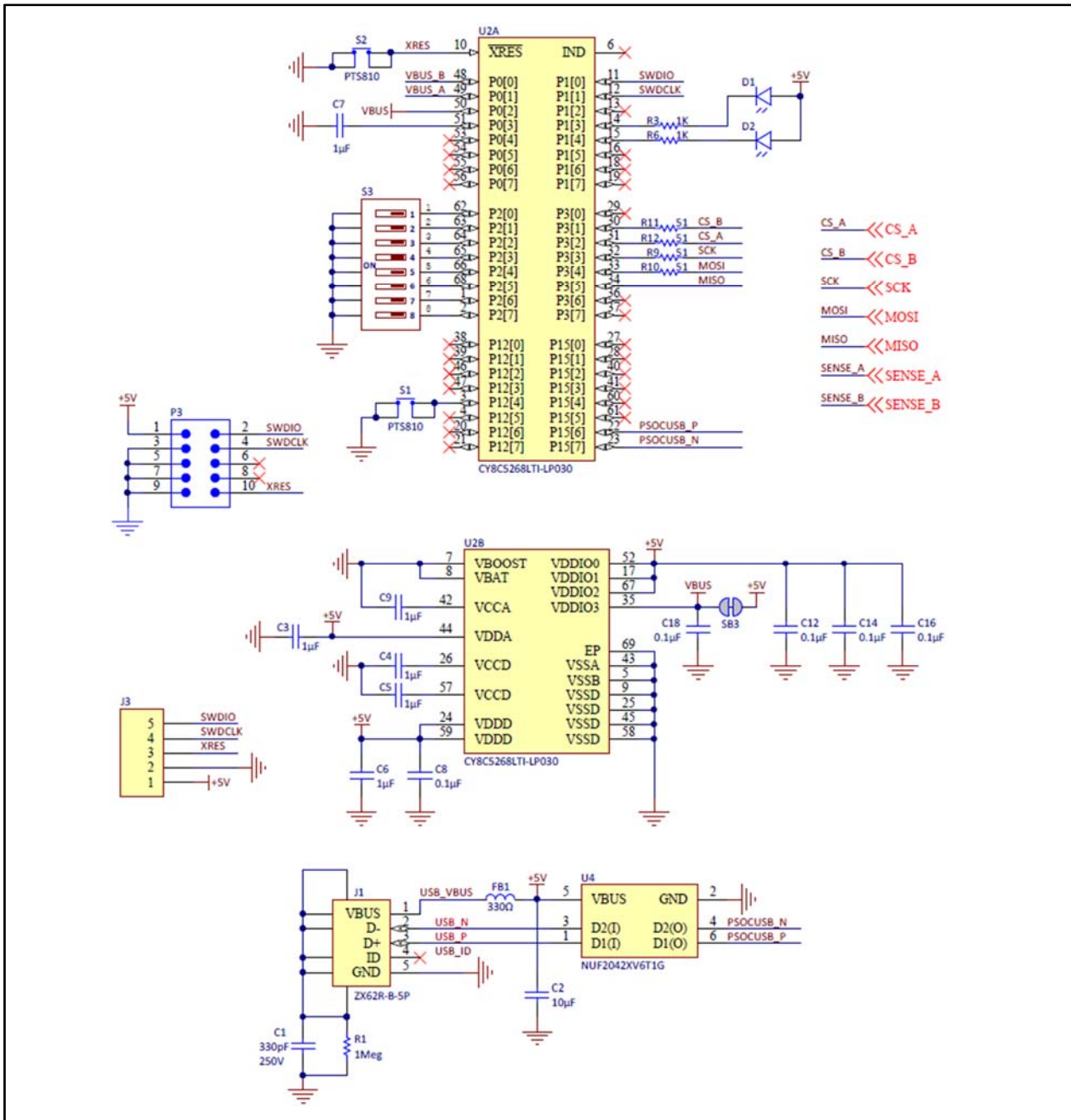
Figure 7: Schematic part 1 – USB and microcontroller.

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Figure 8: Schematic part 2 - BOS1901.

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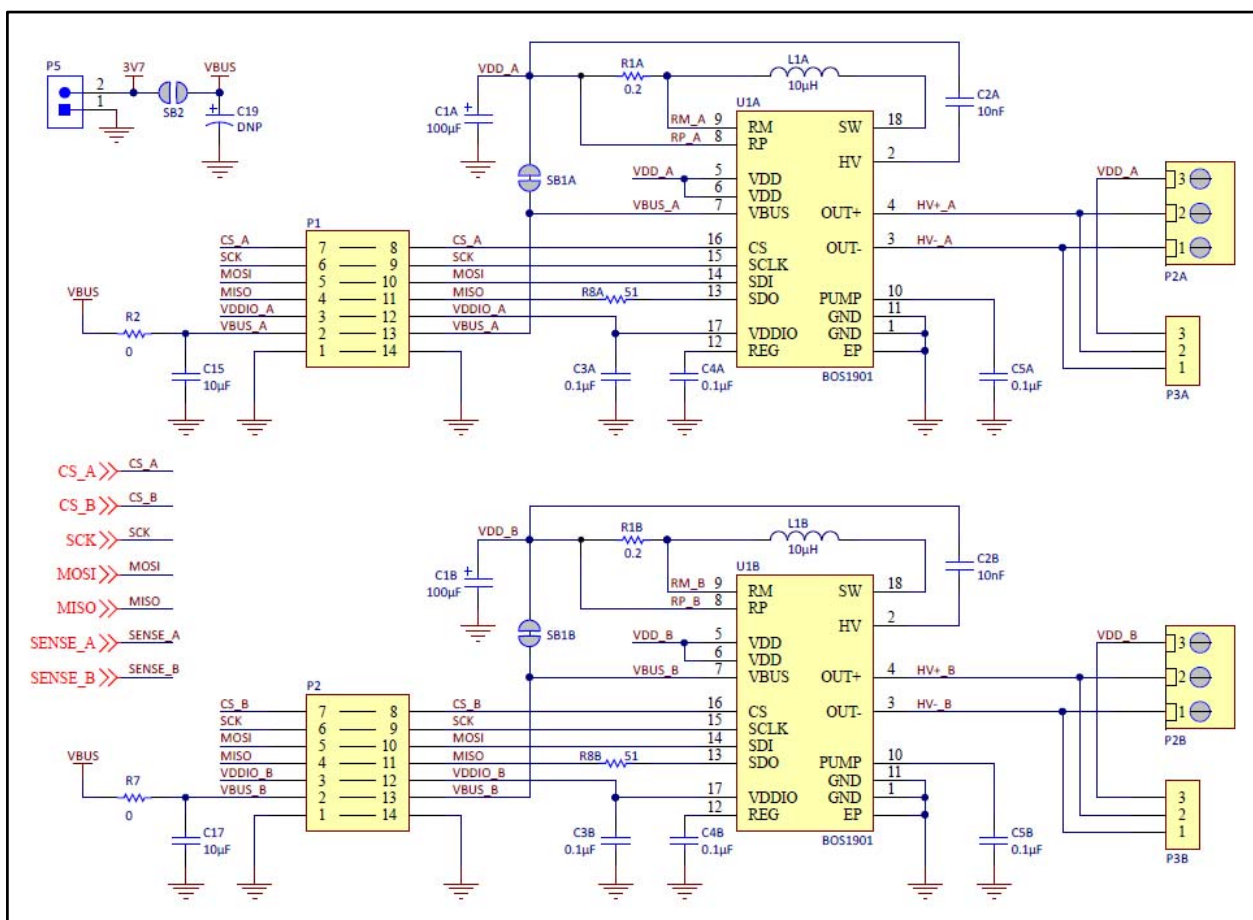
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6.2 PCB Layout
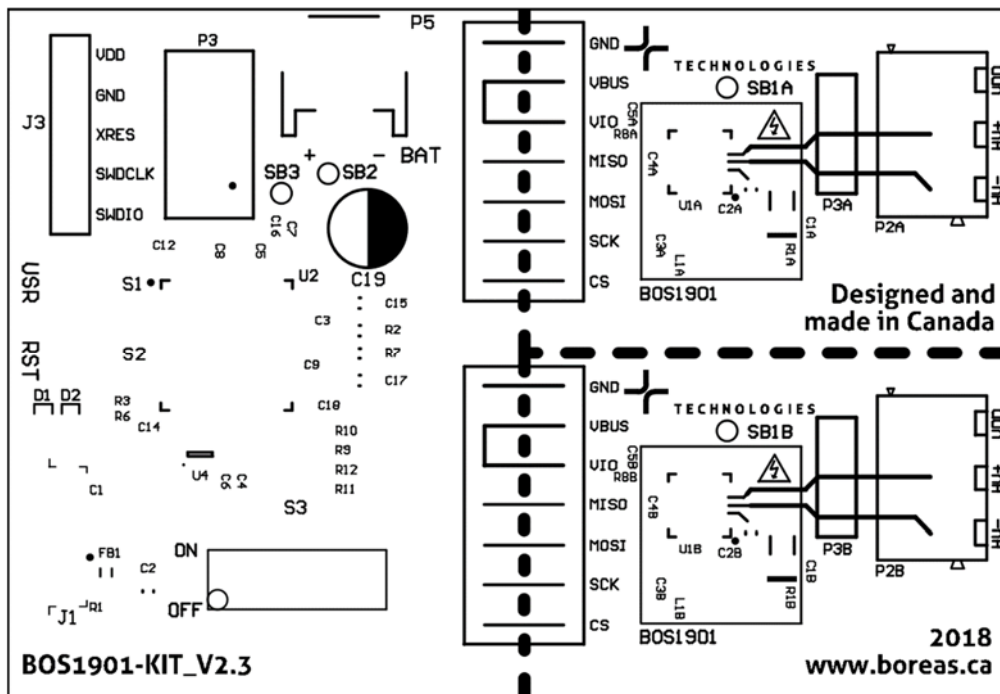
Figure 9: Layout view – top overlay (not to scale).
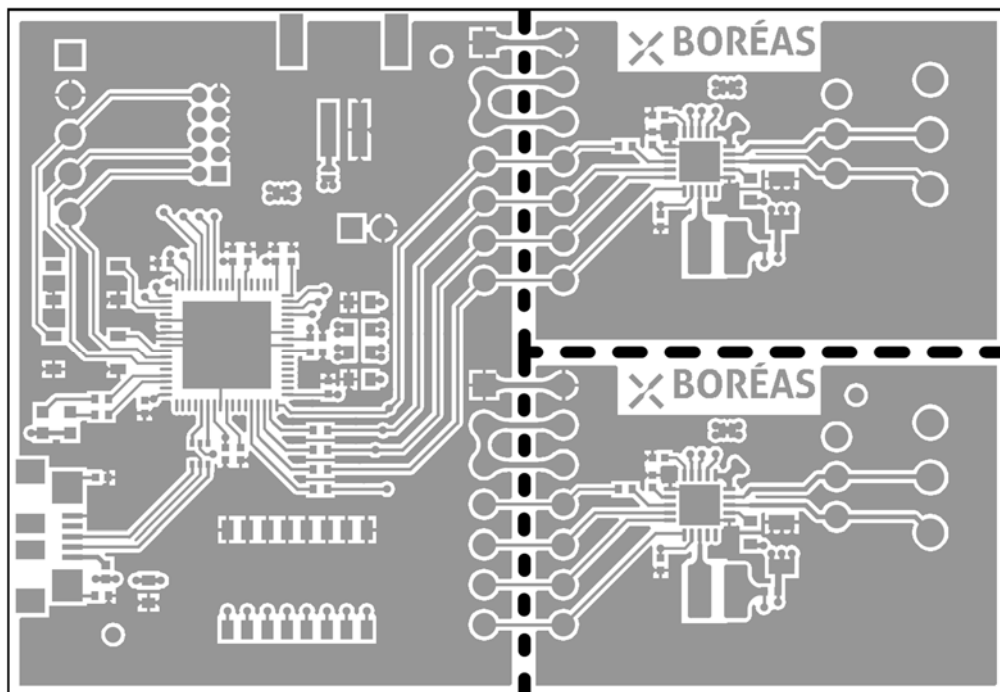
Figure 10: Layout view – top layer (not to scale).

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Figure 11: Layout view – bottom layer (mirrored; not to scale).
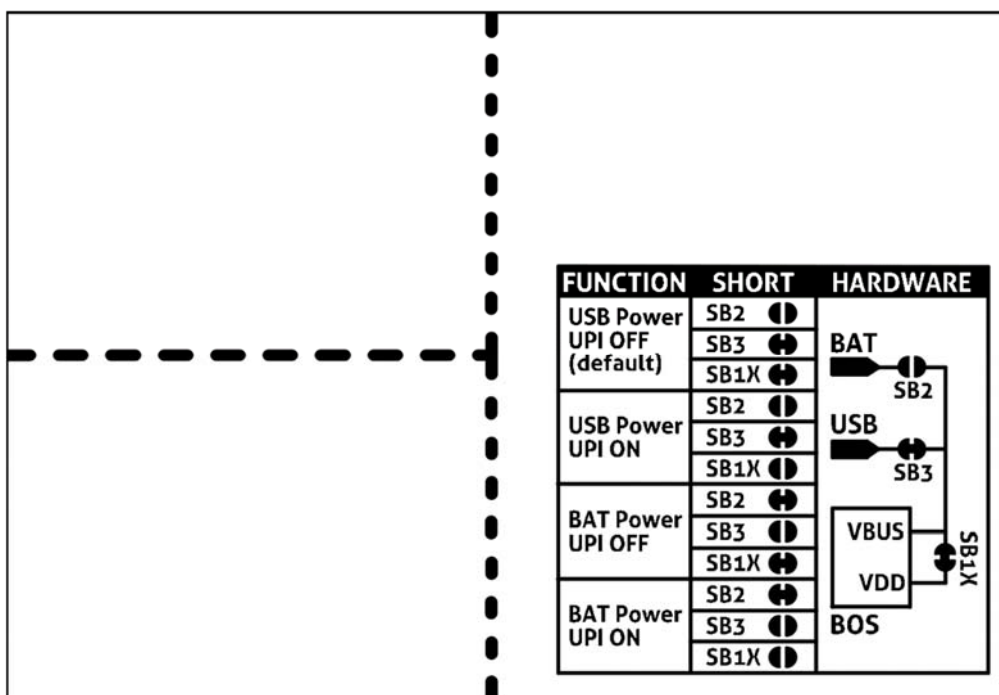
Figure 12: Layout view – bottom overlay (mirrored; not to scale).

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6.3   Bill of materials

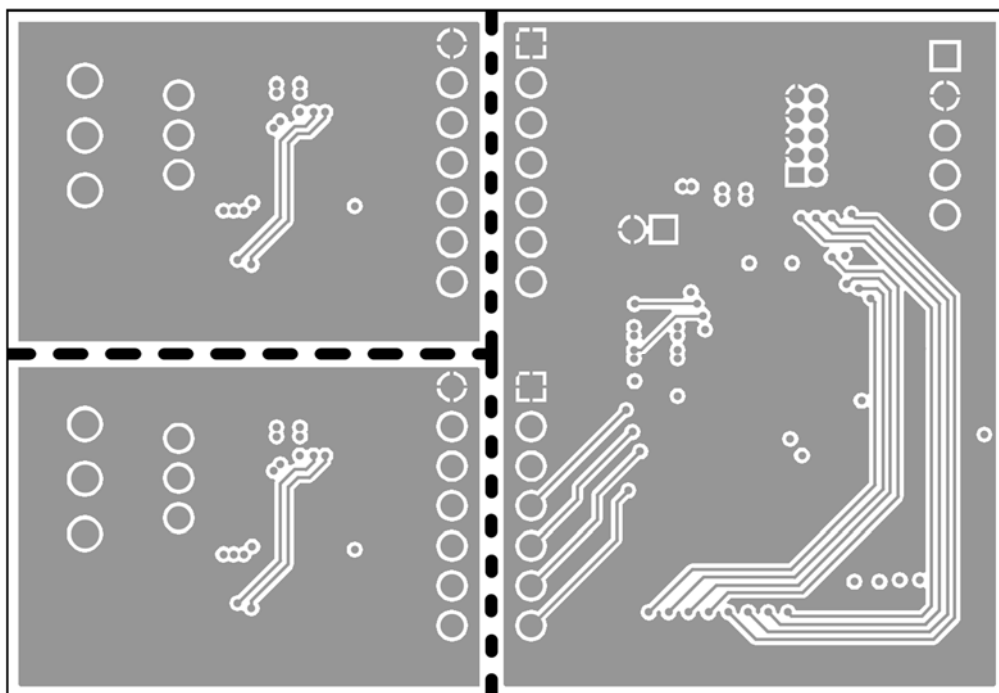The following is a list of the components that populate the evaluation PCB. If the exact part number is not available, the components can be replaced by ones with equivalent package and specifications. All components marked with an asterisk (*) are not populated on the PCB, the proposed part numbers are for reference only.

Table 4: Bill of materials

DESIGNATOR	QTY	VALUE	DESCRIPTION
C1	1	330 pF	CAP CER 330PF 250V C0G/NP0 0402
C1A, C1B	2	100 µF	CAP TANT POLY 100UF 6.3V 1206
C2, C15, C17	3	10 µF	CAP CER 10UF 10V X5R 0603
C2A, C2B	2	10 nF	CAP CER 10000PF 200V X7R 0603
C3, C4, C5, C6, C7, C9	6	1 µF	CAP CER 1UF 10V X6S 0402
C3A, C3B, C4A, C4B, C5A, C5B, C8, C12, C14, C16, C18	11	0.1 µF	CAP CER 0.1UF 25V X5R 0402
*C19	1	33 µF	CAP ALUM 33UF 20% 10V RADIAL
D1	1	-	LED YLW/GREEN DIFFUSED 1608 SMD
D2	1	-	LED RED DIFFUSED 1608 SMD
FB1	1	-	FERRITE BEAD 330 OHM 0402 1LN
J1	1	-	CONN RCPT USB MICRO B SMD R/A
J3	1	-	CONN HEADER .100" SNGL STR 5POS
L1A, L1B	2	10 µH	FIXED IND 10UH 1.2A 322 MOHM SMD
P2A, P2B	2	-	TERMINAL BLOCK 3.5MM 3POS PCB
P3A, P3B	2	-	CONN HEADER FEMALE 3POS .1" GOLD
*P3	1	-	CONN HEADER 10POS DUAL .05" T/H
P5	1	-	CONN HEADER PH SIDE 2POS 2MM SMD
R1	1	1 MΩ	RES SMD 1M OHM 1% 1/16W 0402
R1A, R1B	2	0.2 Ω	RES 0.2 OHM 1% 1/8W 0402
R2, R7	2	0 Ω	RES SMD 0 OHM JUMPER 1/10W 0603
R3, R6	4	1 kΩ	RES SMD 1K OHM 1% 1/16W 0402
R8A, R8B, R9, R10, R11, R12	6	51 Ω	RES SMD 51 OHM 1% 1/10W 0402
S1, S2	2	-	SWITCH TACTILE SPST-NO 0.05A 16V
S3	1	-	SWITCH SLIDE 8 DIP SPST 25MA 24V
U1A, U1B	2	-	Piezo Haptic Driver
U2	1	-	IC MCU 32BIT 256KB FLASH 68QFN
U4	1	-	FILTER RC(PI) 22 OHM/42PF SMD

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7   FAQ and troubleshooting

Please refer to Boréas website for FAQ and Troubleshooting information, which will be maintained throughout the BOS1901-KIT lifecycle. It will also contain application note documents that will be helpful for the user writing his/her own code to operate the BOS1901.

8   Notes and warnings

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.

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 work station.
- 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.

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9 Document history

ISSUE	DATE	CHANGES
1.6	May 2019	Formatting changed
1.5	May 2019	Default settings in table 3 changed
1.4	April 2019	Compatibility with Apple and Linux systems. Signal to voltage gain and offset fixed with voltage range clipping. Minor corrections.
1.3	April 2019	Typos corrected
1.2	April 2019	Typnames updated; DIP switch settings updated; new form sheet
1.1	January 2019	Typos in table 1 corrected
1	November 2018	First release

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Cautions and warnings

The piezo component has to be operated in a dry, non-reducing, open environment and atmosphere which must not contain any chemical vapors or substances.

To prevent damages on the piezo component, tensile stresses must be avoided under all driving conditions.

We expressly point out that in case of non-observance of the aforesaid notes, in particular due to reasons attributable to chemical vapors, a malfunction of the piezo sample or failure before the end of their usual service life cannot be completely ruled out, even if they are operated as specified.

Depending on the individual application, piezo samples are electrically connected to voltages and currents, which are potentially dangerous for life and health of the operator. Installation and operation of piezo sample have to be done only by authorized personnel. Ensure proper and safe connections, couplers, and drivers.

Caution: Piezo component are highly efficient charge storing capacitors. Even when they are disconnected from a supply, the electrical energy content of a loaded actuator can be high and is held for a long time. Always ensure a complete discharging of an actuator (e.g. via a 10 kΩ resistor) before handling. (Do not discharge by simple short-circuiting, because of the risk of damaging the ceramic.)

Electrical charges can be generated on disconnected actuators by varying load or temperature. *Caution:* Discharge an actuator before connecting it to a measuring device/electronics, when this device is not sufficiently voltage proofed.

Remark

The products delivered are engineering samples, prototypes or pre-series products, which are not intended for commercial use in series products of the purchaser. EPCOS assumes no warranty for these products. Any use is at the sole risk of the purchaser.

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Display of ordering codes for TDK Electronics products

The ordering code for one and the same product can be represented differently in data sheets, data books, other publications, on the company website, or in order-related documents such as shipping notes, order confirmations and product labels. **The varying representations of the ordering codes are due to different processes employed and do not affect the specifications of the respective products**. Detailed information can be found on the Internet under www.tdk-electronics.tdk.com/orderingcodes.

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The following applies to all products named in this publication:

1. Some parts of this publication contain **statements about the suitability of our products for certain areas of application**. These statements are based on our knowledge of typical requirements that are often placed on our products in the areas of application concerned. We nevertheless expressly point out **that such statements cannot be regarded as binding statements about the suitability of our products for a particular customer application.** As a rule we are either unfamiliar with individual customer applications or less familiar with them than the customers themselves. For these reasons, it is always ultimately incumbent on the customer to check and decide whether a product with the properties described in the product specification is suitable for use in a particular customer application.

2. We also point out that **in individual cases, a malfunction of electronic components or failure before the end of their usual service life cannot be completely ruled out in the current state of the art, even if they are operated as specified.** In customer applications requiring a very high level of operational safety and especially in customer applications in which the malfunction or failure of an electronic component could endanger human life or health (e.g. in accident prevention or life-saving systems), it must therefore be ensured by means of suitable design of the customer application or other action taken by the customer (e.g. installation of protective circuitry or redundancy) that no injury or damage is sustained by third parties in the event of malfunction or failure of an electronic component.

3. **The warnings, cautions and product-specific notes must be observed.**

4. In order to satisfy certain technical requirements, **some of the products described in this publication may contain substances subject to restrictions in certain jurisdictions (e.g. because they are classed as hazardous)**. Useful information on this will be found in our Material Data Sheets on the Internet (www.tdk-electronics.tdk.com/material). Should you have any more detailed questions, please contact our sales offices.

5. We constantly strive to improve our products. Consequently, **the products described in this publication may change from time to time**. The same is true of the corresponding product specifications. Please check therefore to what extent product descriptions and specifications contained in this publication are still applicable before or when you place an order.

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6. Unless otherwise agreed in individual contracts, **all orders are subject to our General Terms and Conditions of Supply.**

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