EPSON

Application Note

Sound Input/Output application note

Rev.1.1

セイコーエプソン株式会社

Table of Contents

1. Overview

This application note is a reference document for voice input/output in **Epson's Speech LSIs and Voice/Sound MCUs (hereinafter called "Voice/Sound devices").** Some functions may not be supported depending on the voice device you are using. Please check the applicable models in Table 1 first, and then refer to the appropriate chapter for your purpose.

Table 1 Applicable models in each chapter

Chapter		Product model number					
		Speech LSI			Voice/Sound MCU		
		S1V3G340	S1V3F351	S1V3F352	S1C31D50	S1C31D51	S1C31D41
Chapter 2	Sound creation	✓	✓	✓	✓	✓	✓
Chapter 3	Sound output by Speaker	✓	✓	✓	✓	✓	✓
Chapter 4	Sound output by Buzzer	-	✓	✓	-	✓	✓
Chapter 5	Board design precautions	✓	✓	✓	✓	✓	✓
Chapter 6	Enclosure design precautions	✓	✓	✓	✓	✓	✓
Chapter 7	Sound input by microphone	-	✓	✓	✓	✓	✓
Appendix A	Electromagnetic buzzer Spice model of recommended circuit for connection	-	✓	✓	-	✓	✓

2. Sound generation

Sound ROM data to be played back on Epson Voice/Sound devices is created using the Epson Voice Data Creation PC Tool (ESPER2) provided by Epson. For details, please refer to the ESPER2 Setup Guide and the ESPER2 Simple Manual.

3. Sound Output by Speaker

3.1 Recommended Circuit for Speaker Connection

Figure 3.1.1 and Figure 3.1.2 show the recommended circuits for connection when using Epson Voice/Sound devices with speakers. Figure 3.1.1 shows a reference circuit diagram for a two-pin output from a Voice/Sound device, and Figure 3.1.2 shows a one-pin output.

The names of the buzzer sound output pins shown in Figure 3.1.1 differ for each model. Please refer to Table 3.1.1 and Table 3.1.2 to check the output pins to be connected to the amplifier circuit.

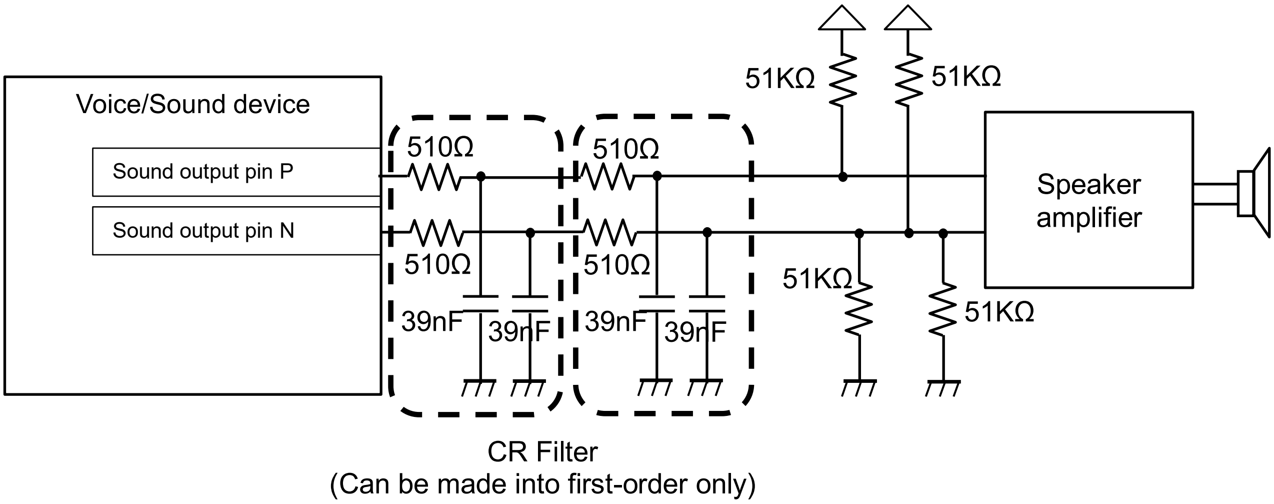


Figure 3.1.1 Recommended circuit for speaker connection (2 pins)

Table 3.1.1 Sound output pins for speaker (S1V3F351/S1V3F352)

Model	Output mode configuration	Sound output pin
S1V3F351	Set *Sound_Out_Sel* to 0x00 in the *ISC_SOUND_OUTPUT_CONFIG_REQ* message	SPEAKER_OUT_P SPEAKER_OUT_N
S1V3F352	Set *Sound_Out_Sel* to 0x00 in the *ISC_SOUND_OUTPUT_CONFIG_REQ* message	SPEAKER_OUT_P SPEAKER_OUT_N

Table 3.1.2 Sound output pins for speaker (S1C31D41/S1C31D51)

Model	Output mode configuration	Sound output pin
S1C31D41	Set 0x0 to *SDAC2MOD.PWMMODE[1:0]* register	SDACOUT_P/P50 SDACOUT_N/P51
S1C31D51	Set 0x0 to SDACMOD.MODE register	SDACOUT_P/P50 SDACOUT_N/P51

As shown in Figure 3.1.1, we recommend using differential 2-pin outputs and a low-pass filter (LPF/second-order CR filter) with a pop noise prevention circuit (pull-up/pulldown resistor) in its subsequent stage. Adopting differential 2-pin outputs can reduce the influence of board noise.

3. Sound Output by Speaker

3.1.1 Low-Pass Filter (LPF)

By setting the LPF cutoff frequency to 8 kHz, which is the fs(sampling frequency)/2, noise outside the voice bandwidth can be removed and the bandwidth in which voice components exist can be restored. In the example in Figure 3.1.1, an 8 kHz LPF (C = 39 nF, R = 510 Ω) is set.

To reduce the number of peripheral components, the CR filter can be made first-order only (omitting one dotted line box in Figure 3.1.1); however, if the CR filter is first-order only, the LPF cutoff characteristic will be gradual, which may reduce voice sound intelligibility.

3.1.2 Pop Noise Prevention Circuit

A pop noise prevention circuit (pull-up/pulldown resistor (R=51KΩ)) in the rear stage of the LPF maintains the sound signal at intermediate potential and prevents pop noise generated at power-on.

In the case of differential 2-pin outputs, pop noise at power-on is cancelled between the two pins, possibly reducing the impact on sound quality, so the number of components can be further reduced by omitting peripheral components.

In addition, since it may depend on the specifications of the amplifier used, please make a judgment after conducting a thorough sound quality evaluation including this circuit and the amplifier.

3.1.3 1-Pin Output

As shown in Figure 3.1.2, using a single sound output pin eliminates the need for peripheral circuits for one pin, thus reducing the number of peripheral components. However, since it is more susceptible to board noise, please be careful when designing the board.

As with the 2-pin output, the number of components can be further reduced by omitting the CR filter in the first stage (omitting one dotted line box in Figure 3.1.2) and the pop noise prevention circuit (pull-up/pulldown resistor) in the second stage, respectively. However, please evaluate the sound quality sufficiently in terms of voice sound intelligibility and pop noise before use.

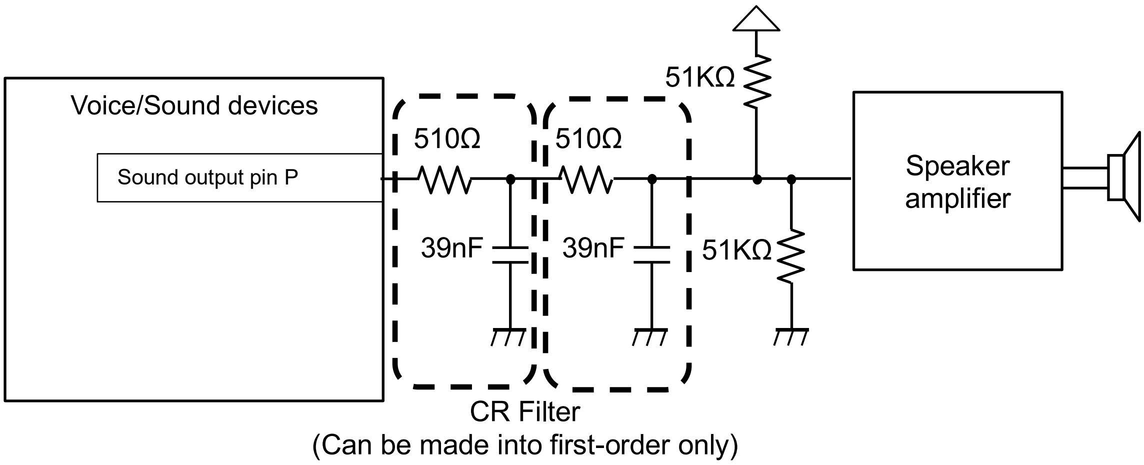


Figure 3.1.2 Recommended circuit for speaker connection (1 pin)

*The sound output pins names in Fig. 3.1.1, 3.1.2 differ for each model. Please refer to the technical manual of each model.

3.2 Speaker Amplifier Selection

Class-A, Class-B, Class-AB, and Class-D speaker amplifier products are available. In this section, we limit our discussion to the commonly used Class-AB and Class-D products and show their features, pros, and cons.

Figure 3.2.1 shows the waveform image when a Class-AB amplifier is selected as the speaker amplifier. Figure 3.2.2 shows the waveform image when a Class-D amplifier is selected.

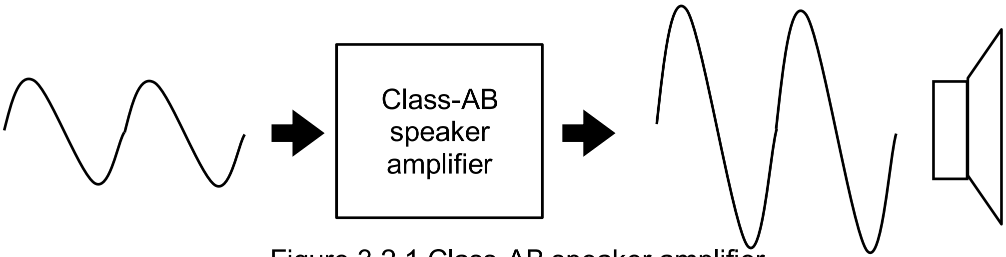


Figure 3.2.1 Class-AB speaker amplifier

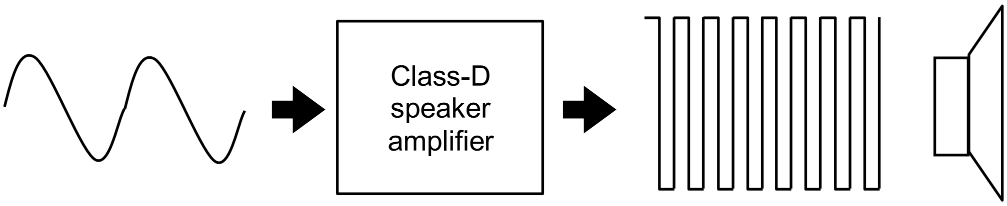


Figure 3.2.2 Class-D speaker amplifier

Class-AB speaker amplifiers output amplified analog signals, and Class-D speaker amplifiers output digital signals (PWM signals).
Class-AB speaker amplifiers output signals that are band-limited to the voice sound bandwidth, so they are less susceptible to radiation noise, power supply noise, etc., and have an advantage in terms of sound quality over Class-D speaker amplifiers. On the other hand, since a bias current is always flowing, power efficiency is low and current consumption tends to be high.

Class-D speaker amplifiers are advantageous in terms of heat generation and current consumption due to their highly efficient power conversion. On the other hand, the high-frequency noise emitted may affect other electrical equipment (radiated noise). Also, since the signal level is VDD-GND, if there is noise in the power supply, the noise on VDD-GND will directly affect the sound quality.

Consider the above generally recognized advantages and disadvantages to select the appropriate speaker amplifier for your application.

Table 3.2.1 Comparison of Class-AB/Class-D speaker amplifiers

	Class-AB Speaker Amplifier	**Class-D speaker amplifier**
Output	Analog	Digital (PWM)
Distortion	Low	Medium
Efficiency	Low	High
Heat generation	Large	Small

3.2.1 Radiated Noise Countermeasures

Radiated noise emitted by the Class-D amplifier can be counteracted by cutting the carrier frequency component of the PWM by inserting an LC filter as shown in Figure 3.2.1. Please refer to this section if necessary.

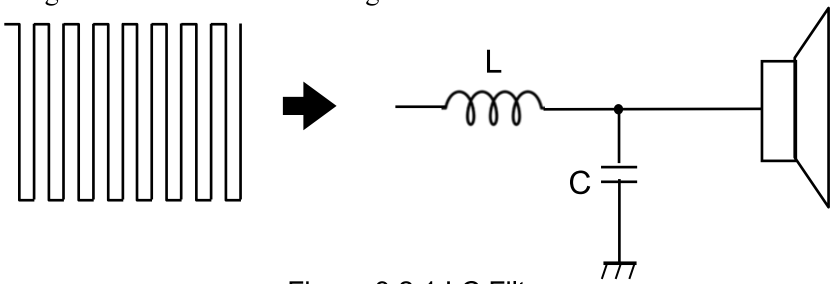


Figure 3.2.1 LC Filter

The cutoff frequency fc according to the circuit in Figure 3.2.1 is shown in Equation 3.2.1.

$$fc = \frac{1}{2\pi\sqrt{LC}} \qquad \text{(Equation 3.2.1)}$$

From the use of Equation 3.2.1, with L = 33uH and C = 0.033uF,

$$fc = \frac{1}{2\pi\sqrt{(33(uH)) * (0.033(uF))}} \fallingdotseq 152(kHz)$$

The cutoff frequency is 152 kHz, which can be counteracted by cutting PWM carrier frequency components of the order of MHz.

4. Sound Output by Buzzer

Epson Voice/Sound devices use **piezoelectric buzzers (piezoelectric sounders) and electromagnetic buzzers to play back voice sound and melody (hereinafter referred to as "Buzzer voice/melody")** with Epson's proprietary technology. This chapter shows recommended external amplifier circuits and other information for playing sound on a buzzer when using Epson Voice/Sound devices.

4.1 Amplifier Circuit for Piezoelectric Buzzer Connection

The amplifier circuit when connecting a piezoelectric buzzer is shown in Figure 4.1.1. For the resistor values R1 to R3 in Fig. 4.1.1, select the optimum value based on the supply voltage (VDD1) to the piezoelectric buzzer and the target current shown in Table 4.1.1.

In selecting MOSFETs for Q4A/Q4B, be careful to select R1/R2 so that the applied voltage (VDD1) does not exceed the withstand voltage value of the MOSFET and the rated current of the MOSFET.

The names of the buzzer sound output pins shown in Figure 4.1.1 differ for each model. Please refer to Table 4.1.2 and 4.1.3 to check the output pins to be connected to the amplifier circuit.

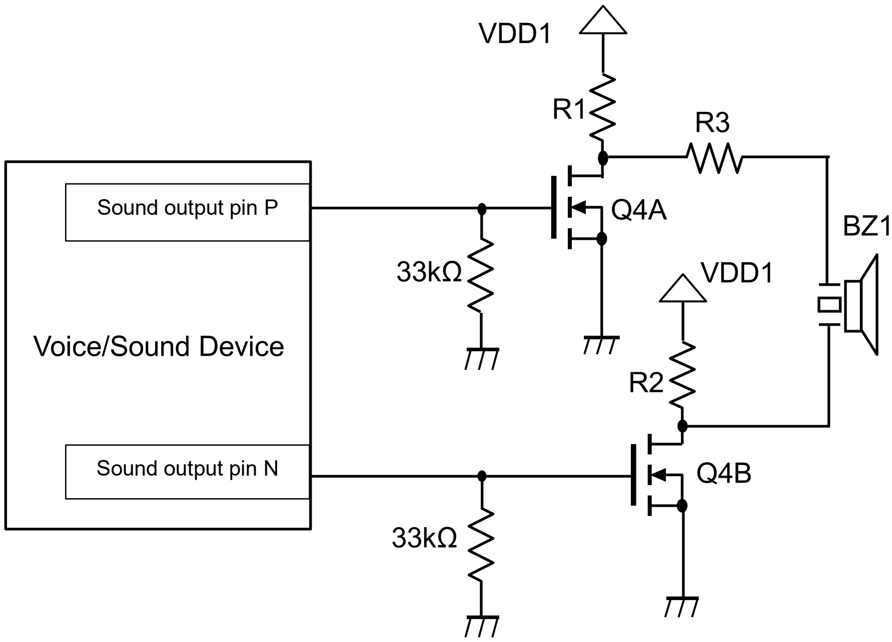


Figure 4.1.1 Amplifier circuit when piezoelectric buzzer is connected

Table 4.1.1 Recommended resistance values when piezoelectric buzzer is connected

VDD1 (V)	Target Current(mA)	R1,R2(Ω)	R3(Ω)	VDD1 (V)	Target Current(mA)	R1,R2(Ω)	R3(Ω)
15	30	560	220	5	30	180	100
15	20	820	220	5	20	270	100
15	10	1.8 k	220	5	10	560	100
15	5	3.3 k	220	5	5	1.0 k	100
12	30	470	180	3	30	100	47
12	20	680	180	3	20	150	47
12	10	1.5 k	180	3	10	330	47
12	5	2.7 k	180	3	5	560	47

Table 4.1.2 Sound output pins for piezoelectric buzzer (S1V3F351/S1V3F352)

Model	Output mode configuration	Sound output pin
S1V3F351	Set *Sound_Out_Sel* to 0x05 in the *ISC_SOUND_OUTPUT_CONFIG_REQ* message	BUZZER_OUT_P BUZZER_OUT_N
	Set *Sound_Out_Sel* to 0x07 in the *ISC_SOUND_OUTPUT_CONFIG_REQ* message	SPEAKER_OUT_P SPEAKER_OUT_N
S1V3F352	Set *Sound_Out_Sel* to 0x07 in the *ISC_SOUND_OUTPUT_CONFIG_REQ* message	SPEAKER_OUT_P SPEAKER_OUT_N

Table 4.1.3 Sound output terminals for piezoelectric buzzer (S1C31D41/S1C31D51)

Model	Output mode configuration	Sound output pin
S1C31D41	Set 0x1 to *SDAC2MOD.PWMMODE[1:0]* register	SDACOUT_P/P50 SDACOUT_N/P51
		P04/SDACOUT_P/UPMUX(*1) P05/SDACOUT_N/UPMUX(*1)
S1C31D51	Set 0x1 to *SDACMOD.MODE* register	SDACOUT_P/P50 SDACOUT_N/P51

*1: The default state of the P04 and P05 pins is input/output port. If you want to use these pins as sound output pins, change the pin setting to sound output (SDACOUT_*). For details on changing the pin setting, refer to the S1C31D41 technical manual.

4.1.1 High Current in Piezoelectric Buzzer

A Piezoelectric buzzer acts as a capacitor because of its structure of two metal plates stacked on top of each other. In this case, when the electric charge stored in the piezoelectric buzzer starts to flow, a very large current flows around the piezoelectric buzzer instantaneously, and in some cases the MOSFETs may be damaged. To suppress this large current, a resistor (R3) is connected in series with the buzzer (BZ1) as shown in Figure 4.1.1. The instantaneous large currents can be prevented by depending on the value of the resistor (R3).

4.2 Amplifier Circuit for Electromagnetic Buzzer Connection

There are two types of recommended amplification circuits for connecting an electromagnetic buzzer: one for 4-pin outputs and one for 2-pin outputs. However, only two models, S1C31D41 and S1V3F351, can be selected for the 4-pin outputs circuit.

4.2.1 4-Pin Output

Figure 4.2.1 shows the recommended amplifier circuit for 4-pin outputs. Select the resistance values R1 to R4 best suited for the electromagnetic buzzer (BZ1) to be connected. Table 4.2.1 shows the recommended resistance values when using each electromagnetic buzzer. These values can be calculated by Spice model simulation based on the supply voltage to the electromagnetic buzzer (VDD1) and the specifications (DC resistance and maximum current). For electromagnetic buzzers other than those listed in Table 4.2.1, please refer to the example netlist of the Spice model in Appendix A.

A diode is provided at the rear stage of Q1/Q2 transistors to prevent device breakdown due to back EMF of the electromagnetic buzzer.

The names of the buzzer sound output pins shown in Figure 4.2.1 differ for each model. Please refer to Table 4.2.2 and Table 4.2.3 to check the output pins to be connected to the amplifier circuit.

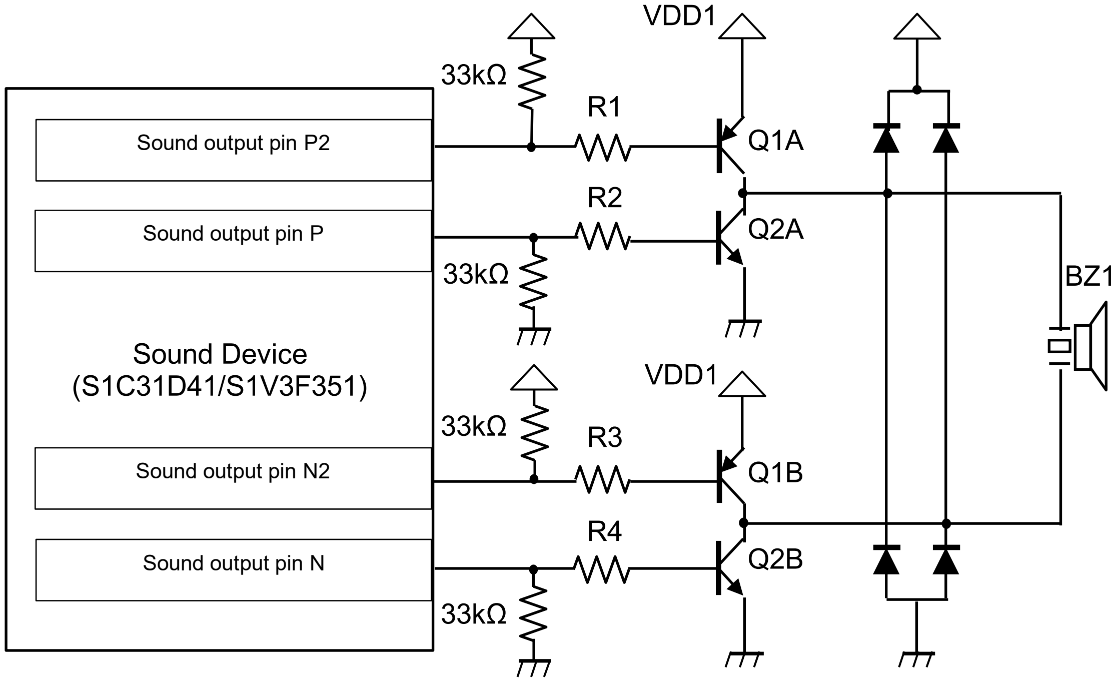


Figure 4.2.1 Amplifier circuit for electromagnetic buzzer 4-pin outputs connection (S1C31D41/S1V3F351)

Table 4.2.1. Recommended resistance values for electromagnetic buzzer connection

Buzzer(BZ1) model number	**Buzzer characteristics and specifications**			**Recommended Resistance R1～R4(kΩ)**	**Feed-through current Peak value (mA)**
	Supply voltage (VDD1 (V))	**DC Resistance (Ω)**	**Current Io-(mA)max.**		
SD160709 (TDK Corporation)	3	70	40	4.7	130
	5	70	70	2.2	260
SDR08540M3-01 (TDK Corporation)	3	16	85	6.8	90
	5	16	85	13	60
SD160701 (TDK Corporation)	3	50	60	2.7	220
SD1614T5-A1 (TDK Corporation)	5	70	80	4.7	140

Table 4.2.2 Sound output pins for electromagnetic buzzer 4-pin outputs(S1V3F351)

Model	**Output mode configuration**	**Sound output pin**
S1V3F351	Set *Sound_Out_Sel* to 0x06 in the *ISC_SOUND_OUTPUT_CONFIG_REQ* message	BUZZER_OUT_P2 BUZZER_OUT_P BUZZER_OUT_N2 BUZZER_OUT_N

Table 4.2.3 Sound output pins for electromagnetic buzzer 4-pin outputs (S1C31D41)

Model	Output mode configuration	Sound output pin
S1C31D41	Set 0x1 to *SDAC2MOD.PWMMODE[1:0]* register	P03/SDACOUT_P2/UPMUX(*1) P04/SDACOUT_P/UPMUX(*1) P06/SDACOUT_N2/UPMUX(*1) P05/SDACOUT_N/UPMUX(*1)

*1: The default state of the P03, P04,P05 and P06 pins is input/output port. If you want to use these pins as sound output pins, change the pin setting to sound output (SDACOUT_*). For details on changing the pin setting, refer to the S1C31D41 technical manual.

4.2.2 2-Pin Output

Figure 4.2.2 shows the recommended amplifier circuit for 2-pin outputs. In the circuit shown in Figure 4.2.2, when both transistors Q1 and Q2 are turned on while (a)/(b) are in the Hi-Z state, **there is a possibility of board damage due to high current.** Therefore, when using this circuit, **never supply VDD1 power when (a)/(b) are in the Hi-Z state.**

The VDD1 control circuit to prevent this high current is shown in Figure 4.2.3. In the circuit shown in Figure 4.2.3, the control pin connected to this circuit is set to "L" (VDD1 ON) just before the start of sound playback, and the control pin is set to "H" (VDD1 OFF) immediately after the end of playback to avoid the state where large current keeps flowing in the Hi-Z state shown in (a)/(b).

In the circuit shown in Figure 4.2.2, a diode is provided at the rear stage of the Q1/Q2 transistors to prevent device breakdown due to back electromotive force of the electromagnetic buzzer.

The names of the sound output pins shown in Figure 4.2.2 and the names of the control pin shown in Figure 4.2.3 differ for each model. Please refer to Table 4.2.4, 4.2.5 and 4.2.6 to check the output pins to be connected to the amplifier circuit.

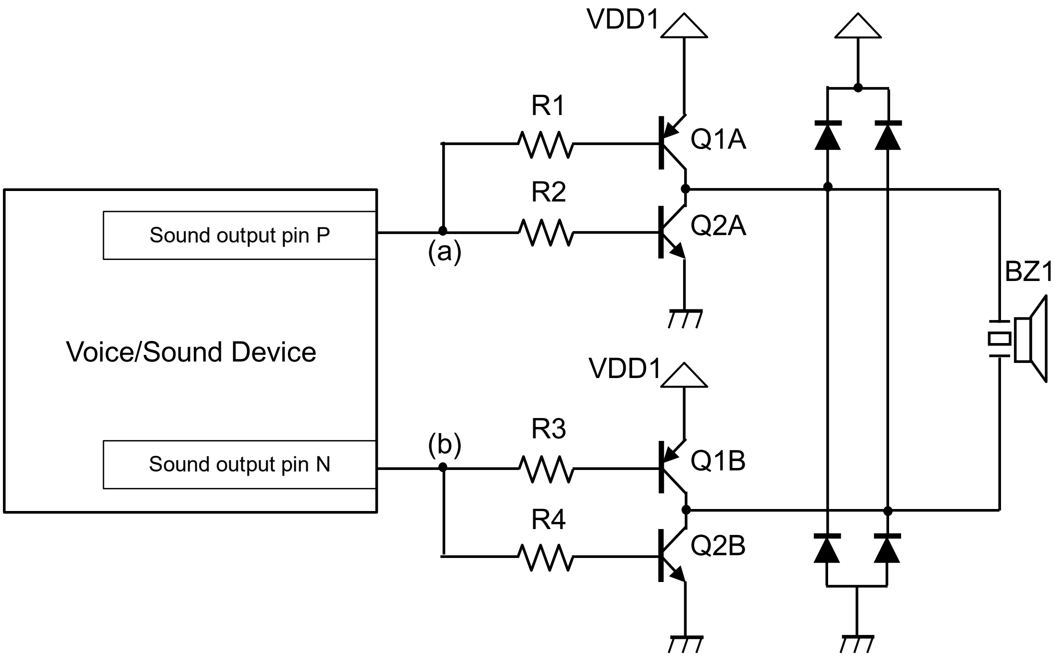


Figure 4.2.2 Amplification circuit for connecting an electromagnetic buzzer 2-pin output

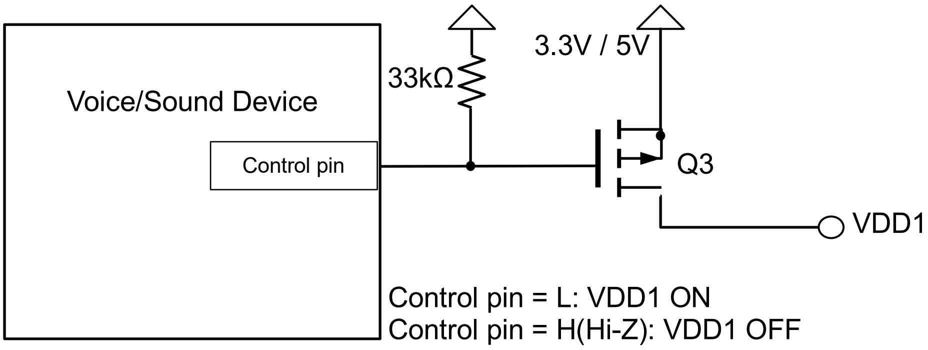


Figure 4.2.3 Power supply control circuit for electromagnetic buzzer 2-pin output amplifier circuit

Table 4.2.4 Sound output pins for electromagnetic buzzer 2-pin output (S1V3F351/S1V3F352)

Model	Output mode configuration	Sound output pin
S1V3F351	Set *Sound_Out_Sel* to 0x05 in the *ISC_SOUND_OUTPUT_CONFIG_REQ* message	BUZZER_OUT_P BUZZER_OUT_N
	Set *Sound_Out_Sel* to 0x07 in the *ISC_SOUND_OUTPUT_CONFIG_REQ* message	SPEAKER_OUT_P SPEAKER_OUT_N
S1V3F352	Set *Sound_Out_Sel* to 0x07 in the *ISC_SOUND_OUTPUT_CONFIG_REQ* message	SPEAKER_OUT_P SPEAKER_OUT_N

Table 4.2.5 Sound output pins for electromagnetic buzzer 2-pin output (S1C31D41/S1C31D51)

Model	Output mode configuration	Sound output pin
S1C31D41	Set 0x1 to *SDAC2MOD.PWMMODE[1:0]* register	SDACOUT_P/P50 SDACOUT_N/P51
		P04/SDACOUT_P/UPMUX(*1) P05/SDACOUT_N/UPMUX(*1)
S1C31D51	Set 0x1 to *SDACMOD.MODE* register	SDACOUT_P/P50 SDACOUT_N/P51

*1: The default state of the P04 and P05 pins is input/output port. If you want to use these pins as sound output pins, change the pin setting to sound output (SDACOUT_*). For details on changing the pin setting, refer to the S1C31D41 technical manual.

Table 4.2.6 Power supply control pin for electromagnetic buzzer 2-pin output (S1C31D41/S1C31D51)

Model	Control pin
S1V3F351	EXT_CIRCUIT_CTRL
S1V3F352	EXT_CIRCUIT_CTRL
S1C31D41	Any of the input/output ports excluding the sound output pins (P50, P51, P03, P04, P05, P06)
S1C31D51	Any of the input/output ports excluding the sound output pins (P50, P51, P03, P04, P05, P06)

4.2.3 Through-Current in Bipolar Transistors

In the recommended circuit for an electromagnetic buzzer (Figures 4.2.1 and 4.2.2), the PWM signal output from the Voice/Sound device is input to the bipolar transistor section through a resistor as shown in Figure 4.2.4. In this circuit, two transistors may be turned on simultaneously, where a through-current flows. If this through-current exceeds the rated current of the bipolar transistor used, the **transistor may be damaged due to the large current,** so it must not exceed this rated current.

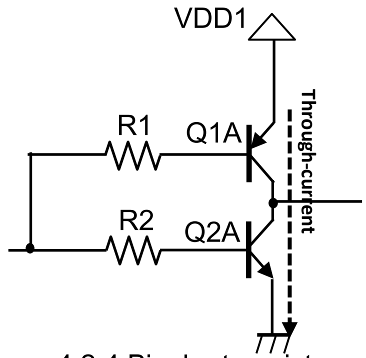


Figure 4.2.4 Bipolar transistor section circuit

- The current between the collector and emitter of a NPN-type (Q2A) bipolar transistor can be controlled by the amount of current in the base-to-emitter current.
- The current between the emitter and collector of a PNP-type (Q1A) bipolar transistor can be controlled by the amount of current in the base current in the base-to-collector current.

In the circuit shown in Figure 4.2.4, the base current is limited by the resistors (R1, R2) in front of the base so that the through-current does not exceed the rated current of the bipolar transistor.

Table 4.2.1 shows the calculated values of the through-current flowing through bipolar transistors when using the recommended circuit for electromagnetic buzzers, the specifications and characteristics of each buzzer, and the recommended resistance values (R1 to R4). When selecting a bipolar transistor, the peak collector current and current rating must be greater than the through-currents shown in Table 4.2.1.

4.3 Buzzer Selection

The sound quality of the Epson Voice/Sound devices to realize the Buzzer voice/melody also depends on the characteristics of the buzzer to be selected.

- Frequency characteristic of buzzer

The frequency characteristic of the buzzer greatly affects the sound quality of the Buzzer voice/melody. In selecting a buzzer, the following conditions are particularly important to obtain good sound quality of the Buzzer voice/melody.

The peak frequency of the frequency response should be 2.5 kHz ± 0.5 kHz.

These conditions include the enclosure. Please refer to Chapter 6 for details regarding the enclosure.

- Size of buzzer

The larger the plate area and enclosure size of the buzzer, the better the sound quality and sound pressure of the Buzzer voice/melody.

- Enclosure of product

When a board on which a buzzer is mounted is incorporated into a product, the sound quality and sound pressure may be greatly enhanced due to the resonance effect caused by the housing of the product. For this reason, when evaluating the buzzer sound, please evaluate the buzzer with the buzzer installed in the product, even if it is a simplified evaluation.

- Comparison of piezoelectric buzzer and electromagnetic buzzer

Table 4.3.1 compares the characteristics and specifications of piezoelectric buzzers and electromagnetic buzzers. Since the operating principles of the buzzers are different, these characteristics and specifications are also different. Please understand these characteristics before selecting the appropriate buzzer for your application.

Table 4.3.1 Comparison of piezoelectric buzzer and electromagnetic buzzer

	piezoelectric buzzer	**electromagnetic buzzer**
Driving method	Voltage drive (Higher voltage = louder sound)	Current drive (Higher current = louder sound)
Operating voltage range	10 to 30(V)	2 to 6(V)
Current consumption	low	high

- Three-terminal buzzer

In the case of a three-terminal buzzer as shown in Figure 4.3.1, only terminals (a) and (c) in the figure can be used for control. Terminal (b) may be left unused or connected to terminal (a).

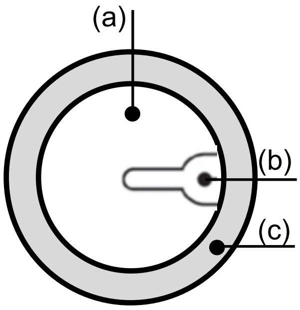


Figure 4.3.1 Three-terminal

5. Precautions in Board Design

This chapter shows precautions related to board design for Voice/Sound devices.
Please also refer to the "Mounting Precautions" in the technical manual for each model.

In this chapter, each power supply/GND is described by the symbols listed in Table 5.1.

Table 5.1 Name of each power supply/GND symbol

Power supply	Symbol	GND	Symbol
Voice/Sound device (logic) power supply	VDD	Voice/Sound device (logic) GND	GND
Speaker amplifier power supply	AVDD	Speaker amplifier GND	AGND
Buzzer external circuit power supply	VDD1	Buzzer External Circuit GND	GND1
Microphone power supply	AVDD1	Microphone GND	AGND1

5.1 Power Source

- For power supply IC used with the Voice/Sound device, use products that meet the EMI standards for the product application. This will reduce the impact of noise from the power supply IC to the Voice/Sound device.
- It is recommended that the microphone power supply (AVDD1/AGND1) be separated from the Voice/Sound device (logic) power supply (VDD/GND) or speaker amplifier power supply (AVDD/AGND).
- Connect bypass capacitors between VDD and GND, between AVDD and AGND, between VDD1 and GND1, and between AVDD1 and AGND1. The bypass capacitors should be placed as close as possible to the VDD/GND pins of the Voice/Sound device, and the wiring pattern should be as wide as possible to connect to the pins.

5.2 Wiring of Signal Lines

- Analog and digital signal lines should not be crossed or placed in parallel.
- High-speed clock signal lines should be guarded by GND patterns.
- Insert damping resistors on the synchronous serial interface and I2C signal lines as necessary.
- The wiring between the Voice/Sound device and the speaker amplifier should be designed to be as impervious to noise as possible. If noise is placed on this wiring, the noise will be amplified by the amplifier in the subsequent stage.
- To suppress EMI, the wiring lengths between the Voice/Sound device and the speaker amplifier, and between the Class-D amplifier and the speaker should be as short as possible.
- Since the electromagnetic buzzer is current driven, the wiring of the buzzer peripheral circuit should be as thick as possible.

6. Precautions in Enclosure Design

This chapter provides notes on designing enclosures for Speaker and Buzzer to be installed in products.

6.1 Speaker Enclosure Design

When installing a speaker unit into a final product, the enclosure must be designed. The design of the enclosure affects sound pressure and sound quality.

6.1.1 Interference Prevention of Sound Waves from Both Sides of the Speaker

Speakers convert electrical signals to vibrations of the diaphragm, and the changes in air pressure caused by these vibrations produce sound. Sound is produced from both the front and back surfaces of the speaker, but because the air vibrations from the front surface and the air vibrations from the back surface are in opposite phases, when the speaker unit alone outputs sound (see Figure 6.1.1 (a)), the vibrations from both surfaces interfere and cancel each other out, resulting in a low volume.

In contrast, the speaker enclosure design prevents interference between this surface sound wave and the backside sound wave, thereby ensuring sound volume. Figure 6.1.1(b) shows a single board preventing surface/backside interference. In Figure 6.1.1(c), the back surface is further surrounded by a board. In Figure 6.1.1(d), the entire backside is sealed with a board. In your enclosure design, we recommend that you use (d) to prevent interference, but at least (b) and even (c) can be effective in terms of preventing sonic interference.

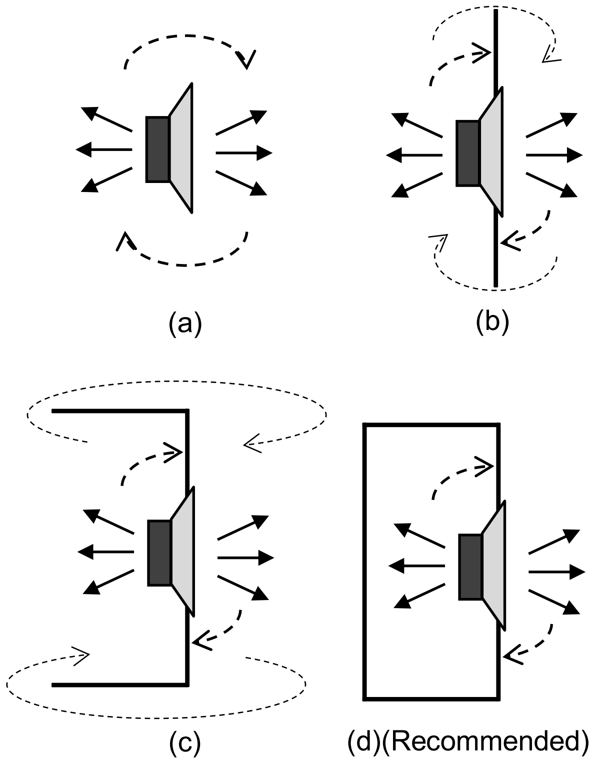


Figure 6.1.1 Image of sound waves output from a speaker

6.1.2 Speaker Enclosure

- Rear enclosure

The rear enclosure seals the back of the speaker (see Figure 6.1.2). As the volume of the enclosure decreases, the air inside is more compressed, pushing the speaker back. This results in lower volume. Increasing the volume of the rear enclosure whenever possible will help ensure volume. Additionally, using sound-absorbing material on the boards behind the speaker to absorb the sound from the back of the speaker will also help to maintain volume. We recommend that the speaker diameter and the depth of the rear enclosure be the same length, but the size and volume of the rear enclosure should be considered within the constraints of the product and equipment size.

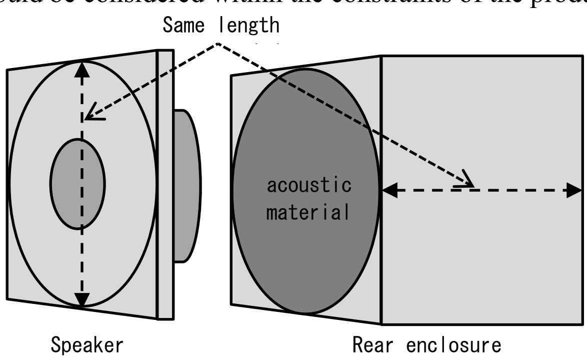


Figure 6.1.2 Example of rear enclosure

- Front enclosure

When mounting the enclosure on the front of the speaker, it is recommended to place a rubber band or similar between the speaker and the front enclosure to prevent noise generation due to vibration. The rubber band should not touch the vibrating part (cone paper) of the speaker. (Some speaker products are sold with the rubber band pre-attached to the speaker.)
If the front of the speaker is completely sealed by the front enclosure, the volume will be reduced, so it is necessary to make holes in the enclosure. It is recommended that the total area of the hole is at least 20% of the speaker surface area. (See Figure 6.1.3)
Even when waterproofing is used, the design should take into account the transmission of equivalent air vibrations to the outside of the front enclosure.

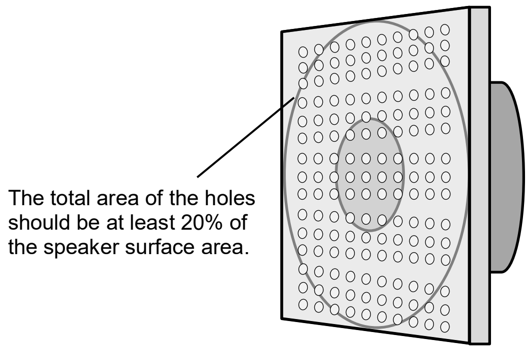


Figure 6.1.3 Example of front enclosure

6.2 Buzzer enclosure design

Commercial buzzers in an enclosure (Figure 6.2 left figure) have the enclosure designed to increase the volume of a specific frequency suitable for playing a single tone or sound effect. On the other hand, if a piezoelectric buzzer (Figure 6.2 right), which is still a metal plate, is to be incorporated into a product, the enclosure must be designed. In order to increase the volume of the desired frequency band with a buzzer, there is a need to use a resonance box or resonance tube, and to devise the choice of material, size, and thickness of the buzzer itself.

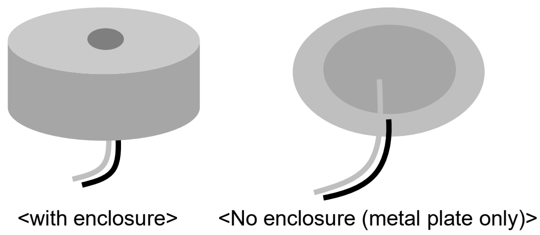
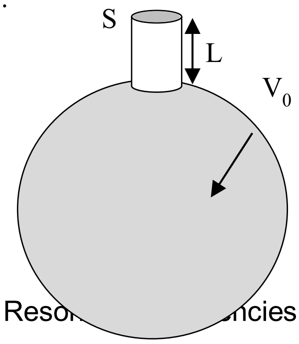


Figure 6.2 Buzzer forms

6.2.1 Resonance Box

The relationship between the shape of the resonance box and the desired resonant frequency is based on the "Helmholtz resonance" formula (see Figure 6.2.1.2), and this relationship can be used to design the resonant frequency to the desired value.



$$fH = \frac{v}{2\pi} * \sqrt{\frac{S}{V_0 L}}$$

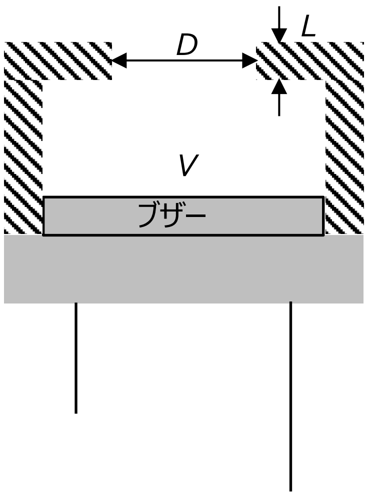
fH: Resonant frequency
v: Speed of sound

Figure 6.2.1.2 Resonant frequencies of Helmholtz resonance with a resonance box

Using the Helmholtz's resonant frequency equation in Figure 6.2.1.2, for example,
$V0=200(cm^3)$, $S=25(cm^2)$, $L=0.6(cm)$
The resonant frequency fH of the enclosure at $v = 340$ (m/s) is

$fH = 34000(cm/s)/(2\pi) * \sqrt{25(cm^2)/(200(cm^3)*0.6(cm))}$
$\approx 2470(Hz)$

This value can be expected to amplify the sound by resonating with a buzzer with a peak frequency (2.5 kHz ± 0.5 kHz), for example, as recommended in section 4.3.



$$fv = \frac{vD}{4} * \sqrt{\frac{1}{\pi V(L + 0.750)}}$$

fv: Resonant frequency (Hz)
V: Resonator volume (mm^3)
D: Sound emission hole diameter (diameter) (mm)
L: Sound hole length (mm)
v: Speed of sound(mm/sec) ≒344000(mm/sec)

Figure 6.2.1.2 Helmholtz resonance effect equation

6.2.2 Resonance Tubes

In the case of a tube with one closed end, a node (node) is formed at one end, while the open end forms a belly (anti-node) and is the free end. (See Figure 6.2.2)

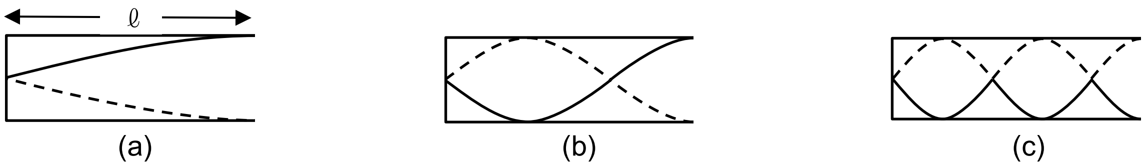


Figure 6.2.2 Resonance Tubes and Sound Wavelengths
(Tubes Closed on One Side Only)

Let λ be the wavelength of the sound and ℓ the length of the tube,
In Figure 6.2.2(a), $\lambda = 4\ell$ the speed of sound v then the sound frequency $f = v/(4\ell)$
In Figure 6.2.2(b), $\lambda = 4\ell/3$ the speed of sound v then the sound frequency $f = v/(4\ell/3)$
In Figure 6.2.2(c), $\lambda = 4\ell/5$ the speed of sound v then the sound frequency $f = v/(4\ell/5)$

If the speed of sound $v = 340$ (m/s) and $\ell = 15$ (cm),

In Figure 6.2.2(a), 340/(4*0.15) = 567(Hz)
In Figure 6.2.2(b), 340/(4*0.15/3) = 1,700 (Hz)
In Figure 6.2.2(c), 340/(4*0.15/5) = 2,833 (Hz)

These are the resonant frequencies.

This value, for example, in the case of Figure 6.2.2(c), is expected to resonate with the buzzer at the peak frequency (2.5 kHz ± 0.5 kHz) recommended in Section 4.3 and amplify the sound.

6.2.3 Resonance of Buzzer Metal Plate

Piezoelectric buzzers themselves also have a resonant frequency, which depend on the material, size, and thickness of the buzzer. Please contact the buzzer manufacturer for the desired resonant frequency.

※ Installation of piezoelectric buzzer

When using a piezoelectric buzzer with a metal plate set to a certain resonant frequency, as shown in Figure 6.2.3, the resonant frequency shifts to a higher frequency because the vibrating portion of the piezoelectric buzzer becomes smaller when the portion used to secure the buzzer is present. Therefore, it is necessary to design the housing and select the metal plate assuming this resonance frequency shift. Please contact the buzzer manufacturer for details.

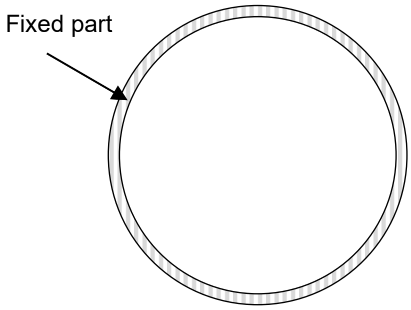


Figure 6.2.3 Piezoelectric buzzer (metal plate)

7. Sound input by microphone

When using an A/D converter (ADC) to capture sound input from a microphone with an analog circuit, a standard circuit using the MAX4466 is shown in Figure 7.1 as an example.

*MAX4466 (manufactured by Maxim)
https://www.analog.com/en/products/max4466.html
(*Information as of September 2023)

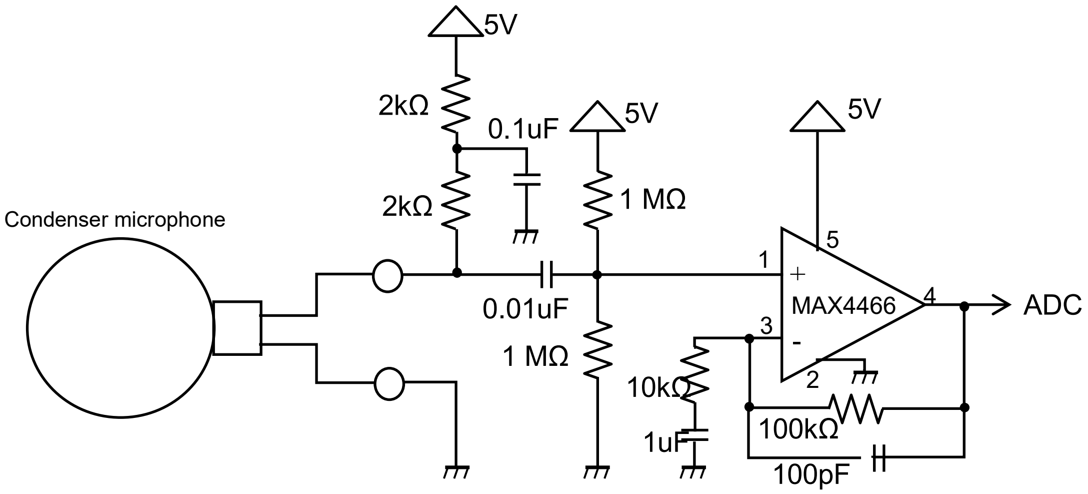


Figure 7.1 Standard Circuit Using MAX4466 (Maxim)

Appendix A Spice Model of Recommended Circuit for Electromagnetic Buzzer

An example netlist of the Spice model (using LTSpice) for the recommended circuit for electromagnetic buzzer connection (Figure 4.2.2/Figure 4.2.3) is shown below.

※ LTSpice (from Analog Devices) is a free analog circuit simulation software.
https://www.analog.com/jp/design-center/design-tools-and-calculators/ltspice-simulator.html
(*Information as of September 2023)

- How to use with LTSpice

① Create a working folder and save the Spice models of the FETs to be used in the working folder. The FETs used in this example are BC807DS and BC817DS. Copy the netlist of the FETs from the following URL to a text file and save it with the extension "BC807DS.lib" and "BC817DS.lib".
https://assets.nexperia.com/documents/spice-model/BC807DS.txt → <BC807DS.lib>
https://assets.nexperia.com/documents/spice-model/BC817DS.txt → <BC817DS.lib>
(*Information as of September 2023)

② Correct the sections below the dotted line in the text file saved in ①. (Red part)

< BC807DS.lib>

```
...
...
.SUBCKT BC807DS 1 2 3
Q1 1 2 3 Transistor 0.9101
Q2 11 2 3 Transistor 0.08993
RQ 11 1 40.42
D1 1 2 Diode
*
.MODEL Transistor PNP
...
...
```

→

```
...
...
*.SUBCKT BC807DS 1 2 3
*Q1 1 2 3 Transistor 0.9101
*Q2 11 2 3 Transistor 0.08993
*RQ 11 1 40.42
*D1 1 2 Diode
*
.MODEL BC807DS PNP
...
...
```

< BC817DS.lib>

```
...
...
.SUBCKT BC817DS 1 2 3
Q1 1 2 3 MAIN 0.938
Q2 11 2 3 MAIN 0.06196
RQ 1 11 84.59
D1 2 1 DIODE
*
.MODEL MAIN NPN
...
...
```

→

```
...
...
*.SUBCKT BC817DS 1 2 3
*Q1 1 2 3 MAIN 0.938
*Q2 11 2 3 MAIN 0.06196
*RQ 1 11 84.59
*D1 2 1 DIODE
*
.MODEL BC817DS NPN
...
...
```

③ Copy the netlist below the dotted line on the next page into a text file and save it with the extension "xxx.asc" in the working folder of ①.

④ The file saved in ③ is loaded into LTSpice for simulation.
(This example is based on supply voltage (VDD1) = 3V, DC resistance = 4.7kΩ, maximum current = 40mA, DC resistance = 70Ω.)

```
Version 4
SHEET 1 2136 1348
WIRE -672 -720 -1584 -720
WIRE -352 -720 -672 -720
WIRE -1584 -688 -1584 -720
wire -1584 -576 -1584 -608
wire -896 -560 -1168 -560
WIRE -768 -560 -816 -560
WIRE -576 -512 -960 -512
WIRE -464 -512 -496 -512
WIRE -672 -480 -672 -720
WIRE -352 -480 -352 -720
wire -768 -432 -768 -560
WIRE -736 -432 -768 -432
WIRE -464 -432 -464 -512
wire -416 -432 -464 -432
wire -1584 -352 -1728 -352
wire -1168 -352 -1168 -560
wire -1168 -352 -1584 -352
wire -896 -352 -1168 -352
WIRE -768 -352 -816 -352
WIRE -352 -352 -352 -352 -384
WIRE 48 -352 -352 -352
WIRE 208-352 128-352
wire -672 -336 -672 -384
wire -224 -336 -672 -336
wire -1584 -288 -1584 -352
WIRE -1424 -288 -1584 -288
WIRE -960 -288 -960 -512
WIRE -960 -288 -1360 -288
WIRE -576 -288 -960 -288
WIRE -464 -288 -496 -288
wire -672 -272 -672 -336
WIRE -352 -272 -352 -352
wire -1728 -256 -1728 -352
WIRE -224 -240 -224 -336
WIRE 208-240 208-352
WIRE 208 -240 -224 -240
wire -768 -224 -768 -352
wire -736 -224 -768 -224
wire -464 -224 -464 -288
wire -416 -224 -464 -224
wire -1728 -96 -1728 -176
WIRE -672 -32 -672 -176
WIRE -352 -32 -352 -176
flag-1728-96 0
flag -672 -32 0
FLAG -352 -32 0
flag -1584 -576 0
symbol voltage -1728 -272 r0
WINDOW 123 0 0 Left 2
WINDOW 39 24 124 Left 2
SYMATTR SpiceLine Rser=10m
SYMATTR InstName V1
SYMATTR Value PULSE(0 3.3 0 0.01u 0.01u 32u 64u 40)
```

```
SYMBOL voltage -1584-704 R0
WINDOW 123 0 0 Left 2
WINDOW 39 24 124 Left 2
SYMATTR SpiceLine Rser=1m
SYMATTR InstName V2
SYMATTR Value 3
SYMBOL Digital¥inv -1424 -352 R0
WINDOW 3 0 0 Invisible 2
SYMATTR Value Vhigh=3.3V
SYMATTR InstName A1
SYMATTR Value2 Vlow=0V
SYMBOL res 32-368 M90
WINDOW 0 0 56 VBottom 2
WINDOW 3 32 56 VTop 2
SYMATTR InstName R1
SYMATTR Value 70
SYMBOL res -800 -576 R90
WINDOW 0 0 56 VBottom 2
WINDOW 3 32 56 VTop 2
SYMATTR InstName R2
SYMATTR Value 4700
SYMBOL res -480 -528 R90
WINDOW 0 0 56 VBottom 2
WINDOW 3 32 56 VTop 2
SYMATTR InstName R3
SYMATTR Value 4700
SYMBOL res-800-368 R90
WINDOW 0 0 56 VBottom 2
WINDOW 3 32 56 VTop 2
SYMATTR InstName R4
SYMATTR Value 4700
SYMBOL res -480 -304 R90
WINDOW 0 0 56 VBottom 2
WINDOW 3 32 56 VTop 2
SYMATTR InstName R5
SYMATTR Value 4700
SYMBOL pnp -736 -384 M180
SYMATTR InstName Q1
SYMATTR Value BC807DS
SYMBOL pnp -416 -384 M180
SYMATTR InstName Q2
SYMATTR Value BC807DS
SYMBOL npn -736 -272 R0
SYMATTR InstName Q3
SYMATTR Value BC817DS
SYMBOL npn -416 -272 R0
SYMATTR InstName Q4
SYMATTR Value BC817DS
TEXT -1736 -24 Left 2 ! .tran 5m
TEXT -1544 -24 Left 2 ! .include BC807DS.lib
TEXT -1544 24 Left 2 ! .include BC817DS.lib
```

Revision History Table

appendix -1

Rev. No.	Date	Page	Classification	Revised contents (including old contents) and reason for revision
Rev. 1.0	Sep. 25, 2023	All pages	new	Newly enacted
Rev. 1.1	Dec. 25, 2024	P.3 - P.11	Addition	Added Table 3.1.1, 3.1.2, 4.1.2, 4.1.3, 4.2.1, 4.2.2, 4.2.3, 4.2.4, 4.2.5 and 4.2.6.
		P.7 - P.11	Modification	Modified Figure 4.1.1, 4.2.1, 4.2.2 and 4.2.3.
		P.3 - P.11	Modification	Modified explanation in section 3.1, 4.1 and 4.2.

EPSON

International Sales Operations

America

Epson America, Inc.

Headquarter:
3131 Katella Ave.
Los Alamitos, CA 90720, USA
Phone: +1-800-463-7766

San Jose Office:
2860 Zanker Road Suite 204
San Jose, CA 95134, USA
Phone: +1-800-463-7766

Europe

Epson Europe Electronics GmbH
Riesstrasse 15, 80992 Munich,
Germany
Phone: +49-89-14005-0 FAX: +49-89-14005-110

Asia

Epson (China) Co., Ltd.
4th Floor, Tower 1 of China Central Place, 81 Jianguo Road, Chaoyang District, Beijing 100025 China
Phone: +86-10-8522-1199 FAX: +86-10-8522-1120

Shanghai Branch
Room 601-603, Building A One East, No.325 East Longhua Road,
Shanghai 200023, China
Phone: +86-21-5330-4888 FAX: +86-21-5423-4677

Shenzhen Branch
Room 804-805, 8 Floor, Tower 2, Ali Center,No.3331
Keyuan South RD(Shenzhen bay), Nanshan District, Shenzhen
518054, China
Phone: +86-755-3299-0588 FAX: +86-755-3299-0560

Epson Taiwan Technology & Trading Ltd.
15F, No.100, Songren Rd, Sinyi Dist, Taipei City 110. Taiwan
Phone: +886-2-8786-6688

Epson Singapore Pte., Ltd.
438B Alexandra Road,
Block B Alexandra TechnoPark, #04-01/04, Singapore 119968
Phone: +65-6586-5500 FAX: +65-6271-7066

Epson Korea Co.,Ltd
10F Posco Tower Yeoksam, Teheranro 134 Gangnam-gu,
Seoul, 06235, Korea
Phone: +82-2-3420-6695

Seiko Epson Corp.
Sales & Marketing Division

MD Sales & Marketing Department
JR Shinjuku Miraina Tower, 4-1-6 Shinjuku,
Shinjuku-ku, Tokyo 160-8801, Japan

Document Code: 414459901
First Issue September 2023
Revised December 2024
in JAPAN