AN4598
Application note

Pre-amplifying the analog output of a MEMS microphone

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Introduction

MEMS microphones are an innovative way of recording sound.

STMicroelectronics provides a good portfolio of MEMS microphones. Products include the MPxAxx family (e.g. MP23AB02B).

Such products have an analog output. Generally, this output signal is quite low and needs to be amplified to reach the desired level required for the next stage (from microphone level to line level).

This application note describes how to perform this “pre-amplification”.

Contents

1 Output signal amplitude and gain setting

The analog signal on the output of the microphone contains the audio signal plus some noise.

The amplitude of the audio output signal depends on the acoustic pressure.

The relationship between sensitivity (S_o) and gain (G_{micro}) at 1 kHz is given in the MP23AB02B datasheet and is calculated using *Equation 1*.

Equation 1

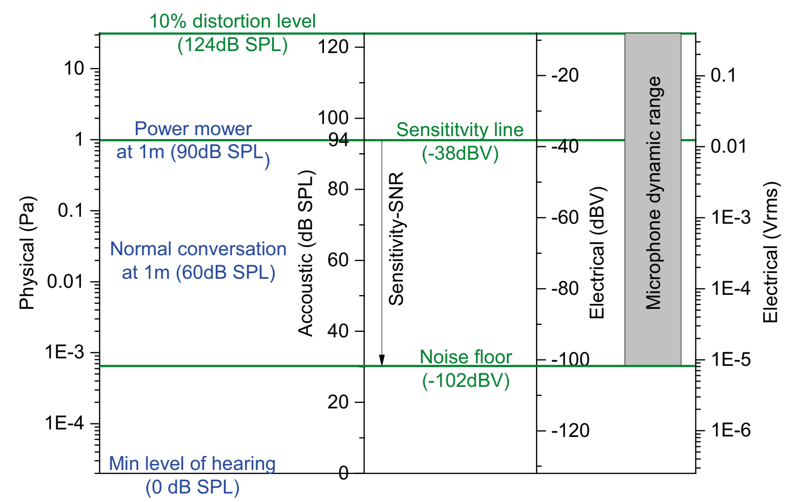
$$G_{micro} = 10^{\frac{S_o}{20}}$$

Where S_o is measured in dBV/Pa and G_{micro} in V/Pa.

In terms of scale, 20 µPa is the minimum level of hearing, while talking produces an acoustic pressure around 20 mPa. Acoustic pressure can also be expressed in dB SPL (sound pressure level) where: dB SPL ↔ 20 log (P/20 µPa). So, 1 Pa is equivalent to 94 dB SPL.

The acoustic and electrical relationships of the MP23AB02B are illustrated in *Figure 1*.

Figure 1. Acoustic and electrical relationships of the MP23AB02B



Note that acoustic pressure drops with distance from the source.

Assuming free field conditions, if we double our distance from the source, the acoustic pressure is divided by:

- 2 if the source is considered to be a point like a speaker (i.e. -6 dB SPL)
- √2, if the source is considered to be a line such as a road (i.e. -3 dB SPL)

Knowing the acoustic pressure applied to the microphone and the desired amplitude after the amplification stage tells us how much the gain should be.

The maximum gain setting (G_{max}) is calculated using *Equation 2* by considering the maximum sensitivity of the microphone (S_{omax}), the maximum output signal amplitude needed after the amplification stage ($Vout_{rms\_max}$), and the maximum acoustic pressure (P_{max}).

Equation 2

$$G_{max} = \frac{Vout_{rms\_max}}{10^{\frac{S_{omax}}{20}} P_{max}}$$

If $Vout_{rms}$ = 1 Vrms, S_{omax} = -35 dBV/Pa, and P_{max} = 1 Pa, G_{max} = 56.

2 Noise

Overall noise includes the noise generated by the microphone and the noise generated by the amplification stage.

The noise level (e_{rms}) on the output of the microphone is calculated using *Equation 3* by considering the signal-to-noise ratio (SNR) as given in the MP23AB02B datasheet.

Equation 3

$$e_{rms} = 10^{\frac{S_o - SNR}{20}}$$

Where e_{rms} is expressed in Vrms and SNR in dBA.

e_{rms} is shown as the noise floor in *Figure 1*.

Note that the SNR is A-weighted in order to consider noise as a human ear would hear it.

SNR is the difference (in dB) between a 94 dB SPL signal (whose amplitude is S_o (dBV/Pa) * 1 (Pa) = S_o (dBV)) and the noise level (dBV).

The typical noise level in the MP23AB02B is 7 μVrms.

This is equivalent to a white noise source (e_o), over a 20 kHz bandwidth, as calculated using *Equation 4*.

Equation 4

$$e_o = \frac{e_{rms}}{\sqrt{20000}}$$

Where e_o is expressed in nV/√Hz.

In case of the MP23AB02B, e_o is 56 nV/√Hz.

Independent noise sources (measured in Vrms) can be combined together by taking the square root of the sum of their squares.

If we consider a positive gain amplification of the output of the microphone (as shown in *Figure 2*) and if the noise level generated by the op amp is only half the noise level generated by the microphone (erms), the resulting overall noise is only 1.12 * erms.

Then, considering the same 20 kHz bandwidth, using an op amp whose equivalent white noise density is only 28 nV/VHz only increases the noise level by 12 % for the MP23AB02B.

To avoid decreasing significantly the noise level and therefore the signal-over-noise ratio, an op amp with a white noise of less than 20 nV/√Hz is recommended and less than 10 nV/√Hz is perfect.

Note that the overall noise level at the amplification output depends greatly on the shape of the gain stage (cutoff frequencies and filter orders).

Also, it is important when designing a circuit to bear in mind that resistors are a source of noise and that a resistor, R kΩ, generates a white noise source of 4√(R) nV/√Hz.

So, it is important to keep impedances relatively low.

3 Distortion

The signal distortion on the output of the microphone depends on the acoustic pressure as specified in the datasheet.

For the MP23AB02B, the signal distortion is less than 0.5 % at 94 dBSPL (which is equivalent to 1 Pa).

For high acoustic pressure, the distortion level increases. A 10 % distortion level is shown in *Figure 1*. The microphone can be used from the noise floor up to the distortion level. This is its dynamic range.

The signal distortion should be compared with the total harmonic distortion (THD) which is introduced by the op am. Generally op amps are not limiting for this parameter.

But we should bear in mind that the THD increases when frequency increases, for large output signals and low load values.

A pure sine waveform on the output of the op amp can calculated using *Equation 5*.

Equation 5

$$V_P \sin(2\pi f)$$

The maximum slope of such a waveform is $2\pi f V_p$.

Therefore, the op amp needs to have a slew rate greater than $2\pi f V_p$.

If we consider a 20 kHz waveform with a 3 V_{pp} amplitude, the op amp minimum slew rate must be 0.19 V/us. A margin (of at least a factor of two) should be considered on this value to ensure the smallest distortion of the signal.

4 Op amp choice

The MP23AB02B microphone supply voltage is between 1.6 V and 3.6 V.

If we want to have only one power supply domain in our application, we should use a low voltage op amp which is output rail-to-rail (especially at these low voltages where losing 1 V really makes a difference).

Considering the noise level, slew rate, and THD requirements, the recommended operational amplifiers are given in *Table 1*.

Table 1. Recommended op amps

	Vcc (V)	Noise (nV/√Hz)	Slew rate (V/µs)	Rail-to-rail output	Minimum load (Ω)
TS971	2.7 to 10	4	4		2 k
TS982	2.5 to 5.5	17	0.7	Yes	16
TS922	2.7 to 12	9	1.3		32
MC33078	5 to 30	4.5	7	No	600

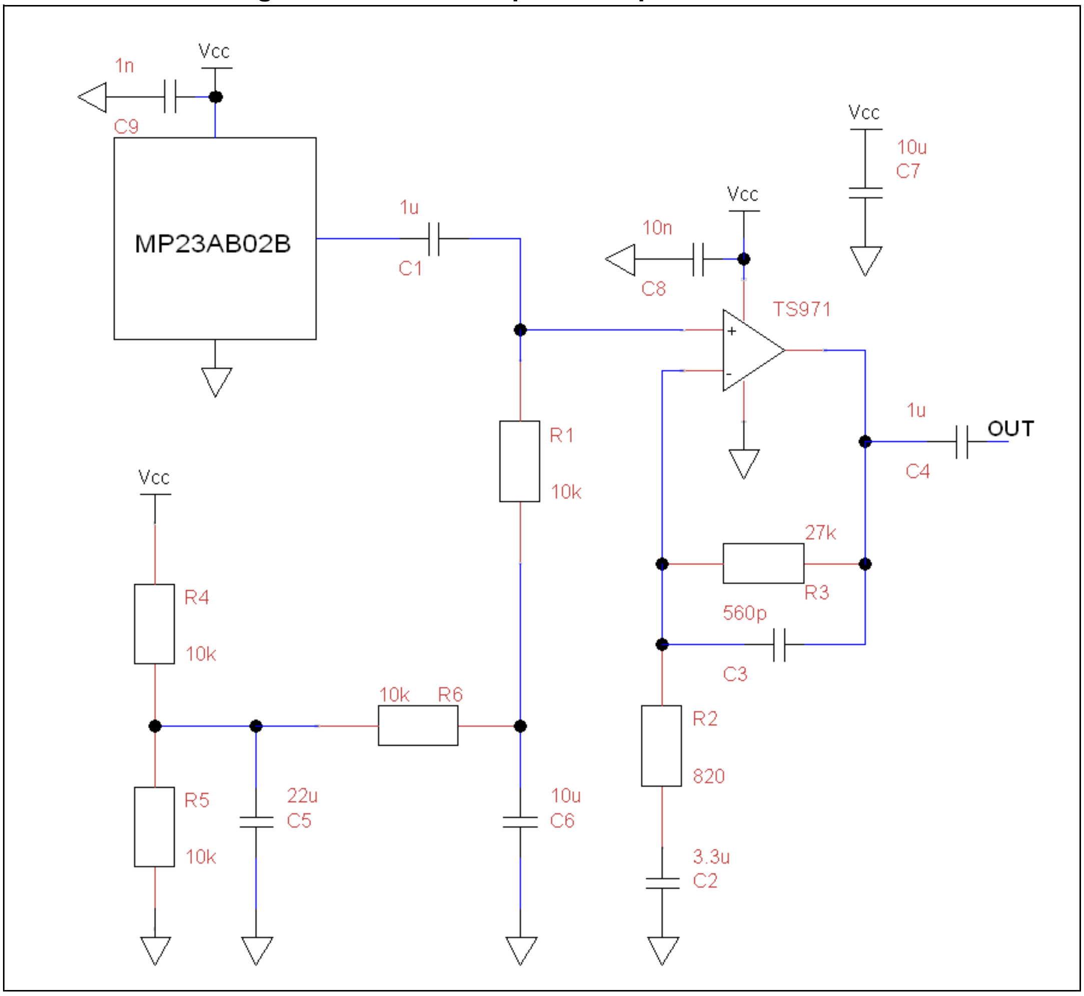
Note that all these op amps are available in automotive grade versions.

The first choice is the TS971. For driving low loads the TS922 or TS982 should be used. If the op amp has a dedicated high-voltage power supply (single or dual supply), the MC33078 should be used.

5 Designing the circuit

A typical pre-amplification circuit is shown in *Figure 2*.

Figure 2. MEMS microphone amplification circuit



R4 and R5 are used to generate a voltage reference to bias the input common mode voltage of the op amp at Vcc/2.

C5 allows the noise of the power supply (and of the equivalent R4 and R5 resistors) to be reduced. Generally, this noise would be amplified by the op amp.

R6 and C6 create a low pass filter which also helps to reduce noise, resulting in an overall second order, low-pass filtering.

R1 and C1 allow AC coupling of the microphone signal. The op amp is DC biased by Vcc/2 and in AC i.e. above ~1/2π R1C1 (16 Hz) its input receives the microphone signal.

Note that if the op amp is used with a dual supply configuration, ground is used as the input common mode voltage (R1 is directly connected to ground).

R2 and C2 create a high-pass gain so as not to amplify the DC biasing of the op amp (including input offset voltage). The cutoff frequency is f_{hp} = 1/2π R2C2 which is 59 Hz.

R3 and C3 create a low-pass gain so as not to amplify noise beyond the audio bandwidth. The cutoff frequency is f_{lp} = 1/2π R3C3 which is 10.5 kHz.

Between f_{hp} and f_{lp} the voltage gain of the amplification stage is calculated using *Equation 6*.

Equation 6

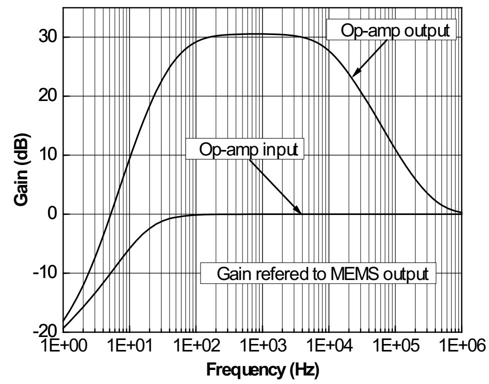
$$G = 1 + \frac{R3}{R2}$$

Figure 3 shows the transfer function of the proposed schematics.

For high frequencies the gain is 1.

In order to remove the input noise beyond the audio frequency, an additional low-pass RC filter can be used on the OUT node.

Figure 3. Voltage gain vs frequency

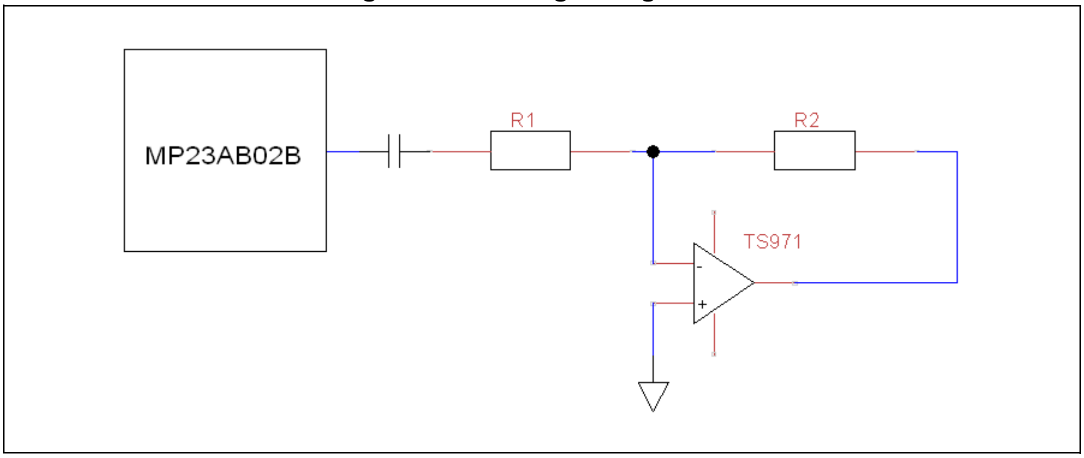


Note: C8 and C9 decoupling capacitors should be placed as close as possible to the op amp and microphone.

6 Inverting configuration

Other circuits are of course possible. For example, *Figure 4* shows an inverting configuration where the main architecture (without any filtering and biasing of the input at Vcc/2) has a gain of –R2/R1.

Figure 4. Inverting configuration



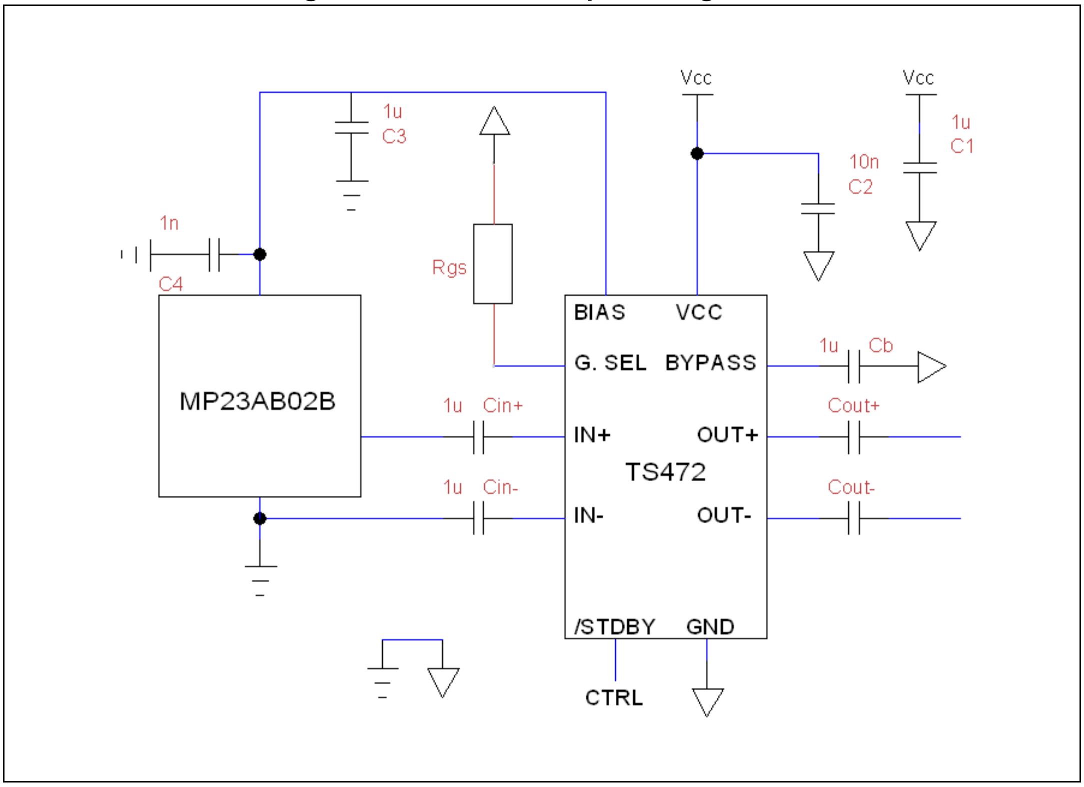
To design a circuit with a differential output, we can simply cascade an inverting stage (with R2 = R1) to the output of the first stage amplifier.

Both outputs would then be with the same amplitude, but with a phase inversion.

7 Differential output configuration

In case a differential output signal is needed, we recommend the use of the TS472 device, as illustrated in *Figure 5*.

Figure 5. Differential output configuration



The TS472 comes with standby mode which is effective on the biasing of the microphone if the 2-V bias embedded in the chip is used.

The footprint on the PCB is reduced because the TS472 is available in flip-chip and because this device requires less surrounding passive components than with a standard op amp.

Finally, if the microphone is far from the op amp, the differential input of the TS472 allows a better immunity to ground noise.

The gain for this device is determined by the R_{gs} value or it can be set to 20 dB if the gain select pin is connected to the bias pin (or a voltage above 1 Vdc).

Note: C2 and C4 decoupling capacitors should be placed respectively as close as possible to the op amp and microphone.

8 Conclusion

This application notes describes the key parameters related to pre-amplification of the output signal of an analog MEMS microphone (MP23AB02B). A solution is proposed based on the TS971 op amp. For a differential output configuration, we can consider using the TS472. The information in this document should allow you to design your own circuit suitable for your application. You can find the best-adapted MEMS microphone and op amp from STMicroelectronics.

9 Revision history

Table 2. Document revision history

Date	Revision	Changes
21-Jan-2015	1	Initial release