An Introduction to MEMS Microphone Specifications

EXECUTIVE SUMMARY

This applications note provides an introduction to Micro Electro Mechanical Systems (MEMS) microphones. It explains:

- What MEMS microphones are, including basic information on their mechanical construction
- The advantages of MEMS microphones over equivalent ECM parts
- How to interpret the acoustic and electrical datasheet specifications

INTRODUCTION

MEMS microphones are small form factor microphones, which translate acoustic sound pressure input into an electrical output response. They utilise the silicon wafer processes from the microelectronic industry to create high performance microphones of increasingly smaller geometries.

These processes give MEMS microphones a number of advantages over conventional electret condensing microphones (ECM), which has resulted in a general market transition to MEMS technologies for many of the latest consumer applications, including those requiring multi-microphone support or high quality capture.

The aim of this applications note is to enlighten readers with little or no experience of MEMS microphones to a point that they are confident in basic terminology and able to understand datasheet information to make product selections.

WHAT ARE MEMS MICROPHONES?

MEMS microphones are small form factor packaged silicon devices of approximately 3x2x1 mm in dimension, which convert sound pressure into electrical signals. They are available in 4 varieties:

1. Analogue Bottom Port
2. Analogue Top Port
3. Digital Bottom Port
4. Digital Bottom Port

Each type provides different options for mechanical mounting and have slight differences in their acoustic and electrical properties, which are discussed later in this document.
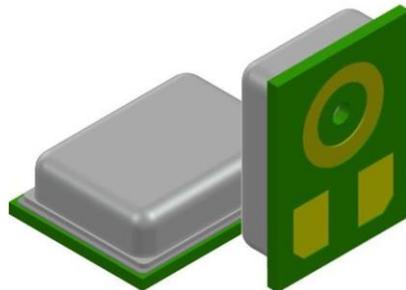
Figure 1 Analogue Bottom Port Package   **Figure 2 Digital Top Port Package**
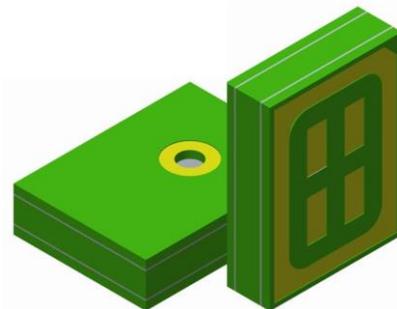
Figure 1 and Figure 2 show the differences between top and bottom port devices. The main difference is the location of the port hole (i.e the hole where sound enters the device), which is either on the same side as the solder pads (bottom port) or on the opposite side from the solder pads (top

port). Other key differences are the materials the packages are made out of (metal case on the left and laminate material on the right); and the number of electrical contacts.

Within one of these packages, a typical MEMS microphone consists of two components bonded together. As shown in Figure 3.

1. The transducer **is the MEMS component, which consists of a flexible silicon membrane that converts acoustic sound pressure to electrical energy.**

2. The ASIC **(Application Specific Integrated Circuit) is the electronics component that amplifies the electrical signal generated by the transducer and produces the microphone output.**
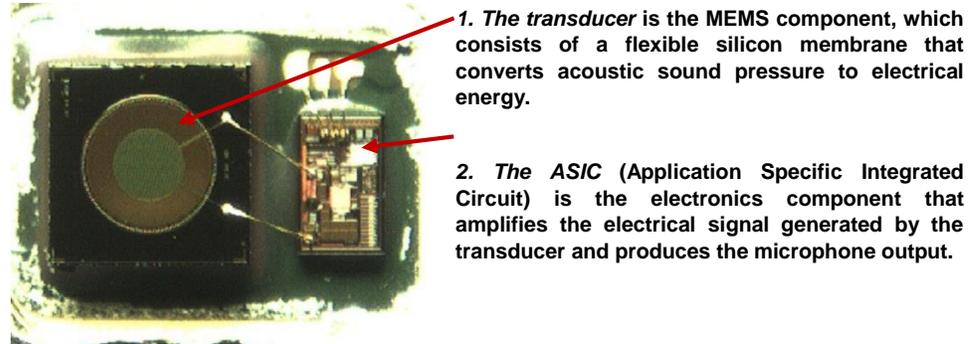
Figure 3 Internals of a typical MEMS microphone package

Cirrus also produces integrated microphones where the MEMS and ASIC components are built together on a single CMOS die.

Electrically, a MEMS microphone can be simplified as a variable capacitor (*the transducer*) connected to an amplification stage (*the ASIC*). The variable capacitor changes capacitance as sound pressure changes, then the ASIC converts this into a voltage for interfacing to a CODEC or Audio IC. Figure 4 shows a block diagram of an analogue MEMS microphone. Note the 'Charge Pump' component which in simplistic terms provides a voltage reference to the transducer.
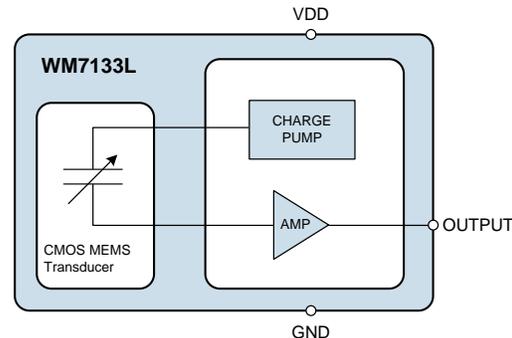
Figure 4 Analogue MEMS Microphone Block Diagram

A digital MEMS microphone consists of similar components but the ASIC has an additional analogue to digital conversion (ADC) stage to produce a PDM modulated digital output. It also has a control block to manage different clock rates and operational modes.
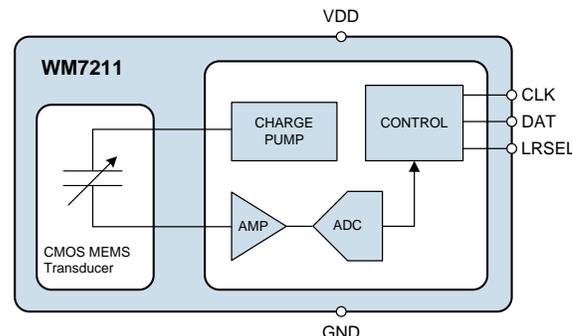
Figure 5 Digital MEMS Microphone Block Diagram

WHAT ARE THE ADVANTAGES OF MEMS MICROPHONES?

Some of the main advantages of Cirrus MEMS microphones are:

- Small footprint, low profile packaging suitable for space constrained applications
- Tightly controlled sensitivity distributions and matching between devices
- Robust silicon membrane technologies, with proven quality assurance
- Sound quality improvements, with high SNR and low THD at high sound pressure levels
- Low power consumption
- Repeatable performance

These make Cirrus MEMS microphones ideal for applications such as smartphones, wearables, always on devices or new use cases such as the internet of things, amongst many others.

INTERPRETING ACOUSTIC AND ELECTRICAL CHARACTERISTICS

There are a number of unique specifications associated with MEMS microphones that are a combination of the electrical and acoustic properties of these devices, which make interpreting a microphone datasheet somewhat challenging.

This section aims at clarifying some of the electro-acoustic terminology used within Cirrus datasheets. It also provides further explanations of the specifications described within the 'Acoustic and Electrical Characteristics' sections.

Figure 6 and Figure 7 below can be used as a general reference to illustrate the input and output characteristics of MEMS microphones. These figures will be referred to throughout the following reading, where each of the specifications will be explained in more detail.
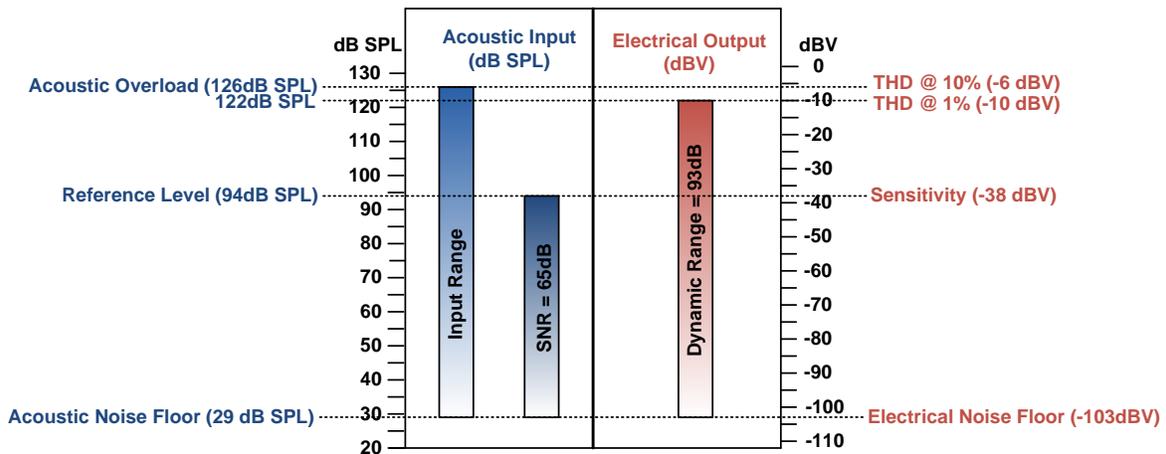
Figure 6 Analogue Microphone Specifications Reference Diagram (based on WM7133L)
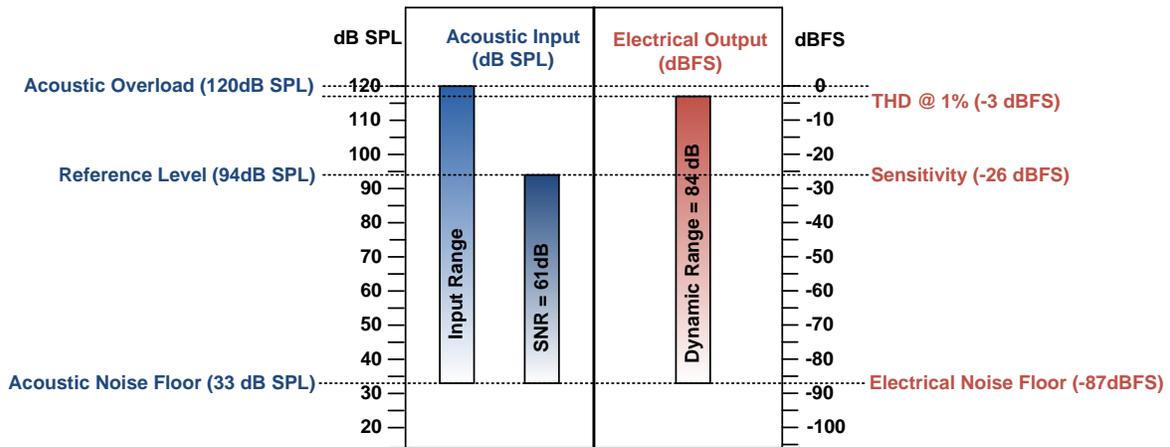
Figure 7 Digital Microphone Specifications Reference Diagram (based on WM7211)

STANDARD REFERENCE LEVEL

Microphone performance specifications are based around an industry standard reference level, defined by the American National standards Institute (ANSI/ASA S1.1-2013). The reference level is:

1kHz sine wave with 1Pascal (Pa) of sound pressure

= 94dB SPL (Sound Pressure Level)

This allows acoustic sound pressure to be described in terms of dB, and since microphones have an electrical output which can also be described in dB, it gives a common scale from input to output.

SENSITIVITY

Microphone sensitivity is a key performance parameter defining the translation from acoustic sound pressure to electrical voltage. It is based on the above standard reference point and is defined as follows:

For analogue MEMS microphones:

Sensitivity is a measure of the microphone's output response (dBV) to the acoustic pressure of a 1kHz 94dB SPL (1Pa) sine wave.

For digital MEMS microphones:

Sensitivity is a measure of the microphone output response (dBFS) to the acoustic pressure of a 1kHz 94dB SPL (1Pa) sine wave.

Sensitivity determines the amount of output voltage generated by a fixed sound pressure input. Microphones with a higher sensitivity produce a larger voltage at their output compared to microphones with lower sensitivity for the same fixed input. It is shown in Figure 6 and Figure 7 as a line at 94dB SPL on the left and sensitivity can be read as the output voltage in dB on the right.

The units used for sensitivity depend on whether the microphone is analogue or digital, and is a negative number in both cases. Thus, a sensitivity of -26dBV is higher than a sensitivity of -38dBV.

Table 1 shows typical sensitivity values for the various types of MEMS microphone.

TYPE	TYPICAL SENSITIVITY	UNITS
Bottom Port Analogue Microphone	-38	dBV
Top Port Analogue Microphone	-38 or -42	dBV
Bottom Port Digital Microphone	-26	dBFS
Top Port Digital Microphone	-26	dBFS

Table 1: Typical MEMS Microphone Sensitivity

For a typical Bottom Port Analogue Microphone, inputting acoustically a 1kHz sine wave of 94dB SPL (1Pa) sound pressure will produce an electrical sine wave of -38dBV on the output pin of the microphone.

ACOUSTIC NOISE FLOOR

The acoustic noise floor specifies the smallest acoustic input amplitude which a microphone is able to convert to an output.

The acoustic noise floor can also be referred to as the 'Effective Noise Floor (ENL) and both terms can be used interchangeably. Acoustic noise floor is represented in datasheets with units in dB SPL and is determined by the point at which the mechanical/electrical limits of a microphone are reached for small amplitudes. These are due to the physical properties of the device package, MEMS transducer and the electrical properties of the ASIC circuitry; combining to create a noise floor for the microphone.

If an input signal is applied to a microphone at a lower amplitude than the acoustic noise floor, then the microphone will not be able to interpret the signal as it will be lost in noise. The output will equal the output amplitude associated with the acoustic noise floor, which in a typical MEMS microphone would be ~30dB SPL.

ELECTRICAL NOISE FLOOR

The electrical noise floor is effectively an electrical representation of the 'Acoustic Noise Floor' since it specifies the output amplitude relating to the smallest acoustic signal that can be interpreted by the microphone.

In Figure 6 and Figure 7 the electrical noise floor can be seen as a line relating to the acoustic noise floor. The value is typically A-weighted.

SIGNAL TO NOISE RATIO (SNR)

Signal to Noise Ratio (SNR) specifies the amplitude difference between the standard reference input (1kHz, 94dB SPL, sine wave) and the acoustic noise floor (dB SPL).

Figure 6 and Figure 7 illustrate SNR. It is shown as a bar on the input side but can also be represented in a similar way at the output as the amplitude difference between Sensitivity level and the Electrical Noise Floor (dB).

In both cases SNR is represented in dB units and typically specified with A-weighting and across a 20Hz to 20kHz bandwidth, which is necessary to obtain comparable values to the Cirrus datasheets. If a smaller bandwidth is used, SNR will appear greater due to less noise components being included. Conversely if a larger bandwidth is used SNR will appear less than that specified in the datasheet.

In terms of measurement - SNR is measured by comparing the difference in output amplitudes, when applying the standard reference input (1kHz, 94dB SPL, sine wave), and when applying no input (or a *very* quiet anechoic input). This electro-acoustic definition of SNR presented in microphone datasheets therefore differs fundamentally from the electrical definition of SNR presented in CODEC datasheets, and care should be taken when comparisons are made.

TOTAL HARMONIC DISTORTION (THD)

Total Harmonic Distortion (THD) defines how distorted the output is compared to an ideal input reference tone and has units in percentage (%), where smaller numbers indicate less distortion and larger numbers indicate greater distortion at the output.

For MEMS microphones, it is common to make reference to the 1% THD point where it is generally accepted that below 1% THD, the distortion has negligible impact on any audio recording. The upper limit being the 10% THD point, which is the onset of unacceptable levels of distortion at the output.

THD is an ideal measurement but in real systems it is almost impossible to separate distortion products from noise products at the output, especially for smaller amplitudes where the contribution of the noise floor begins to dominate compared to the signal content. It is often therefore described as THD plus noise (THD+N) where measurements are concerned, which includes the noise products as well.

Cirrus datasheets provide a plot of the THD+N(%) v Input sound pressure level (dB SPL), which describes performance of a typical device:
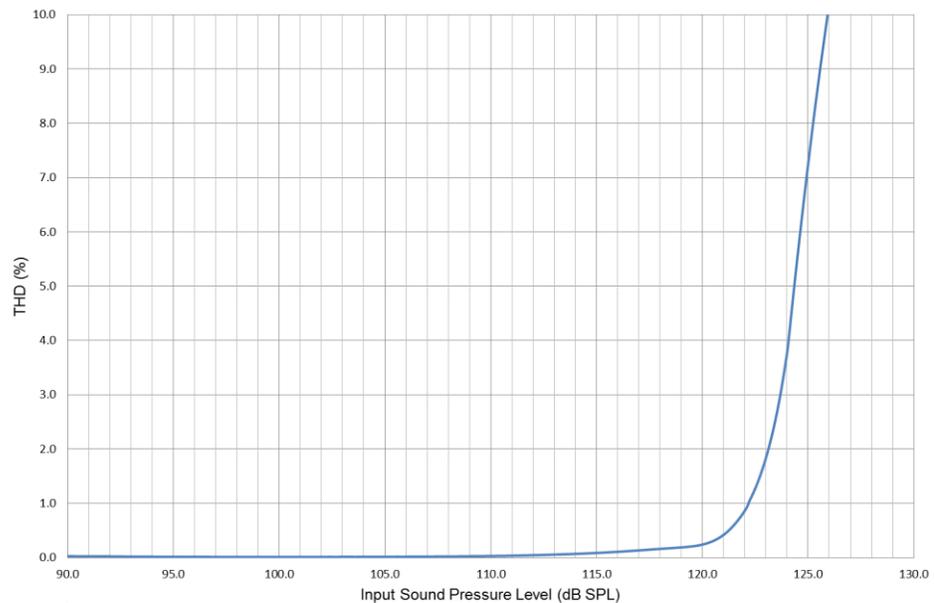
Figure 8 WM7133L THD+N v Input Sound Pressure Level Plot

The WM7133L has class leading THD+N where it can be seen that for inputs up to 122dB SPL, THD is less than 1%. This means that the WM7133L is able to receive very loud input pressures and at the same time produce an output with exceptional clarity and detail.

In specifying the datasheet THD figures, it can be noted that there is often a 1% value presented in the TYP column as well as the MAX column. The TYP value describes the sound pressure level at which the mean value from a distribution of devices have 1% THD. The MAX 1% value gives a guarantee that no device will have THD above 1% at the specified input sound pressure level.

ACOUSTIC OVERLOAD

Acoustic overload describes the maximum sound pressure level that a microphone is able to convert to an output without introducing excessive distortion artefacts. It effectively describes the onset of clipping and occurs when the sound pressure level is so large that mechanical limitations within the MEMS are reached and the output becomes non-linear.

For analogue microphones, acoustic overload is defined as the sound pressure level (dB SPL) where THD at the output of the microphone equals 10%.

For digital microphones the same definition applies, however digital microphones are also limited by the range of available PDM output codes. In most Cirrus devices the output range is designed so that 10% THD is not achievable and the acoustic overload point equates to the sound pressure level associated with the maximum available PDM output. This is typically 120dB SPL but devices exist where the maximum available PDM output has been designed to match higher sound pressure levels.

The main consideration with acoustic overload is to ensure that the microphone is specified to have an overload point greater than the sound level being recorded. So when recording high volumes or in loud environments, it would be desirable to have a larger acoustic overload point to prevent excessive distortion in the recordings. For low sound pressure levels the acoustic overload point is not important.

DYNAMIC RANGE

Dynamic range describes the useable amplitude range in dB of a microphone where it operates linearly with negligible distortion at the output.

In Cirrus datasheets, it is defined as the difference in dB between the acoustic noise floor and the sound pressure level associated with 1%THD at the output (relative to a sine wave input).

Large dynamic range means a device can accurately translate a larger range of sound pressures from smaller amplitudes to larger amplitudes. This might be useful when recording an orchestra for example, which has lots of varying sound levels. Other recordings may not require such a large dynamic range, for example recording low level noises such as insects or environmental noises.

When comparing dynamic range between devices, care should always be taken to compare to dynamic range to the 1%THD point as different microphone vendors specify dynamic range to differing THD values.

FREQUENCY RESPONSE

The frequency response is the output level of a microphone shown across a frequency range, where the amplitude is based on the 'Standard Reference Level'.

Since the 'Standard Reference Level' is within the sweep, the 1 kHz point of the frequency response plot will equal the 'Sensitivity' of the microphone. Therefore it is common to normalize the frequency response amplitude around the 1 kHz point. This enables side by side comparisons of microphones with different sensitivities. All Cirrus datasheet plots are normalized for this reason.
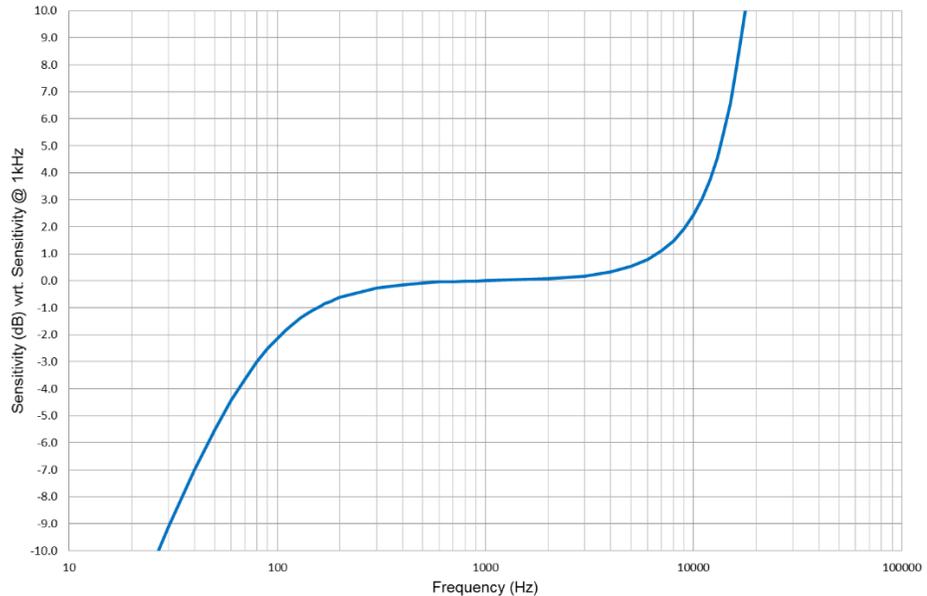
Figure 9 Typical MEMS Microphone Frequency Response Plot

The key parameters when comparing frequency responses are the +/-3dB points and flatness:

- The -3dB point indicates the low frequency cutoff where a value of <90Hz is suitable for most applications. Cirrus's portfolio includes -3dB points from <20Hz to 85Hz, with tight tolerances for specific applications that require exact cutoff requirements.

- The +3dB point indicates the high frequency cutoff for a single microphone and represents the upper bandwidth limit for recordings with a given microphone. It should be noted that this point is heavily dependent on the size and shape of port hole so adding a gasket to the microphone can lead to a significant reduction in +3dB point if not done correctly. Please refer to WAN_0284 'General Design Considerations for MEMS Microphones' for more info on gasketting.

- Flatness is important in insuring levels are consistent across frequency and in achieving recordings that are a true representation of the input. To bound this parameter, Cirrus datasheets typically incorporate a 'Frequency Response Flatness' specification where a bandwidth is given whereby the response will not exceed +/-1dB.

POLARITY

Polarity indicates whether the output responds positively or negatively in response to a positive sound pressure at the input.

For analogue microphones – Positive polarity implies a positive sound pressure at the input creates a positive voltage at the output. Negative polarity implies a positive sound pressure at the input creates a negative voltage at the output.

For digital microphones - Positive polarity implies a positive sound pressure at the input creates more 1's in the PDM output stream. Negative polarity implies a positive sound pressure at the input creates more 0's in the PDM output stream.

Cirrus microphones are typically positive polarity.

DIRECTIVITY

Directivity indicates the sensitivity of a microphone at different angles. Typically directivity is measured by mounting a microphone in a free field, anechoic space and measuring the response to a frequency swept sine wave at differing angles. The results being displayed as a microphone polar pattern.

Cirrus MEMS microphones are all classed as omni-directional, which means they have equal sensitivity at all angles. This is mainly resultant of the small form factor of the MEMS microphones where there is very little physical material around the port hole and hence very little to obstruct the surrounding acoustics.

It should be noted that the omni-directionality relates only to the microphone itself and if designing a microphone into a mechanical housing then the directionality is likely to be affected by the surrounding structures and directivity will be changed.

POWER SUPPLY REJECTION RATIO (PSRR)

Power Supply Rejection Ratio (PSRR) is a figure of immunity to variations in the power supply. It describes the variation on the output for a fixed sinusoidal variation in power supply voltage.

Within the microphone datasheets PSRR is defined with a 217Hz, 100mVpp sine wave superimposed onto the typical supply voltage. The output variation is then presented as a ratio in dB with respect to this input signal. As an example, if a 100mVpp ripple results in a 0.1mVpp ripple at the output then PSRR would be calculated as 20 log (100/0.1) = 60dB.

PSRR is a positive value where a larger value indicates better immunity to the variations in the supply.

POWER SUPPLY REJECTION (PSR)

Power Supply Rejection (PSR) is similar to PSRR in that it gives a figure of immunity to variations in the power supply. The crucial difference is that PSR is not represented as a dB ratio. Instead the units relate only to the units of the microphone output (dBV or dBFS).

PSR is generally (but not exclusively) used to define the effect of signals superimposed onto the supply that have multiple frequency components, such as to define the variation in output due to a square wave superimposed onto the supply or due to a swept sinewave superimposed onto the supply. In both these cases the output cannot easily be represented as a ratio.

Within Cirrus datasheets a 100mVpp, 217Hz square wave is typically superimposed onto the supply and PSR is a negative value where a smaller (more negative) value indicates better immunity to the variations in the supply.

CURRENT CONSUMPTION

Current consumption indicates the amount of current consumed by a microphone when the VDD pin is powered (at datasheet typical voltage), the microphone is under quiescent conditions (i.e no input stimulus), and no load is applied to the output.

- Analogue MEMS microphones tend to have the lowest current consumption (tens uA),

- Digital MEMS microphones typically have current consumption in the region of hundreds uA.

When compared in isolation, analogue microphones have a clear advantage over digital microphones in terms of current consumption. However, when connecting to a digital system and including the whole input path, the choice over which type has lowest current consumption is less clear cut.

Analogue MEMS microphones require an additional ADC digitization stage (typically provided by an audio codec), whereas digital MEMS microphones already include the ADC digitization stage within the microphone, so less additional circuitry is required.

Therefore when considering the overall current consumption of an input path, the microphone type is a bespoke choice based on many design factors. The codec that the microphone connects to is very important and the overall application use case, audio performance, signal bandwidth, sample rate, etc. all need to be taken into consideration.

REVISION HISTORY

DATE	REV	DESCRIPTION OF CHANGES	PAGE	CHANGED BY
JAN '15	1.0	Initial version		CT

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