Introduction to Microphone Polar Patterns

Microphones are categorized by their *polar pattern*. The polar pattern describes how the sensitivity of a microphone varies based on the signal's direction of arrival (DoA). Designing a system to have a specific polar pattern is useful to control what sounds are picked up so that the signal of interest is most prominent in the recording. The fundamental polar patterns for microphones are omnidirectional and dipole seen below. All other first order patterns are created from a mixture of these two.

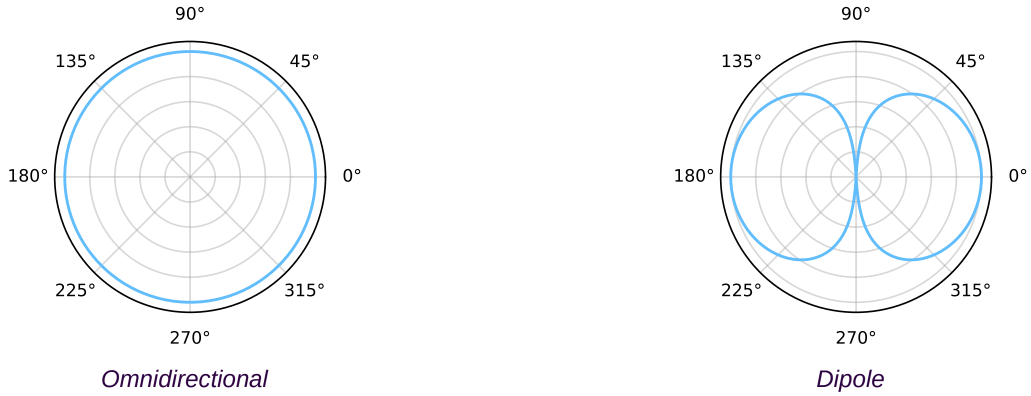


Figure 1: Microphone polar patterns

A microphone with an *omnidirectional* polar pattern picks up sound equally from all directions. A dipole picks up sound equally from the front and back while rejecting sounds from the sides. Dipoles have a *null,* where sound is rejected the most, at 90º and 270º. The polar pattern also shows where sound begins to drop off. A dipole has -3 dB gain at ±45º compared to 0º. Soundskrit microphones feature a dipole polar pattern.

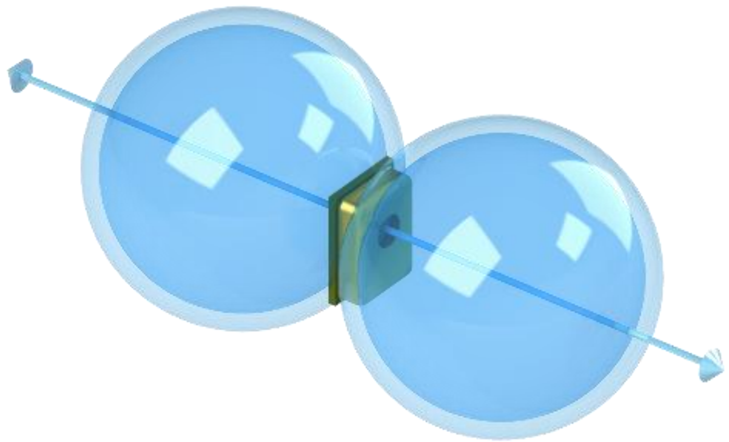


Figure 2: Soundskrit microphone polar pattern

Directivity Index and Unidirectional Index

It is useful to describe microphone polar patterns with a single figure that represents how much noise they reject and from where. The two primary measures are the *directivity index* (DI) and *unidirectional index* (UI).

The **directivity index** measures the ratio of the microphone output for a sound positioned directly in front of the microphone (θ = 0º) versus sound with the same amount of total acoustic power coming from all directions equally. The DI of an omnidirectional microphone is 0 and the DI of a dipole microphone is 4.8 dB.

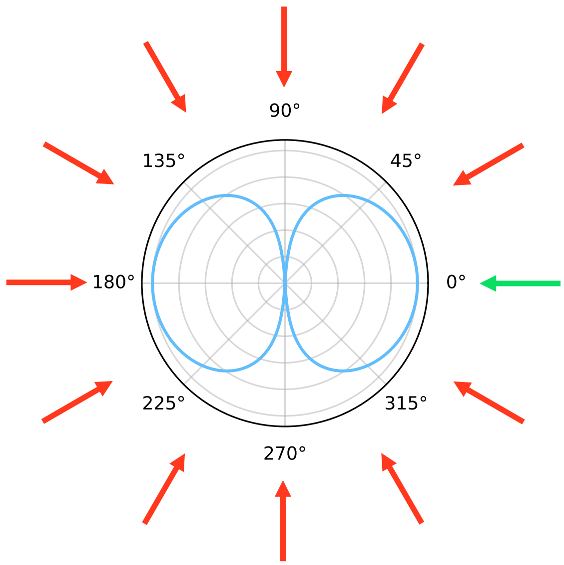


Figure 3: Directivity Index

The **unidirectional index** measures the ratio of the microphone output for a sound positioned in front of the microphone versus sound with the same amount of total acoustic power coming from the back of the microphone. Both omnidirectional microphones and dipole microphones have a UI of 0 dB.

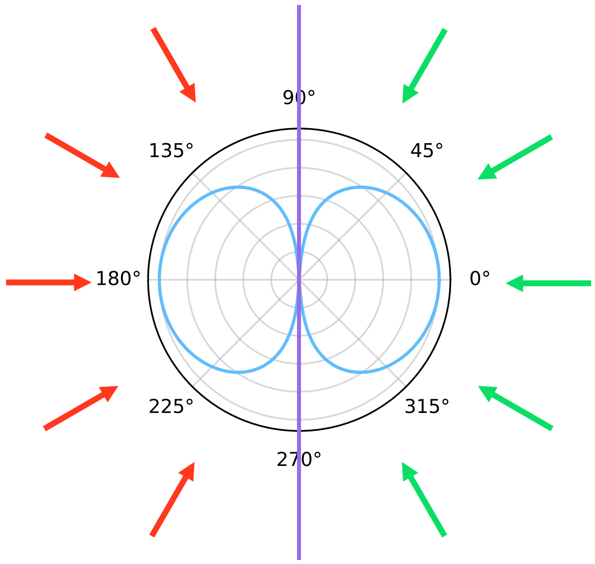


Figure 4: Unidirectional Index

 www.soundskrit.ca

Cardioid Microphones

A **cardioid** polar pattern rejects noise coming from the backside. A cardioid microphone will have a DI of 4.8 dB and a UI of 8.4 dB.

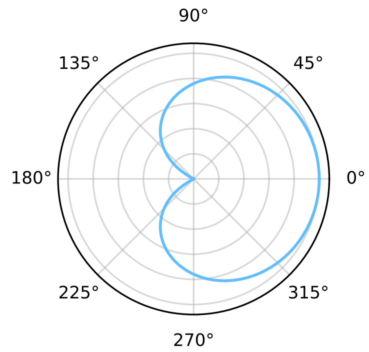


Figure 5: Cardioid polar pattern

A cardioid microphone can be created by combining the signals from an omnidirectional microphone and a dipole microphone located near each other. An omnidirectional microphone outputs the same signal regardless of the direction of the sound. The polarity of the signal from the dipole is inverted depending on whether the signal comes from the front or rear of the microphone. The rear lobe of the dipole will have a negative polarity compared to a signal coming from the front.

Due to this inverted polarity, the summation of an omnidirectional and a dipole microphone will create a cardioid polar pattern. This summation creates a cardioid as when sounds come from the rear, the signal from the dipole will be inverted compared to the omnidirectional microphone and the signals will destructively interfere and cancel. Sound coming from the front will have the same polarity on both microphones so the signals will constructively interfere and sum. Signals coming from the sides will be rejected by the dipole and will not impact the signal from the omnidirectional microphone. This summation is illustrated in figure 6 below:

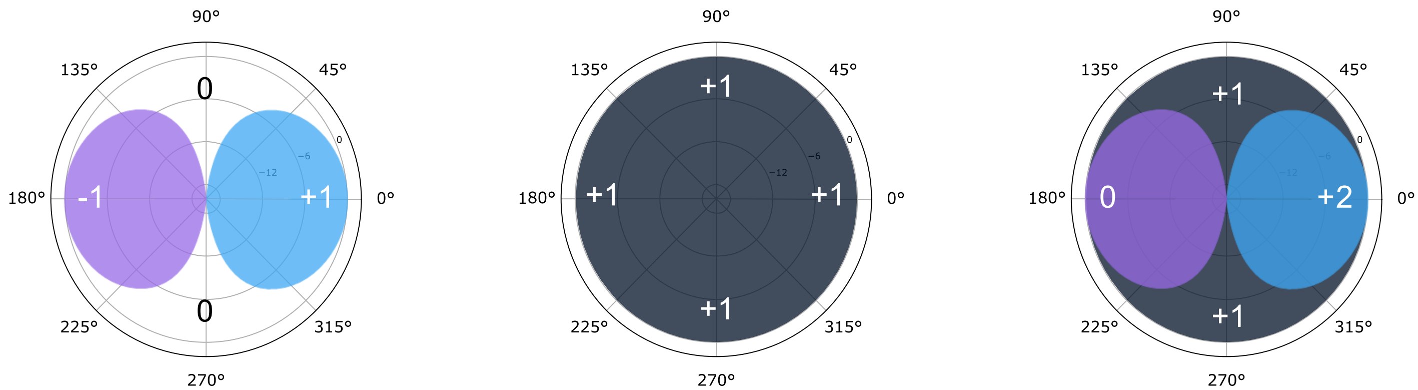


Figure 6: Illustration of the summation of a dipole and omnidirectional microphone

Variants of Cardioids

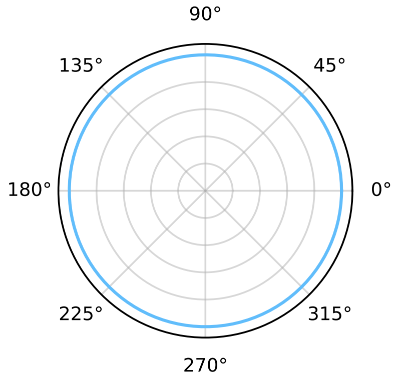
<table>
<tr><th>Polar Pattern</th><th>DI (dB)</th><th>UI (dB)</th><th>Dipole-Omni Ratio</th><th>Null Angles</th><th>Description</th></tr>
<tr><td>

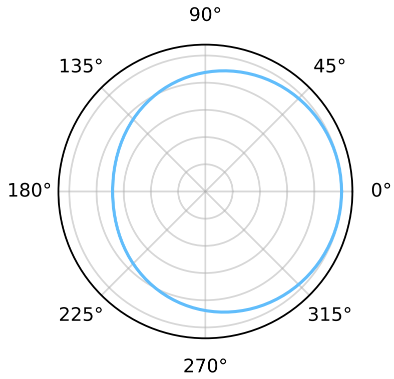
Figure 7: Omnidirectional</td><td>0</td><td>0</td><td>0:1</td><td>N/A</td><td>The omnidirectional microphone is one of the basic microphone patterns. Traditional MEMS microphones are omnidirectional. The omnidirectional microphone collects sound equally from all directions</td></tr>
<tr><td>

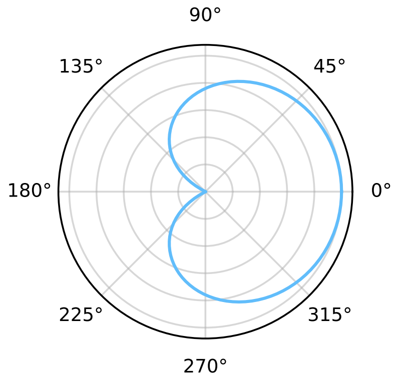
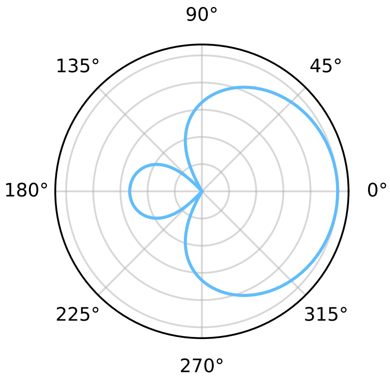
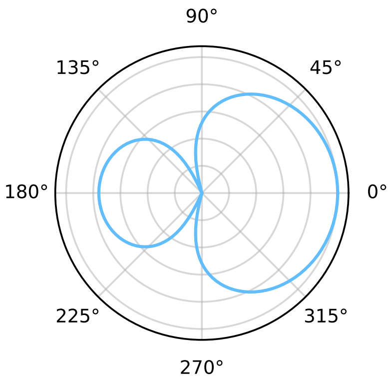
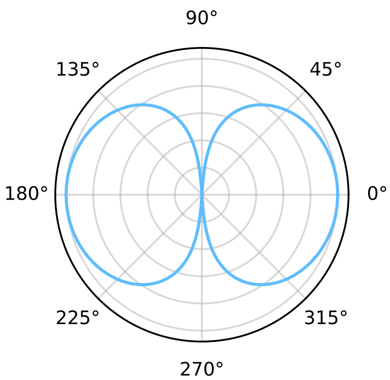
Figure 8: Subcardioid</td><td>3.2</td><td>4.3</td><td>3:7</td><td>N/A</td><td>The subcardioid microphone is more weighted toward the omnidirectional signal than the dipole signal resulting in a less directional polar pattern without a null point and 10dB attenuation to the back. This polar pattern might be used when a wider pickup angle is required than a cardioid, but some background attenuation is still beneficial, such as recording a large group</td></tr>
<tr><td>

Figure 9: Cardioid</td><td>4.8</td><td>8.4</td><td>1:1</td><td>180º</td><td>A cardioid polar pattern is weighted equally between an omnidirectional and dipole microphone resulting in a microphone with the strongest rear rejection and a wide pickup angle. A cardioid is best suited when you need to reject the maximum noise directly from the rear, such as when two subjects are sitting across the table from each other and speaking into separate microphones.</td></tr>
</table>

Polar Pattern	**DI** (dB)	**UI** (dB)	**Dipole-Omni Ratio**	**Null Angles**	**Description**
 *Figure 10: Supercardioid*	5.7	11.4	5:3	127º 233º	The **supercardioid** weighs the dipole signal more heavily than the omnidirectional signal. This creates a small rear lobe but has a higher DI and UI than either a cardioid or a dipole. Supercardioids are useful in applications where there is not direct interfering noise behind the microphone, but the subject still needs to be able shift around, such as when filming.
 *Figure 11: Hypercardioid*	6.0	8.5	3:1	110º 250º	The **hypercardioid** polar pattern has the highest DI and will reduce the most ambient noise. This is useful when most of the background noise is not direct and maximum noise rejection is required. A hypercardioid polar pattern would be beneficial for someone talking on the phone using wireless headphones in a crowded environment.
 *Figure 12: Dipole*	4.8	0	1:0	90º 270º	The **dipole** microphone is the other basic microphone pattern. A dipole collects sounds equally in the front and back and most strongly rejects sound from the sides. Directional MEMS microphones from Soundskrit are dipole microphones.

Matching the Dipole and Omnidirectional Microphones

For optimal performance across the frequency range, it is important to match the frequency response, sensitivity, and phase of the omnidirectional and dipole microphones as closely as possible.

Omnidirectional microphones typically have a flat frequency response over a wide frequency range, while dipole microphones have a sloped frequency response. Figure 13 below shows the frequency response and sensitivity of a Knowles Lazarus omnidirectional microphone and the Soundskrit SKR0600 dipole microphone.

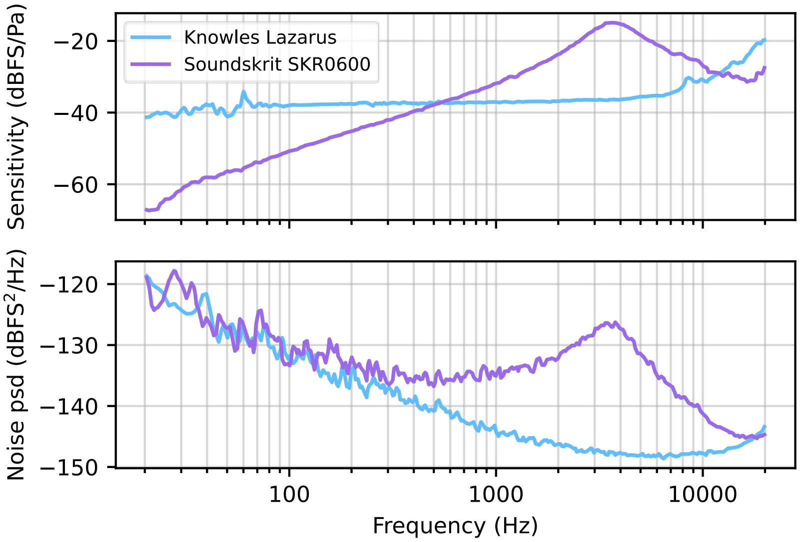


Figure 13: Frequency response of an omnidirectional and dipole microphone in freefield

Figure 13 is measured in freefield, however, microphones will also be impacted by the acoustic effects of the end product as well. To minimize this, the microphones should be integrated as closely as possible.

To match these two microphones, record a pink noise signal from a source located directly behind (180º) the desired polar pattern. It is important to place the source in the location of the desired null. By matching the frequency and phase response in the desired null, the resulting summation will have the best possible cancellation at this location. If there is an integrated speaker that you are looking to cancel, use the speaker as the noise source to maximize the cancellation of the exact speaker and location found in the final product. The recording should be taken in a room with a low reverberation time. Then implement an adaptive filter to match one of the signals to the other. To determine whether to correct the signal from the omnidirectional or the dipole microphone, record an impulse signal to measure the group delay of both microphones. Match the microphone with the shortest group delay to the microphone with the longer group delay to ensure the filter will be causal.

The correction filter could be a FIR or an IIR filter. There are a multitude of filter designs and adaptive training approaches for both types of filters. In most cases, we recommend using an IIR filter as IIR filters generally have lower resource requirements and lower latency. For more information on implementing an IIR filter, refer to chapter 23 "Adaptive IIR Filters" by Geoffrey A. Williamson in *Digital Signal Processing Handbook*[1].

Conclusion

Combining a dipole and omnidirectional microphone into one system allows flexibility to select a polar pattern for the product's use case. Using traditional DSP or machine learning algorithms, this can even be done dynamically to adjust the polar pattern to reduce as much background noise as possible.

Additional Support

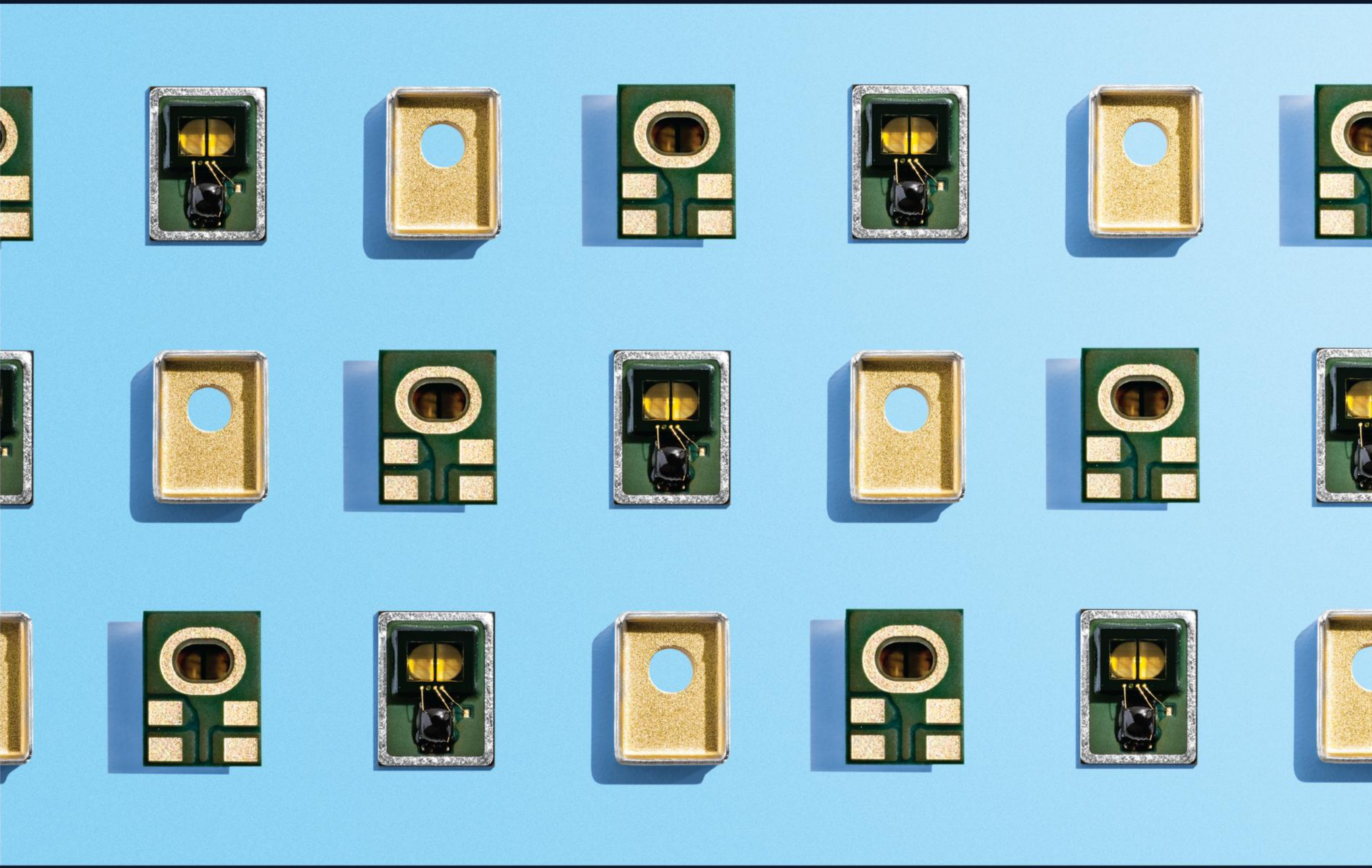
For further information on Soundskrit's products, visit our website at http://www.soundskrit.ca where you can find more application notes, datasheets, and purchasing information. If you have any questions or need technical support, please reach out to applications@soundskrit.ca.

Revision Label	Revision Date	Sections Revised
-	April 2023	Initial release
B	February 2025	Minor improvements, plot update

[1] G. A. Williamson, "Digital Signal Processing Handbook," V. K. Madisetti and D. B. WIlliams, Eds., CRC Press LLC, 1999.

Soundskrit developed the first high-performance directional MEMS microphone on the market, leveraging years of research in bio-inspired MEMS based on how spiders and other insects in nature hear. In combination with Soundskrit's in-house audio processing algorithms, directional microphones can be used to capture and isolate any sound in an environment with a fraction of the size, power, and computation of traditional omnidirectional-based microphone arrays.

Soundskrit was founded in 2019 and is headquartered in Montreal, Quebec with an R&D facility in Ann Arbor, Michigan.



soundskrit
Hear the impossible.