Microphones

Microphones are the most critical element in the recording chain. Every sound not created purely electronically must be transduced through a microphone in order to be recorded. There is a bewildering array of available microphones and each may be optimally suited to a different application. One of the most important areas of knowledge for a recording engineer is the proper application of microphones: selection and placement both require a solid understanding of how microphones work to obtain the best possible results. This is ultimately achieved through experience, but understanding the properties of the various microphones can accelerate the process.

Microphones may be classified both according to the physical method of transduction and to their spatial sensitivity pattern. While these behaviors are related, the relationship is complicated and requires a thorough examination of the different physical transducer types. The main types of commonly used transducers are dynamic, where a conductor moves within a magnetic field in response to the force applied by an incident sound wave, and condensor, where one plate of a capacitor moves relative to the second plate. There are variations on these themes and some other types are beginning to be developed, but we can begin by examining the standard dynamic and condensor types.

Dynamic microphones depend on the principle that a changing magnetic field induces current flow in a conductor in that field. It doesn't matter which is changing, the field strength or the conductor's position within the magnetic field. In the case of moving-coil dynamic microphones, the conductor is a coil of very fine diameter wire, situated within a fixed magnetic field and attached to a diaphragm in contact with the air. As the pressure varies, the diaphragm moves in response to the changing force applied by the moving air. The coil produces a small voltage as it moves in the fixed magnetic field. The voltage is proportional to the velocity of the coil movement through the magnetic field. This voltage is fed, usually through a transformer, to an external amplifier optimized for low input impedance and high gain. While conceptually simple, the implementation of the dynamic microphone is not so straightforward. The mass of a coil of wire is not negligible, so the construction of the element requires special care to make sure the element can move easily enough to allow the small air pressure variations to produce a measurable voltage at all audible frequencies. There are also acoustical considerations necessary to produce a consistent output level for sounds originating from different directions and of different frequencies. This often leads to complicated acoustical labyrinths built into the housing of the microphone in order to control the frequency response and directional sensitivity.

Capacitor (condensor) microphones work on a different principle: one plate of a capacitor is accessible to the air while the other plate is fixed. The capacitor is charged by an applied voltage or by a permanent charge on one of the plates. As air pressure changes, it causes the distance between the plates to change, thus changing the capacitance. The output voltage of the capacitor microphone is proportional to the displacement of the diaphragm rather than to its velocity as is the case for dynamic microphones. The change in capacitance is monitored electronically and converted to a proportional voltage by the microphone’s electronics. Unlike the dynamic microphone, the capacitor microphone requires a supplied source of voltage to operate. It also requires electronics in the microphone to convert the capacitance change to a voltage. The advantage of the capacitor microphone comes largely from its low mass moving element, making it easier for small, high-frequency air pressure changes to generate a proportional output voltage. As in the case of the dynamic microphone, capacitor microphones may also employ acoustical labyrinths to create a particular spatial sensitivity pattern.

In addition to the type of microphone construction, we also classify the way the microphone responds to sounds coming from different directions. A microphone may be equally sensitive to sounds regardless of direction, a type known as omnidirectional, or it may favor sounds from a certain direction over others, in which case we call it a directional microphone. It is very difficult to make a microphone that behaves perfectly according to theory; for example, omnidirectional types have some sensitivity differences to sounds at particular frequencies coming from some directions. All real microphone sensitivity patterns vary from theoretical predictions and these imperfections contribute to the distinctive sounds of the microphones we use. Understanding how theory relates to practice is the goal of recordists who must use microphones to begin the recording process.

Within each basic type of microphone, dynamic and capacitor, variations in design produce differences in how the microphone sounds, given the same input. These differences relate to the construction of the transducing element itself and to the acoustical elements of the microphone body. The size of the sensing element affects how it interacts with sounds of different wavelengths. The mass of the sensing element determines how effective the transduction is at different frequencies and intensities. The acoustical design of the housing affects the sensitivity and frequency response to sounds coming from different directions. The efficiency of the conversion from sound pressure to voltage affects the noise level inherent in the microphone. All of these factors contribute to the overall sound of the particular microphone.

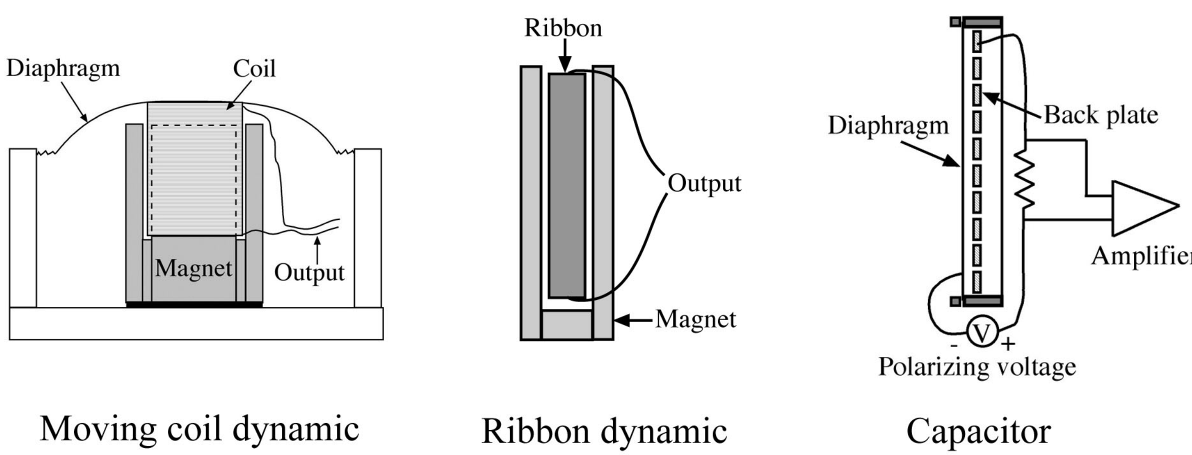


Fig 1 Microphone transducer types

Dynamic microphones work on the principle of a moving electrical conductor within a stationary magnetic field. The most common type of dynamic element is the moving coil in which the diaphragm and attached coil moves in and out through a magnetic field, producing a voltage in the coil. A second type of dynamic microphone is the ribbon microphone, in which a small thin ribbon of corrugated metal is placed within a magnetic field and allowed to move in response to air movement. Ribbon microphones have lower conversion efficiencies and produce lower output voltages for a given sound level, but they are lower in mass than a moving coil element and can produce better high-frequency transduction. Because both the front and back of the ribbon are in contact with moving air, the ribbon microphone is sensitive to sounds from the front and rear but not to sounds from the sides. This produces the distinctive figure-eight polar sensitivity pattern, although the pattern may be altered by applying acoustical chambers to alter the access of the air to the ribbon.

Dynamic microphones tend to be rugged, although some ribbon microphones can be very sensitive to air blasts that permanently distort the ribbon and older such microphones may be damaged by improper storage or the accidental application of phantom power. Some ribbon microphones have markings to assure they are stored oriented so that the ribbon does not sag over time. A favorite use for dynamic microphones is the hand-held vocal microphone, with the Shure SM-57 and SM-58 being two typical examples, since they are relatively insensitive to rough handling. (The joke about using them as hammers in an emergency may be an exaggeration, however.) Dynamics also tend to be favored where high sound levels occur, as with percussion instruments and guitar amplifiers.

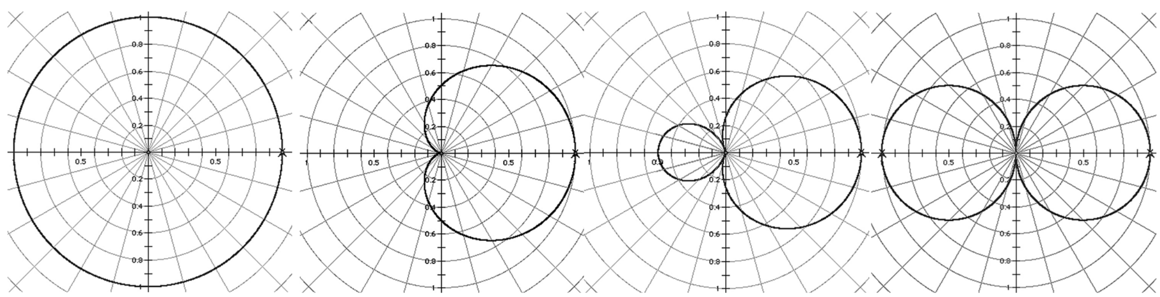
Probably the most sought-after microphones are the large diaphragm capacitor microphones made early in the 20th century by companies like Neumann, Telefunken and AKG. These microphones create a larger-than-life sonic image that we associate with the top recording artists of all time, like Frank Sinatra, Bing Crosby, and Ella Fitzgerald. To understand how these microphones produce “that sound”, we need to understand how they produce their output and how they interact with incident sound waves.

The concept of capacitor element operation is quite simple: one plate of a capacitor is stretched tightly by a supporting ring and placed close to a second plate. A voltage is applied between the plates so that as the stretched plate moves in and out a tiny distance, it changes the capacitance of the element, which forces charge to flow from plate to plate. The small current is made to flow through a very large resistor and the resulting voltage drop is amplified to become the output of the microphone. The implementation of this system is imperfect, so there are compromises that must be made to create a usable microphone. Some capacitor microphones use a permanently charged plate, usually the back plate, instead of an applied voltage to polarize the capacitor: they are known as electret capacitor elements. Electret capsules still require an applied voltage to power the electronics. The construction of the capacitor element involves art as well as science and the technical details of production are closely guarded secrets in many cases. The materials used play a role as well as the design and manufacturing techniques: there are many variables in building a capacitor microphone and the quality can vary dramatically for two similar-looking microphones. Since the mass of the diaphragm is important, the composition, thickness, coating and tensioning of the diaphragm are critical. The tensioning of the diaphragm must be precise and accurate, which makes the hand-assembly of capacitor capsules necessary and increases the cost of high-grade capacitor microphones. A variation on the capacitor microphone is manufactured by Sennheiser, who instead of a DC polarization uses a radio frequency signal to measure the changing capacitance.

Directional sensitivity

Microphones may be classified by their spatial sensitivity as well as by their transducer type. A microphone may be equally sensitive to sounds reaching the capsule from any direction, or it may be more sensitive to sounds coming from some directions than from others. In applying a directional microphone, the spatial sensitivity is important because it affects the quality of the sound coming from off-axis directions differently than sounds originating on-axis and that can significantly change the recorded sound.

While there is no direct relationship between transducer type and spatial sensitivity pattern, there is an aspect of microphone behavior that relates directly to spatial sensitivity. Microphones may be classified as to whether they are sensitive to absolute pressure, in which case they are necessarily omnidirectional, or to a pressure gradient from front to back, in which case they are directional. Pressure microphones are sensitive only to the pressure at the front of the capsule and have no way of determining from which direction the pressure wave originates. Pressure gradient microphones produce an output proportional to the difference in pressure between the front and back of the capsule and therefore react differently to sounds from different directions. Pressure gradient microphones often employ acoustical signal manipulation within the body to achieve the desired spatial sensitivity by delaying and attenuating the sound that strikes the microphone rear ports. By changing the path length and acoustical resistance, the microphone can be designed to create the desired spatial sensitivity pattern.



omnidirectional	cardioid	hypercardioid	figure eight
$r=1$	$r=0.5+0.5\cos\theta$	$r=0.25+0.75\cos\theta$	$r=\cos\theta$

Fig. 2 Polar patterns and their polar equations

The polar patterns shown in Figure 2 show the various spatial sensitivity patterns and the equations that describe them. Often called polar patterns, the radius r is a measure of the microphone's sensitivity at the angle θ relative to the front of the microphone, which here is the positive x-axis. It can be seen that the overall spatial sensitivity is the sum of contributions from an omnidirectional (pressure) term and a bi-directional cosine (pressure gradient) term. By varying the ratio of the terms, we can create any desired polar pattern. In fact, variable-pattern microphones accomplish this by combining two capsules, although not always the two mentioned: a back-to-back cardioid pair is often used, as it is easier to construct.

Unfortunately, the polar patterns presented by manufacturers may be somewhat misleading. Real spatial sensitivity patterns deviate from the ideal ones and often vary dramatically with frequency. Off-axis response can seriously alter the sound of a microphone in real-world use, since in a room there are reflections of the direct sound picked up off axis and combined with the on-axis signal. The combination can radically alter the transduced sound quality through frequency-dependent reinforcements and cancellations. One of the major differences between great microphones and others is the smoothness of the off-axis frequency response. Since omnidirectional microphones have better off-axis response than directional microphones, they tend to produce less coloration in practical use.

For directional microphones, an important characteristic is the ability of the transducer to select sounds coming from the on-axis direction and reject those coming from other directions. The nulls in the polar patterns indicate the direction from which little or no pickup will occur. The figure-8 pattern has very good rejection of sounds approaching from the sides and can be used to record a singer also playing guitar, for example, if the null of the guitar mic is aimed at the singer's mouth surprisingly little vocal sound will appear in the guitar microphone. Since off-axis sounds are generally ambient sounds, the ratio of on-axis to off-axis pickup gives a measure of the microphone's ability to focus on the desired direct sound and reject ambient sound. This characteristic is known as the "reach" of the microphone, a measure of how far the microphone may be placed from the source while maintaining the ratio of direct to reflected sound. It is often desirable to place microphones at some distance from an instrument, since that allows sound radiated from the whole instrument to be picked up. A simple measure of a microphone's directional selectivity is the distance factor (DF), whereby the microphone's selectivity is measured against that of the omnidirectional pattern. With the omnidirectional DF=1, the cardioid and figure-eight have DFs of 1.7 and the hypercardioid has a DF of 2, hence a hypercardioid can be twice as far from the source as an omnidirectional and maintain the same ratio of direct to ambient sound. Other ways to measure this characteristic include the random energy efficiency (REE) and the directivity factor. All give essentially the same information. Figure 3 shows the relative distances for equivalent direct-to-ambient pickup.

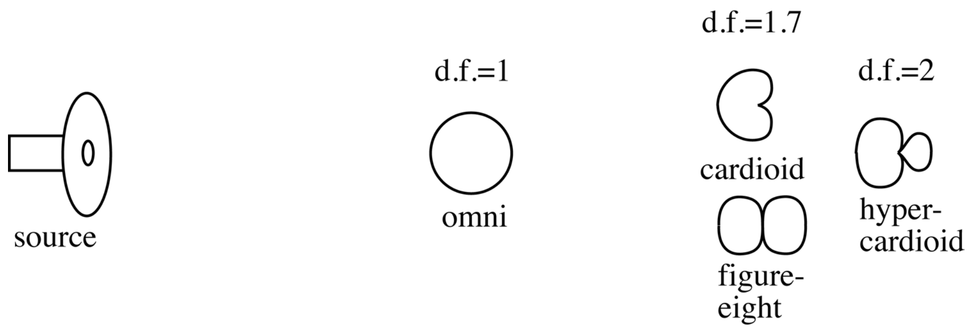


Fig.3 Distance factor

Directional microphones all exhibit some degree of proximity effect, an increase in output level for low-frequency sounds as the distance from the source decreases. For cardioids, often used for close vocal recording, this means that the closer you sing to the microphone, the more the lower frequencies are boosted. While the effect can be used artistically, it may also cause problems since it tends to increase the effect of breath sounds and plosives like p and b phonemes. Many directional microphones have selectable high-pass filters built-in to reduce the effect when not desired. The cause of the phenomenon is explained by the assumption that sounds behave as point sources and therefore propagate as spherical waves in the near field. Very close to a vibrating object, the majority of the sound energy is contained in the velocity of the particles; it takes some time for the pressure to build. Further from the source, the energy in the pressure increases relative to the velocity. At great distance, both pressure and velocity decrease slowly with increasing distance as the sound wave develops a planar shape. When a microphone is placed close to a sound source, the pressure gradient is large for long wavelengths (low frequencies) so a directional microphone, sensitive to pressure gradient, produces more output than at greater distance. Pure pressure gradient (figure-8) microphones have the most pronounced proximity effect while cardioids display about 6 dB less.

The dimensions of a microphone affect the way the sensing element interacts with sound waves. Since the behavior of waves depends on their wavelengths relative to the size of the object with which they interact, we need to consider the capsule dimensions relative to the sound wavelengths we need to transduce. Most microphone elements are in the 12mm (1/2") to 25mm (1") range. There is a definite difference in the behavior of microphones even within this relatively small range of diaphragm dimensions. Large diameter elements, 25mm or larger, begin to exhibit shadowing behavior at higher audible frequencies. Larger diaphragms also begin to exhibit inherent resonances that alter the output signal.

For this reason, small diaphragm elements produce better results in many applications, especially in distant room miking situations.