How Microphones Work: Part 1

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A big part of the science (and art) of recording involves microphones: which ones to use and where to put them. They are the tools of the recording engineer's trade and they come in many different flavours. The engineer needs to understand sound and how microphones capture it if they are to get the best result during a recording session. So, how do microphones differ? Why are some large and some small? How do they pick up sound from different directions? Coming up over the next few pages is a physicist's guide to microphone technologies and techniques (i.e. what they are and what to do with them).

Before looking at the workings of a microphone, it's worth remembering what they're for: capturing sound. OK, that's the easy bit, but what *is* sound and how can we capture it? Well, we're surrounded by an atmosphere which is handy because, amongst other things, it contains the oxygen we need to breathe in order to stay alive! This atmosphere exerts a pressure on us. We're not aware of this atmospheric pressure because it's always been there and it doesn't change much, and even if it does change, it changes slowly. When you watch the weather forecast you hear about regions of high and low pressure. When our weather changes from rainy to sunny (perhaps because of a change from low to high pressure) this change takes some time to occur. But if this pressure was to vary up and down very quickly – between twenty times a second and twenty thousand times a second – then we would sense these pressure variations as sound. In fact we'd often sense these pressure variations as a *very* loud sound, because pressure changes that occur in our weather cycles are usually much bigger than those that are caused by objects that make sound. So, changes in atmospheric pressure that occur when something is making a noise are fast and small; changes in atmospheric pressure that occur as part of our weather are (relatively) slow and big.

Our atmosphere, the air that surrounds is, is the medium through which sound travels. It travels as a disturbance in that medium, in the same way that the ripples caused by throwing a pebble into a pond travel outwards as a disturbance of the pond water. In fact the waves that ripple out from the point where the pebble hits the water are similar to the invisible pressure variations that travel outwards from an object making a sound. We can't see these variations but, thanks to the extraordinary sensitivity of our ears, we can hear them. If we want to record sounds then we need a device which will capture these pressure variations and convert them into an electrical signal which can be recorded (or transmitted or amplified). A key part of any microphone is its diaphragm which, just like the ear drum, is light-weight but has a large surface area. The low mass

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means that it has low inertia (making it easy to get moving) and the large surface area captures a larger force (more work is done to move it): remember that pressure is defined as 'force per unit area', so a larger area will lead to a larger force. Just like our ear drums, as the pressure changes at the microphone diaphragm, so these cause the diaphragm to move.

The arrangement shown in Figure 1a is one that is found in many microphones. The air in the space behind the diaphragm is constantly at atmospheric pressure: it is difficult for air to enter or leave this enclosure and so the amount of air (and therefore its pressure) can only change very slowly. This means that the pressure behind the diaphragm can change with the slow changes in overall atmospheric pressure, but not with the fast changes due to sound waves. If the air in front of the diaphragm is higher in pressure then the diaphragm will be pushed inwards, towards the enclosure. If the air in front of the diaphragm is lower in pressure than the atmospheric pressure in the enclosure then it will be pushed outwards, away from the enclosure. So, as a sound wave (which remember is a series of high and low pressures moving through the air), arrives at the microphone the diaphragm moves inwards and outwards. This kind of microphone is known as a 'pressure' (P for short) microphone, because it responds to changes in pressure in front of the diaphragm.

Another type is the 'pressure gradient' microphone which is shown in Figure 1b. Whereas a pressure microphone has an enclosure which keeps the pressure constant on one side of the diaphragm, a pressure gradient microphone has a diaphragm which is exposed to the variations in pressure on *both* sides. This is referred to as a 'pressure gradient' (PG) microphone because it measures the difference in pressure between the front and back of the diaphragm; in other words it measures the slope, or the gradient, of the pressure across the diaphragm. For a P mic waves arriving from any direction will cause the diaphragm to move in the same way and to the same extent. Therefore it has an 'omnidirectional' pick up pattern, meaning that it is equally sensitive to sound from all directions (omni means 'everywhere'). You can see this directivity pattern in Figure 2a. This pattern is different to that for a PG microphone. A PG microphone is most sensitive to sounds arriving from directly in front and behind it and is not sensitive to sounds arriving from the sides. In fact for sounds arriving at 90 and 270 degrees from the front of the microphone sound is not picked up at all. This directivity pattern is shown in Figure 2b and, for obvious reasons it's usually referred to as a 'figure of eight' pattern. Because a PG mic is sensitive to sound arriving from two directions it is also referred to as 'bi-directional' mic.

So, why does a PG microphone have this distinctive directivity pattern? Well, when sound waves arrive from the front (or from behind) there is a difference in pressure between the two sides of the diaphragm; but when waves arrive from the side the pressure on either side of the diaphragm is the same. You can see this in Figure 3: the darker areas represent regions of high pressure and the lighter bands are regions of low pressure. Although the PG is equally sensitive to sounds arriving from the front and the rear, the diaphragm moves in the opposite direction for a sound arriving from the rear to that which it moves in when the same sound arrives from the front. In the technical jargon the *phase* of its output is *reversed* for sounds arriving from the rear.

Whilst omni microphones are good for capturing sounds from all directions (useful if you want to capture the reverberation of a room, or you have a large number of performers spread right around the microphone), the bidirectional microphone is useful for drama, interviews or any situation where there are two people facing each other and you just want to capture the sound that they are making, rather than sounds from the sides too. Having this choice between omni and bi-directional is very useful. Yet there are many situations in which we want to be able to favour sound which arrives from one direction only, for example where we want to capture the voice of a singer but not the sound made by the audience to the sides and in front of them. How can we make a microphone which has this 'uni-directional' capability? The answer is to combine pressure and pressure gradient operation.

Imagine that we place a pressure and a PG microphone side by side and we add together, in equal amounts, the signals that they produce. Let's first think about sound arriving from the front. Both microphones respond in the same way: they are sensitive to sound arriving from this direction and their diaphragms move in the same way. When we add the two signals together we get a very strong combined signal, meaning that our P + PG microphone is very sensitive to sound arriving from the front. Moving around to the side there is no signal from the PG mic, but there is still output from the P mic: this means our combined signal is only half as strong as it was for sounds arriving from the front. For sounds arriving directly from the rear the P diaphragm moves in one direction and the PG diaphragm moves the *same* amount in the *opposite* direction. When these equal and opposite movements are combined they cancel each other out, so there is no signal at all from the P + PG microphone. So, we have very good sensitivity to sounds arriving directly on-axis from the front, medium sensitivity to sounds from the side and no sensitivity at all to sounds arriving directly from behind. This gives rise to the directivity pattern shown in Figure 4. This is known as a 'cardioid' pattern because it resembles a simple heart shape ('cardioid' is from the same family of words as 'cardiac'). This is a uni-directional mic, because it is most sensitive in one direction, rather than all (omnidirectional) or two (bi-directional) directions.

In fact there are a number of different types of cardioid: sub-cardioid is somewhere between an omnidirectional and cardioid. Super- and hyper-cardioid patterns are at different points between a cardioid and a figure-of-eight; they are shown in Figure 5. They all have their different uses in the studio: they each capture different amounts of reverberation, they enable different kinds of stereo techniques to be used and, because of differences in the sonic character between P and PG diaphragms, they offer a different sound quality. If recording engineers properly understand how their microphones are capturing and converting sound energy into electrical energy, then they know how those microphones will transfer sound between the live performance and the loudspeakers. This is essential if recording engineers are to get the sound that they want in the studio.

Directivity isn't the only thing to consider when selecting a microphone for a particular recording job. The way in which the movement of the diaphragm is converted into electrical energy is very important to the sonic character of the mic. We'll look into how microphones perform this conversion from one form of energy (acoustic) to another (electrical) in the next article in this series.

Biography
Jez is a lecturer in the Department of Music at the University of York, before that he spent eight years in the Department of Electronics. In both departments he has lectured and conducted research in Music Technology. He also works as a freelance recording engineer, DJs and is a trustee of Accessible Arts and Media, a York-based charity.

Figure 1a: pressure microphone

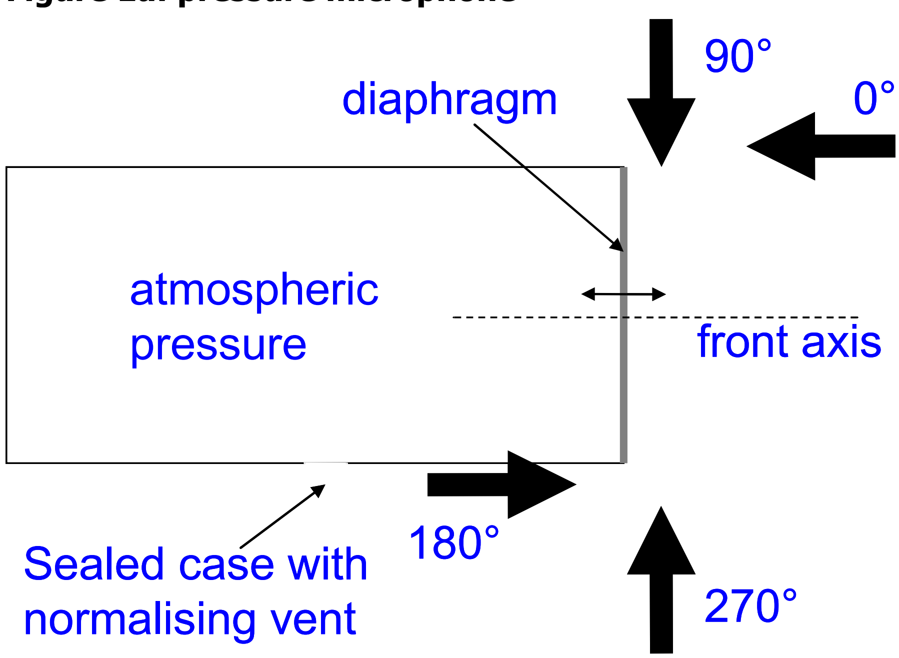


Figure 1b: pressure-gradient microphone

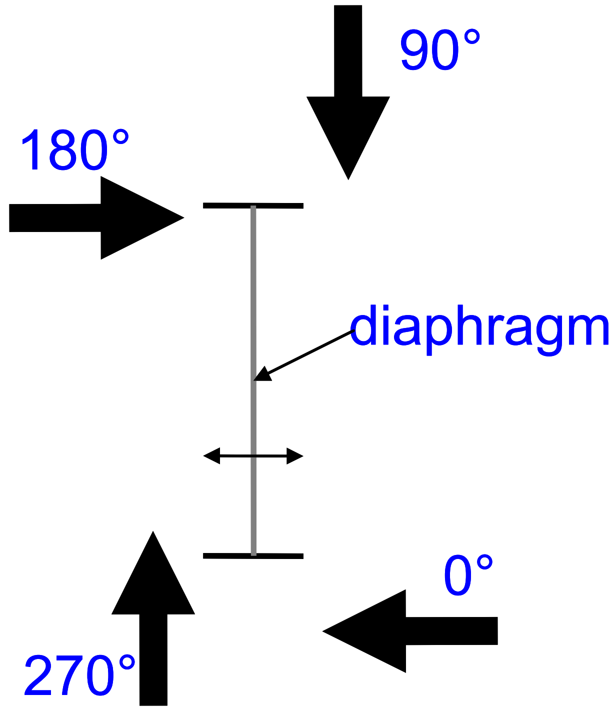


Figure 2a: omnidirectional pickup pattern

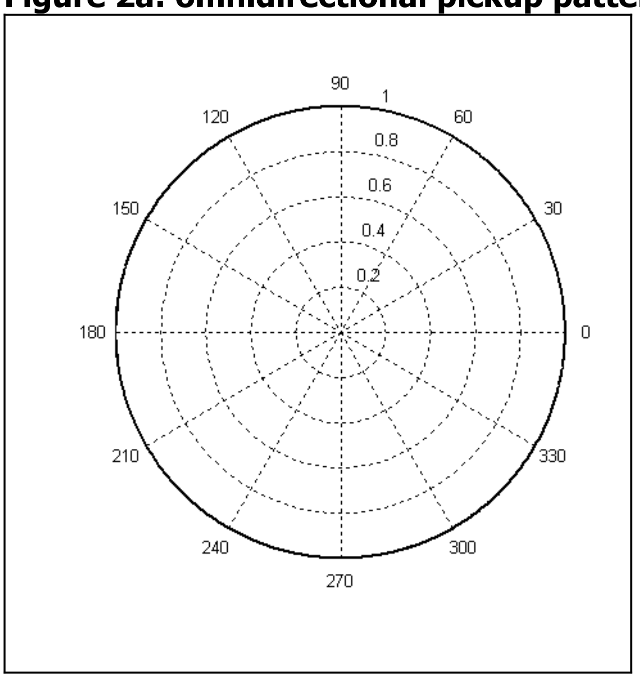


Figure 2b: Figure-of-eight pickup pattern

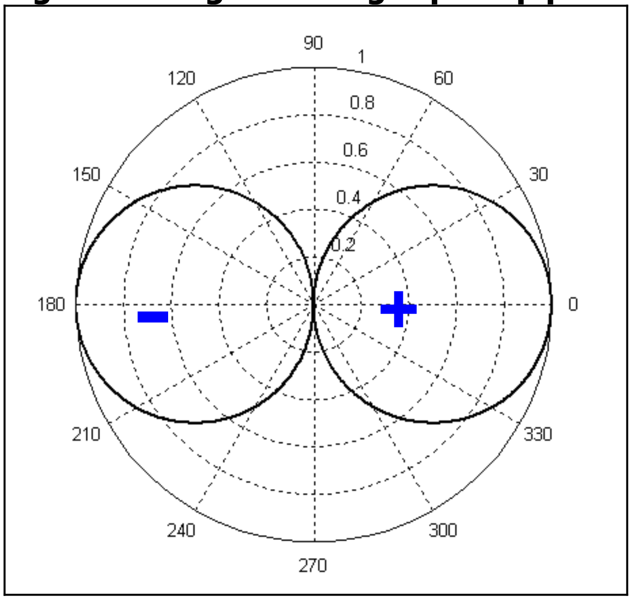


Figure 3 (top): Pressure gradient for sound arriving from in front of (or from behind) the diaphragm. Because there is a difference in pressure between the different sides of the diaphragm it will move in response to sound arriving from this direction.

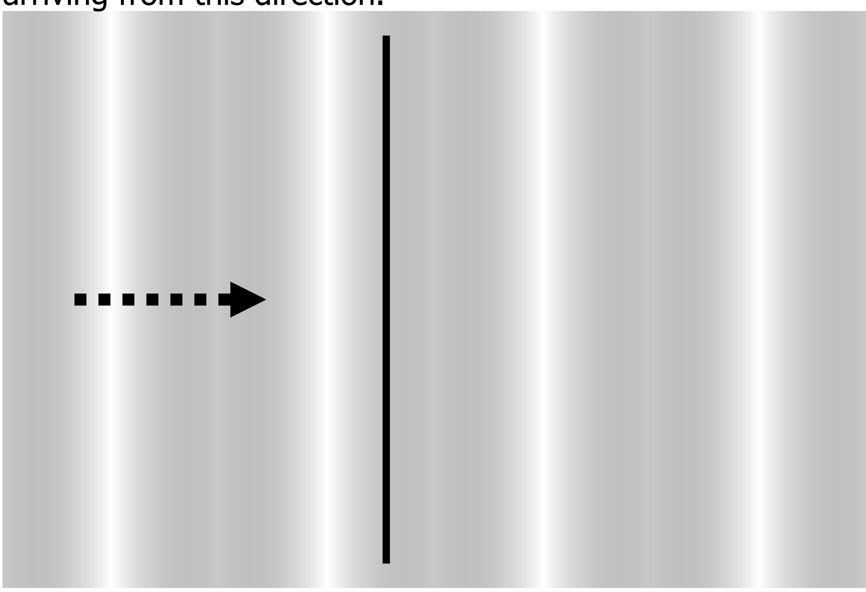


Figure 3 (bottom): Pressure gradient for sound arriving from the side of the diaphragm. Because sound waves are arriving from the side the pressure at any point along the diaphragm is the same on either side. This means that there is no net force acting on it and it does not move, so there is no output from this mic for sounds arriving from this direction.

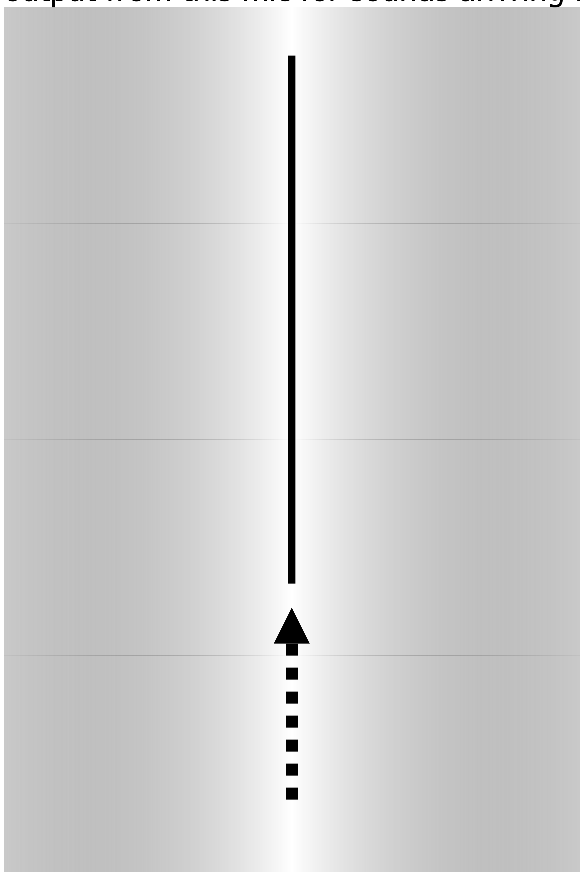


Figure 4: Cardioid pickup pattern

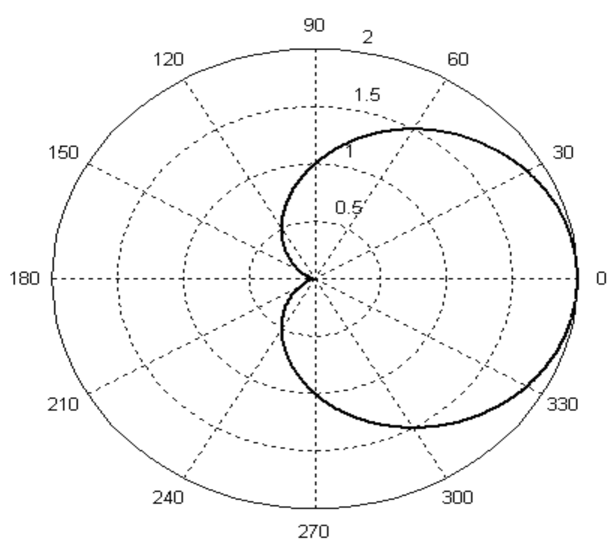


Figure 5a: Super-cardioid pickup pattern

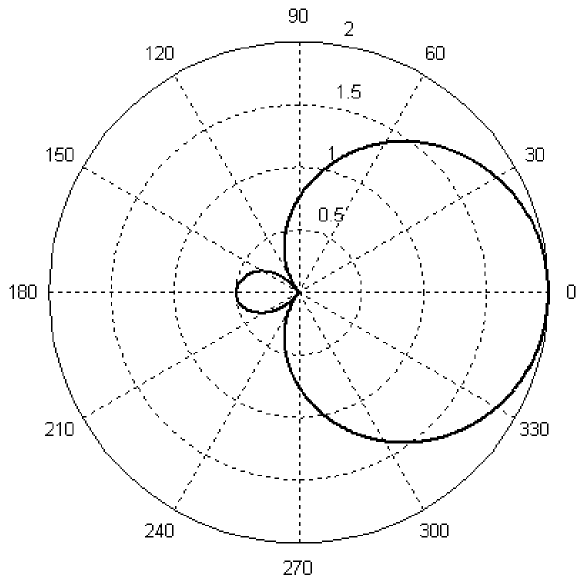
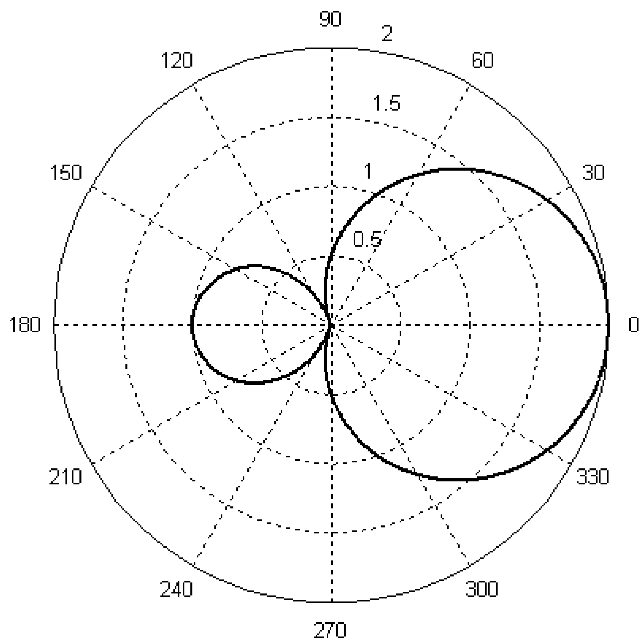


Figure 5b: Hyper-cardioid pickup pattern



Possible background image: