technique using directional mics

polar exploration

UNDERSTANDING AND USING DIRECTIONAL MICROPHONES

Many of us do the vast majority of our recordings using mics with a cardioid polar pattern, but alternative patterns can give radically different — and sometimes much better — results. Hugh Robjohns explains the differences between these designs and the applications to which they're suited.

All microphones work by sensing the pressure difference on either side of a thin sheet known as a diaphragm. Ultimately, there are really only two fundamental microphone principles — pressure-operated (omnidirectional) and pressure-gradient (directional). In a pressure-operated mic, one side of the diaphragm is open to the atmosphere and is able to respond to the microscopic changes in pressure representing sound. The other side faces an enclosed volume which effectively contains a fixed 'reference' air pressure so the diaphragm moves in response to the difference between the passing sound wave and the reference. It doesn't matter from which direction the sound wave comes, or where it is headed, the microphone merely senses its presence, and is therefore omnidirectional in its polar pattern.

In a pressure-gradient mic, the diaphragm is still sensitive to the difference in pressure on either side, but this time both sides are exposed to the atmosphere, and therefore to the changing pressure caused by passing sound waves. A sound arriving in the plane of the diaphragm will present identical pressures on both sides and, consequently, there will be no net movement. There is no pressure gradient across the diaphragm and so the microphone is deaf to sounds on this axis. In contrast, sounds arriving perpendicular to the diaphragm will create a large pressure difference between front and rear, and it will be moved a maximum amount as a result. This mechanism's polar pattern therefore looks like a figure eight, with the maximum sensitivity to sound on-axis to the diaphragm and the minimum sensitivity perpendicular to this.

There is one other important point to note about pressure-gradient microphones. A suck on the front produces the same output as a blow on the back! In other words, the microphone has polarity, since a positive pressure on the front of the microphone moves the diaphragm in the opposite direction to a positive pressure at the rear: the two lobes of the polar pattern are of opposite polarity. This becomes significant when we start to combine microphone polar patterns... which we will do now! Every other pattern is derived from some combination of the pressure-gradient and pressure-operated designs (though some sources refer to the pressure-gradient design as a 'velocity' microphone).

The Cardioid Combination

The most common microphone pattern has to be the cardioid. However, the cardioid is not a primary microphone design, but is actually a combination of both pressure-operated and pressure-gradient components. During the early development of microphones back in the 1930s, a cardioid response was achieved by mounting two separate microphone capsules — an omni and a figure-of-eight — within the same physical housing. There outputs were combined electrically and the resulting polar pattern was cardioid. These days slightly more elegant methods are used, but the underlying principle is the same, and I'll come back to it in just a moment.

First, let us consider how combining an omnidirectional pattern and a figure-of-eight produces the classic cardioid. Consider the two with equal on-axis sensitivity and overlaid such that their centres are aligned. The combined sensitivity to sound can be arrived at by simply adding together the sensitivity in each direction (see Figure 1). Starting on-axis (at the zero-degree point of the circle), both patterns are equally sensitive and in the same polarity, so the result is doubled sensitivity in the forward direction. Moving around to the side, the figure-of-eight makes no contribution at all, so the resulting polar pattern closes in to the same sensitivity as the omni.

Looking now to the rear, the omni and figure-of-eight have the same sensitivity — but the figure-of-eight is operating in the opposite polarity to the omni, so the two therefore cancel and there is no sensitivity to the rear at all. The shape of the resulting polar pattern can be loosely described as an inverted heart shape — hence the name 'cardioid'.

The other familiar polar patterns — sub-cardioid, hypercardioid and supercardioid — are created by varying the proportions of the omni and directional components. If, for example, there is a greater amount of omni, the combination tends towards sub-cardioid, with a much weaker rear rejection. If the figure-of-eight component is larger, a small opposite-polarity rearward tail will remain, giving the hyper- and supercardioid patterns.

Most modern cardioid microphones also employ a mechanical time-delay technique to maximise rejection of rearward sounds. The diaphragm is arranged to be open to the front of the microphone, but its rear faces into a labyrinthine chamber which is open to the rear (or sides). The

Selecting A Directional Mic

The right choice of directional mic will depend very much on its intended application. For example, if you are looking for a studio vocal mic which will be used at a reasonable distance from the signer's mouth (and hopefully behind a decent windscreen), don't select something which is designed to be used right up against the teeth in a live PA environment!

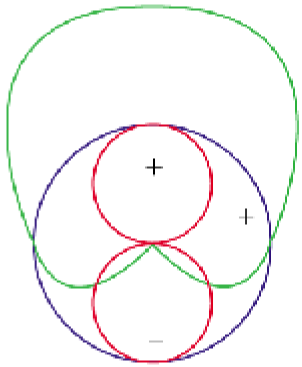
If the mic will be used by several people simultaneously, such as a backing trio, make sure the frontal acceptance angle of the mic is broad enough to accommodate them — a wide cardioid is called for here, rather than a narrow one. Check out the published polar response plots and try moving across the front of the mic whilst listening to its output to establish how tight or broad the useful working area is. It is also important to listen to the character of the mic with off-axis sounds. Does the response change smoothly? Is the rejection null equally strong and at the same angle for all frequencies?

If you are selecting a pair of microphones for a coincident stereo application they will need to be well matched. A good test is to mount the mics one directly above the other, as close as you can, but both facing in the same direction. Feed one to each channel of the monitoring and have someone walk in a circle around them talking all the time. Although the signal level will rise and fall according to the polar pattern, the stereo image should remain solidly in the centre. If you find the image wanders, or certain parts of the frequency spectrum (sibilants of low frequency usually) appear to come from somewhere other than the centre, the chances are that the microphones do not paths through the chamber to the rear face of the diaphragm are sufficiently convoluted to take sound a finite time to traverse (see Figure 2), and that time is set equal to the time taken for sound to travel from the rear of the microphone to the front. Thus rearward sounds will arrive at both sides of the diaphragm simultaneously and cancel out, while frontal sounds will be picked up with great sensitivity and the familiar cardioid response results.

have identical polar responses at all frequencies, and are therefore not suitable for coincident stereo applications.

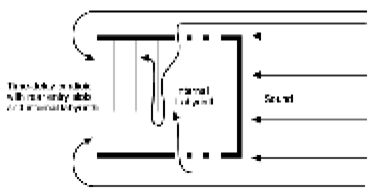
Directional Characteristics

Armed with the fundamental principles of first- and second-order directional microphones, there are now a few practical points to consider. A pressure-operated microphone simply compares sound-pressure variations in the environment around the microphone with the fixed internal reference. Accepting that the diaphragm will be too stiff and heavy to respond to very high frequencies or very small pressure changes, the system is inherently capable of equal sensitivity across the entire frequency range. The same is not true, however, of a pressure-gradient microphone, and this is the reason for some peculiarities inherent in the behaviour of any microphone with some degree of directionality.



The first problem is one of sensitivity to low frequencies. Sound — especially low-frequency sound — can find a way *around* a pressure-gradient capsule, given time (see Figure 3). After a pressure wave arrives at the front of the diaphragm (causing the diaphragm to move), it passes around the mic and impinges on the rear, creating a pressure gradient. The nature of high-frequency sound is that the pressure changes occur very fast, and the time taken for the sound to move from the front to the rear of the diaphragm means that the two pressure waves are essentially unrelated. However, the pressure changes that represent low-frequency sound are very slow, and so the pressure wave at the rear of the mic will be very similar to that at the front. Consequently, the pressure gradient will be very small, which means a small deflection of the diaphragm and very low signal output. If you were to plot the sensitivity of this arrangement against frequency you would find a rising response at 6dB/octave with very little output at all at low frequencies.

Clearly, this would not be a popular microphone, so the manufacturers design the mechanics of the diaphragm and capsule in such a way as to be much more receptive to low frequencies. Essentially, the suspension of the diaphragm allows it to move more easily at low frequencies. If designed properly, this results in a flat overall frequency response, but has two knock-on effects. The first is that directional mics are all inherehently sensitive to unwanted low-frequency vibrations, such as handling noise, wind, popping and so forth.



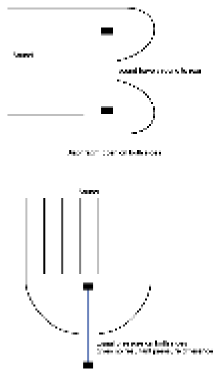
Secondly, the energy in a sound wave decreases with distance — because low-frequency sound radiates in circular waves whereas high-frequency sound tends to be more planar, low-frequency energy decreases much more rapidly over a given distance than high-frequency energy. This means that the low-frequency signal arriving at the rear of the diaphragm will have less energy than that at the front — but the reduction is very dependent on the proximity of the source. The problem with this is that the techniques used to re-equalise the microphone's frequency response have to assume the sound source is at a certain distance from the diaphragm. If the source is closer, the low-frequency portion of the signal will not have

decayed by as much as the designers had expected, and so the microphone will exhibit a significant bass boost. This characteristic is known as the Proximity Effect.

Directional microphones designed to be used very close to the source, such as the ubiquitous Shure SM58 vocal microphone, have a flat response *only* when used with the mic close to the vocalist's lips. Put one on a podium stand 20cm away from someone speaking and it will sound very thin! Conversely, placing a microphone balanced for a distant position close to the source will bring up the bass quite considerably. This is not a problem, as long as you are aware of it and use the appropriate microphone for the task, or take account of the proximity effect in some way.

Uniformity

Not all cardioids are the same! Although manufacturers like to apply a generic term to their microphones, the polar patterns can vary considerably. For example, some 'cardioid' mics have patterns that are quite narrow and relatively insensitive to sounds from the side, whilst others are much broader. Both can still be called cardioids, but suit different applications and have to be used differently.



Similarly, the polar response is rarely the same shape across all frequencies. There is a common tendency for the pattern to head more towards omni at low frequencies and become much narrower at high frequencies, sometimes even developing a hypercardioid-like tail. What this means in practise is that if the microphone has a flat response on-axis, moving around to the side will typically result in the response tilting so that there is more bass and less treble output. In other words, the character of the mic will change as sources move off-axis. Again, this variation in frequency will often determine the selection or suitability of a microphone for a specific purpose. In a multi-mic situation where the mic is used close and on-axis with the source, off-axis response is of little consequence. However, two cardioids mounted in a coincident stereo pair rely on uniformity of polar and frequency response across a very wide frontal angle. Any variations here will cause blurring and confusion of the sound stage, as well as introducing quality variations with spatial position.

Some Consequences Of Directional Designs

There are some fundamental rules that can be derived from the knowledge we now have of directional microphones. The first is that an effective form of shockmounting is essential to minimise their susceptibility to vibration. Many microphones have this kind of feature built-in, so that the capsule is mounted in soft rubber bushes, for example. Others rely on an external shockmount cradle where the microphone is suspended from elastic or rubber bands which isolate it from external interference. The bass roll-off switch found on many directional condenser mics is not intended primarily to remove rumbles caused by vibration — although it does help, of course — and a decent shockmount is by far the preferred solution.

Vibrations will not only reach the microphone through the mic stand. They can also enter the microphone body through the XLR connector and the cable, particularly if it is quite stiff. The best way to overcome this is to use the lightest and most flexible cable you can, and to clamp or tape it firmly to the stand to stop vibrations being carried into the mic. Location sound recordists for film and television use very light flexible tails between the mic and pole, and then a more robust cable back to the mixer, simply to avoid vibrations coming from this means of entry. Vocalists using a hand-held directional microphone can isolate cable vibration by making a loop of cable and trapping it between the fingers (not touching the microphone body) so that vibration along the cable is stopped when it reaches the hand, the onward loop to the mic being (hopefully) vibration-free. This technique also avoids straining the XLR connector with the weight of cable as the vocalist moves about the stage.

The other noise source directional mics are prone to is wind, which is essentially a low-frequency change in air pressure. The solution here is to include a windscreen of some form. Most manufacturers incorporate some form of protective wire mesh with a thin fabric gauze and rely on the user to add a foam windshield when further protection is required. Microphones intended for vocal use usually have a rather more effective windscreen as standard (the SM58 is a good example again), although further protection is often required, particularly if the vocalist has a poor technique. The worst offenders are the plosive sounds — Ps and Bs — which cause popping. Rather than directing these at the microphone, it can help a lot if they are directed slightly off-axis so that the worst of the wind blast misses the diaphragm. This is a technique which any vocalist can develop if they are made aware of the problem. It takes a little practise to make it instinctive, but it makes all the difference to a recording or live performance and is well worth the effort.

Sometimes the source of wind is not immediately apparent. I recall a Proms season at the Royal Albert Hall, many years ago, where cardioid microphones suspended from the roof above the audience functioned perfectly during the rehearsals, but were unusable during the performance due to wind noise. Everybody emits heat and an audience generates a great deal of heat. Hot air rises and on this particular occasion created sufficient wind to cause a major problem which was subsequently cured by fitting windshields!

The high-pass filter switch on the microphone is normally intended to provide a degree of compensation for the inherent proximity effect, which is why there are sometimes two different settings to allow close, medium, or far-field usage, all with reasonably flat responses. However, as the proximity effect only creates a fairly gentle bass boost, a little low-frequency shelving on the mixing console can normally tame it very well, particularly if the ability to tune the turnover frequency is available.

Techniques

There are three basic reasons why you might use a directional microphone rather than an omni design. The primary reason is to discriminate against sounds from certain directions, either to reject unwanted noises or to provide the varying sensitivity required in coincident stereo techniques. A second reason might be to take advantage of the non-linear nature of the polar response — the changes in character as sounds move off-axis, which can be used creatively in certain applications. Finally, a lot of DJs and radio presenters actually like the way in which the proximity effect enhances the quality and depth of their voice.

Considering the primary application first, the fundamental technique in using any directional mic is to identify the unwanted noise source(s) and aim the unresponsive side of the microphone in that direction, whilst keeping the wanted sound on-axis. Simple! The reality is often rather more complex than this sounds, but this is the essence of good mic technique. In practise, it may be necessary to move the noise sources, or reposition the wanted source in order to arrive at appropriate relative positions. It may also determine the choice of microphone pattern. A cardioid rejects sounds from 180 degrees relative to the on-axis position (ie. directly behind the mic), whereas a hypercardioid has nulls at around 130 and 230 degrees, and a figure-of-eight has nulls at 90 and 270 degrees. However, it should also be remembered that the last two patterns also incorporate a rear-facing pickup lobe which will capture an amount of sound from 180 degrees.

When Is A Directional Mic Not Directional?

Directional microphones, as I explained in the main text, work by having sound reach both sides of the diaphragm through the front grille and, usually, side slots. However, these side apertures are not always obvious — the Shure SM58 is, once again, a good example. Unscrew the protective grille and the rear entry ports can be seen towards the base of the capsule, but these become invisible when the grille is replaced. If the rear ports are closed off, the microphone effectively becomes pressure-operated and has the corresponding omnidirectional polar pattern, so if a vocalist holds the microphone in such a way that their hand blocks off these ports, all directionality and discrimination against unwanted sounds is lost! In a live PA situation, that means instant feedback, and in a recording environment it will mean a profound change in character of the ambient room sound or spill. It is not just vocalists' handling techniques that can create this problem. I have seen the set list taped to a microphone on stage with the tape blocking the ports, and also an oversized foam windshield taped on with the same result.

Let's put these ideas into some typical applications. Consider a stage vocalist with a single foldback speaker. The vocalist has to face forwards from the stage, and his position determines the on-axis angle of the microphone. If a cardioid was used, the foldback monitor would have to be placed directly behind it for the greatest rejection of spill. On the other hand, if a hypercardioid vocal mic is used it would be better to move the speaker around a little to intercept at the 130 or 230 degree angle — you could even use a pair of monitors at those angles if required.

Another example — and this is one of my favourites — concerns techniques for recording a singing acoustic-guitarist. Ignoring the possibility of obtaining an acceptable balance with a single mic, the typical solution would be to employ a pair of mics, one for the voice and the other for the guitar. In my experience, about 90 percent of engineers would choose a couple of cardioids and place one of them close to the vocalist's mouth and the other close to the sound hole of the guitar. You can see this done every day on the television and it obviously works, to a degree — but try listening to each mic individually. Unless the cardioids are very narrow in pattern and very insensitive, there will be almost as much guitar on the vocal mic as there are vocals on the guitar mic. In other words, there is little separation or discrimination and, consequently, little control available to balance voice and guitar (or, more importantly), to process them independently.

Thinking about the relative positions of the noise sources, it is clear that cardioid or hypercardioid mics can never be positioned in such a way that the axis of greatest rejection can face the unwanted noise source. However, a pair of figure-of-eight mics could be: the dead side of the vocal mic can be arranged to face the guitar and the dead side of the guitar mic to face the singer's mouth. If you try this, with careful orientation you can achieve stunning levels of separation — 20dB is achievable! I'm not claiming that this is the perfect solution (the rear lobes will capture a lot of room sound and the proximity effect may prove a problem, although these issues can be overcome without too much difficulty) but it certainly demonstrates the point about maximising discrimination between wanted and unwanted sounds.

Miking drum kits is another good example of using the dead axes of polar patterns to advantage. Drums are noisy and cymbals are noisier still, so angling and positioning mics to provide the greatest possible level of isolation is important. Often small changes in angle can make all the difference, particularly if the rejection null is as narrow and well defined as it tends to be with figure-of-eight mics and hypercardioids.

Glossary

http://www.sospubs.co.uk/sos/regular_htm/glossary.htm

SOUND ON SOUND

Europe's No1 Hi-Tech Music Recording Magazine Sound On Sound

Go To SOS Website Homepage

Media House, Trafalgar Way, Bar Hill, Cambridge CB3 8SQ, UK.
Telephone: +44 (0)1954 789888 Fax: +44 (0)1954 789895
Email: info@sospubs.co.uk Website: www.sospubs.co.uk