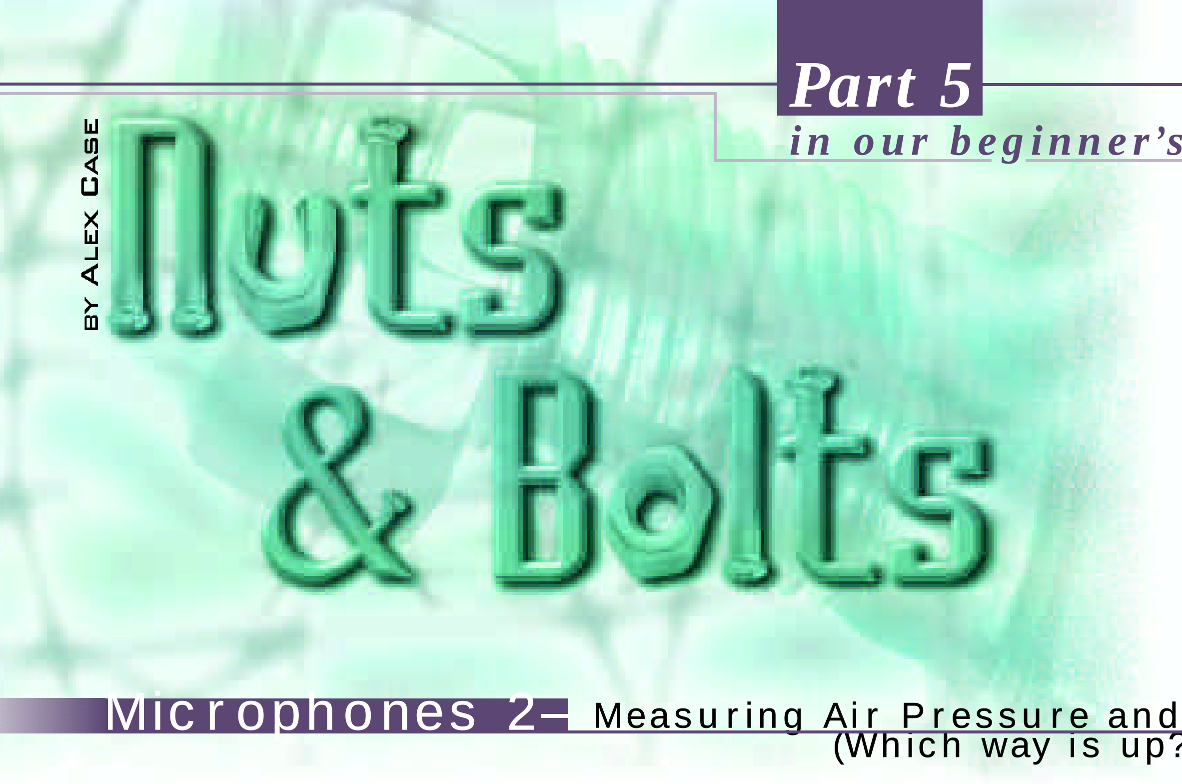

Part 5
in our beginner's series

BY ALEX CASE

Nuts & Bolts

Microphones 2– Measuring Air Pressure and Air Velocity (Which way is up?)

Consider the mighty kick drum, which today usually has its back head removed so that it is completely open on the audience side. The single-headed kick drum provides a useful picture for seeing how acoustic sound is created.

A component of the acoustic wave begins every time the drummer hits the kick drum. The beater strikes the head. The initial motion of the drum head is towards the audience, squishing the air together immediately in front of the drum head. This is an increase in pressure that radiates outward toward the audience.

Following the initial attack of the beater striking the head, the head vibrates freely back and forth. The unique pattern and speed of this vibration spells out that characteristic 'thump' we all know and love. Within this pattern, each motion of the drum head toward the audience creates a temporary increase in pressure, while the recoil of the head away from the audience creates a decrease in pressure.

In this way a series of compressions and rarefactions is created. The compressions represent a temporary and usually very slight increase in pressure relative to the silent, undisturbed, ambient pressure that had been in the room before the music started. Likewise, the rarefaction represents merely a decrease in pressure relative to ambient pressure. It is not a total vacuum, just a pocket of air pressure that is just slightly lower than it would have been in silence.

Those changes in pressure push our ear drums in and pull them out so that we can hear the beat—and tap our feet. When it's working well we call this music. But it gets a little messy when we take this concept to logical extensions beyond the kick drum.

The acoustic sound of the piano is created by the motion of its soundboard in air, which is itself motivated to move by the elaborate machinery around it (fingers, keys, hammers, strings, and the like). Same goes for the guitar and the violin. The player makes strings vibrate. The strings (through the bridge) push the sound board up and down and everything connected to it starts moving, changing the air pressure around it.

The result, somehow, is music.

It is the job of the microphone to capture this complex pattern of changes in air pressure and convert it into an electrical property we can manipulate (amplify, equalize, compress, distort, delay, and so on). The microphone creates in the electrical domain an analogy for what had been happening in the air—hence the term analog audio. The microphone maps air pressure changes into voltage changes.

The idea is that a microphone in a silent room puts out 0 volts. As music plays, the positive air pressure is converted into a positive voltage. In the subsequent rarefaction, where the air pressure is a negative (i.e. below ambient) air pressure, the microphone's output is a negative voltage.

Really high pressure displacements lead to higher voltages.Extreme reductions in pressure produce high amplitude negative voltages. The mic cable then contains a pattern of voltage changes that are identical in shape to the pattern of air pressure changes that occurred at the microphone capsule.

Interacting with air

How does a mic go from air pressure patterns in to voltage patterns out? The voltage part we covered in last month's column. In the studio, we generally employ a moving coil, ribbon, or condenser apparatus to create our voltage output based on the motion induced on some capsule by the air.

Starting from there, you can achieve a total understanding of how microphones work by understanding how the capsule interfaces with the air. It's important to understand what is pushing the coil, moving the ribbon, or flexing one side of the capacitor.

With the exception of the ribbon microphone, it is perfectly appropriate to picture the diaphragm of a microphone as a taut, round membrane like a drum head. (Apologies to Sweden's Pearl Labs, who put rectangular diaphragms in their mics.) It is suspended from its circumference and free to move most at its center. If you ever had the pleasure of playing on a round trampoline, you've got total, intimate knowledge of how a capsule diaphragm behaves.

Microphones 2– Measuring Air Pressure and Air Velocity
(Which way is up?)

Much of a microphone's behavior is determined by the following simple distinction: is the diaphragm open to air on one side or both? Figure 1 demonstrates this distinction. The upper capsule shows a diaphragm that is open on one side but blocked on the other. The lower capsule is open to the acoustic pressure on both sides.

The figure also shows a particularly illustrative snapshot of an ongoing acoustic wave moving across the entire figure from left to right. The capsules are oriented so that they are both open on the left side; they are 'looking' toward the oncoming wave.

The top capsule has a compression wave immediately in front of it. This instant of high pressure pushes the diaphragm of the capsule inward, to the right. Similarly, the lower capsule sees a higher pressure to the left than it does to the right, so it too is pushed to the right.

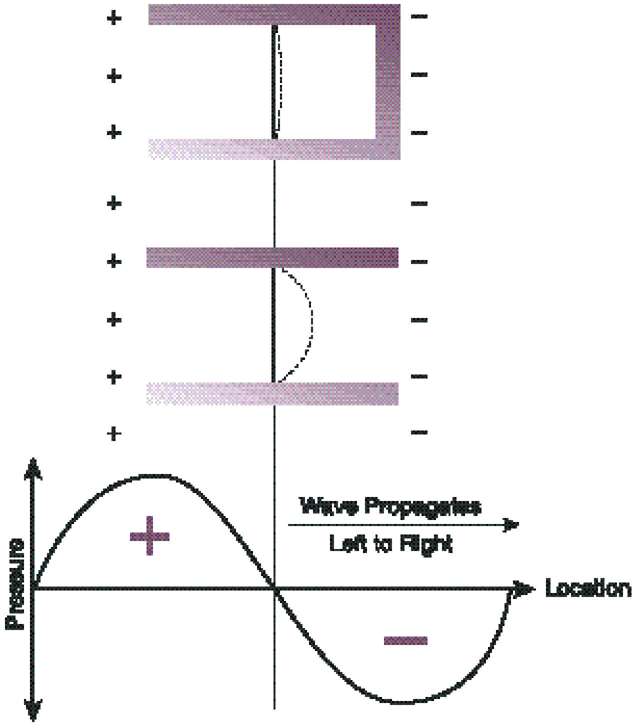

Figure 1: The upper capsule is open on one side only, measuring pressure. The lower capsule is open on both sides, measuring velocity

So far the two types of capsule seem to behave identically. Consider Figure 2, which shows the two microphones rotated 90° so that they are oriented upward. As the acoustic wave rolls by in this instance, the upper capsule is again pushed inward as the pressure on the open outside of the diaphragm is greater than the enclosed inside.

The lower capsule, on the other hand, sees the same high pressure on both sides of the diaphragm. The interesting result is that this diaphragm doesn't move at all—it only moves when there is a pressure difference between the two sides. The upper capsule measures pressure. The lower capsule measures a pressure difference, or to be more mathematically precise, a pressure gradient.

Naturally, the lower capsule is not typically called a pressure difference or pressure gradient mic, at least not in rock in roll. Instead, it goes by the slightly cooler name: a velocity transducer

It is perhaps intuitively obvious that whenever there is a pressure difference in the air (that is, whenever there is noise), the air particles themselves move from the region of high pressure toward the region of lower pressure. They don't get far because the high and low pressure points are changing constantly, but they start moving anyway.

So it would be fair to say that wherever there is an air pressure difference, there is also air particle motion. In other words, it is appropriate to think of the lower capsule as responding to the motion of the air particles, rather than measuring the pressure difference between the two sides.

You can think of the velocity transducer as being like a flag or a sail that responds to the air blowing against it. Unlike flags and sails, though, the velocity diaphragm flaps in the wind at audio frequencies—perhaps as slowly as 20 times per second and as quickly as 20,000 times per second.

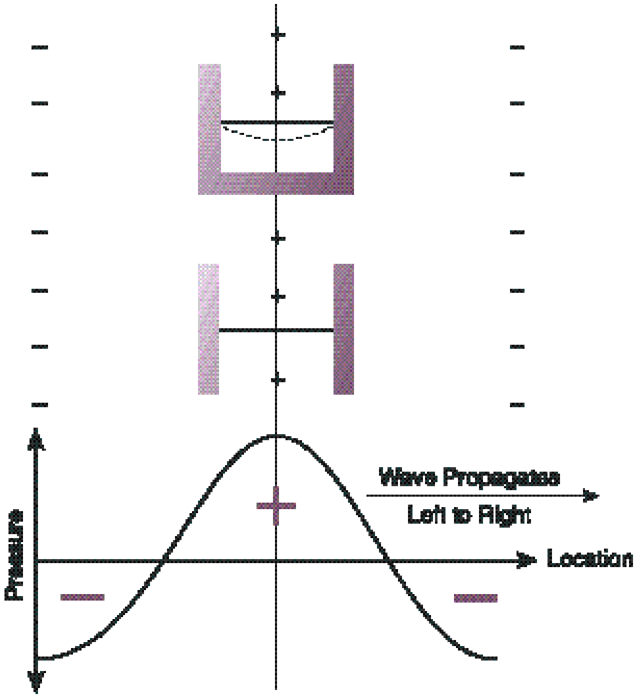

Figure 2: For sound from the side, the diaphram of the upper capsule is displaced. The lower capsule rests, completely uneffected.

These two types of transducers, pressure and velocity, are both perfectly capable of converting music into voltages. Both types are common in any studio's mic closet. But there are differences between them.

Directionality

The physical orientation of the capsule itself is fundamental to determining its directionality. A key difference between the pressure microphone and the velocity microphone has already been demonstrated in Figures 1 and 2. The pressure mic (the upper capsule in each figure) reacts to sound coming from in front or from the side.

In fact, it responds to pressure waves no matter what their angle of arrival. Being equally sensitive to sounds from all directions, it earns the moniker omnidirectional.

The velocity mic (the lower capsule in each figure) demonstrates an ability to 'hear' sound arriving from the front, yet it ignores sound coming from the side.

The arrangement in which the capsule is open on both sides is most sensitive to sound coming straight at the diaphragm—from the front or the rear—and least sensitive to sound coming from the sides. The mic's sensitivity decreases gradually as sound sources move off-axis from front to side.

To understand this better we need to graph it on polar coordinates. If we plot the sensitivity of the microphone as a function of the angle of arrival of the sound from the source, we can make visual the directional discrimination properties of the mic.

> You can achieve a total understanding of how mics work by understanding how the capsule interfaces with the air.

Figure 3 shows the three polar patterns we most often see in the studio. And parts A (omnidirectional) and B (bidirectional) we've just discussed. The omnidirectional pickup pattern shown in 3A is equally sensitive at all angles, and is a natural result of being a pressure transducer.

The bidirectional pattern (also called the figure-eight pattern) shows two points of maximum sensitivity directly in front of and behind the capsule, diminishing sensitivity as the angle of arrival goes toward the side, and finally total rejection for sounds fully at the side.

The bidirectionality of the mic is a byproduct of being a velocity transducer. It only measures the movement of particles against it, ignoring particle velocity that moves alongside, parallel to the diaphragm itself.

But there is a little more to the bidirectional pattern. The front and the back lobes of the figure-eight pattern are not exactly the same.

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Figure 4 shows a velocity microphone's reaction to a given sound wave as it propagates left to right. Figure 4A orients the mic facing left into the sound. The higher pressure, left versus right, suggests the air particles and the diaphragm will move toward the right. This motion will create an output voltage of, say, one volt.

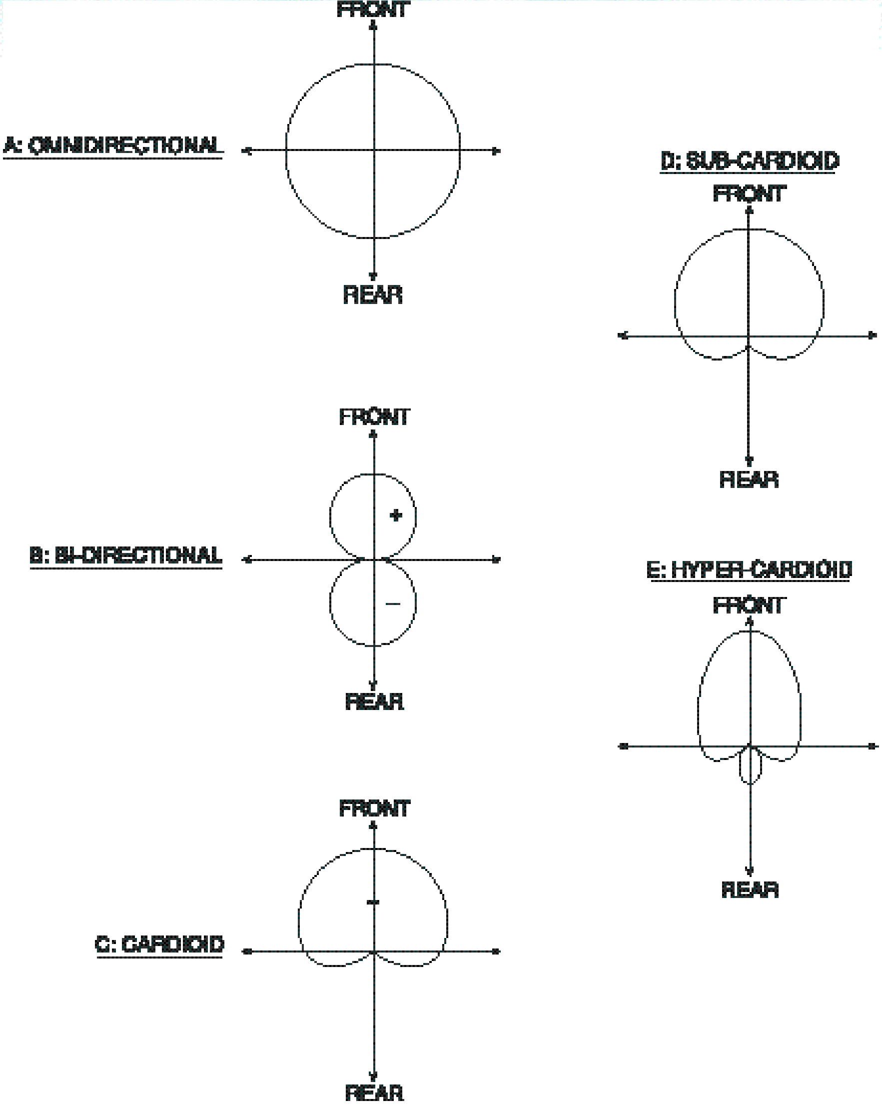

Figure 3: Microphone Polar patterns

Consider placing the same microphone on the same sound wave at the same time, but facing the opposite direction. The higher pressure on the left still pushes the diaphragm to the right. The air causes the same physical motion. But from the perspective of the microphone, this identical sound has caused the diaphragm to move the opposite direction.

Motion of the diaphragm this direction will in fact create a negative voltage. An appropriate conclusion, then, is that the velocity microphone can be equally sensitive to sounds in front of or behind the mic, but it picks up sound from behind with reverse polarity. In front of the mic, a positive pressure creates a positive voltage, while behind the mic, a positive pressure creates a negative voltage.

Look that way

It is this reverse polarity of front versus back that enables us to create a unidirectional microphone. Figure 3C shows this type of pickup pattern, which is most sensitive in only one direction.

This is quite helpful in the studio when you wish to record several instruments at once, but each to its own track. When physical isolation isn't available in the form of isolation booths, engineers achieve a sort of acoustic isolation by using unidirectional microphones aimed directly at their intended instruments, rejecting/minimizing the unwanted neighboring instruments.

If you add up the response of an omni to that of a figure-eight, you end up with the cardioidresponse shown in Figure 3C. (It's called a 'cardioid' because, to someone who knew Latin, it looked heart shaped. But it's a pretty funny looking heart, not the sort of heart that would sell a valentine greeting card. I guess there wasn't a Latin-based way to say "Looks kind of like a pizza with one slice missing.").

Want to build a cardioid response? Grab a pressure transducer (or any omnidirectional microphone) and a velocity transducer (or any bi-directional microphone). Place them as near each other as possible, facing the same way, and mix them together onto one track. If you monitor with the two microphones at equal amplitude, you'll have created a cardioid pick-up pattern using a 2-mic combination.

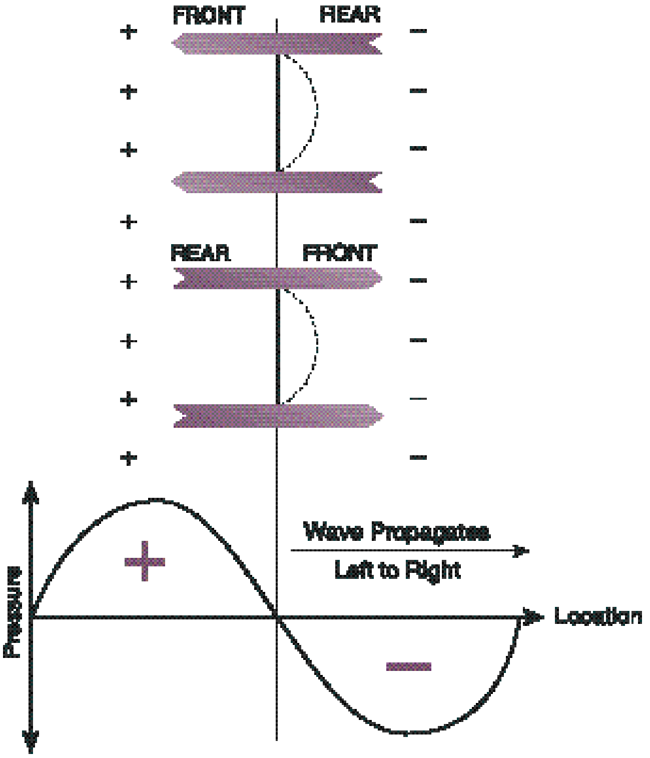

Figure 4: Reversing the orientation of a velocity microphone reverses the polarity of the output signal

To see how a cardioid pattern is born, look closely at some landmark points in the response of the two component patterns of Figures 3A and 3B. Directly in front of the microphone you get a contribution from both capsules. Off to each side, only the omnidirectional pressure transducer picks-up sound.

Behind the microphone you have the contribution of the omnidirectional piece being undone—literally cancelled—by the polarity-reversed rear lobe of the bidirectional mic. Placing a pressure capsule and a velocity capsule in the same place and combining them gives you double the sensitivity in front of the pair and total rejection to the rear.

It's a good trick. The downside is that you get a single mic for the price (and noise floor) of two. There's another way to do it that requires only a single capsule.

Since the goal of a unidirectional microphone is to reject sound coming from behind, clever manufacturers have modified the velocity transducer. The sound coming from behind the microphone needn't reach the diaphragm directly.

All studio microphones are either pressure transducers, velocity transducers, or some combination thereof...

It is possible to delay the components of sound reaching each side of the diaphragm so that for sources behind the mic, they arrive at exactly the same time. Ports into the microphone are configured so that there is no direct path from the rear of the microphone to the rear side of the diaphragm.

The arriving sound must navigate the short detour of an acoustic labyrinth on its way to the back side while simultaneously wrapping around to the front. If the time it takes the wave to diffract around to the front of the mic is equal to the time it takes the same wave to reach the back of the diaphragm via the longer path, the diaphragm will not move.

When the diaphragm is pushed from the front by the positive portion of a cycle, it is simultaneously pushed from the rear by the positive portion of the cycle. This push/push phenomenon emulates the situation of Figure 2 in which sound arriving from the side presents the same pressure on both sides of the velocity diaphragm.

Mission accomplished: acoustic manipulation of the signal achieves rejection from behind. Pretty darn clever.

But there's a little more to it. For this modified microphone to be of any use, sound arriving from sources that are in front of the microphone must still be effective at moving the diaphragm.

...And all of the intermediate mic patterns can be created by mixing variable amounts of two types of transducers.

This is achieved by making sure that the front versus back time-of-arrival difference at the diaphragm for sound arriving from the front of the capsule is exactly (or nearly) equal to 180° of phase difference. In this way the waveform is presented to both sides of the diaphragm in a complementary way. When the diaphragm is pushed from the front by the positive portion of a cycle, it is simultaneously pulled from the rear by the negative portion of the cycle.

Not only does sound arriving from the front of the microphone still move the diaphragm, but it does so in

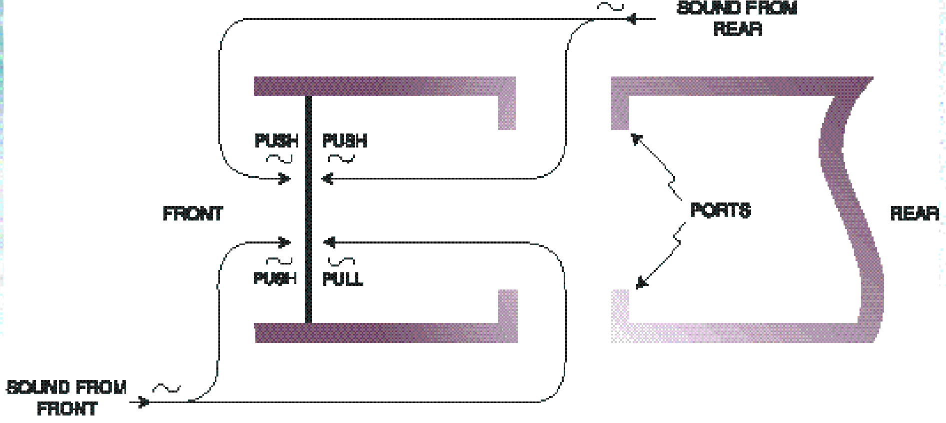

Figure 5: Cardioid pick-up is achieved through acoustic manipulation of sound reaching each side of the diaphragm

this push/pull fashion—it simultaneously pushes on one side and pulls on the other. That translates into increased sensitivity.

This clever manipulation of the waveform as it reaches both sides of the velocity transducer leads to a cardioid pattern: enhanced sensitivity in the front, total rejection at the rear. In fact, all this acoustic signal processing tries to make a single capsule that is half sensitive to pressure and half sensitive to velocity. It is the acoustic combination of the two microphones we combined electrically above. By using a single capsule, though, it accomplishes this at a much more appealing price.

Many single diaphragm cardioid microphones (the famous Shure SM57 and Electro-Voice RE20, among the many good examples) offer a good visual example. It is easy to see the ports on the body of the microphone that are the entry points for the sound into the back of the diaphragm.

As before, all these intermediate patterns can be created by mixing variable amounts of two types of transducers, using two mics and a mixer. The relative levels of the two mics determines the degree of omni versus bidirectional in the net polar pattern. Alternatively, sub- and hypercardioid patterns can be created on a single capsule by acoustically mixing the two types of transduction through the clever design of ports reaching the rear of the diaphragm.

A particularly good visual case study comes via the venerable microphone manufacturer Neumann. They recently released small diaphragm omnidirectional and hypercardioid mics to complement their well known cardioid, the KM184. Check out the photo of the complete Series that shows the mics side by side. The only visible difference among them is the rear ports.

Want to build a cardioid response? Grab any omni mic and any bi-directional mic. Place them as near each other as possible, facing the same way, and mix them onto one track.

Look this way

By mixing differing amounts of pressure and velocity transduction, other polar patterns can be created. We've seen how equal parts pressure and velocity produces a cardioid. More pressure than velocity leads to a directivity that is, not surprisingly, more omni than cardioid. Called a subcardioid, it is slightly more sensitive front versus back; it partially but not completely rejects sounds behind it (Figure 3D).

Conversely, having less pressure than velocity tilts the balance toward the bi-directional pattern. This more directional pattern is usually called a hypercardioid (Figure 3E). It is more sharply focused forward. Because it is less pressure than velocity, however, there is no longer perfect cancellation at the rear. The hyper-cardioid develops a small rear lobe of sensitivity that is the residual rear lobe of the bidirectional component.

Enhanced forward sensitivity comes at the expense of diminished rearward rejection. You'll no doubt find specific session situations where these other patterns are just what you need.

Know it all

All studio microphones are either pressure transducers, velocity transducers, or some combination thereof. In addition, most all studio mics employ one of the following design types: moving coil, ribbon, or condenser.

We've spent two months digging into these concepts and found that within all of these types of microphones lives a knowable, straightforward process. Armed with this knowledge of the physics behind the technology, next month we'll discuss the basic specifications, features and switches you might find on a microphone. You'll find they all stem from these microphone fundamentals.

Deciding which microphone to buy or which microphone to use on a specific instrument in a specific situation will depend on your knowledge of this basic process of transduction from acoustic to electric energy, in combination with your feeling about what sounds best.

Alex Case wants to know what you want to know. Request Nuts & Bolts topics via case@recordingmag.com.