Part III

AMBISONICS COMES OF AGE

BY WILLIAM SOMMERWERCK

In the first two parts of this series, the author explained the background and logistics of Ambisonic technology. This time, he concludes with a description of his home-brewed system and offers construction and recording tips.

PARDON THE HYPERBOLE, but Ambisonics is the most important development in sound recording and reproduction since the advent of electrical recording—and for some reasons you might not have considered.

The importance of electrical recording lies not so much in its elimination of the gross mechanical limitations and colorations of acoustical recording, but rather in its development methodology, which rationalized the audio design process. Maxfield and Harrison, the Bell Labs engineers who invented the electrical recording process, did not "tinker" it together. A rigorous mathematical analysis of the mechanical and electrical aspects of the design guided them. Since then, science has had some influence on the art of sound reproduction.

Likewise, the importance of Ambisonics lies in its rationalization of recording technique. The engineer can now produce almost any arbitrary effect imaginable or create a nearly perfect reproduction of a recording site's ambience. The mind boggles (and the ears twitch) to think what John Culshaw would have done with his classic production of Wagner's "Ring" if Ambisonic technology had been available in 1958.

Constructing the System

There is no practical way to duplicate the SoundField system. The microphone head contains four tiny hypercardioid capsules *(Fig. 16)*, positioned as if they were on the surfaces of a regular tetrahedron. [The *exact* pattern does not matter, as long as it is a reasonable mixture of zero-order (omni) and first-order (figure-8) components. The common cardioid has these components in equal amounts; the hypercardioid has more figure-8s than omnis and thus shows a slight anti-phase back lobe. I assume Calrec chose this capsule because it had the smoothest response and/or the most consistent pattern from sample to sample.] The capsules' outputs are mixed to produce an omni [W] and three figure-8 patterns (X, Y, Z).

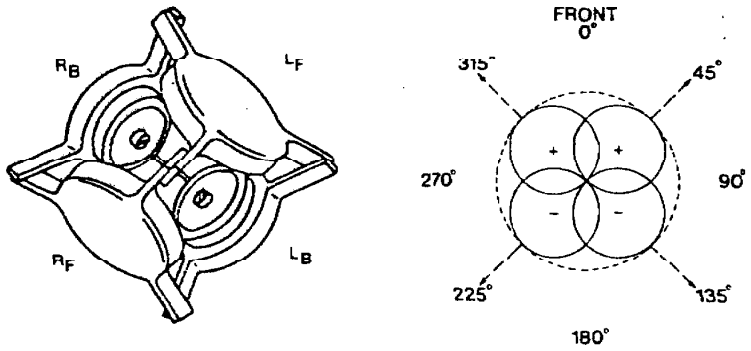

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FIGURE 16: The SoundField microphone head contains four tiny hypercardioid capsules positioned as if they were on the surfaces of a regular tetrahedron.

For this process (akin to solving four simultaneous equations for four unknowns) to work well, the capsules must be matched in amplitude and phase response, as well as have identical patterns. (Hypercardioid is made of omni and figure-8 mixed, so a pattern change represents a change in the relative level of these components, upsetting the process of extracting the correct W, X, Y and Z signals.) If you have the time, money and anechoic chamber required to hand-select the elements, you probably also have the $8,000 needed to buy a SoundField mike.

Clearly, the only practical approach for poverty-stricken amateur recordists is to generate the three (or four) signals of the B format directly. This means using an omni and two (or three) figure-8s pointed in the right directions. All you have to do is crank up the old four-channel recorder, and away you go.

There is a little more to it than that, though. First, you cannot use just any mikes. Not only do mikes

from different companies differ in amplitude and phase response, but they also differ in overall coloration. (Imagine how a recording would sound with a Neuman on one channel and an AKG on the other.) This suggests that you should use variable-pattern mikes from the same company.

I was lucky. When I bought my mikes, I realized that no single pattern could do justice to all types of recording situations, so I bought PML (Pearl Microphone Labs) TC-4v variable-pattern mikes. As you can see from *Fig. 8* in Part II of the series, it was not too hard to find an arrangement that would hold them in the right position. The omni (W) is on the bottom, the left/right (Y) is in the middle, and the front/back (X) is on top. I thought that this would produce the least acoustical interaction among the mikes. (The first Ambisonic recordings were made with four cardioid mikes in a tetrahedral arrangement. This was quickly abandoned when listening showed just how much coloration acoustical interference introduced. In the setups I will discuss, the mikes are smaller and are not so intimately intertwined.) The major problem lies in tightening up everything so that the mikes do not shift or flop over.

Using variable-pattern mikes is not the only possible approach. Another, which I jokingly call "gluing Schoeps capsules together," is also available. Schoeps' "Colette" series uses interchangeable capsules built around the same fabrication technology. This means that, frequency response differences aside, they will have similar colorations. (Schoeps would say "lack of coloration," of course.) This makes it possible to combine them into a coherent sounding array. You can separate the capsules from their electronics in the mike body with a special cable, allowing you to place the body in any position on the stand, with the capsules "upstairs." This reduces acoustical interaction. To glue the elements together, you can use cyanoacrylate glue, which hardens in a few seconds and can be dissolved with a bit of acetone.

What is the best approach for you? Variable-pattern mikes are pretty much out of the question. They are generally expensive and so bulky that it is hard to position them well. (I bought mine when the dollar was worth more and the kroner less. As you can see from *Fig. 8* (Part II), they are reasonably thin in comparison with with Neuman or AKG mikes.) The Schoeps mikes are more practical, and they form the heart of a complete miking system. An omni and two figure-8s, plus power supplies, will cost about $2,000. (For more information about Schoeps mikes, contact Posthorn Recordings, 142 W. 26th St., New York, NY 10001.)

Schoeps is not the only name brand system you can use. AKG's 450 series of microphone preamps and capsules includes the omni and figure-8s needed for a B-format pickup. Prices are comparable to the Schoeps mikes, but the AKGs include no provision for extending the capsule from the preamp. (Contact AKG Acoustics at 77 Selleck St., Stamford, CT 06902.)

At a lower price, I believe that Beyer Dynamic (5-05 Burns Ave., Hicksville, NY 11801) makes a series of omni, cardioid and figure-8 mikes, all using the same ribbon element. I have not been able to find any information on them, however. Can anyone help?

Perverse Suggestion

Of course, although these approaches are a lot less expensive than buying the SoundField microphone, they are still quite costly. Even if you already own AKG or Schoeps mikes, you are probably using cardioids and will have to buy another preamp and three more capsules. Never one to be intimidated, however, I came up with a brilliant alternative that is rather—uh—perverse.

How about using $3 condenser mike capsules from Radio Shack? It should be possible to put together a credible SoundField mike for less than $20. Doing so is actually rather simple. Suppose you placed two cardioid elements back-to-back—i.e., very close to each other and 180 degrees apart. Now, think of a cardioid

Ambisonic Recordings

No B-format recordings are currently available. The following are all UHJ disks and cassette tapes. Nimbus has already released UHJ recordings on compact disk, and Unicorn will if it has not already done so. This list is not comprehensive, but is simply an indication of the kinds of recordings available.

Nimbus was, perhaps, the first firm to use the SoundField mike and has the most UHJ disks available. Most of its UHJ disks are of solo keyboard and chamber music, ranging from Baroque to Late Romantic. The high point is a complete Beethoven sonata cycle (and the Diabelli Variations), all on direct disk. The artist is Bernard Roberts, and if the few pieces I have heard are a true indication, his is one of the great interpretations. Also available are some vocals and nonmusical recordings.

On the other hand, *Unicorn* probably has the greatest variety of offerings. These range from movie music (the sound track for *North-by-Northwest* is the best-known example) to what appears to be becoming a complete traversal of all of Messiaen's organ works. Also available are chamber music, some of Panufnik's orchestral music, a fair amount of Delius, band and college-orchestra music, and some of Peter Maxwell Davies' more recent works.

All of *Libra Realsound's* recordings are on cassette. They include unusual works, such as pieces by Loeillet, Neopolitan madrigals and 18th-century English organ music.

IMF Electronics has concentrated on "popular" music, recording live performances of groups such as The New Reformation Dixieland Band, The Reef Petroleum Big Band and Loose Caboose. Also available is a disk of the Albion Ensemble, a wind chamber group.

Music From York recordings are released on disk and cassette and are principally of church and choral music. The most infamous of the latter is "The Teddy Bears' Picnic," an album of children's songs.

Several other firms offer one or two UHJ recordings. In all, at least 120 UHJ recordings are available, a surprising number when you consider that the system has no support from any major record company. □

as a figure-8 added to an equal-strength omni. With the mikes facing in opposite directions, the figure-8 components are reversed in polarity with respect to each other. (Of course, the omni components have no directionality, so their phasing is meaningless in this context.) If the outputs of the two mikes are added, then the figure-8 components will cancel and the omni components add. If they are subtracted, the figure-8 components will be retained at the expense of the omni.

There are two ways to get these sum and difference signals. The first is simply to wire the capsule outputs together, in series. With the hot of one feeding the ground of the other, they will be in phase, and the output will be omni. Connected hot-to-hot, they will be anti-phase, and the output will be figure-8.

This application requires six capsules: four to create the X and Y signals and another two to make the omni. (Yes, you could use an omni capsule, but remember that you want to match the phase, frequency response and overall colorations.) The capsules would be glued together like that old toy "Lincoln Logs."

With a few op amps, you can reduce the mike count to four. You can add or subtract one pair (or even all four) to produce the omni and one figure-8, with the remaining figure-8 created by the other two mikes. The use of op amps would also allow you to adjust gains to compensate for differences in capsule sensitivity. The later addition of a more complex mixing circuit would allow independent selection of the mike pattern and angular separation for regular stereo recording.

Even when using op amps to adjust level, it will still be necessary to match the capsules for pickup pattern and amplitude/phase response. This is done by summing the outputs of the two capsules under test, out of phase. Using a speaker as a sound source, adjust the capsule levels to get the best null. Then, by noting what sort of residual signal is left and how the residual varies as the capsules are rotated, you can get a good idea of how closely the capsules are matched in phase and pattern.

The absurdity of this idea derives not from the physical principles involved (which, after all, are sound), but rather from the use of cheap microphone elements to build a state-of-the-art microphone. If I could find high-quality capsules, with reasonably consistent performance, the idea would not be so absurd. I think I could design a complete B-format SoundField mike system kit, including a UHJ encoder/decoder and a variable pattern/microphone angle control for about 5 percent of the cost of the Calrec mike.

Make Your Own Recordings

Once your microphone system is ready, you are prepared to make a recording. The first consideration is determining which signal goes into which deck input.

I assume you know that the four tracks on a quarter-track machine are numbered from 1 to 4, top to bottom. Tracks 1 and 3 record left and right, respectively, with 4 and 2 taking the same channels when the tape is flipped. Tracks 2 and 4 carry the left rear and right rear channels in quad recordings. Except for the mono (W) channel, you cannot play Ambisonic tapes directly on existing systems. Therefore, you need not be concerned about compatibility, and technically, the tracks could go anywhere. There is, however, a standard that you should follow.

No matter how accurately the tape is slit or how well the transport is designed, the tape never moves perfectly parallel to the heads. There is always some skew, which continually varies, producing interchannel phase jitter. The closer any two channels are to each other, the less the relative skew and the lower the jitter. The Y signal carries the left/right information, and the ear is more sensitive to variation in its positioning than it is to front/back or up/down. This suggests that you should place the W (omni) and Y tracks next to each other and in a position that has the least skew. You do not have to be Albert Einstein to see that this means the two center tracks. W goes on track 2 (left rear) and Y on track 3 (right front). Front/back accuracy is more important than up/down, so the X signal should be as close as possible to W. Therefore, it is recorded on track 1 (left front), and Z winds up on track 4 (right rear).

Now you are ready to set recording

levels. A rather odd standard appears to have come about because the Ambisonic engineers do not like noise-reduction systems, since tracking errors appear as shifts in image position. This standard dictates that you record the difference channels 3dB higher than the W (omni) channel. Since there is no easy way to calibrate your mikes, you need not follow this standard. A figure-8 pattern picks up less total energy than an omni, so those tracks are recorded at a higher level to get a better S/N ratio. To compensate for this, you adjust the gains in the decoder. If, as I have suggested, you are using uncalibrated mikes, you will have to adjust playback pretty much by listening, so record at whatever level you like.

By the way, feel free to use any noise-reduction system you wish. It is true that tracking errors will cause image shifts, but they appear as a subtle expansion or contraction of the width or depth of the sound field, a most innocuous error. I use dbx II, and I have never heard any side-effects.

I have one final piece of advice on recording: if you are using variable-pattern mikes, set them all to omni and record a minute or two of some disposable part of the performance. This will be useful in adjusting playback levels, as I will explain later.

Because it is not practical to make a calibrated recording, you must set the X and Y playback levels by ear. This takes a bit of practice, but really is not difficult to do. If you have followed me thus far, you should not have much trouble understanding how to get properly balanced playback.

Keep Your Balance

First, set your Ambisonic decoder for B-format reproduction, and connect the appropriate tape deck outputs to the correct B-format inputs. If you use noise reduction, it must go between the tape deck and the decoder. Be sure the forward preference control is turned off. Set the layout control to correspond with the speaker positioning.

Second, turn the output level controls on your tape deck all the way down. Set the gain controls on your amplifiers, front and back, to where you would normally set them for tape playback. Play the tape and advance the W output (track 2, left rear) to the point where the sound is slightly softer than what you would consider a normal playback level. Make sure that all amplifier channels play at exactly the same *electrical* (*not* acoustical) level. Once the channels are balanced, leave the amplifiers' gain control alone.

Third, turn off the rear speakers. Increase the Y level (channel 3, right front) until the sound goes beyond the boundaries of the speakers. The sound might be a little "spacy" or have a hole in the middle, but you will fix this later with the X signal. It is important to get this adjustment right. The decoding equations in the sidebar below show that the difference signals (X, Y, Z) always appear in the outputs at a higher level than the omni. This produces the exaggerated effect you are hearing with only the front speakers and no X channel. If you ignore this consideration and go for a sound that matches regular stereo, you will not achieve the full benefits of Ambisonic reproduction.

Fourth, turn on the rear speakers. Bring up the level of the X channel (track 1, left front) until the performing group is clearly in the front and the ambience is properly disposed around you. If you recorded the X and

Ambisonic Encoding and Decoding

Assume that zero degrees is "straight ahead," that angles advance in a counterclockwise direction, that theta is the azimuthal angle, and that phi is the angle of elevation or depression. Any sound source is encoded onto the four Ambisonic B-format signals by multiplying it by the following weighting factors, sign included: W = 1 (i.e, no weighting); X = $\cos\theta$; Y = $\sin\theta$; Z = $\sin\phi$.

You can achieve this weighting in a studio by a simple adjustment of level and polarity. For live sounds, you can use either a combination of omni and figure-8 mikes or (preferably) the SoundField microphone. You may also use regular miking, with encoded directions conforming to the "position" of the microphone, although this is less than ideal. The earliest Nimbus recordings use this technique, and it works amazingly well.

The decoding process exactly reverses the encoding process. Here, however, the positions of interest are the speaker locations, not the sound sources. No matter how many speakers you use, *all* the speakers receive *all* the signals. Each component is weighted by dividing it by the sine or cosine of the angle at which that speaker is positioned:

W = 1 (i.e., no weighting)
X = $1/\cos\theta_S$ (where S = Speaker)
Y = $1/\sin\theta_S$
Z = $1/\sin\phi_S$

Of course, if you drop the up/down information, you do not use the fourth channel and the extra speakers.

As you can see, you can realize this playback "matrix" very simply with inexpensive op amp circuits. If the speakers are arranged in a rectangle, then the sines and cosines will have the same magnitude for all speaker positions, differing only in polarity. Therefore, the X, Y and Z signals need be weighted only once. (A trapezoidal layout requires the rear speakers to be weighted differently, since front/back symmetry has been destroyed.)

I have not shown the encoding or decoding for UHJ because I think the concepts associated with the Scheiber Sphere are more important. Suffice it so say that the left and right UHJ signals are manipulated to produce close approximations of the original W, X and Y signals. These W', X' and Y' components are applied to the speaker-feed matrix as the pure B-format signals would be. Some additional response contouring is used to make a smooth transition between the various "regions" where the differing psychoacoustic principles apply and to reduce subjective coloration. □

Y signals at the same level, the settings of the output level controls should be very close, too. This is the hardest part of the adjustment. Be patient, listen carefully, and you will get it right. I find this easiest to judge when I am sitting somewhat off-center.

Finally, sit back and enjoy the most realistic reproduction you have ever heard from your system. Note particularly the more accurate reproduction of instrumental timbre, reduced dynamic compression at high volume levels, the way the ambience "relates" to the direct sound of the instruments and performers, and the almost total elimination of the speakers as apparent sound sources. (Although you might question the presence of reduced dynamic compression, the effect *is* audible. Stereo recordings made under identical conditions show a certain amount of dynamic "gagging" at high volume levels. The effect is almost certainly psychoacoustic and is not understood at this time. Perhaps the ears rebel at hearing loud sounds reproduced from only one direction.)

If you are able to record some music with all mikes set to mono, you can speed up the calibration process. This technique assumes that your variable-pattern mikes have the same on-axis output when set for figure-8 as they do in omni. In any case, it will quickly get you in the ballpark. Follow the above instructions up to where you set the overall W level, then take these steps:

1. Turn the layout control to the "square" position (straight up). Turn off all the speakers *except* the right front one. Play the part of the tape with all the mikes set to mono.

2. Increase the Y signal (track 3, right front) until you get the best possible null at low frequencies (below 1kHz).

3. Turn off the right front speaker so that neither speaker is playing. Pull the W cable out of the decoder. Turn on the right front speaker again. Adjust the X signal (track 1, left front) to get the best low-frequency null. Turn off the speaker again and reconnect the W cable to the decoder. Set the layout control to the correct position and enjoy.

Extended listening might indicate the need for slight adjustments. Always leave the W signal alone: it is your point of reference. If you change its level, you will have to start the calibration over from scratch. Also, if the front or back seems too prominent, do *not* change the amplifiers' gains more than a decibel or so. Remember, the speakers are cooperating to produce the sound field, and changing the levels too much might make them audible as separate sources. Instead, move your seat forward or back.

After you have had some time to evaluate Ambisonic reproduction, I have no doubt that you will agree with Michael Gerzon, one of the system's designers: "As it (Ambisonics) is the first system design based on a complete mathematical analysis of both system theory and human psychoacoustics, it is possible to say with some confidence that no system appreciably different from it can exceed its performance in optimal surround-sound decoding, so that no further system change is ever likely to be needed for encoding." □

IF YOU SHOULD HAVE A TECHNICAL QUERY...

. . . please drop us a note explaining precisely what information you need. We will answer your question ourselves or forward your letter to someone with expertise in that area. Make sure to enclose a self-addressed, stamped envelope for our reply, and address your letter to: *Audio Amateur*, Technical Dept., PO Box 576, Peterborough, NH 03458.

Help us out by *not* calling in your question. We have neither the staff nor the time to respond to each query over the phone.

SOURCES

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15. Gerzon, Michael, "Surround Sound Psychoacoustics," *Wireless World*, December 1974.

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NOTE: All the *JAES* articles cited appear in *Quadraphony*, an AES publication covering some of the articles from 1969 through 1975. This only scratches the surface of Ambisonic literature. Except for the few *JAES* articles, everything ever written on Ambisonics up to this point has appeared only in British publications. You might find it fun to grab a stack of *Hi-Fi News & Record Review*, starting around 1970, and work your way through it.