Acoustic Matrixing—A Basis For New Loudspeaker Developments

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Through acoustic matrixing control is exercised over the direction of particle velocity as the sound wave leaves the speaker to achieve wide sound coverage. In application this concept provides a system with unusually fine stereo sound—from a single cabinet.

We've heard a lot about electrical, or electronic, matrixing recently, particularly in relation to stereo broadcasting. While there are some similarities in the acoustic variety we shall discuss in this article, it should be stated at the outset that it is *not* an acoustic way of doing the same thing.

In electrical matrixing, the quantities to be matrixed are scalar; voltages or currents specified completely by instantaneous magnitude and polarity. An algebraic sum and difference process will convert "left" and "right" channels into "mono" and "stereo" by this process, or vice versa.

In acoustic matrixing two additional features complicate matters: propagation and space. Not only does the original scalar quantity, converted into an acoustic wave, take *time* to reach any specific point, determined by propagation velocity and distance; the quantities themselves do not remain scalar. An acoustic wave is possessed of pressure and velocity components that are not simple counterparts of voltage and current in the electrical analog. While the instantaneous sound pressure at a point is a scalar quantity, particle velocity at a point is possessed of direction, which may *or may not* coincide with the direction in which the wave is propagating.

Spherical Waves

It seems as if, so far, most people concerned with applying loudspeakers to stereo have avoided any deliberate use of acoustic matrixing. They have utilized loudspeakers whose radiation is predominantly longitudinal and relatively nondirectional. Within certain limits, a loudspeaker with enclosed back (including bass reflexes, which are effectively closed back at most frequencies) radiates waves of a diverging spherical character.

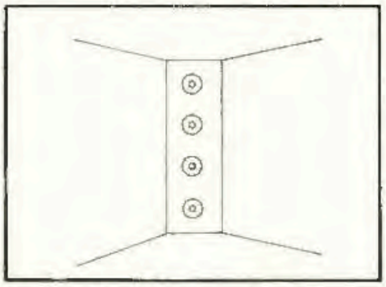

Fig. 2. A vertical line of loudspeaker units will approximate cylindrical radiation with a vertical axis.

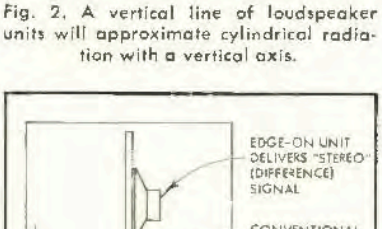

Fig. 3. Basic loudspeaker arrangement used in some of Lauridsen's experiments.

Two such loudspeakers, using a stereo (left and right) source will radiate two sets of spherical diverging waves. The stereo illusion, if it is achieved at all, is the result of the difference between the way these two sets of divergent spherical waves combine at the listener's two ears. There are certain disadvantages to this method, which account for many of the dissatisfactions experienced with stereo reproduction.

Ignoring at first the effect of reflections, the pressure and velocity due to a spherical wave decrease in proportion to distance from the source. If the listener is at a distance greater from each loudspeaker than the loudspeakers are from each other, the difference in intensity received from each will not be too great. Thus far, we might conclude that a scaled-down theater system would achieve equally good effect in a living room, throughout an area corresponding to the part of a theater occupied by the audience. But now we take into account the effect of reflections.

In an auditorium, the distances are such that the direct waves from the loudspeakers reach the listener with a perceptible lead time before any conflicting reverberant waves, wherever the listener is located. Also the difference in distance traveled by the two groups of waves is such that the direct wave maintains a substantial intensity difference above that of the reverberant ones.

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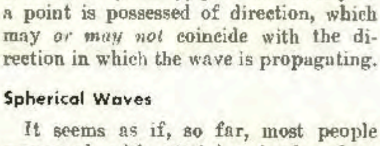

Fig. 1. A hypothetical way of achieving stereo by radiating plane waves from opposite walls of the room.

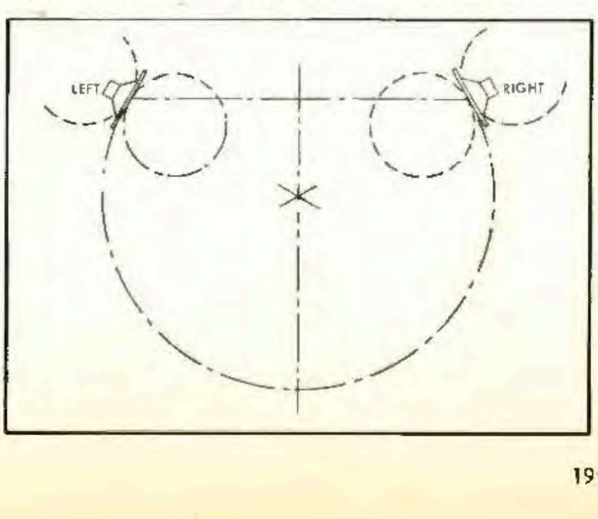

Fig. 4 Construction on which CBS "isophonic" demonstration was based: dashed lines represent polar patterns of individual isophonic units; dot-and-dash lines link points at which received intensity from the two units is equal, when they radiate equal power.

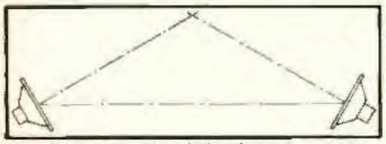

Fig. 5. Each unit will be free from transverse components only along the axis.

In a smaller room, such as more normally used for home listening, a different relationship obtains. The shorter distances serve to "catch" waves radiated in all directions from the loudspeakers, reflecting them inwards again, so the listener at almost any location hears the reflected sound with little time delay or intensity loss from the direct sound. Also the *relative* intensity difference between direct waves from each loudspeaker is apt to be more dependent on listener positioning than in the large auditorium.

This last statement is true for two reasons. To get separation, the loudspeakers need to be further apart in proportion to the major room dimensions. Consequently altering one's location can make the distance ratio from the two loudspeakers change to a greater extent.

The second reason is that spherical radiation reduces its intensity more rapidly than the direct inverse square law at first. At greater distances, both pressure and velocity diminish in inverse proportion to distance. In the shorter distance range, the velocity component of the wave decraeses in inverse proportion to the square of the distance. So deviation of effect with listening position may be even greater in small rooms.

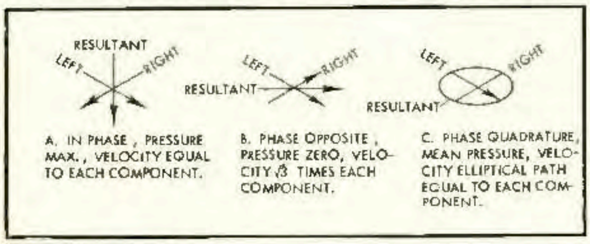

Fig. 6. At the intersection of axes (**Fig.** 5) the pressure and particle velocity (magnitude and direction) depend on the relative phase of signal from the two units.

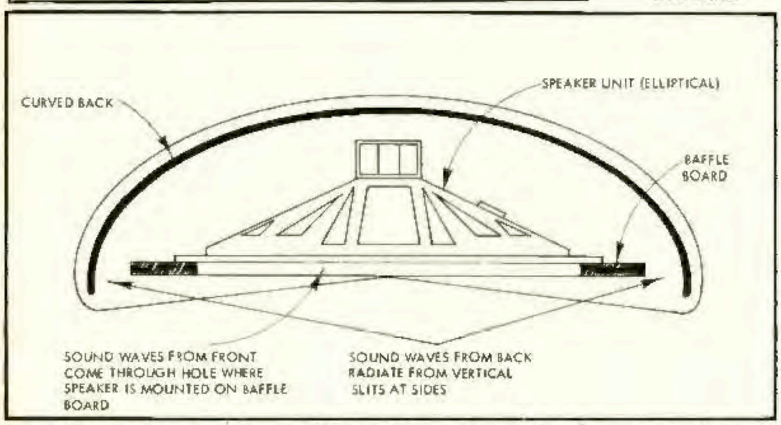

Fig. 7. Cross-section through one of the Heath "satellite" units, showing how the basic CBS isophonic is modified, physically.

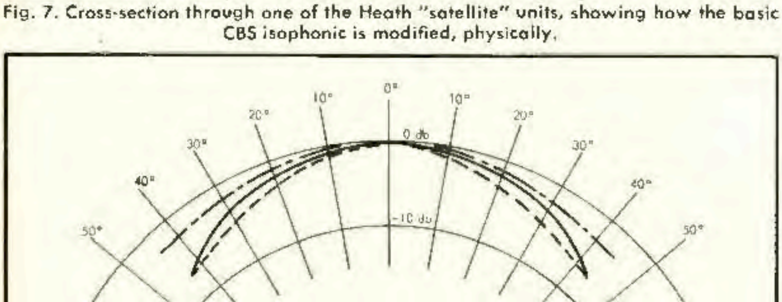

Fig. 8. Directional pattern achieved by the unit of **Fig.** 7. (From data supplied by Heath Company.)

Plane Waves

Some have said that headphone listening is the ideal way to hear stereo. This transmits the sound pressures directly to each ear via the short auricular canal. If the sound from each loudspeaker could be transmitted to each ear without loss or intermixing, either with sound from the other loudspeaker or with reverberation effects from the room, the stereo illusion would be improved.

A plane wave, as opposed to a spherical one, transmits sound with virtually no reduction in intensity. A hypothetical method of utilizing this form of radiation would be to have the two opposite entire walls radiate sound, each handling one channel of the stereo (*Fig.* 1). If each of these walls could also be rendered 100 per cent absorbent to waves from the other side, a very good stereo system would probably result.

However, practical wall surfaces would produce a high degree of reflection, especially to a wave striking them "full on." So, even assuming the whole wall could be rendered into one large transducer, the reflection aspect would probably negate its apparent advantage.

Cylindrical Waves

Splitting the difference, so to speak, between the spherical and plane wave, is the cylindrical wave. In a sense, this is plane one way and spherical the other. So a wave propagated from a vertical line source will travel a given distance with only half the reduction in intensity (measured in db units) suffered by a spherical wave. This will have three advantages for stereo in a normal-sized listening room.

First, the intensity of the direct wave will be greater relative to reflected reverberation components at almost any location.

Second, the difference between the intensity from two loudspeakers due to different listening locations will be reduced.

And third, reflections from floor and ceiling will be practically eliminated, because the waves do not radiate towards them. Thus the increase in ratio of the direct wave intensity over reverberant confusion is considerably increased.

One way to achieve this effect is by approximating the line source with a vertical line of loudspeaker units on each channel (*Fig.* 2). Another method approximates a similar effect by using controlled radiation, as in the Jim Lansing "Hartsfield," spreading sound horizontally and restricting it vertically.

Transverse Waves

But we still have essentially pressure or longitudinal radiations from each loudspeaker. We have not yet introduced the *piece de resistance* of this article.

At the beginning we pointed out that particle velocity at a point may not coincide with the direction in which the wave is traveling. When two radiations of the same frequency combine by intersection from widely separated sources, the particle velocity is a resultant due to both waves. Its magnitude and *direction* will vary quite rapidly with location, and beyond a simple vector sum (as does the pressure component). Even without taking reflections into account, this can become a highly complicated wave pattern at different frequencies.

The acoustic matrixing concept does not utilize the same kind of longitudinal radiation, but controls the direction of particle velocity as the waves leave the loudspeaker(s). The first experiments that deliberately applied this principle were those of Lauridsen, who used it, not for true stereo, but a form of pseudo stereo, delaying the signal fed to one of the units. The same method has been tried with M-S type stereo. In this, an edge-on unit radiates the "stereo" components, while the "monophonic" comes from a conventional pressure radiator at the same location (*Fig.* 3). In Lauridsen's experiment the same audio was fed to the "stereo" unit but with a time delay.

When used on M-S stereo program material, the transverse radiation propagated by the edge-on unit, which behaves approximately (over a limited frequency range) as a doublet sound source, combines with the longitudinal propagation from the front-on unit, to control particle velocity orientation relative to the direction of propagation at all points. The much more complicated pattern due to special separation does not build up.

At the listener's head, and in the mid-frequency range, the obstacle effect utilizes the pressure gradient coincident with the oblique-angled particle velocity to produce a pressure difference at his ears. This generates "left and right" pressure components at the respective ears.

While this method works, it has limitations too, otherwise everyone would probably be using it by now. The limitations can be seen by looking at the properties of a doublet source. First, the transverse component is strongest at the edge-on position, which becomes the front center in Lauridsen's arrangement. Moving to the side reduces the magnitude of the transverse component received from the "stereo" unit.

Second, the intensity from a transverse radiator falls off more rapidly with distance than does that from a longitudinal radiator. At short distances from the radiator, the transverse velocity is inversely proportional to distance cubed. At greater distances (more normally occupied) it is inversely proportional to distance squared. From a normal longitudinal radiator with spherical distribution, it is inversely proportional to distance squared for small distances, becoming inversely proportional to distance directly at greater distances. Thus, regardless of wavelength and distance, the transverse propagation reduces its intensity at a more rapid rate than the longitudinal components.

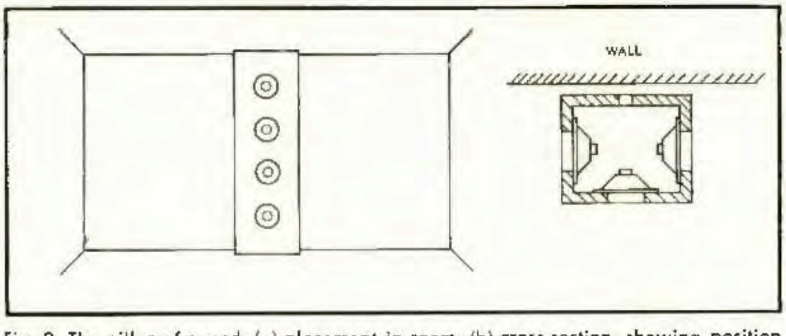

Fig. 9. The pillar of sound: (a) placement in room; (b) cross-section, showing position of speaker groups.

This means the correct stereo illusion can only be achieved over a relatively small area in front of the loudspeaker combination. If you get too close, the transverse component will be too strong (which may give accentuated separation effects!). If you get too far away, the separation will diminish, as it also will by moving to the side.

Widening the Control

One method of overcoming this objection uses separate loudspeakers that do utilize other than the simple transverse radiation effect. First in this group was the experimental system developed and demonstrated by CBS Labs. As there was spacial separation, this system used

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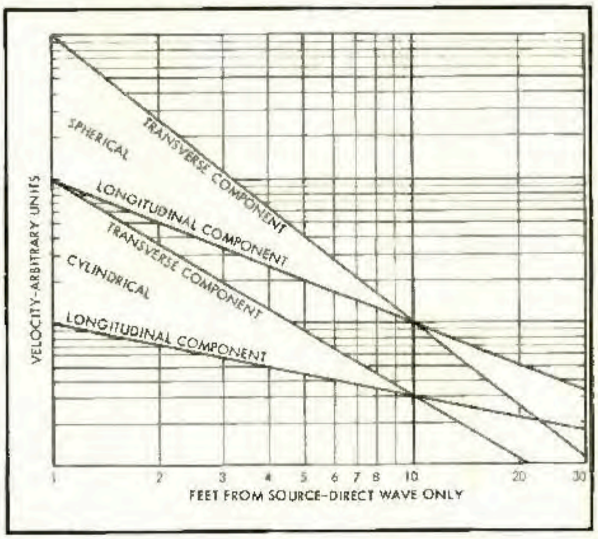

Fig. 10. Variation of velocity components with distance, using cylindrical or spherical radiation. Increased rate of change for very short distances is not shown.

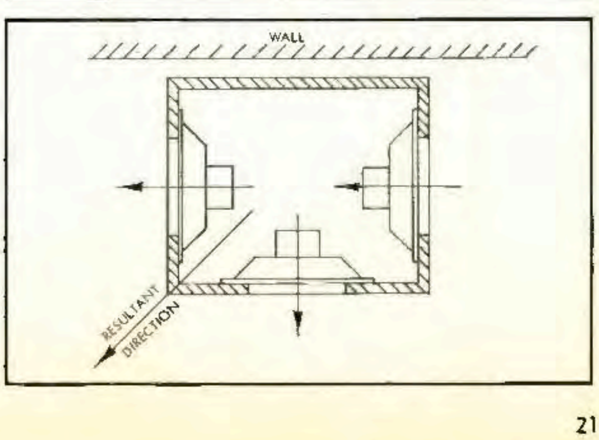

Fig. 11. Relative motion of units' cones when a signal is applied from "left" channel only—no output from "right."

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"left" and "right" channels, rather than "mono" and "stereo" (*Fig.* 4).

The major listening area was not in the edge-on position of either speaker, where transverse radiation predominates. But the characteristics of this type of radiator were used. Each unit was a doublet, but only the front lobe of the "figure 8" pattern was used.

The theoretical explanation accompanying the verbal presentation of the paper was based on relative intensity from the two units, as controlled by the "figure 8" patterns. But there can only be a simple intensity combination at the point where their lines of pure longitudinal radiation intersect (*Fig.* 5).

At this point, resultant velocity, as well as pressure, is controlled by the phase relation between the radiation from the two units (*Fig.* 6). At other points, some transverse radiation is inevitably present too, and undoubtedly helps the intensity gradient in creating the necessary difference at the two ears.

A practical limitation to such a system, using true doublet sources, is the presence of the rear lobe of the "figure 8." If the unit is placed at all near to a wall, reflection occurs and complicates the radiation pattern to the extent of invalidation.

The Heath engineers, who developed a similar system (for kit builders) under license from CBS, controlled the back radiation by allowing it to "escape" through slits at the sides of the unit, pointing forwards (*Fig.* 7). This retains the essential method of the CBS system, without the speaker placement limitation.

Its front radiation is somewhat more directional than the simple doublet

(*Fig.* 8). It probably limits the useable area in similar proportion, but not so much as the CBS method would be limited by misplacement of the units to reflect the rear lobe.

Complex Cylindrical Radiation

Another variation of this approach was developed by the writer for an inexpensive "basement" loudspeaker, called the "pillar of sound" (*Fig.* 9). Although this was arranged to be connected to conventional "left" and "right" amplifier outlets, it used acoustic matrixing.

For monophonic components in the left and right channels, the speakers facing in all three directions, forwards, left and right, work in unison. For "stereo" components (in which left and right are in phase opposition) there is no sound output from the front units and the internal air behaves as a fluid coupler between the backs of the left and right units, so their combined operation is essentially as in Lauridsen's original edge-on unit.

Use of four units vertically in-line for each group results in approximately cylindrical radiation. This reduces the rate at which both longitudinal and transverse waves reduce magnitude with distance. Due to the length of the composite source, the initial rapid reduction does not occur at all. Curious listeners who put their ears close to individual units to find out "how it works," obtain the illusion that each unit (as they listen to it) is not working appreciably: all the sound must be coming from somewhere else. So getting much too close does invalidate the effect.

At greater distances, a cylindrical wave (which this then approximates) reduces its longitudinal magnitude in inverse proportion to the square root of distance, while the transverse component reduces in inverse proportion to the one-and-one-half power of distance (*Fig.* 10). There will still be a variation of effect with listening location. The transverse velocity always reduces a unit power "faster" than the longitudinal component, because it is not accompanied by the usual pressure drop.

But the fact that both follow a lower power order, and the restriction to a horizontal radiation, improves the ratio between the controlled sound waves and unwanted reflections responsible for confusion effects.

Ready action of the air as a coupling fluid for stereo (phase opposition) components will occur throughout the mid-range frequencies. Above this, where the distance between the backs of the units becomes comparable with wavelength, the three sets of units will begin to behave more or less independently, working as left, right and mixed center groups.

Notice that this approach uses a philosophy that is the opposite of other systems that put two stereo radiators in one "box," with various means of reflecting the "left" and "right" sound outwards, in that the design depends on close integration in a horizontal area, whereas other systems try to "bounce" their sound out, beyond their physical boundaries. In this approach, reflection effects are avoided, rather than utilized.

Over the mid-range particularly, an acoustic matrixing occurs, to produce a radiation similar to that from Lauridsen's arrangement on mono and stereo sources. However, the vertical line arrangement produces a cylindrical radiation pattern and the acoustic matrixing avoids any lack of integration due to vertical displacement between the mono and stereo radiators.

A signal originating wholly from the "left" channel will have the left and right units working in phase opposition, which is the same direction in space, and the left ones will be in phase with the front ones. So the resulting sound wave is radiated to the left of the listening area (*Fig.* 11). Similarly sound from any other original position will be radiated in a resultant direction to correspond.

Effect of Program Miking

This last statement is predominantly

true only if the program is miked either with the M-S or Stereosonic technique, or with close-in mikes using electrical mixing to achieve the desired "position" effects. But this does not mean a satisfactory effect cannot be obtained if the program is miked by a method that introduces time as well as intensity differences between individual program components in the two channels (left and right).

Experiments have shown that smaller listening rooms, of the size most often used in homes, achieve the most natural stereo effect *on a given program,* when the loudspeakers are arranged in close proximity and utilize directivity to obtain acoustic channel separation. In the extreme case, where the time differential between channels is such that instantaneous sound in each is virtually unrelated to the other, the matrixing method can be regarded as projecting each channel (left and right) at the extreme angle of its control area.

Thus even program that used a microphone technique not best suited to reproduction in smaller listening rooms, can be projected at least as well by an acoustic matrixing system as by completely separate left and right loudspeakers.

Perhaps one more thing should be clarified. One of the multiplex systems proposed, that we alluded to in our opening paragraph, has made reference to the term "acoustic matrixing," but with a connotation not compatible with that we have used. The system in question proposed to substitute a cross-mixture, consisting of something like 2L-R for "left" and 2R-L for "right," as the transmitted channels. It was suggested that "acoustic matrixing" would cancel the L-R part of "left" with the R-L part of "right," leaving pure L and R which the ears should interpret into a stereo effect.

Quite evidently this use of the term has no reference to the employment of acoustic effects in the ways discussed in this article, and the suggestion itself contains a serious fallacy. Assuming an out-of-phase component (the L-R and R-L parts) *would* cancel acoustically, then *any* differences between one channel and the other would be similarly "averaged out." Stereo is impossible. In point of fact, it is the *failure* of such cancellation, even when the sources are in close proximity, as in the pillar system, that makes acoustic matrixing possible. So, not only is such use of the term incompatible—it is contradictory to the facts.

Conclusion

It is suggested that closer attention to arrangements that employ true acoustic matrixing will probably yield some more effective loudspeaker systems for home stereo listening than have been presented so far. As well as producing more consistent realism, of which two-channel stereo is capable, they avoid the need for two separate locations, at the mystic spacing of seven or eight feet, where separate units are usually recommended. So this approach will also make stereo much more acceptable in the average living room. Æ