REPRODUCING SOUND SOURCES IN THREE DIMENSIONS

To explain how we can locate sound sources fixed in space from any observing location, we must diverge a little and consider how sound waves from live sources actually behave.

Point sound sources make waves in the air that radiate spherically outward, much as ripples radiate outward from a stone thrown into a pool.

Using this pool analogy, ignoring its essentially two dimensional nature and any reflections, if you only saw the waves in the pool at a certain time after starting out from the source, could you work out where the source was – where the stone hit the water?

The answer is yes. At any location and at any observation time (before reflections), we know that the direction of travel of the ripples in the wave front as it expands disclose the source direction. We also know that the height or intensity of the wave drops as it radiates out. But additionally we can see that the curvature of the wave-front contains information on the absolute distance of the source. The wave-front curvature *lessens* as it expands out. The waves are circular and so the source location can be determined by just observing the curvature of the wave-front and the use of basic trigonometry.

This simple analogy can be extended to sound waves radiating spherically from a source in air. Even though these waves propagate in three dimensions rather than the two of the pool surface and travel much faster, there is sufficient information at any wavefront observation point to determine the distance and direction of each or any independent source by observing the wave-front alone.

Whilst you cannot see the acoustic waves in air, you can of course hear them. And you should be able to determine the source distance and direction of a source by observation of the resulting wave-front at any point purely from the properties of the wave at the time and location of observation. You do not have to rely on sound intensity measurement. The key additional measurement is the determination of the resulting wave-front curvature, gradient or divergence.

If it is possible to determine both sound source distance and direction of any source from their propagating wave-fronts, can we recreate sound sources located at specific locations in space by recreating the corresponding wave-fronts and their curvatures?

If this were possible then we would have an alternative approach to placing sound sources in space that would eliminate the sweet spot. Listeners would be able move and turn without deterioration of the sound field – without the recreated sound source objects appearing to move [1].

If at any location you measure the spherical wavefront propagating from a point source, you find that a tighter or smaller radius of curvature means a closer source and a larger radius or a more gradual curvature means the source was further away. This is not just related to the loudness of the sound, it is a property of the shape of the wave front at the measuring location.

A general mathematical term that describes the swelling or expanding nature of a propagating wave is the divergence.

A flat or parallel wavefront has no curvature or divergence and this would mean the source is very far away - at the acoustic horizon or vanishing point, in fact.

What is interesting is that the distance rules and hence the wave-front curvature will correctly scale at any and all observation locations. This is exactly what we need for consistent source location behaviour and shared listening experiences.

Most real life sound sources do not behave as point sources. Nevertheless, the important points to note are:

1. The wavefront curvature (divergence) is a direct measure of the (or each independent) source distance.
2. Treating any acoustic source from the point of view of a complete description of the wavefront it creates (rather than a detailed description of the object that creates it) is a potentially useful approach.
3. The ability to place sound sources at an apparently fixed location in space will reduce to being able to control the wavefront curvature or divergence representing each source as it arrives at the desired observation point or points.

This immediately suggests a method of reproduction to place sounds at a distance in a direction – to place sounds correctly in space that is simple but will enable the elimination of the sweet spot and provide shared listening experiences as in reality. We next explore this further.

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[1] The wave-front would measure as if it came from the specified location whether captured by microphones or a listening person. Human perception of sound source location is an interesting later topic.