Similarly, if instead, the phase of a sine-wave signal output from one of the loudspeakers is shifted relative to the other, the sound "image" in the mind of the listener will shift toward the speaker that is ahead/leading in phase (modulo 2π), as we demonstrated in the P406 POM lectures a while back, for the phenomenon of consonance/dissonance. See also *e.g.* Matt Gilson's Fall Semester, 2000 P406 Final Project Report, posted on the P406 website at:

http://courses.physics.illinois.edu/phys406/406pom_student_projects_fall00.html

If one of the two loudspeakers is instead *e.g.* moved to a greater radial distance away from the listener, the sound "image" also moves toward the nearer sound source, as shown above in diagram (c). If the RHS source is farther way by more than ~ 1/3 *m*, corresponding to an arrival time difference, $\Delta t > 1\,ms$, the sound image then coincides with the LHS sound source (S_L). However, if the sound from the RHS sound source (S_R) is made louder than that from the LHS sound source (S_L), to compensate for it being farther away, then the sound "image" moves back towards the median plane.

Thus, it is possible to trade of pressure amplitude/*SPL* for time delay/phase information, within certain limits.

The extent to which trade-off of pressure amplitude *vs*. time delay/phase information works, and the so-called ***sound trading ratio***, R_T defined as the difference in arrival time divided by the equivalent difference in *SPL*, at this time have not been completely/fully-established, however experimental results obtained thus far seem to indicate that the sound trading ratio R_T is clearly frequency-dependent, since our ability to localize very low frequency sounds ($f < 100$ *Hz*) is increasingly poor, whereas the $100 < f < 1500$ *Hz* region it is mainly due to arrival time differences (or relative phase information) of the sound at our two ears in, whereas the intensity / loudness / sound pressure level difference dominates at high frequencies.

Note that this trade-off is also not perfectly complete/equivalent, in that, although at low- and mid-frequencies, a large fraction of the sound "image" shift due a change in distance from a sound source can be compensated by a change in loudness/*SPL*, the sound "image" {position *C* in diagram (c) above} apparently cannot be completely/perfectly restored to the median plane.

Disagreement currently exists between trading ratio experiment results. At low frequencies, *e.g.* $f \sim 200$ *Hz*, trading ratios ranging from $R_T\left(f \sim 200Hz\right) \sim 60-150\,\mu s/dB$ have been reported, whereas at $f \sim 500$ *Hz*, trading ratios ranging from $R_T\left(f \sim 500Hz\right) \sim 10-200\,\mu s/dB$ have been reported…

Experiments to investigate the nature of sound localization of human hearing can easily be carried out using *e.g.* a home stereo sound system and providing a common signal, *e.g.* output from a signal function generator to the sound system, adjusting the stereo balance control to try to compensate *e.g.* for changing the listener's position from his/her nominal mid-plane location, or to compensate *e.g.* for moving one speaker away from its nominal symmetry position. These experiments can also be carried out as a function of frequency, loudness level, …

The figure below shows the time/*SPL* difference trading and also the approximate range of time and SPL differences over which the *precedence* {*aka Haas*} *effect* applies.