VisiSonics 5/64 Frequency Range and Resolution

There are 2 factors that govern the frequency range of a ridged spherical array. The first is the minimum inter-microphone distance (***ID***) and the second is the overall diameter (***D***) of the array. The ***ID*** of the array governs the maximum frequency that can be effectively imaged before spatial aliasing begins to occur. The overall diameter of the array dictates the lowest resolvable frequency. The VisiSonics 5/64 Panoramic Audio Camera consists of an 8 inch diameter sound hard sphere containing 64 independent microphones. In this configuration the lower bound of the array is 200Hz and the upper frequency limit is 7000Hz. When designing an array one has two methods to control this frequency range.

1) Increasing the channel count. By increasing the channel count we decrease the minimum ***ID*** and therefor push the upper frequency limit higher. The lower frequency limit however is unchanged.
2) Modifying the diameter of the array while keeping the channel count constant effectively shifts the frequency range. Increasing the diameter will lower the lower frequency bound at the expense of increasing the ***ID*** and therefore also lowering the upper frequency bound. Decreasing the diameter increases the lower frequency bound while simultaneously decreasing the ***ID*** and therefor raising the upper frequency limit.

In the case of the VisiSonics 5/64 we have chosen a diameter and channel count that maintains maximum portability and flexibility while still providing reasonable lower and upper frequency bounds.

The VisiSonics 5/64 utilizes a novel spherical harmonic based beamformer that makes use of the additional phase and amplitude modulation induced by the sound hard baffle. This additional directionally dependent modulation affords us a decreased lower frequency limit as compared to an equivalently sized open spherical microphone array. This is in part due to the fact that sound must take a longer path around the sound hard sphere as opposed to the direct path taken in open spherical arrays.

As with any beamforming system the resolution of the acoustic image, often measured by the diameter of the beampattern, is also a function of frequency. As frequencies increase the resolution improves. This is due to the fact that at higher frequencies we can utilize more and more spherical harmonics to reconstruct the acoustic image. A maximum of 7th order reconstruction can be achieved with the VisiSonics 5/64. Table 1 contains a chart that shows at what frequencies at which each order can be achieved.

Frequecny range	Effective order
200-572Hz	2nd
573-1286 Hz	3rd
1287-2000 Hz	4th
2001-2715 Hz	5th
2716-3429 Hz	6th
3430-7000 Hz	7th

Table1. Frequency vs. Resolution

As you can see in the above chart we rapidly reach high order beamforming. Figure 1 contains images generated by playing a white noise source inside of an anechoic chamber. Here we can see the corresponding resolution for each frequency range.

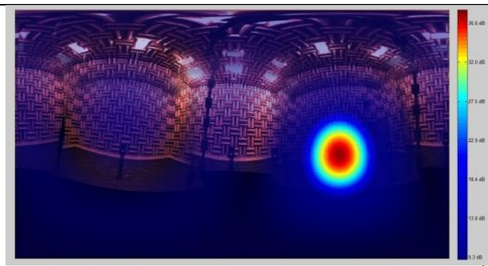
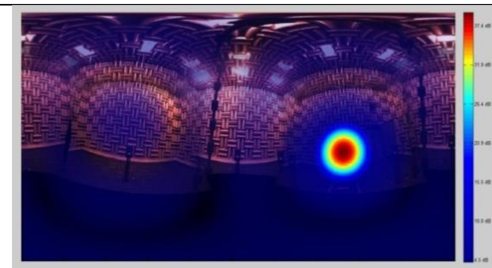
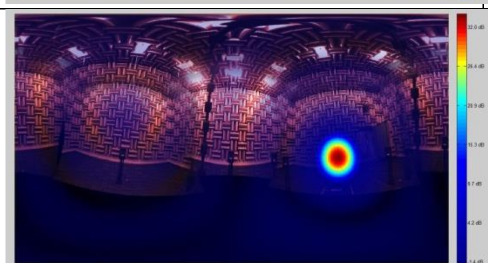
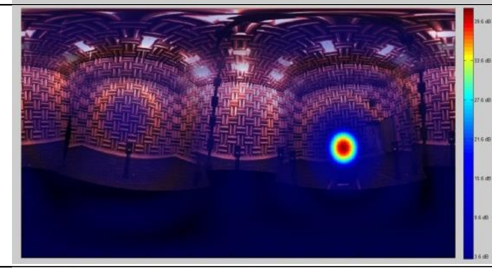
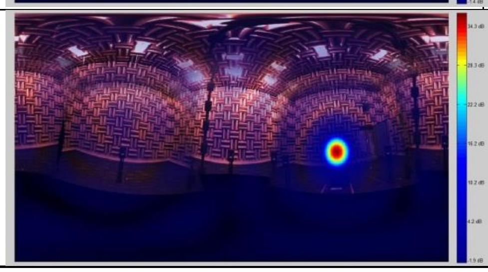
2nd 200 Hz- 572 Hz		**3rd** 573 Hz - 1286 Hz	
4th 1287 Hz - 2000 Hz		**5th** 2001 Hz - 2715 Hz	
6th 2716 Hz - 3429 Hz		**7th** 3430 Hz - 7000 Hz	

Figure 1: Images in an anechoic chamber demonstrating the resolution achievable from 2nd order through 7th order.

The following chart contains the angular beam width for each order and the corresponding physical widths for the following distances 1, 2, 5, 10, and 20. You can use any units you want here.

The relationship between the angular beam width (A) and the corresponding width (W) 2 objects must be at a given distance D is given by W = 2*D*Tan(A/2)

Order	~Angular Beamwidth (Degrees)	1	2	5	10	20	50	100
2	23	0.41	0.81	2.03	4.07	8.14	20.35	40.69
3	18	0.32	0.63	1.58	3.17	6.34	15.84	31.68
4	13	0.23	0.46	1.14	2.28	4.56	11.39	22.79
5	9	0.16	0.31	0.79	1.57	3.15	7.87	15.74
6	6	0.10	0.21	0.52	1.05	2.10	5.24	10.48
7	3	0.05	0.10	0.26	0.52	1.05	2.62	5.24

Even at frequencies below 500Hz we can achieve a high level of accuracy.

There are additional benefits to spherical beamforming vs. other beamforming techniques such as planar beamforming arrays. One such benefit is that with our spherical beamforming algorithms the resolution of the array is completely independent of source direction. In planar arrays the resolution achievable also depends on source location. Additionally, planar arrays suffer from the inability to distinguish sources that are in front of the array from sources that are behind the array. This is due to the fact that the signals received at the microphones are identical in each of these cases. Practically this leads to sources behind the array aliasing into the image at false locations. In the case of measurements made in reverberant or noisy environments this can become a serious problem. Spherical arrays however do not suffer from this ambiguity by virtue of independent and equal resolution in all possible look directions.

In comparison to the open sphere array, a solid spherical array has several advantages:

1) The theoretical situation matches closely to the practical one (all wires and frames for holding the microphone do not contribute to scattering), and thus noise is lower.
2) The whole unit is much more portable and robust.
3) Most importantly, it can be shown theoretically that the beampatterns achieved with a solid spherical array can reach higher frequencies than an open array. This has been extensively studied in several papers [Li05, LD06, BR07], and confirmed experimentally.

It is for these reasons that the VisiSonics 5/64 is the most versatile, portable and nimble array available. The ease of use, compact form factor, and high resolution imaging makes the VisiSonics 5/64 an extremely powerful tool for any acoustics laboratory.

[Li05] Z. Li, The Capture and Recreation of 3D Auditory Scenes, Ph.D. Thesis, University of Maryland, 2005.

[LD06] Z. Li and R. Duraiswami, "Flexible and optimal design of spherical microphone arrays for beamforming," in Proceedings of the IEEE Conference on Speech and Audio Processing, 2006.

[BR07] Ilya Balmages and Boaz Rafaely, Open-Sphere Designs for Spherical Microphone Arrays, IEEE Transactions on Audio, Speech, and Language Processing, Vol. 15, NO. 2, February 2007 727