Parabolic Dish Microphone System

Prepared by: Zhixin Chen (Ph.D. Student),
with the assistance of Robert C. Maher (Associate Professor)
Montana State University

A parabolic dish microphone is like a mirror telescope for sound. A parabolic reflector is used to collect and focus sound waves to a microphone receiver **[1, 2]**. The parabolic shape has the property that all sound waves impinging parallel to the central axis of the dish are reflected to its focus point. When the dish is aimed at a distant sound source it is safe to assume that all the sound waves from the source to the dish are parallel to the central axis of the dish. Therefore, a sensitive microphone placed at the focus point will receive an enhanced signal level due to the acoustic energy arriving over the entire aperture of the dish. Since the dish microphone is effective in enhancing sounds from distant objects, it is often used to obtain the sound of animal vocalizations and other nature recordings **[1]**. This paper describes several theoretical and practical aspects of a conventional parabolic dish microphone system.

1 Computation of Dish Microphone Parameters

In this section we consider the computation of some important theoretical parameters of the dish microphone.

1.1 Parabolic Dish Gain

The inherent acoustical gain of a dish microphone is similar to that of a dish antenna since the wave physics are essentially the same. Thus, we can utilize the well-known expressions of the gain and half power beamwidth of the dish antenna and then apply them to the dish microphone.

The gain and half power beamwidth are the fundamental characteristics of an antenna. The gain is a measurement of how much of the input power is concentrated in a particular direction compared to a hypothetical isotropic antenna that receives energy equally in all directions **[3, 5]**. We should note that here we assume the antenna's characteristic is a *far-field pattern*, which often exists at distance that is much greater than $\frac{r^2}{\lambda}$, where r is the radius of the signal source and λ is the wavelength **[5]**. The wavelength can be expressed as $\lambda = \frac{c}{f}$, where c is the speed of sound and f is the frequency in Hz. The parabolic dish gain is expressed as $G = \eta \frac{4\pi}{\lambda^2} A$, where A is the area of the parabolic dish bore (i.e., the projected area) and η is the *dish efficiency*, determined by its material properties and construction details. So, for a dish diameter D, the area is $A = \frac{\pi D^2}{4}$ and the dish gain is expressed as $G = \eta (\frac{\pi D}{\lambda})^2$ **[3, 4]**.

Practically, the efficiency η of a dish microphone is in the range of 45% to 70% (we assume here that it is 50%). At 25°C the sound velocity is 346.3 m/s. Thus, we can compute the gain of the dish as a function of frequency and dish diameter, as shown in Figure 1.

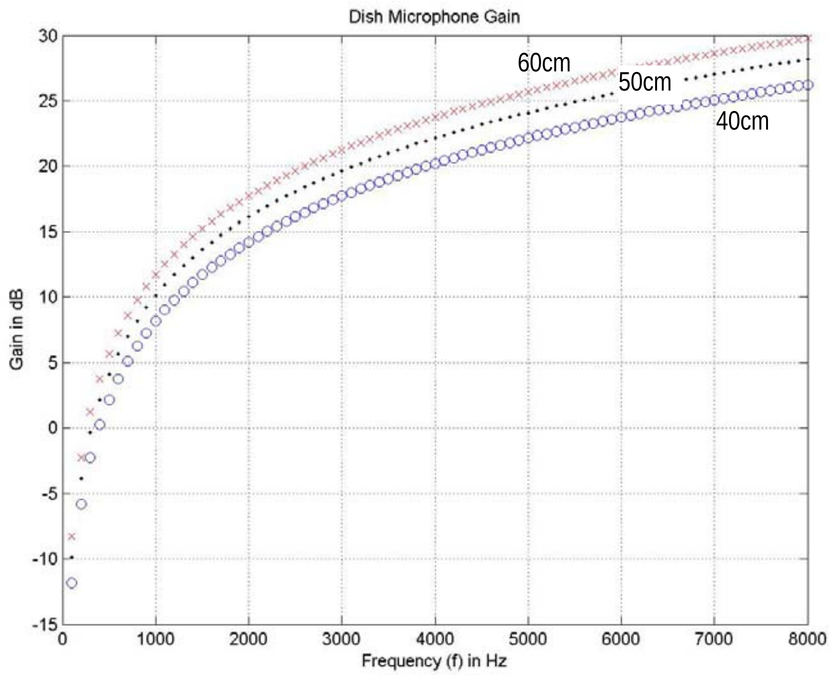

Figure 1: Theoretical gain characteristics of a parabolic dish (25°C).

In Figure 1 we can see that the gain is proportional to f^2, meaning the dish becomes increasingly effective as the wavelength becomes small compared to the dish dimensions. If it is desired to have a flat response over a range of audio frequencies, we can design a filter to compensate for this frequency dependence. For example, a 2nd-order analog Butterworth low pass filter with the cutoff frequency 100Hz has the frequency response shown in Figure 2.

Cascading the lowpass compensation filter with the dish response gives the overall characteristic shown in Figure 3. Careful attention to signal levels is necessary to avoid degrading the signal-to-noise ratio of the complete microphone system.

1.2 Dish Focal Length

Another critical dimension is the *focal length*. The focal length (L) of the dish can be expressed as: $L = \frac{D^2}{16d}$, where D is the dish diameter and d is the depth of the dish **[6]**. Usually, the L/D ratio ranges from 0.25 to 0.65. Given a choice, a dish with a larger L/D (0.5 to 0.6) is preferred because it is more efficient and less sensitive to geometrical errors.

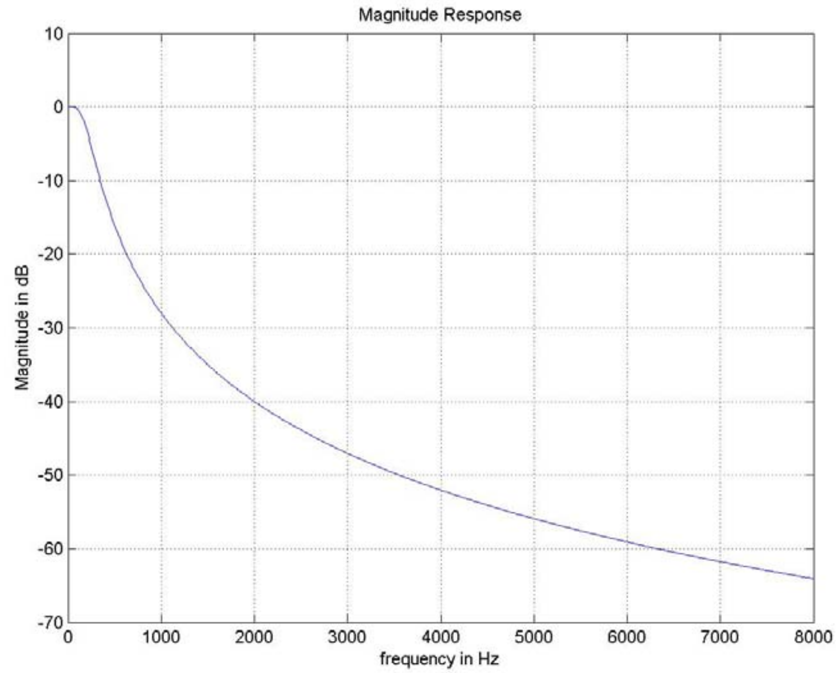

Figure 2: Frequency-compensating filter characteristic.

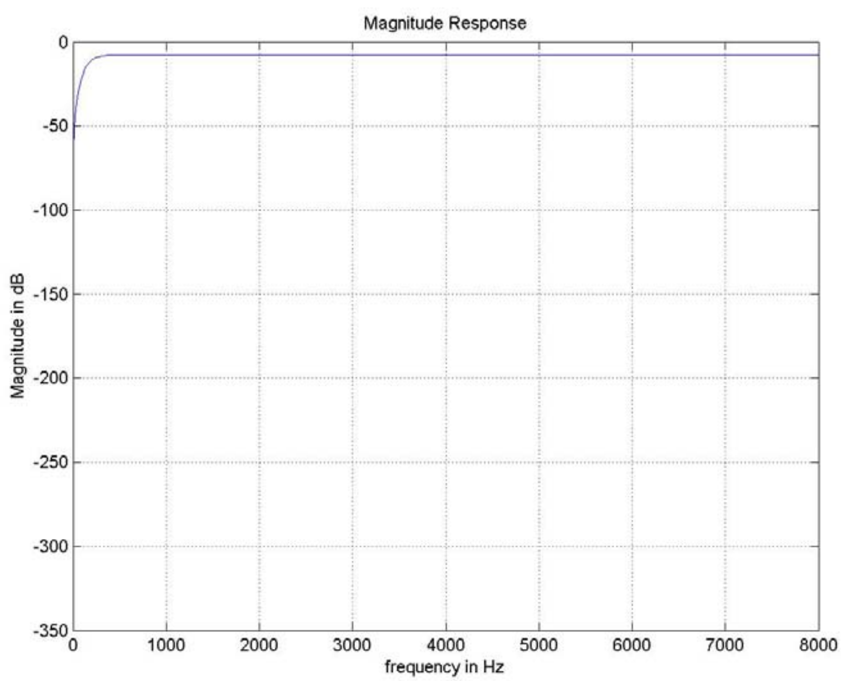

Figure 3: Frequency-compensated system response.

If we let L/D=0.5, we can calculate the required dish depth d to be $D/8$. For example, if the diameter D is equal to 40 cm, the depth will be 5 cm. The commercial parabolic dish microphone used in our experiments (*DetectEar* by Silver Creek Industries) is 50 cm in diameter and has a depth of 12.5 cm, giving a focal length L of 12.5 cm and a relatively small L/D of 0.25.

1.3 Half-power Beamwidth

It is shown in **[3]** that the half power beamwidth is the angular separation between the half power points of the antenna directional pattern, i.e., where the gain is one half the maximum on-axis value. For a dish antenna the beamwidth can be expressed as: $B = \frac{k\lambda}{D}$, where λ and D are the wavelength and the diameter of the dish microphone, respectively, and k is an angular proportionality factor that depends on the shape of the reflector and the method of illumination. For a typical antenna, k = 70°. Note that the half power beamwidth decreases (becomes more directional) as either the frequency increases (shorter wavelength) or as the dish diameter increases. In the case of the commercial *DetectEar* dish microphone with 50 cm diameter, the theoretical beamwidth is approximately 50° at 1 kHz, 12° at 4 kHz, and only 6° at 8 kHz.

2 Dish Microphone Measurements

In this section we explain a set of measurements performed in the laboratory using the *DetectEar* dish. The measurements were carried out in a relatively small acoustically isolated room, so the assumptions of far-field conditions and anechoic measurements are unlikely to be completely accurate. Nevertheless, the results provide a useful frame of reference compared to the theoretical predictions.

2.1 Measurement Method

To measure the performance of the dish microphone we set up a system consisting of a studio monitor loudspeaker and a microphone fixture (Figure 4). A personal computer (PC) in the lab was used to generate the test signal driving the loudspeaker and simultaneously to record the signal received by the microphone.

The PC was used to generate a series of fixed amplitude sine waves with frequencies of 500, 1000, 2000, 3000, 4000, 5000 and 8000 Hz, first with a calibrated omnidirectional studio microphone in the test fixture, and then with the *DetectEar* parabolic dish microphone. The center of the loudspeaker and the diaphragm of the microphone were both set to be 118.1 cm above the floor and the distance between the speaker and the microphone was 182.9 cm. As depicted in Figure 4, the distance for the direct sound from the speaker to the microphone is 182.9 cm while the first reflected sound from the speaker via the floor to the microphone is 298.7 cm, so the path length difference between the direct and reflected sound is 115.8 cm. At 25°C, the sound velocity is 346.3 m/s, so the effectively anechoic duration that can be measured is only about 3.4 ms. Furthermore, the sound field is not expected to be a perfect far-field pattern since the dimensions of the speaker are a relatively large fraction of the direct path distance.

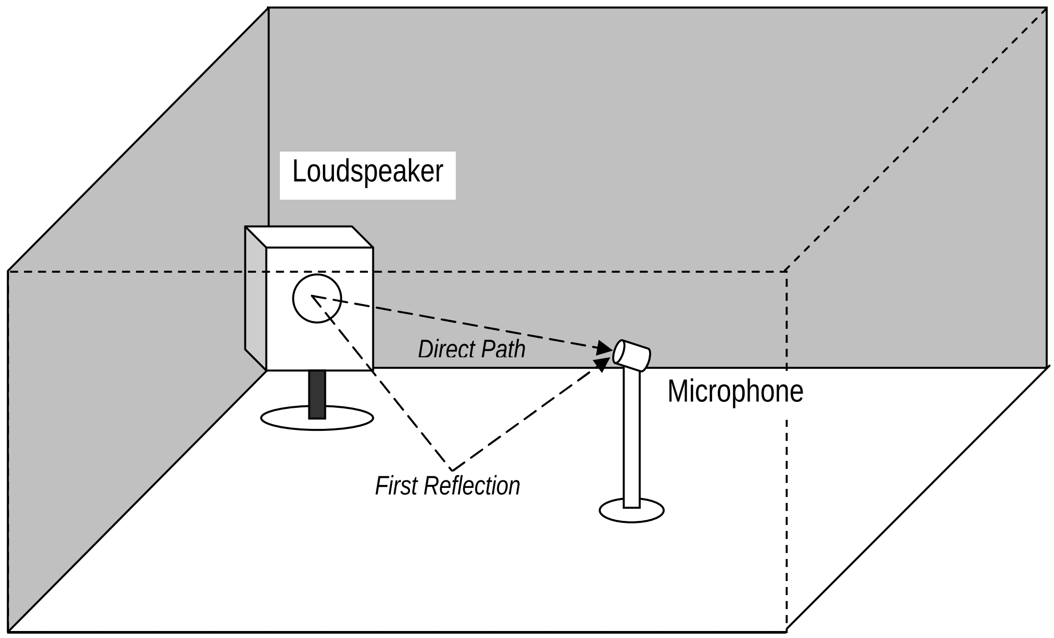

Figure 4: Measurement Configuration.

2.2 Measurement Results

Before we measured the performance of the dish microphone, we measured the gain using a DPA 4004 omnidirectional electret condenser studio microphone with 170V power supply and matching calibrator. The DPA mic can be regarded as a measurement microphone. We also measured the gain of the inexpensive Panasonic microphone used in the *DetectEar* product but without the parabolic dish., i.e., the gain of the microphone element alone. Finally, we measured the gain and beamwidth of the complete dish microphone system. The gain of these three cases is shown in Table 1 and Figure 5. The 1 kHz to 4 kHz frequency range was examined since this is the bandwidth expected to be of interest to the Birdstrike system.

Table 1: Microphone Gain Test

Frequency (Hz)	DPA		Panasonic		Dish Microphone	
	Amplitude	*dB*	*Amplitude*	*dB*	*Amplitude*	*dB*
500	2600	68.3	1736	64.8	5270	74.4
1000	1400	62.9	1000	60.0	2077	66.3
2000	1200	61.6	950	59.6	5960	75.5
3000	1170	61.4	890	59.0	8255	78.3
4000	1900	65.6	1720	64.7	13101	82.3
5000	1300	62.3	1710	64.7	12850	82.2
8000	700	56.9	/	/	15300	83.7

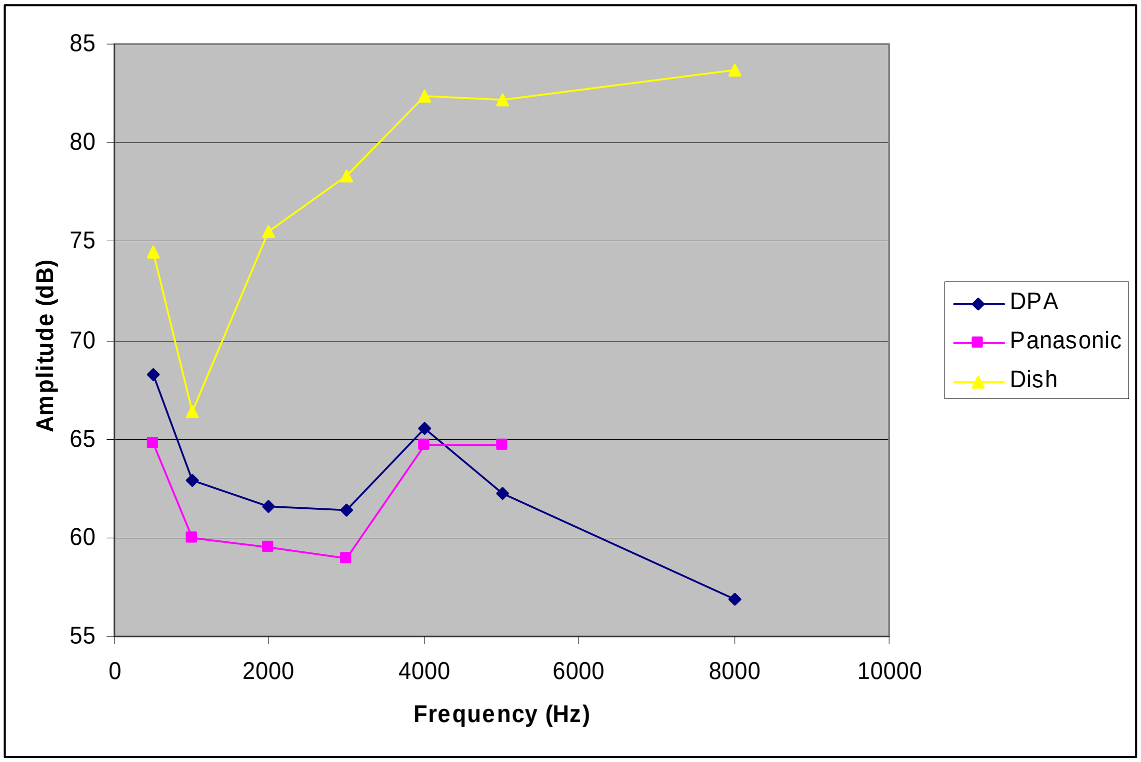

Figure 5: Microphone Gain Test.

We can see that the performance of the Panasonic microphone is comparable to that of the measurement microphone in the 1000 – 4000 Hz band. Also, in this frequency range the dish microphone gain versus frequency is almost the standard square law, as predicted by the theoretical result. As mentioned in Section 1.1 above, a flat frequency response can be obtained by equalizing the dish output with a corresponding lowpass filter characteristic.

To measure the beamwidth of the dish, we first steered the microphone so that its central axis was aligned with the speaker and labeled this case 0°. We then measured the dish gain repeatedly as the dish axis was steered in steps of 15° clockwise until the angle between the dish and the speaker is 180°. The results are shown in Table 2 and Figure 6.

We can see that the beamwidth becomes narrower with increasing frequency. For example, the half power beamwidth for 500 Hz is found to be about 60° while that for 2000 Hz is only 15°. It can be shown that the gain decreases as the angle increases overall. However, there are several exceptions such as near 120° and 180°, which indicate either the presence of significant sidelobes or some other non-ideal behavior. Further study will be needed to identify these details.

Table 2: Directional Pattern Measurement

Frequency (Hz)	Level in dB @ Specified Angle												
	0°	*15°*	*30°*	*45°*	*60°*	*75°*	*90°*	*105°*	*120°*	*135°*	*150°*	*165°*	*180°*
500	66.2	65.8	64.4	62.0	59.8	58.5	56.3	54.6	56.7	50.2	50.4	54.8	56.3
1000	62.5	58.4	50.8	52.9	53.4	52.6	51.0	49.8	52.3	49.2	52.9	57.0	57.9
2000	68.2	61.7	56.8	54.2	51.1	49.2	48.3	45.8	56.7	52.4	49.2	50.4	54.2
3000	72.4	55.2	54.8	54.7	54.4	52.0	46.8	45.3	63.0	55.1	47.4	48.6	57.7
4000	76.6	64.6	60.2	59.4	60.0	57.5	50.6	52.0	67.4	50.8	49.8	52.7	59.4
5000	76.5	60.5	58.9	60.7	59.3	54.3	51.5	48.9	57.1	52.1	43.5	50.6	57.8
8000	80.5	57.1	55.6	52.9	51.8	53.3	48.8	40.8	64.7	57.8	47.8	48.6	54.7

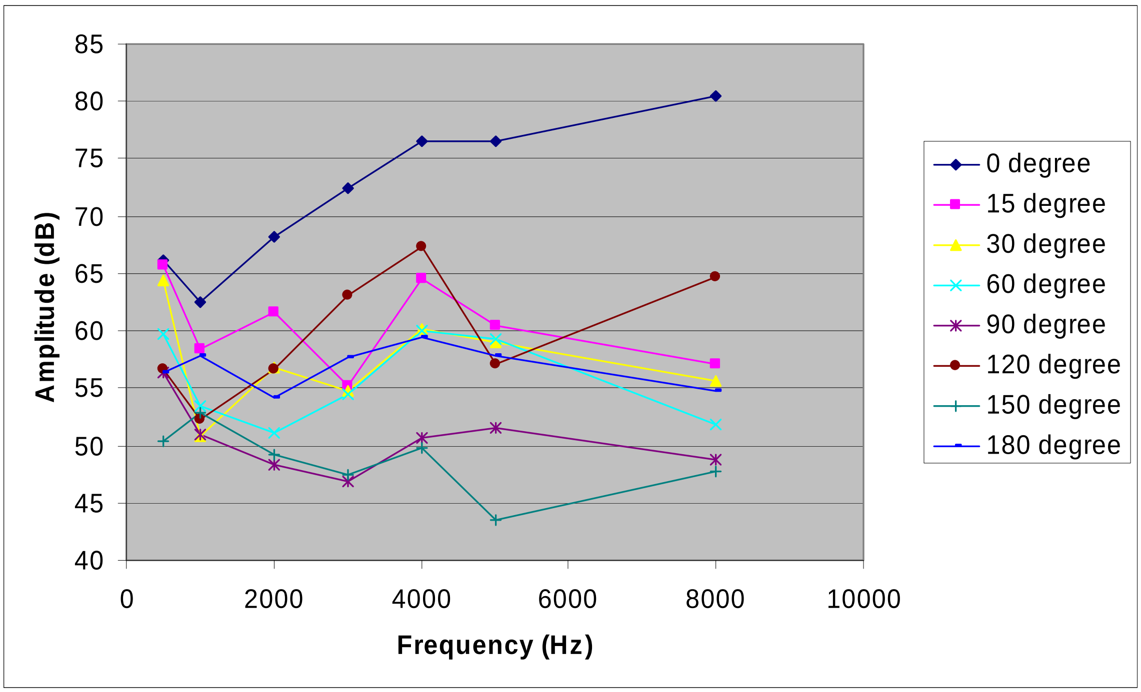

Figure 6: Gain vs. Azimuth as a Function of Frequency

3 Conclusion

The general results indicate that the measured dish performance is reasonable compared to the theoretical predictions, especially in the desired frequency range from 1000 to 4000 Hz. Similarly, the half power beamwidth generally follows the expected trends and predictions. In the future the measurements can be improved by using a larger room to more closely approximate an anechoic measurement, and also to create a more accurate far-field situation.

4 Electronic References

[1] Patricia Clay, Telescopes and Microscopes
http://rabi.phys.virginia.edu/HTW/telescopes_and_microscopes.html

[2] Wikipedia, Parabolic Microphone
http://www.fact-index.com/p/pa/parabolic_microphone.html

[3] Robert A. Nelson, Antennas
http://www.aticourses.com/antennas_tutorial.htm

[4] Paul Wade, Parabolic Dish Antennas
www.qsl.net/n1bwt/chap4.pdf

[5] Telecom Glossary 2000, far-field diffraction pattern
http://www.its.bldrdoc.gov/projects/devglossary/t1g2k.html

[6] Kasra Barkeshli, Parabolic Reflector Antennas
http://sina.sharif.ac.ir/~barkeshli/antennas