Delay and Sum Algorithm- Assignment 8

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Overview

The aim of this assignment is to reconstruct an image using the Delay-and-Sum (DAS) algorithm that is commonly used in Ultrasound image reconstruction.

Delay-and-Sum Algorithm (DAS)

The delay and sum (DAS) algorithm is a beamforming algorithm that is used to focus the output of a microphone array on a specific direction of arrival (DOA). The algorithm works by delaying the signal from each microphone by a different amount, and then summing the delayed signals together.

Assumption

The signal received by each microphone is assumed to be the just source wave function plotted with the time delay taken for the sound wave to reach the mic be shifted to be t = 0 and the time before that is negative. This resulted in the received waves being symmetric about the microphones time delay. This is the same assumption used in the assignment handout and hence was followed. In actuality the received signal has an impulse at the delay time as the signal sent by the source has an impulse at t = 0.

Procedure

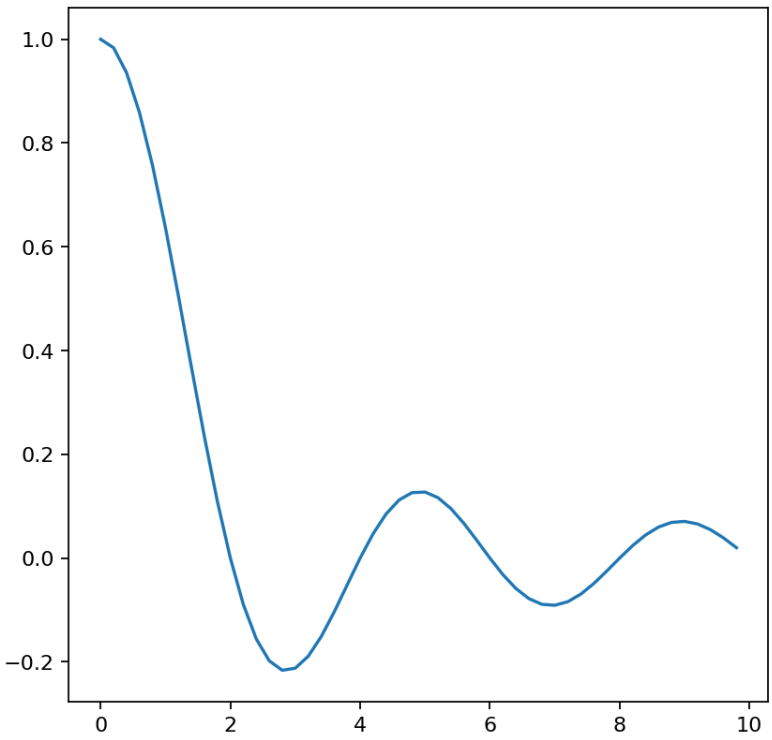
1. First the microphones separated by the `pitch` are arranged along the Y axis symmetrically about the source which is at the origin.
2. Then using the distance between samples (`distance_between_samples` , which is the distance travelled by the sound wave in the time between samples, and the speed of the sound wave `C` , the time between samples, `sampling_time` , is found in the following way,
   `sampling_time` $\times$ `C` = `distance_between_samples` .
3. Using the sampling time, an array of time from 0 to `Nsamp` $\times$ `sampling_time` separated by the `sampling_time` is created which is the times during which the wave is sampled.
4. The `wsrc()` function is used to generate the wave emitted by the source during the sampling interval, and this wave signal is plotted against time.
5. Functions `pointDistance(pt1, pt2)` and `dist(src, pt, mic)` are defined to find the distance between two points and the length of the path from the source to a point and from the point to a microphone.

6. The delay for each microphone to receive the signal that has been reflected from a point obstacle is calculated.
7. The wave received by each microphone is plotted with some vertical shift to visualize the signal.
8. Then the Delay and Sum Algorithm is used at every single point on the 2D space whose Y axis is divided into `Nmics` levels and whose X axis goes till the distance the sound wave can travel in the 2 to 3 times the maximum delay of a microphone, or for simplicity's sake distance travelled by the sound wave in `Nsamp` time intervals.
9. Plotting a heatmap of the data obtained in using the DAS algorithm gives us an estimate for the location of the obstacle.

Outputs for various combinations of the Number of Microphones and the Number of Samples

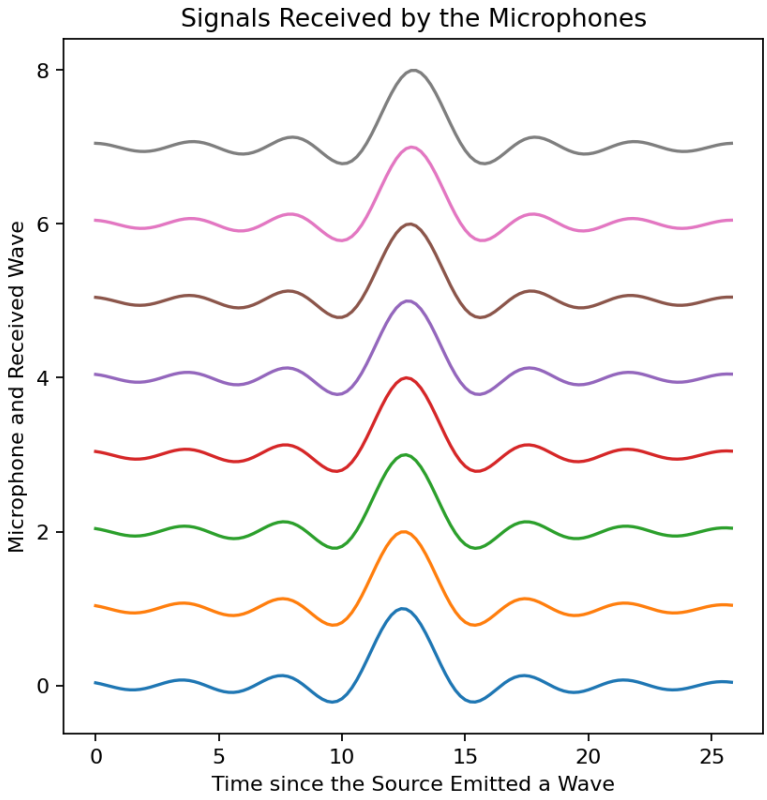
The signal is sampled 50 times, `Nsamp` = 50

Since the wave produced by the source depends only on the number of samples and the speed of sound, and not the number of microphones, the source wave will be the same for all cases having the same number of samples.

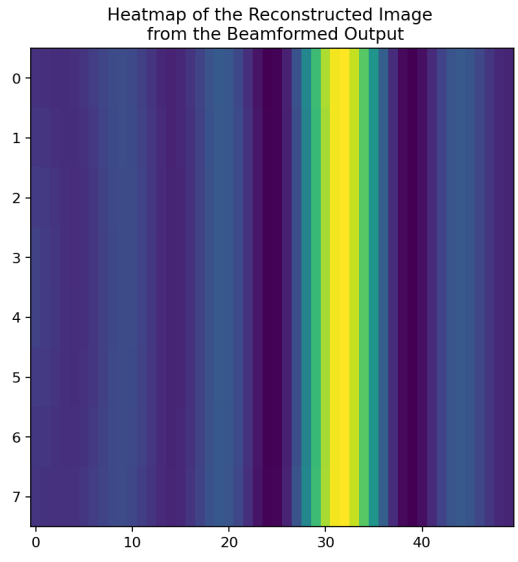
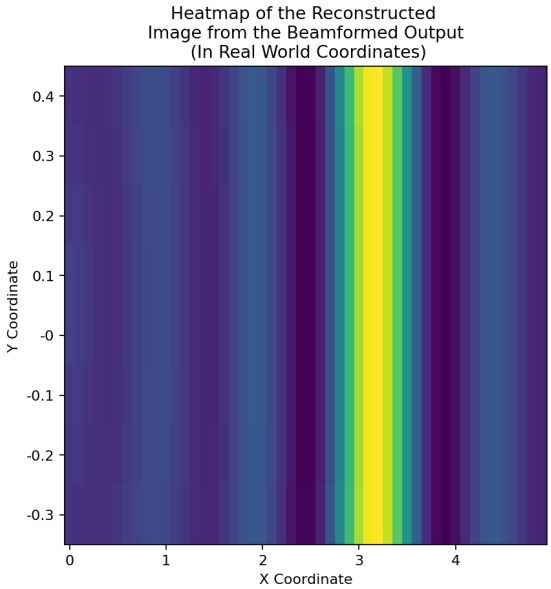


The Microphone array has 8 mics, `Nmics` = 8

The signals received by the microphones is plotted below



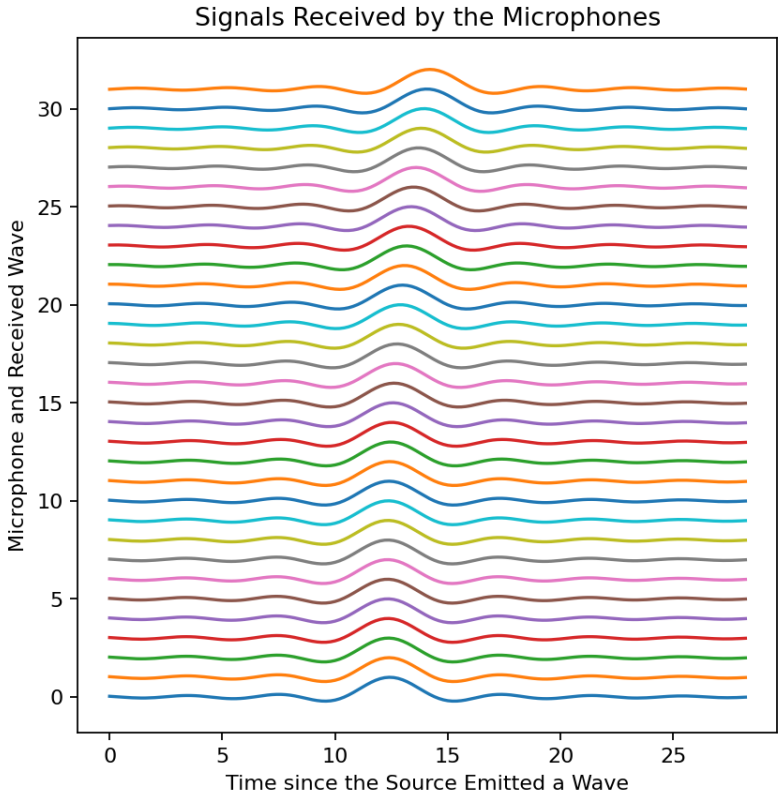
The heatmaps of the Reconstructed Images obtained on using the Delay and Sum algorithm to estimate the position of the obstacle are below

Reconstructed Image	Reconstructed Image with real world coordinates
	

Having 8 microphones gives a y - coordinate range of [-0.35, 0.35] which does not include -1, hence the y - coordinate of the obstacle can not be inferred from the above reconstructed images where as the x - coordinate of the obstacle can be estimated.

The Microphone array has 32 mics, `Nmics` = 32

The signals received by the microphones is plotted below



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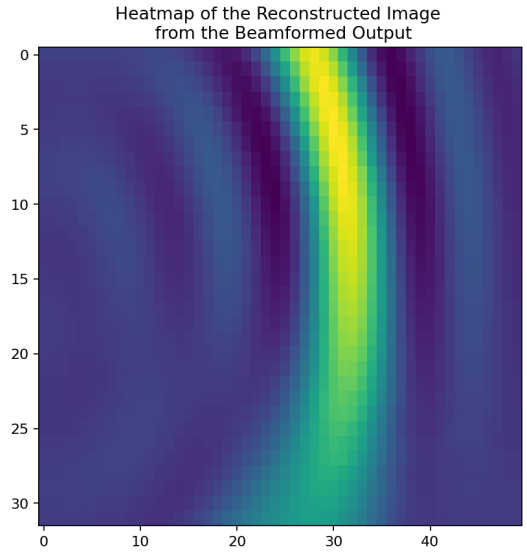
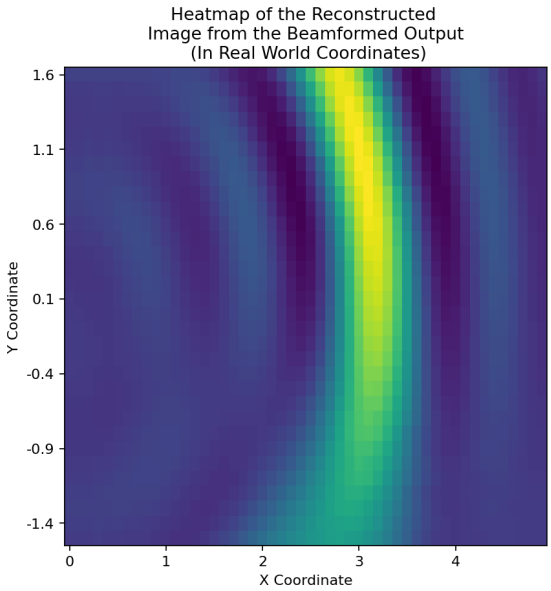
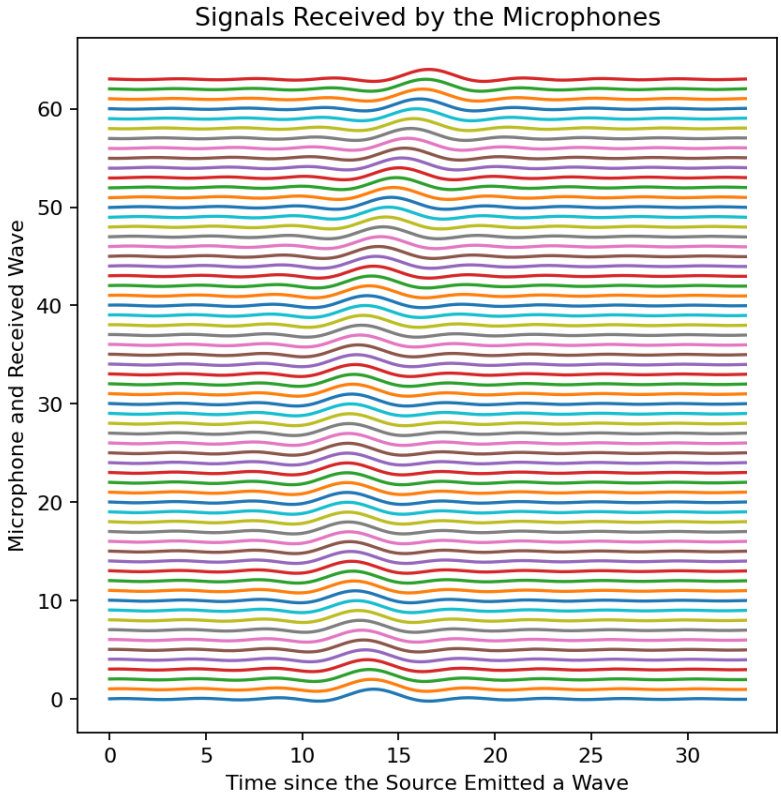
	

Having 32 microphones gives a y - coordinate range of [-1.55, 1.55] which even though includes -1 does not span wide enough about -1 to give us a clear estimate of the y - coordinate, hence the y - coordinate of the obstacle can not be very clearly estimated from

the above reconstructed images. This is because the maximum vertical distance from the source that can produce a clear reconstructed image would be, roughly as a rule of thumb, half the distance of the farthest microphone from the source which is 0.775 in this case and is less than 1. The x - coordinate of the obstacle can be somewhat clearly estimated.

The Microphone array has 64 mics, `Nmics` = 64

The signals received by the microphones is plotted below



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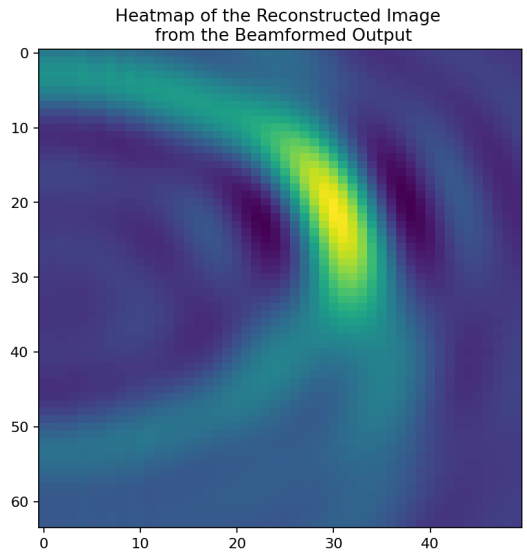
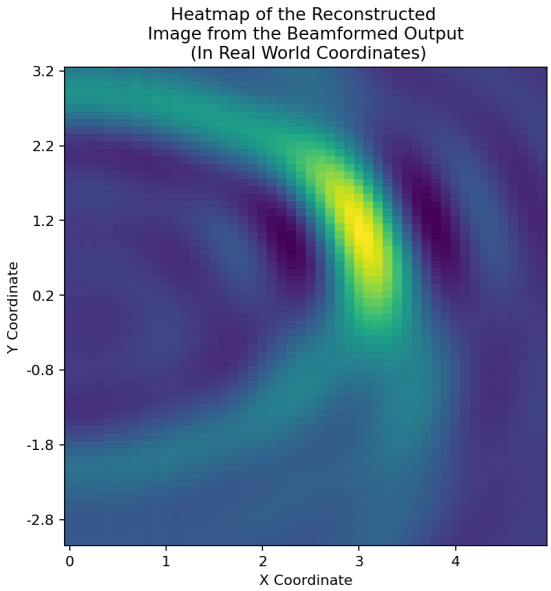
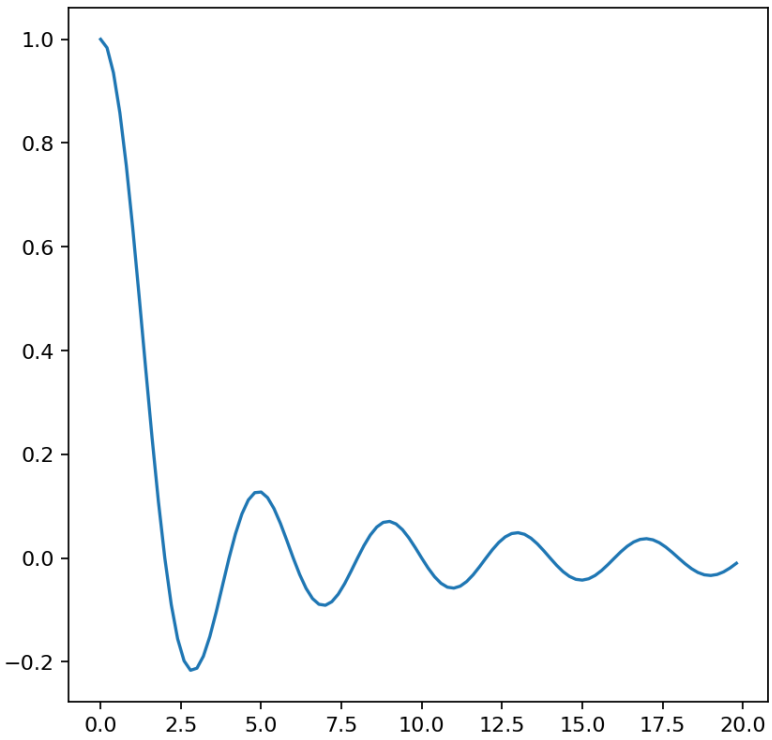
	

Having 64 microphones gives a y - coordinate range of [-3.15, 3.15] which includes -1 and does span wide enough about -1 to give us a clear estimate of the y - coordinate, hence the y - coordinate of the obstacle can be estimated from the above reconstructed images along with the x - coordinate.

The signal is sampled 100 times, `Nsamp` = 50



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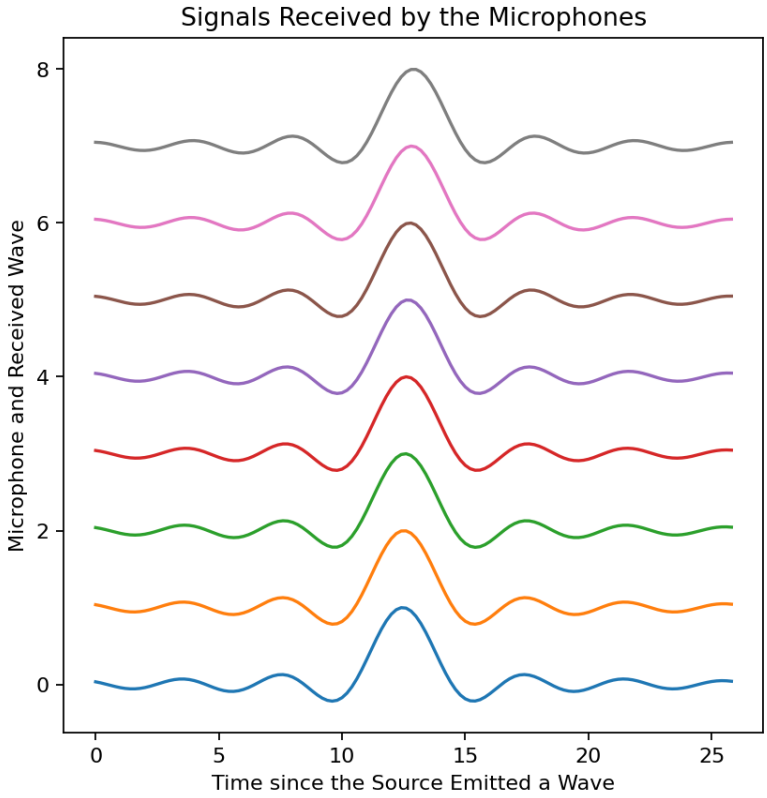

The heatmaps of the Reconstructed Images obtained on using the Delay and Sum algorithm to estimate the position of the obstacle are below

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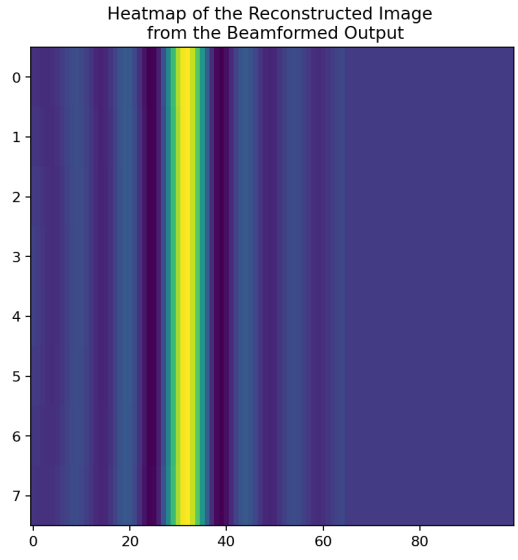	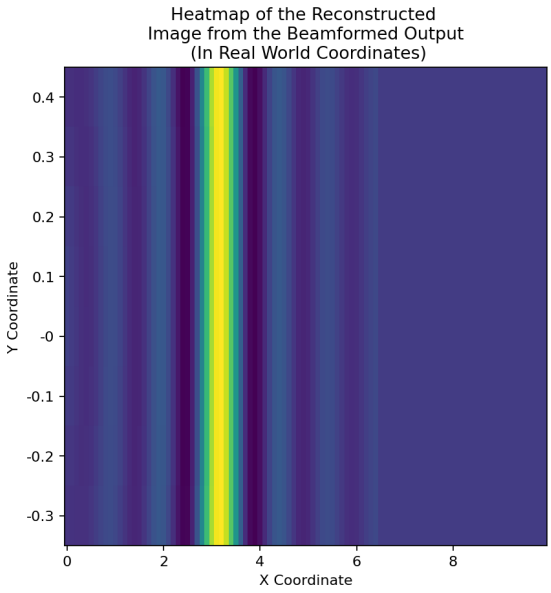

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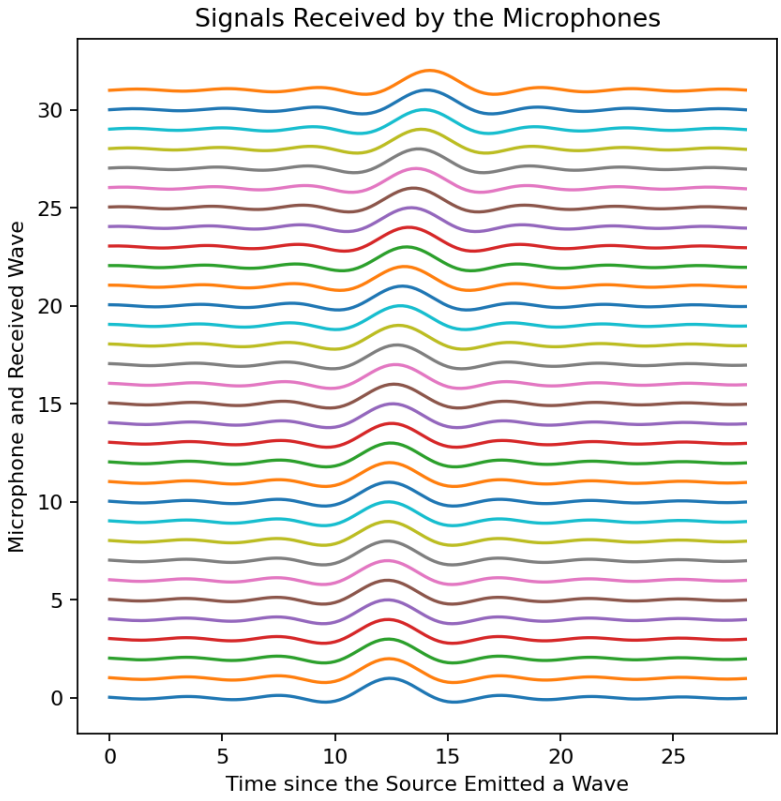

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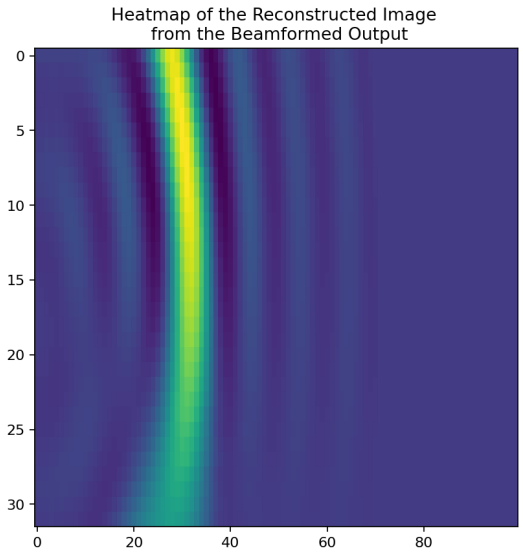	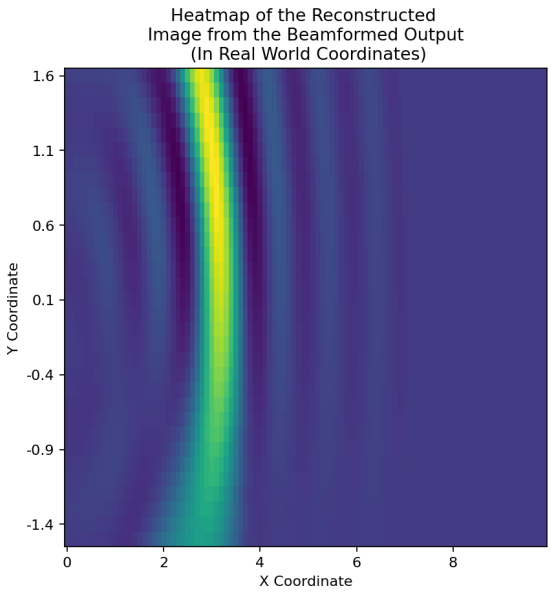

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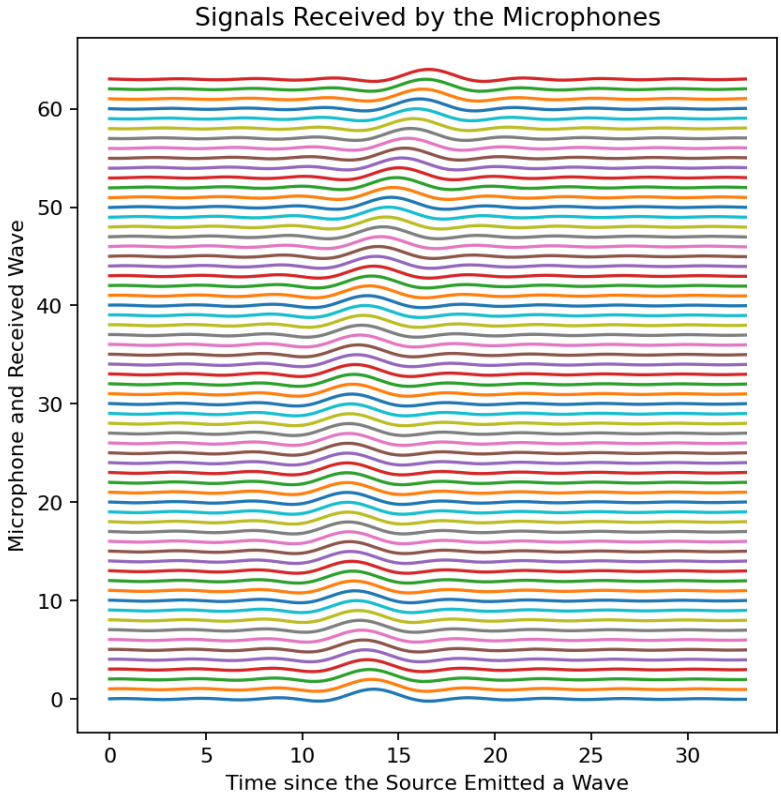

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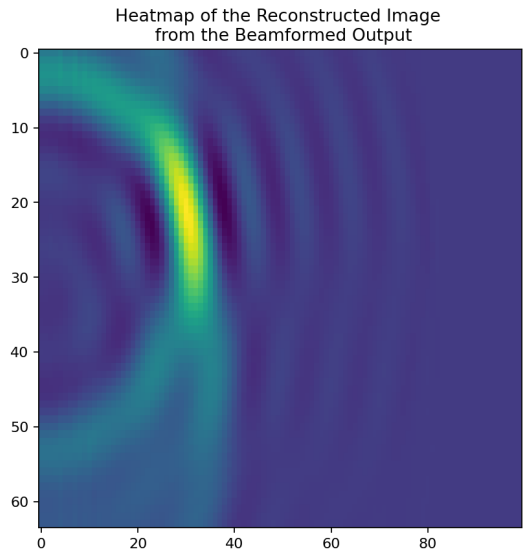	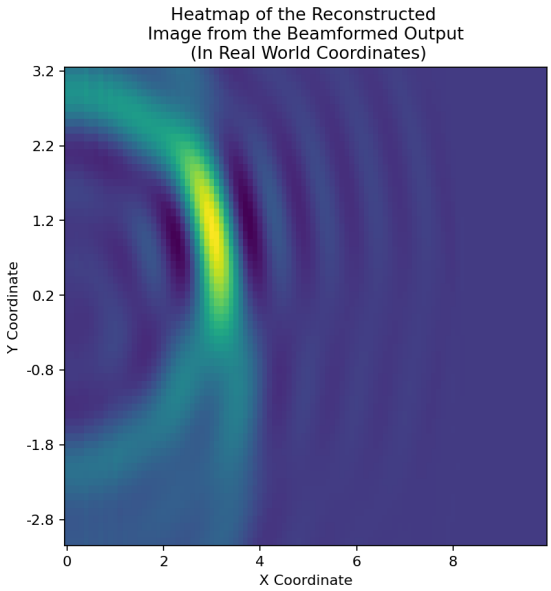

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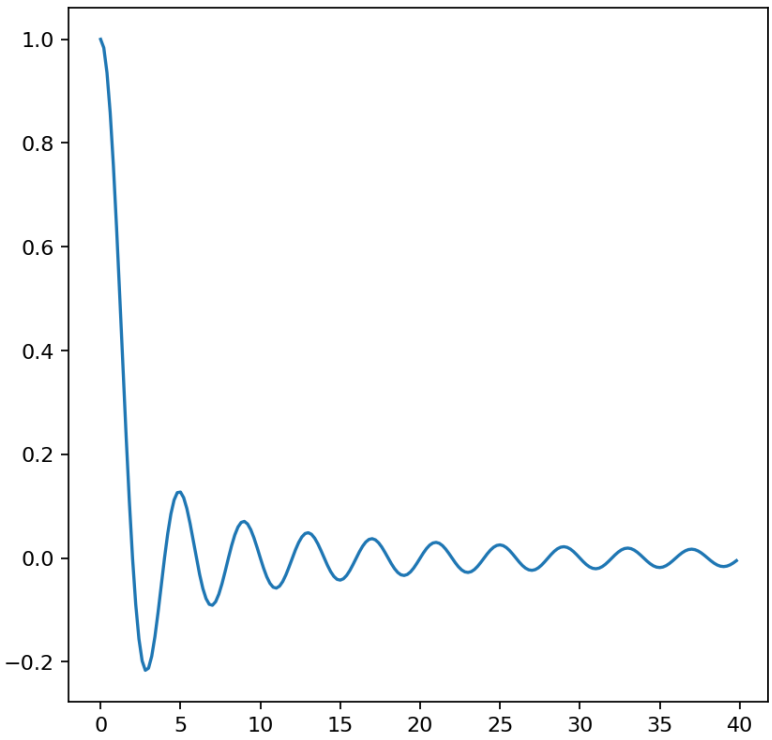
The signal is sampled 200 times, `Nsamp` = 50



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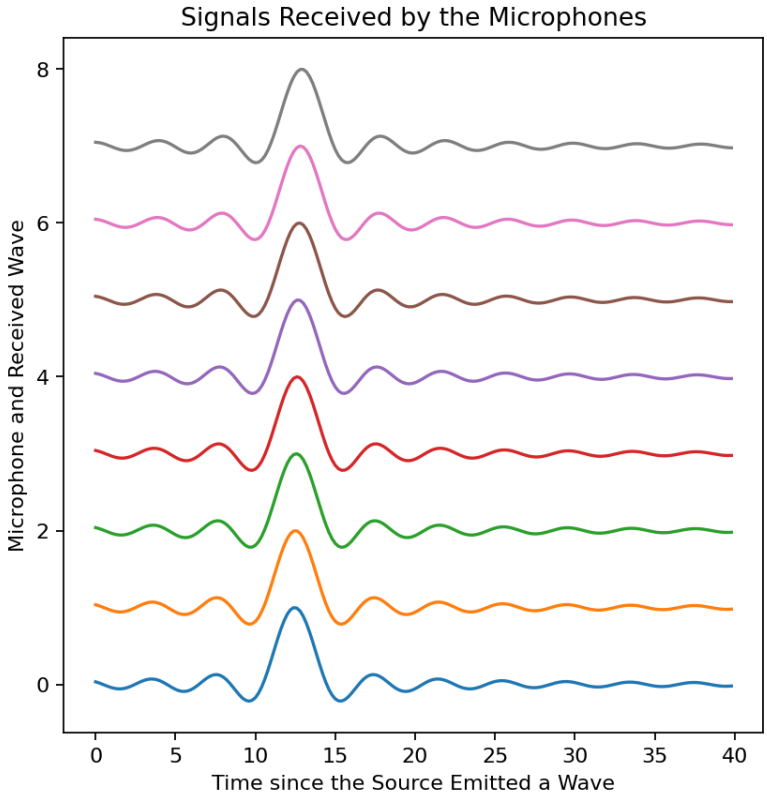

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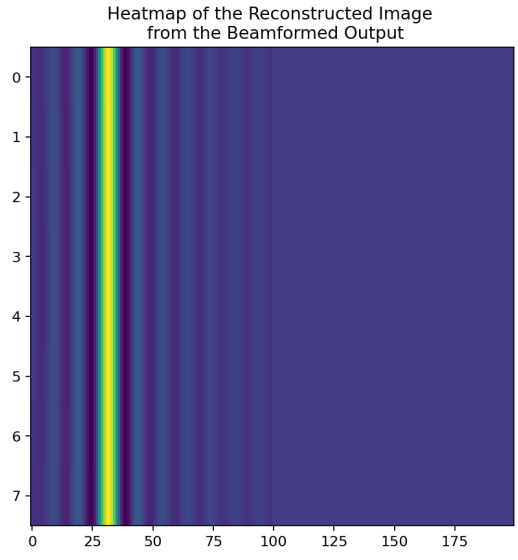	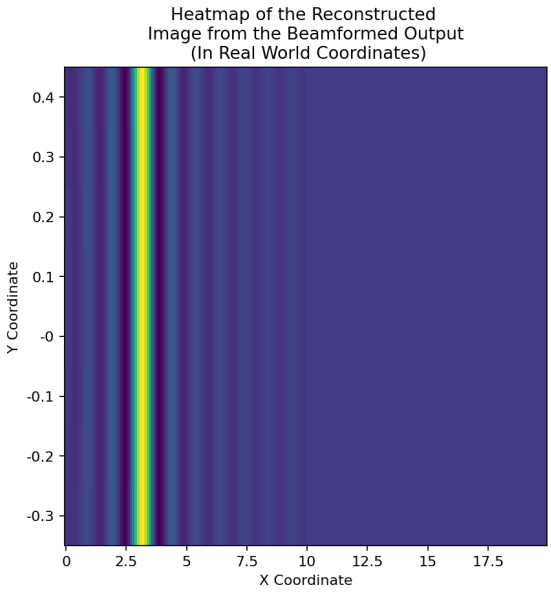

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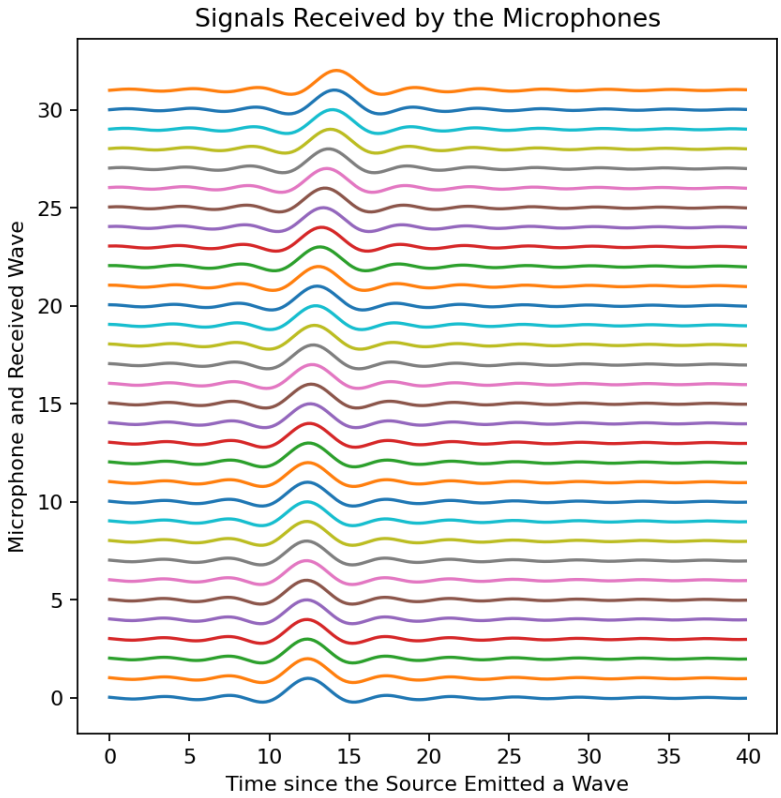

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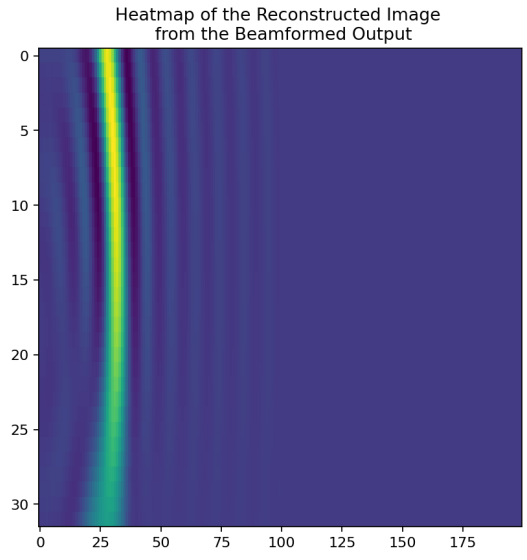	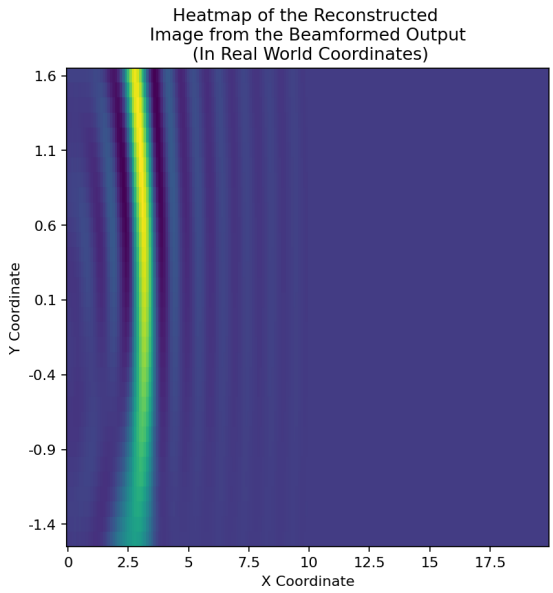

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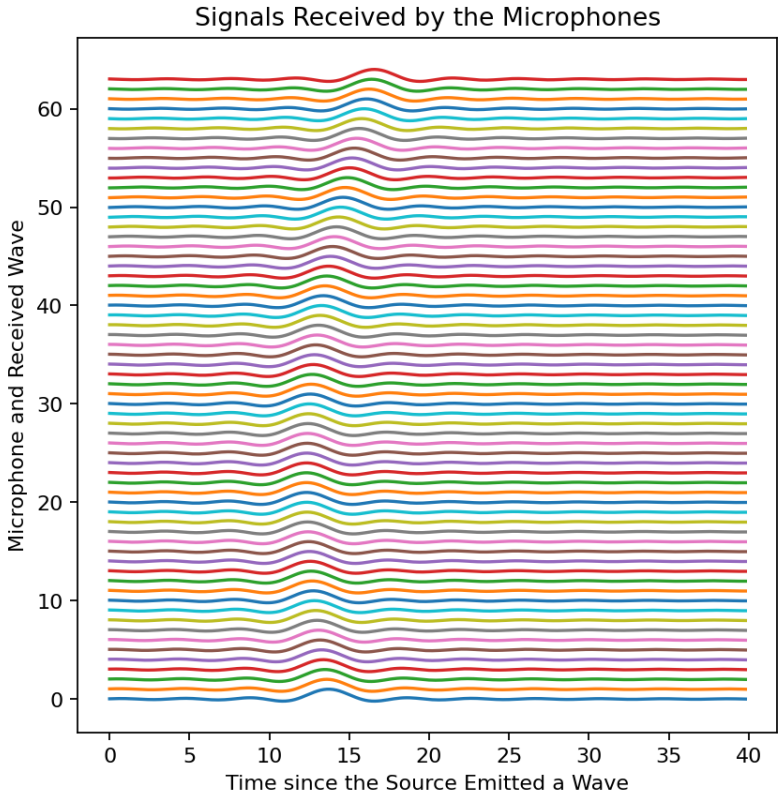

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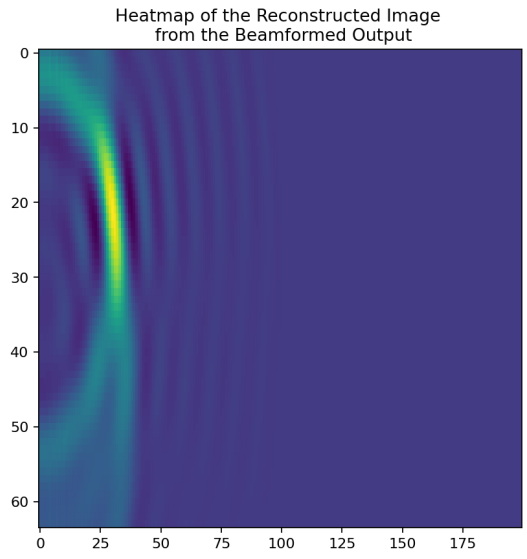	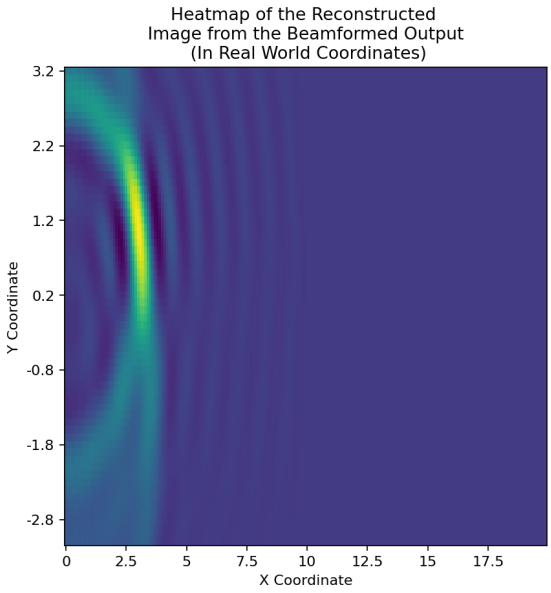

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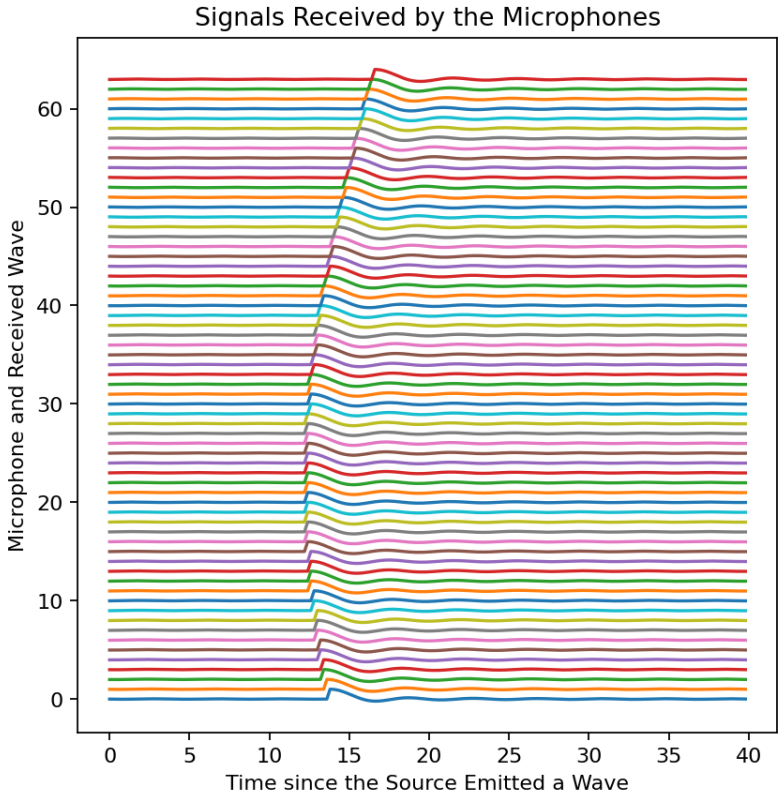
Observations and Inferences

- Since the above experiments or "Ultrasound Scans" were done having an obstacle at the real world coordinates (3, -1), having 64 microphones was able to give us a clear estimate of the y coordinate of the obstacle whereas having 8, 32 mics was not.
- The 64 microphone reconstructed images gave the coordinates of the obstacle as roughly (30, 22) which is (3, -1) in real world coordinates. Hence the obstacle's position is fairly clearly estimated.
- As the number of microphones increases, the vertical range that can be detected increases resulting in better image reconstructions and estimations.
- A major problem to the clarity of the reconstructed images and our ability to estimate the position of the obstacle from them is the low number of samples. If the number of samples increases, the clarity of the images increases.

Assumption

The signal received by each microphone is assumed to be the just source wave function plotted with the time delay taken for the sound wave to reach the mic be shifted to be t = 0 and the time before that is negative. This resulted in the received waves being symmetric about the microphones time delay. This is the same assumption used in the assignment handout and hence was followed. In actuality the received signal has an impulse at the delay time as the signal sent by the source has an impulse at t = 0.

Below are the plots when this is not assumed and a signal with an impulse is used.



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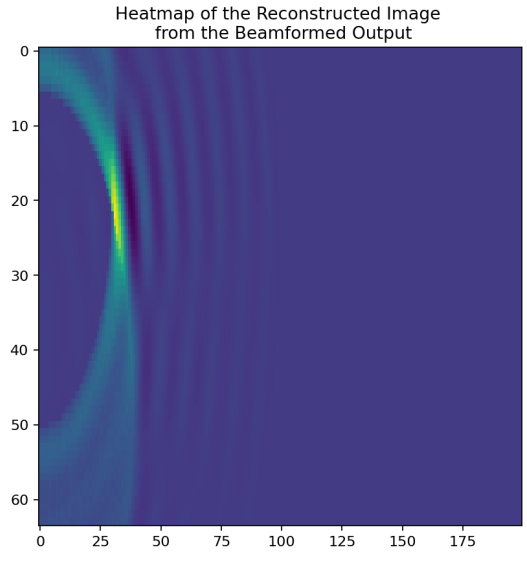
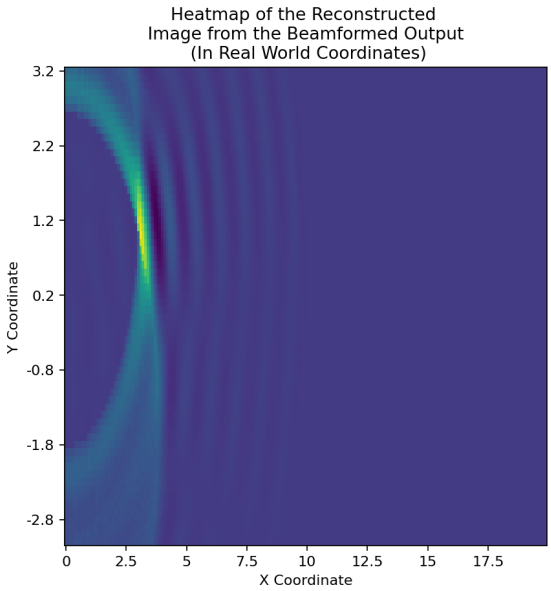
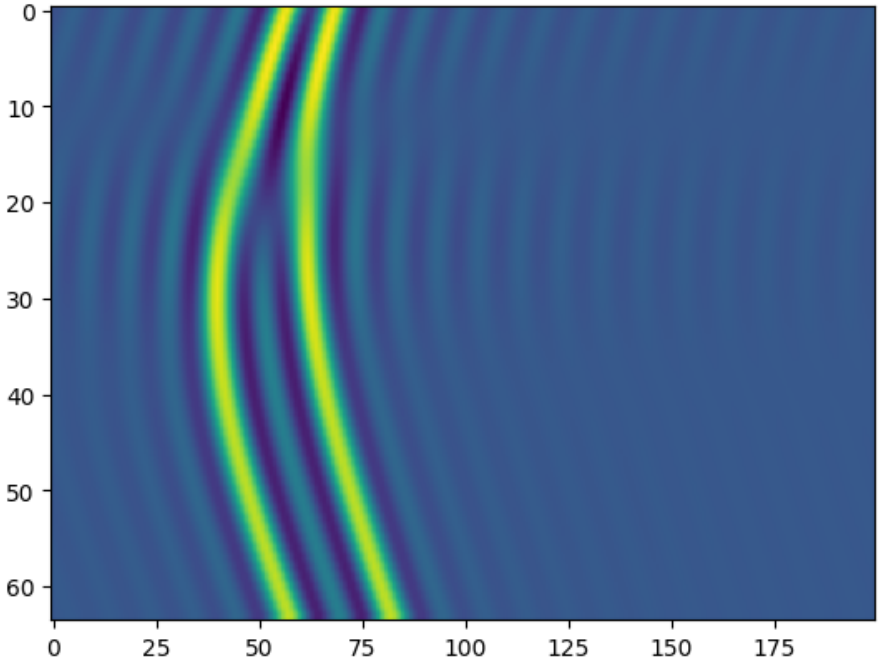
	

The image is sharper just to the right of (30, 22), this is because the impulse narrowed the possible positions of the obstacle.

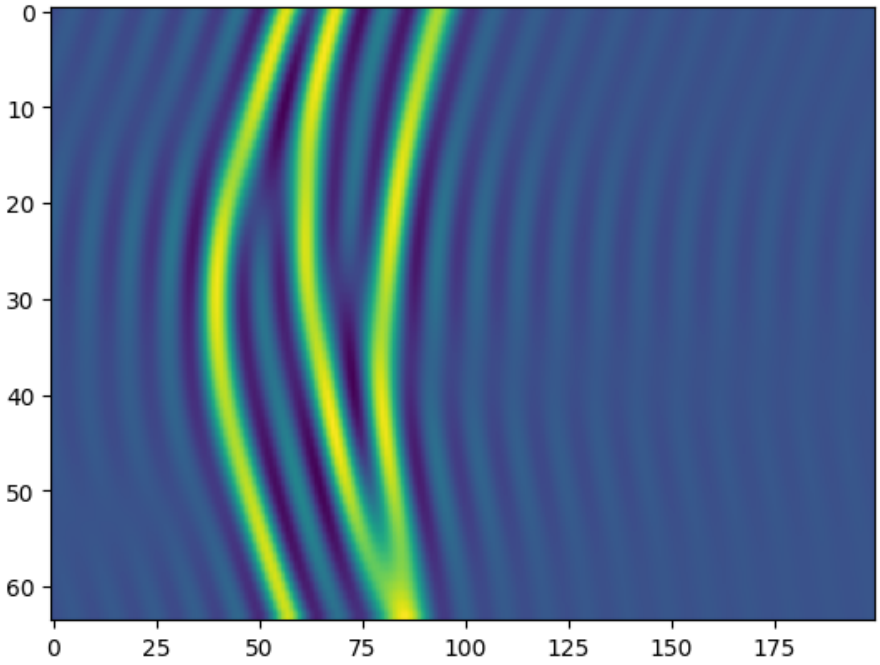
Observations from the data in `rx2.txt` and `rx3.txt`

- Plotting the data given in `rx2.txt` resulted in the following heatmap of the signals received by the microphones.



One can observe that this has two waves with maxima travelling from the right to the left, this implies that there are two obstacles. Since the "bulge" of the leading wave is lower than the lagging one, it can be concluded that that obstacle is higher up that the other. The difference in times of receiving the waves implies that they are at different distances from the microphone array. One wave is leading because it got reflected early and hence it is closer to the microphone array than the other obstacle.

- Plotting the data given in `rx3.txt` resulted in the following heatmap of the signals received by the microphones.



One can observe that this has three waves with maxima travelling from the right to the left, this implies that there are three obstacles. The obstacle resulting in the leading wave is closer to mic array than the second one, which is in turn closer to the mic array than the last one.

NOTE: Reconstruction of the images from both of the given data has not been done.