Ultrasonic source localization with Beamforming

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Problem Description

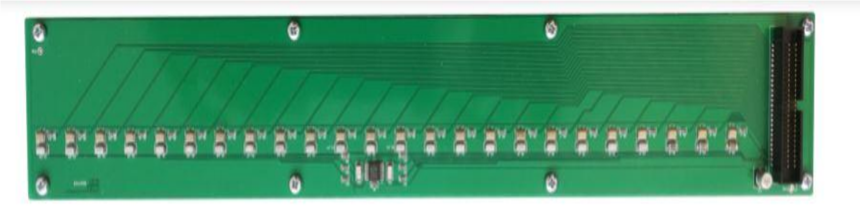
- To design a system to track a moving robot on a factory floor.
- Acoustic source is mounted on the robot.
- The tracking equipment is fixed on a wall and has no moving parts.

Requirement / Specifications

To system to be designed should be able to :

- Track an ultrasonic source (eg: fixed on a robot) in 2D space.
- Detect the change in the position of the source with a latency of less than one second.
- Detect the source movements of more than two degrees in the cone of interest.
- Use a fixed frequency audio source
- Display the co-ordinates of the source in real time.

Hardware



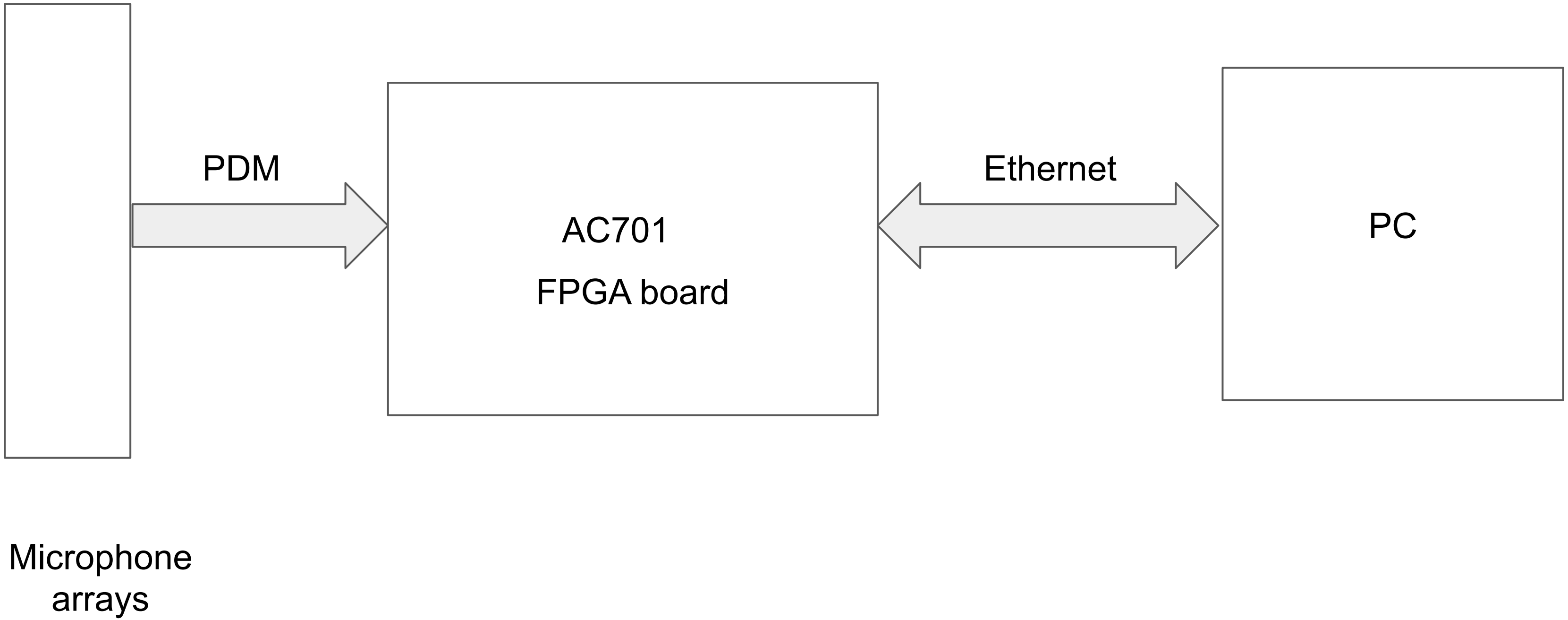
Microphone array

Xilinx AC701 FPGA

FMC Breakout board

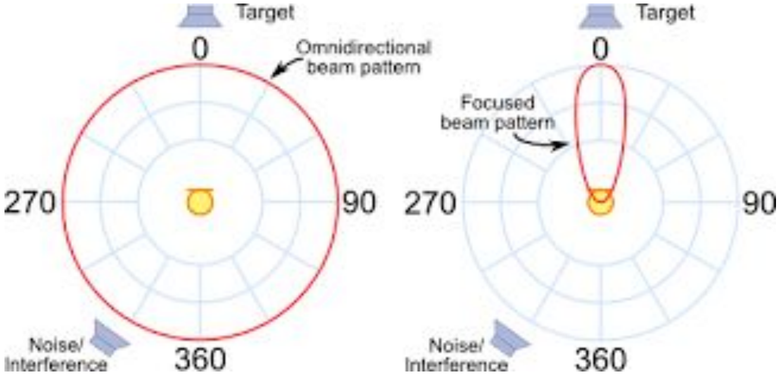
Source :Syntronic

Design



Beamforming with the microphones

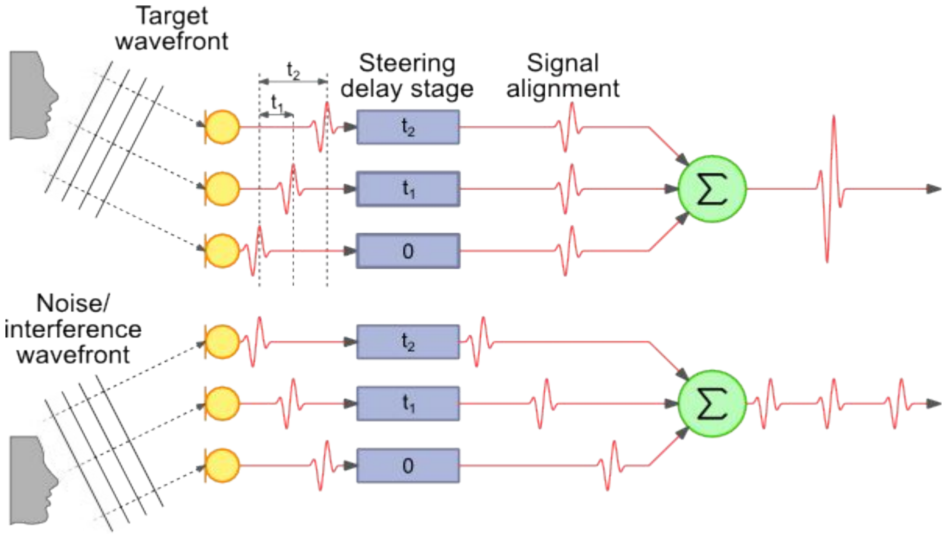
- Beamforming (spatial filtering) technique where we use sensor arrays to send or receive in a particular direction.
- We use the microphones here to listen in a particular direction and attenuate all other signals from other directions.



Source: Delay sum beamforming, The Lab book pages

Techniques for beamforming

- **Delay and sum** (used in this project)
- Filter and sum
- Frequency domain beamforming



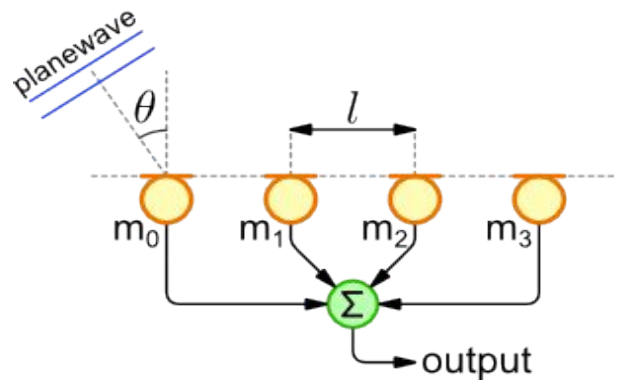
Delay and sum beamforming

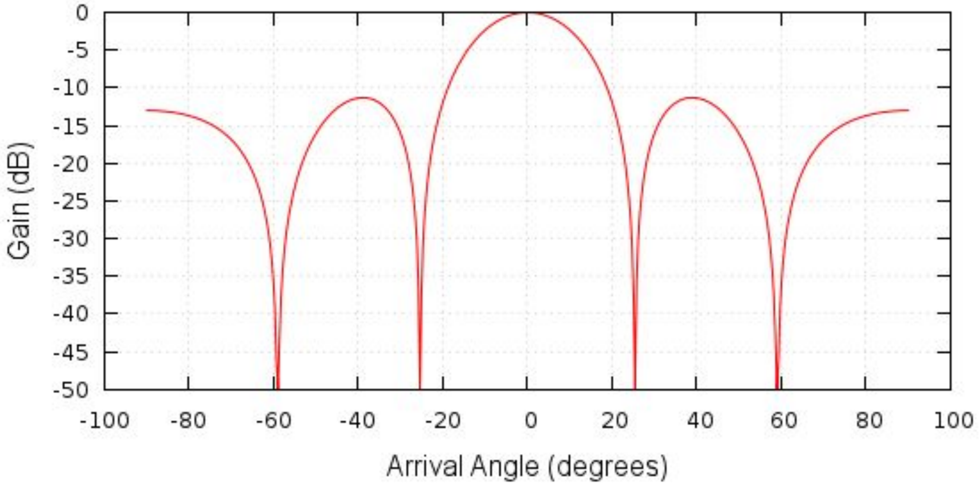
Source: The Lab Book Pages

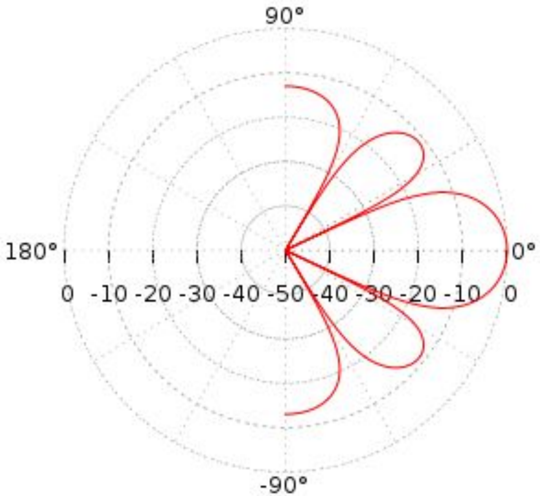
Delay and Sum

- When we constructively add the signals, the output is given by,

$$output = 20\log_{10}\left(\frac{1}{N}\sum_{i=0}^{N-1} e^{\frac{j\,2\pi f\,i\,l\,\sin(\theta)}{c}}\right)$$



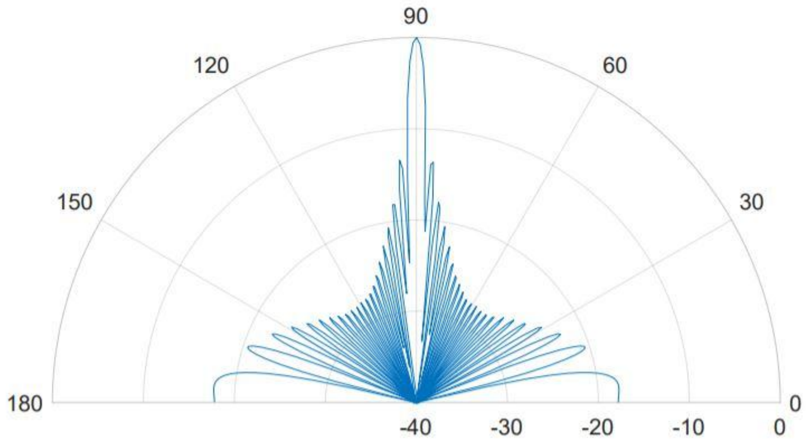




source : The Lab book Pages

- The beam patterns depend on:
  - Speed of sound, **c**.
  - Distance between microphones **d**.
  - Frequency of the incoming signal **f**.
  - Number of microphones, **N**.

- **f(max) = c/d** = 30Khz (approx)
- Here the distance between microphones is fixed 11.43mm.
- **Delay = (N*d*cosθ) / c**
  - **ψ** is the incident angle of the wavefront on the microphone array.
  - **θ** is the "look-direction" of the microphone array.

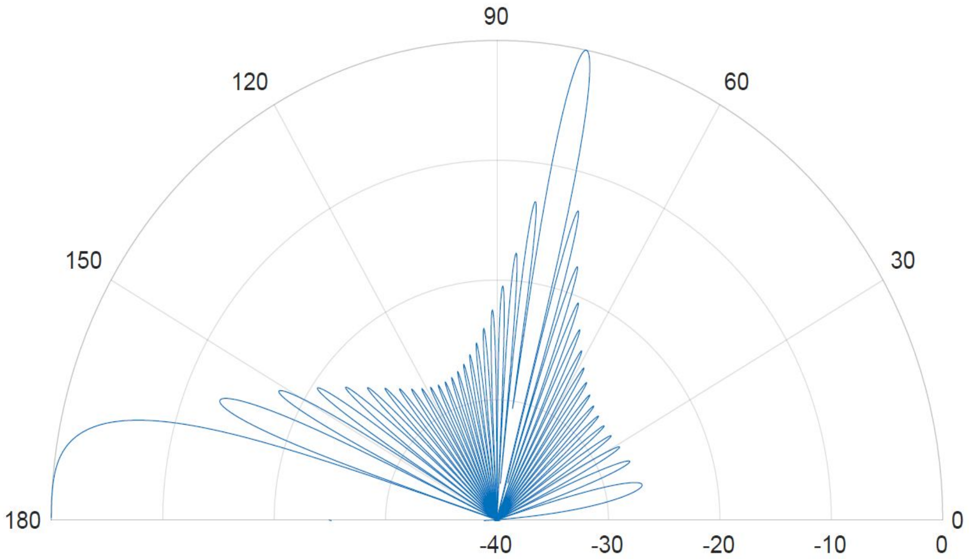


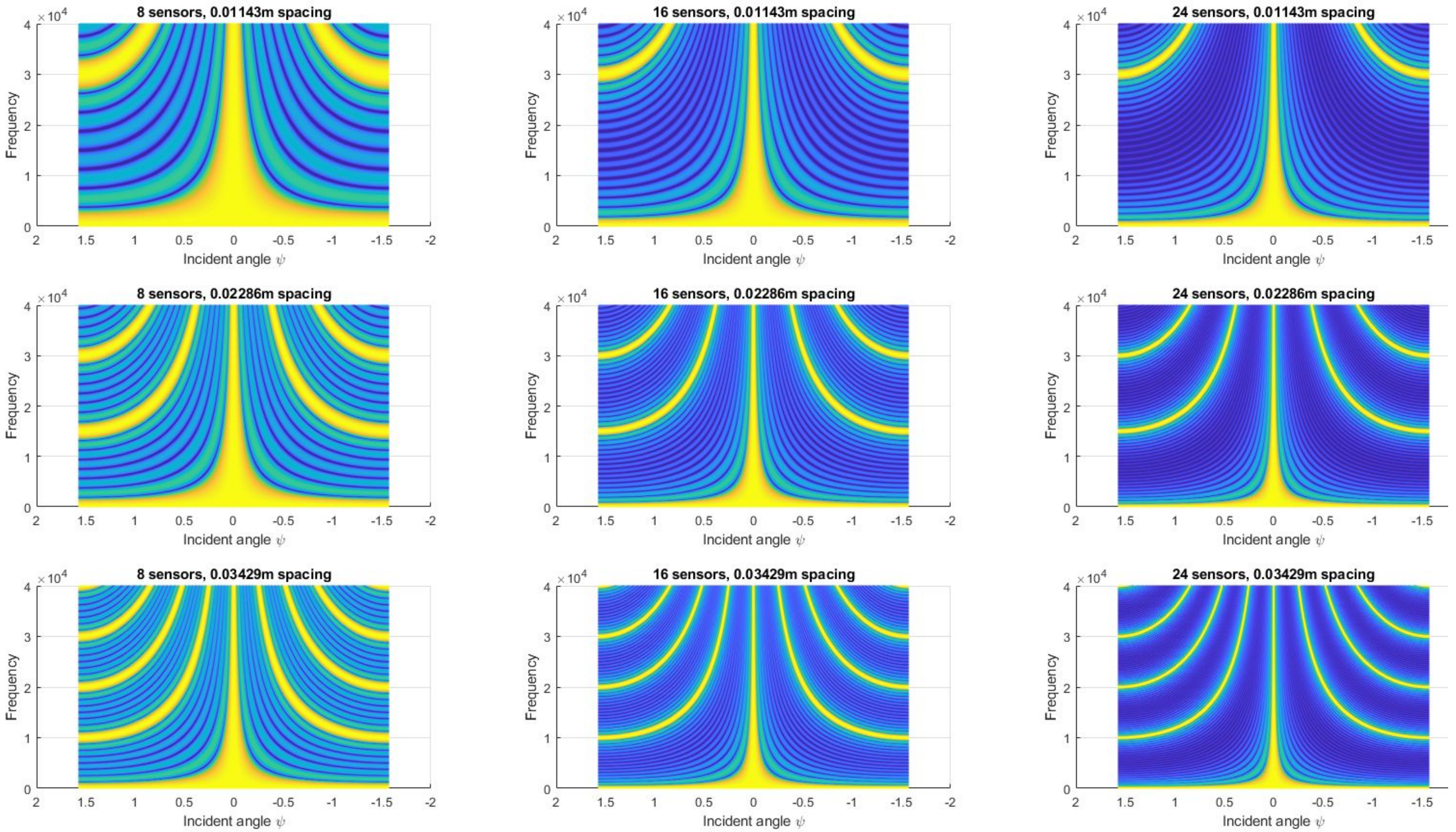
Beam pattern of 24 microphones with source frequency of 27 KHz

$$|W(\psi,\theta)| = \left| \frac{\sin\left(N\pi \frac{fd(\cos\psi - \cos\theta)}{c}\right)}{N\sin\left(\pi \frac{\mathrm{fd}(\cos\psi - \cos\theta)}{c}\right)} \right|$$

Spatial aliasing

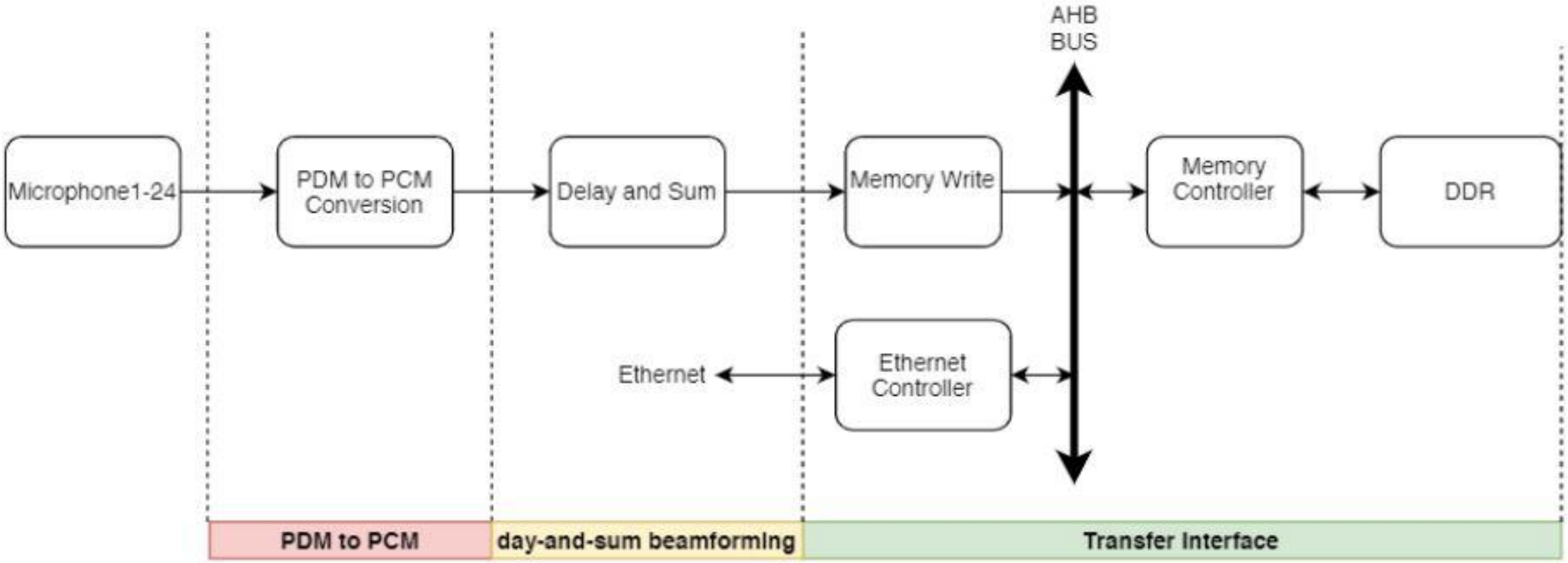
Un-attenuated lobes in directions other than the look direction.



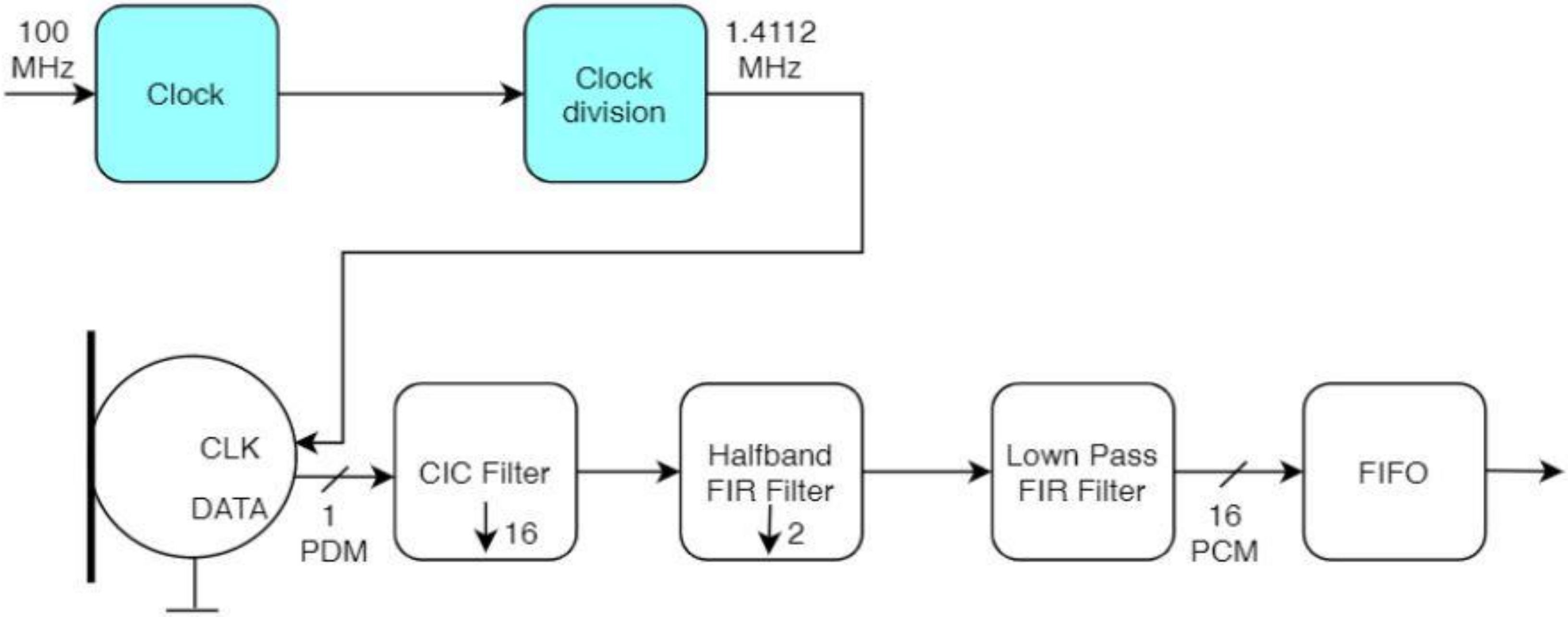


8 sensors, 0.01143m spacing
16 sensors, 0.01143m spacing
24 sensors, 0.01143m spacing
8 sensors, 0.02286m spacing
16 sensors, 0.02286m spacing
24 sensors, 0.02286m spacing
8 sensors, 0.03429m spacing
16 sensors, 0.03429m spacing
24 sensors, 0.03429m spacing
Frequency
×10^4
Incident angle ψ

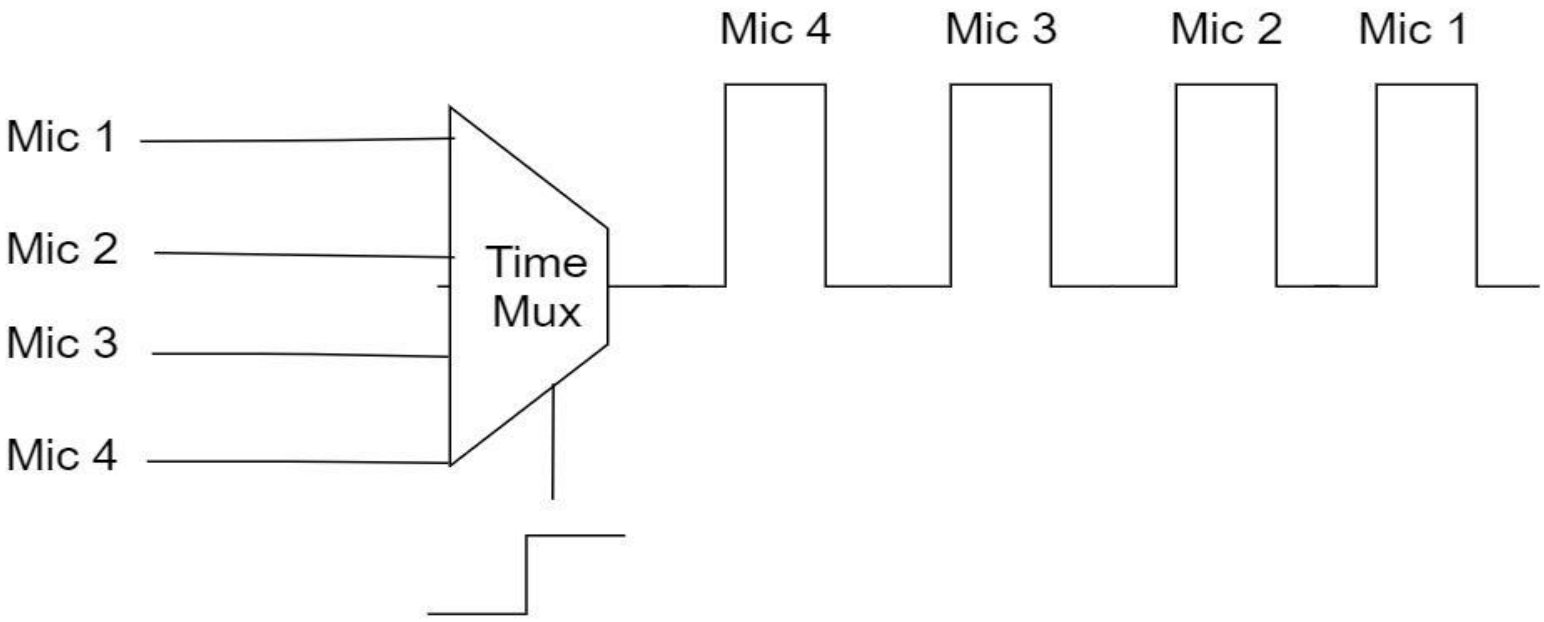
Implementation



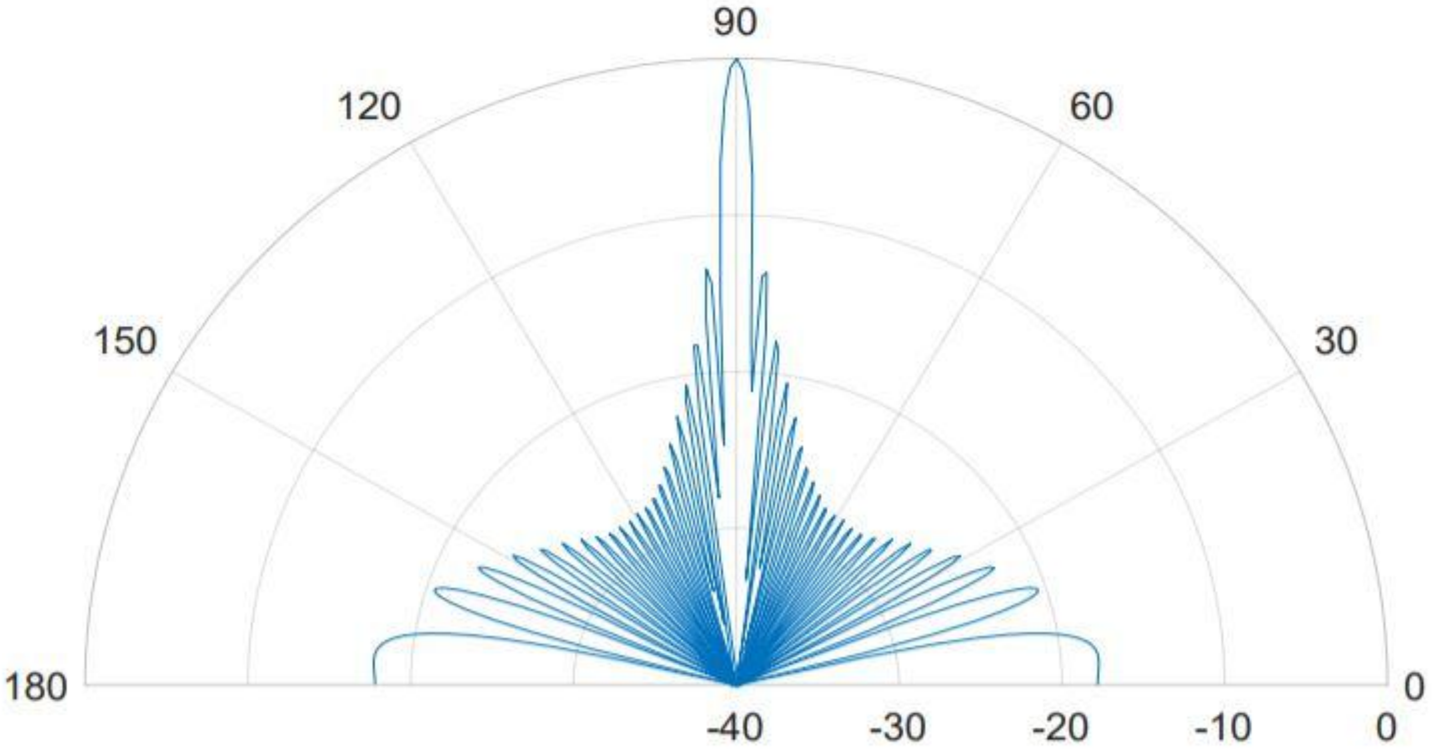
PDM to PCM


100
MHz
Clock
Clock
division
1.4112
MHz
CLK
DATA
1
PDM
CIC Filter
16
Halfband
FIR Filter
2
Lown Pass
FIR Filter
16
PCM
FIFO

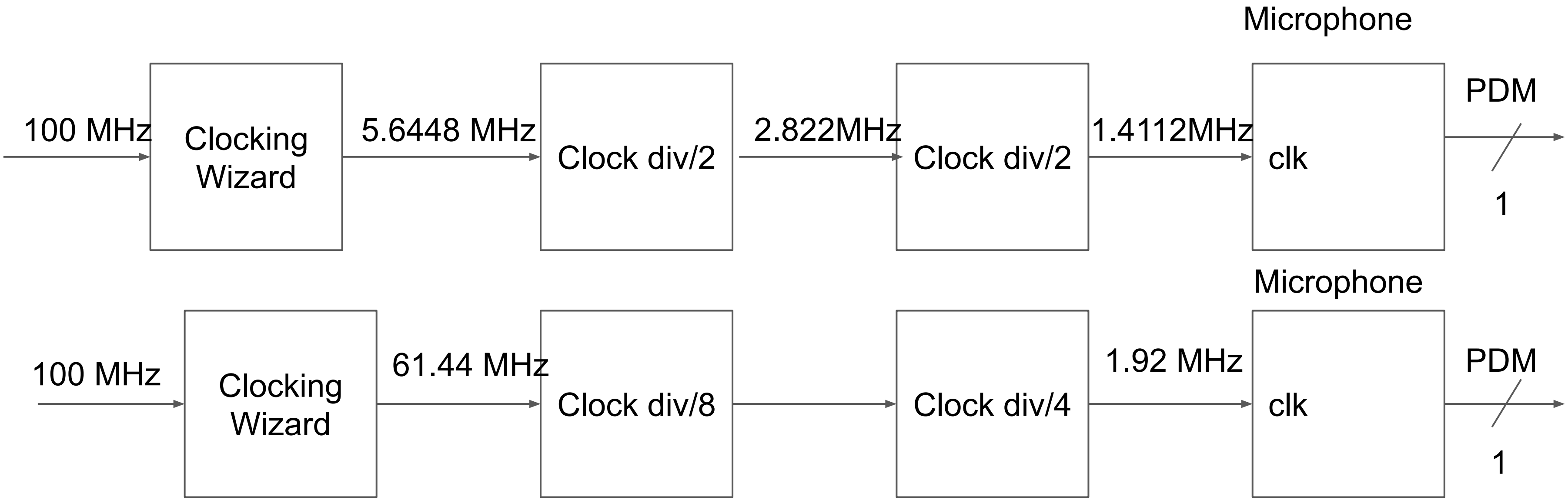
Multiple channels



Beam pattern for 27kHz source



Sampling frequency for ultrasonic range



Half Time Result

- The delay values for each microphone for every angle in the range 0 to 180 is calculated using the MATLAB script.
- By using the multi-channel mode in the CIC and FIR filter blocks given in the reference design, audio was recorded with multiple microphones. We listened to the recorded audio using AUDACITY and confirmed that the signals were sampled properly.

Future work

- Implement the delay block and incorporate all the 24 microphones.
- Implement beamforming using shift registers and work on the data transfer.
- Work on the algorithm for delay and sum.