ENGR-E 511; ENGR-E 399

Machine Learning for Signal Processing

Module 14:

Array Processing

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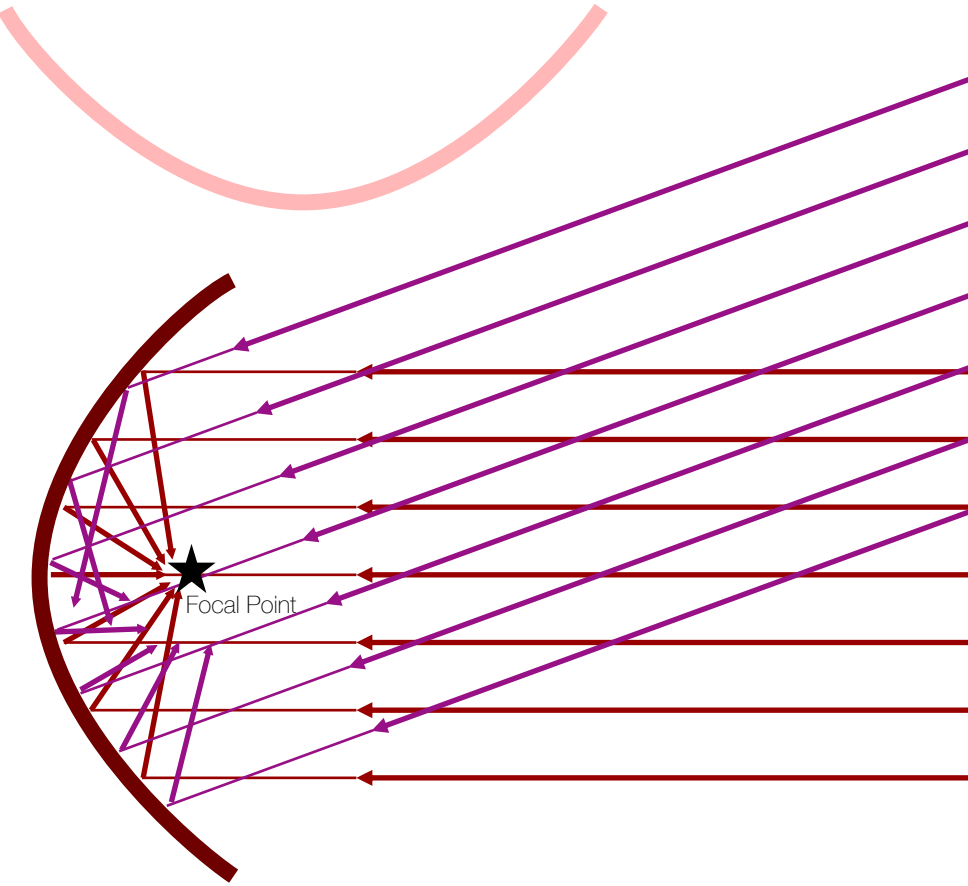
An Antenna System

- How the parabolic shapes work

- There are two source of signals
  - The receiver observes a mixture of them
- I have a parabolic antenna. How do I focus on one of the sources?
  - Steering the parabolic antenna towards the source direction
- We can concentrate the rays on a spot
  - Since the angles of incident and reflection should be the same
- How about the other source?
  - Doesn't work (unless you rotate the parabola)
- With parabolic antenna, we can focus on a certain direction
  - And accentuate the source coming from there



An Antenna System

- How the parabolic shapes work

- For audio, how do we do this?
- This is what your pinna does

- Can we do this for a cellphone?
  - Can we attach a pinna cup to the microphone of iPhones?
  - Jobs wouldn't have allowed it

- Beamforming does this in an algorithmic way

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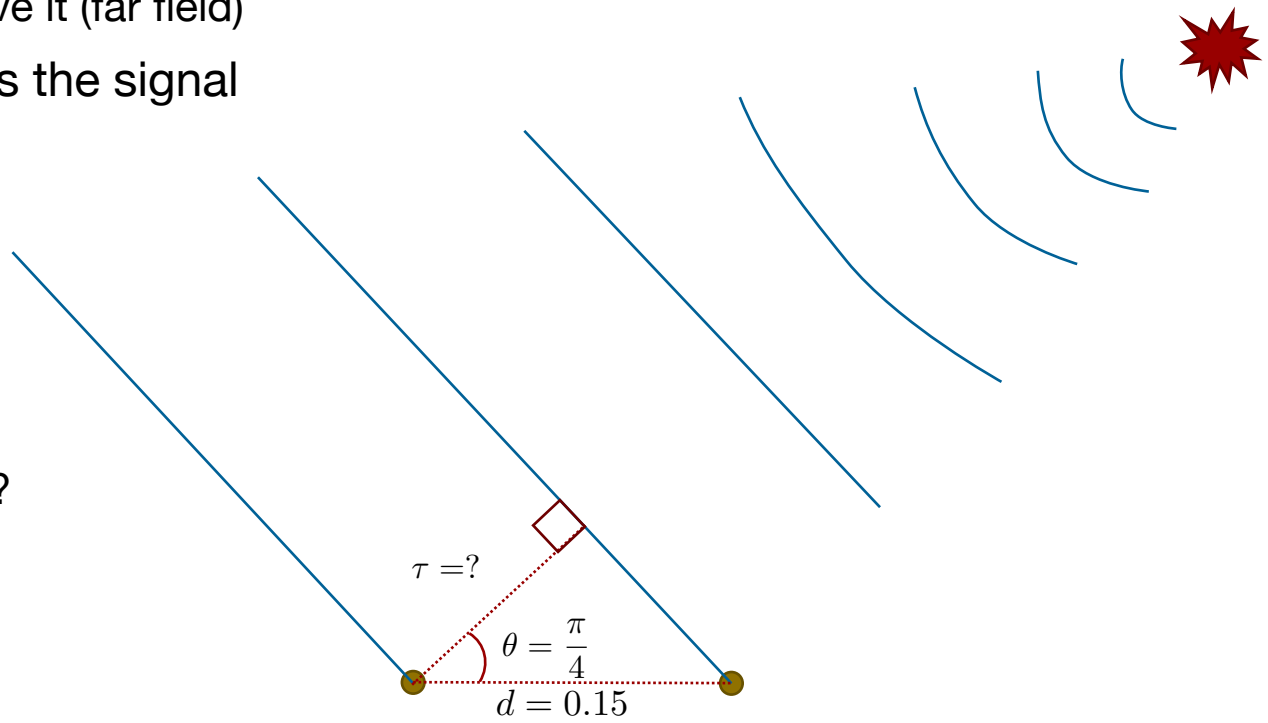
Delay-and-Sum Beamforming

- Delay?

- You've got a point source far away
  - So the wavefront is a line when you observe it (far field)
- There is a microphone array that records the signal
- How do they sound?
- What you know:
  - The distance between the sensors
  - The angle of the incoming signal
- What you want to know:
  - What's the delay between the two arrivals?

$$\tau = \frac{d\cos(\theta)}{340(m/s)} = \frac{0.15}{\sqrt{2}\cdot 340} = 0.000312$$

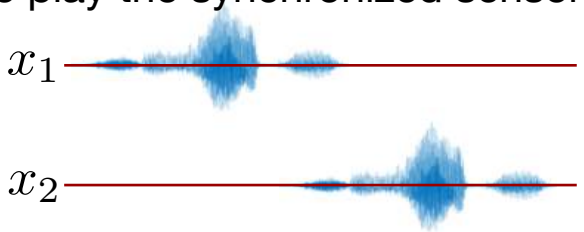
- Why are we doing this?
  - For a selective attention towards a direction

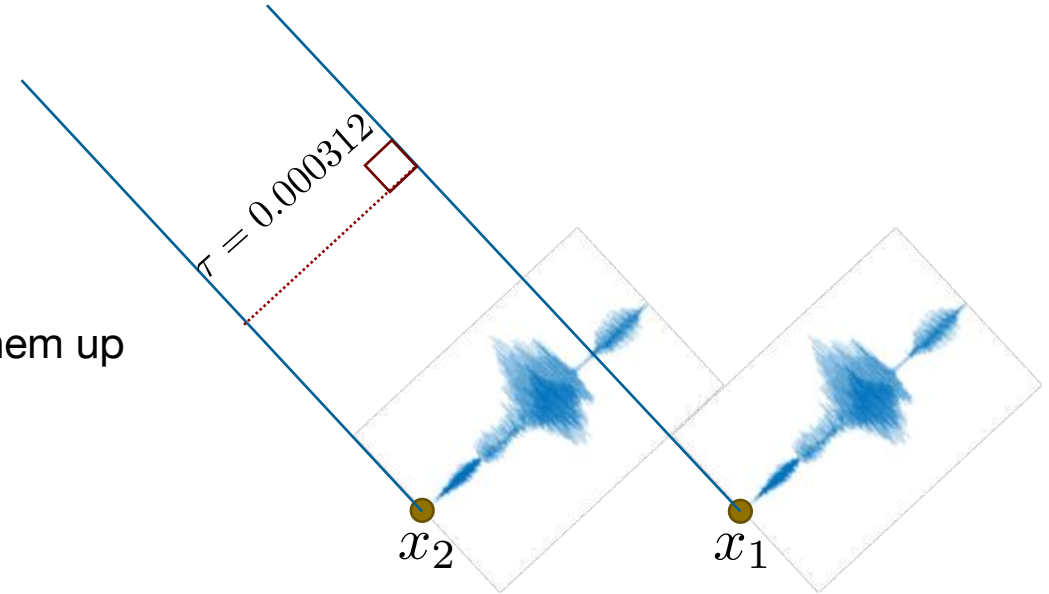


Delay-and-Sum Beamforming

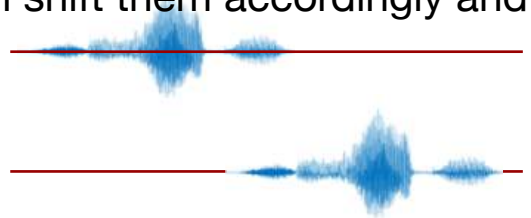
- Delay-and-sum?

- So you found that the delay
  - is dependent on the microphone array configuration and the direction of the source
- First, what does a delay mean?
  - If we play the synchronized sensor recordings one of them begins τ seconds earlier





- Then what?
  - We can shift them accordingly and sum them up



- Maybe we need another example

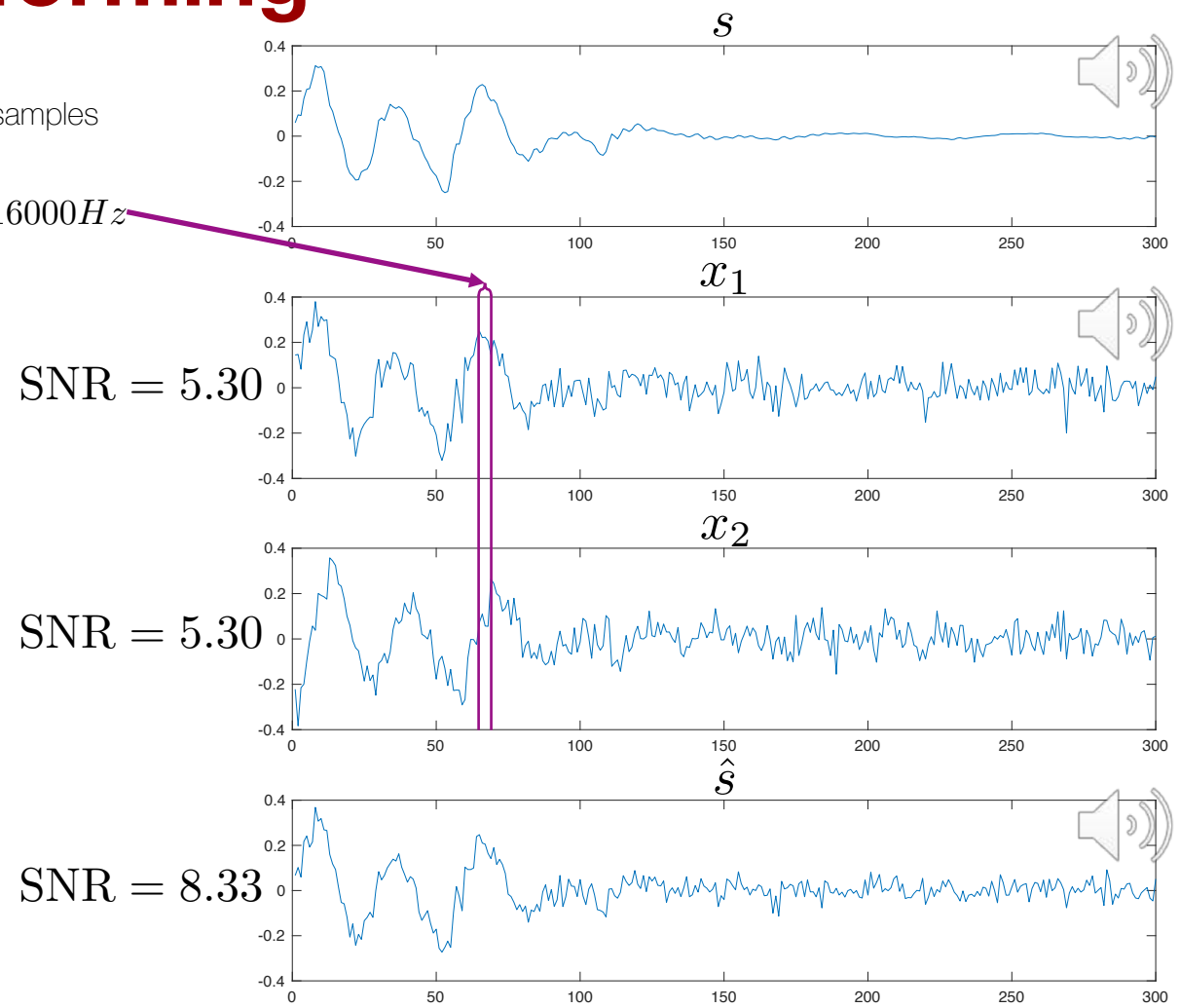
Delay-and-Sum Beamforming

- Gaussian noise; two mics

- If the observed signals are delayed versions of the clean source, there's no need to do beamforming
  - You can just pick up one of the channels
- Then, when do we need it?
  - When there's something else in the scene
- Observations are contaminated by Gaussian noise
- First, the delay-and-sum works
  - It averaged out the Gaussian noise
  - Improved SNR
  - Sounds better
- Not satisfied with the results?

Note the delay in samples

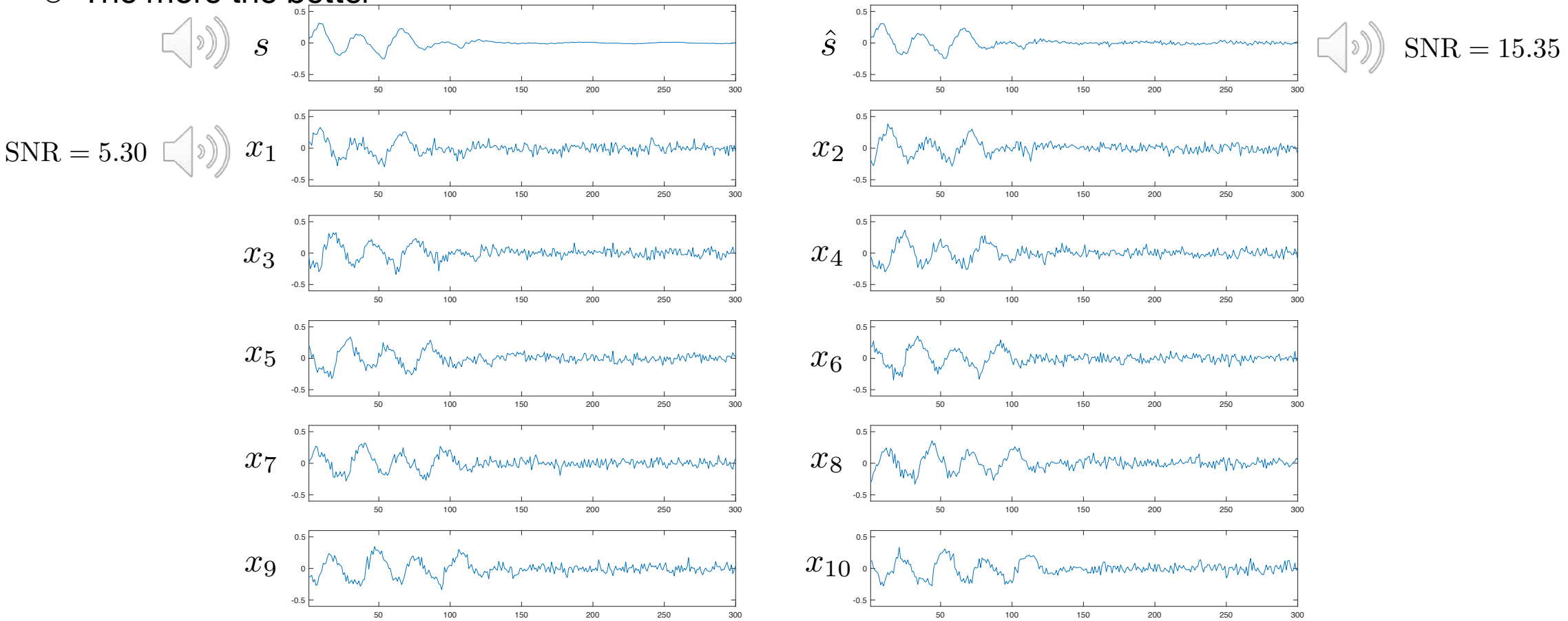
$$\delta = \tau \cdot SR$$
$$= 0.000312 \cdot 16000Hz$$
$$\approx 5$$



Delay-and-Sum Beamforming

- Gaussian noise; ten mics

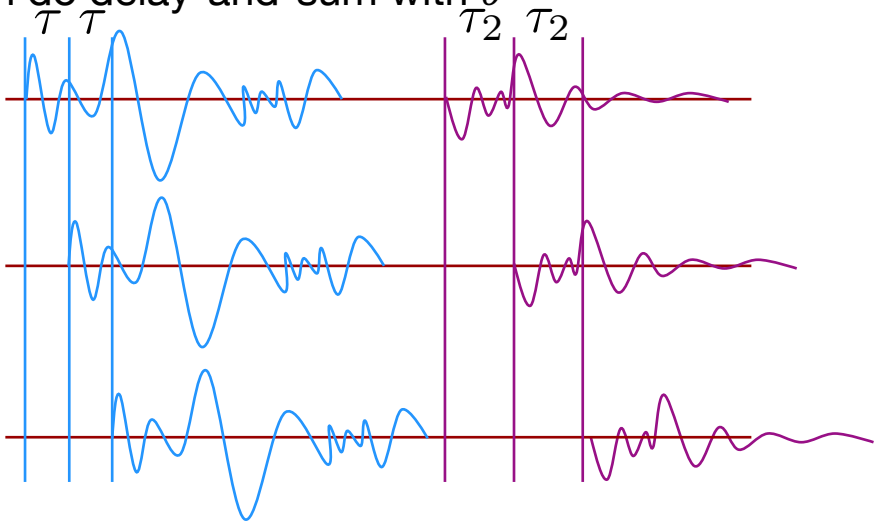
- The more the better

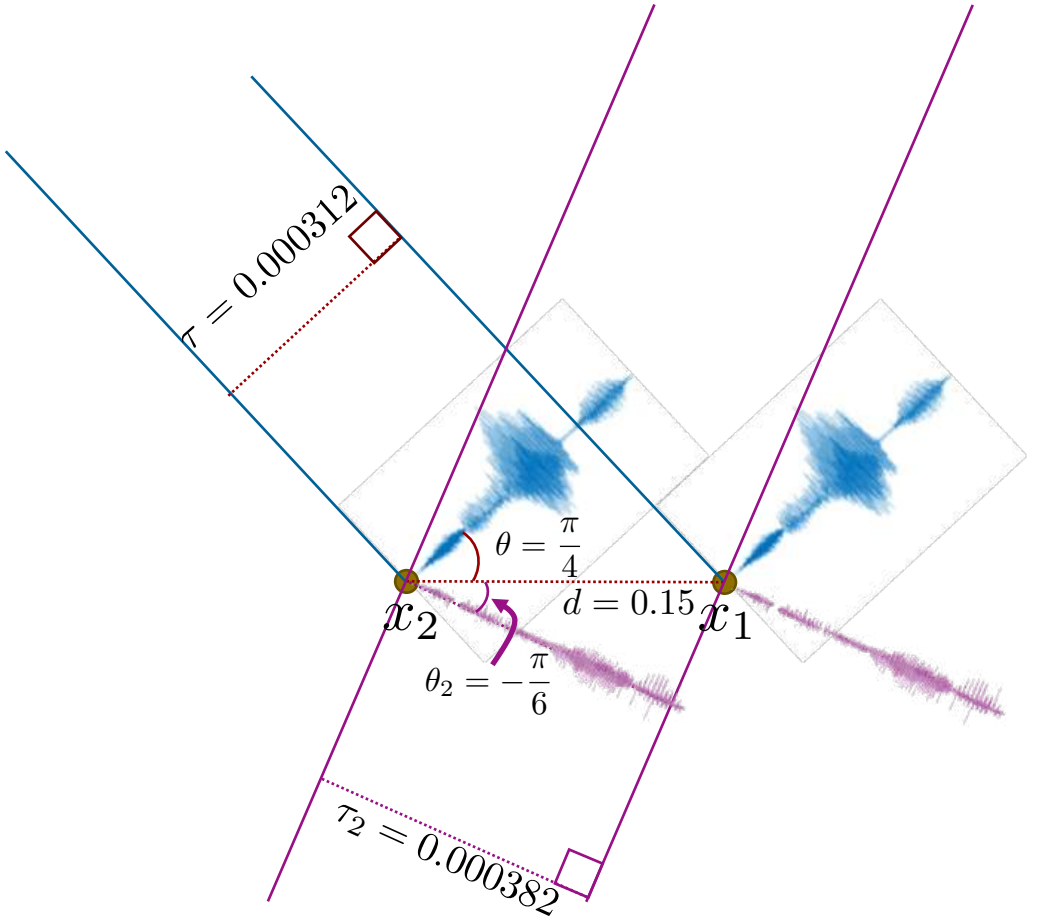


Delay-and-Sum Beamforming

- Non-stationary interference

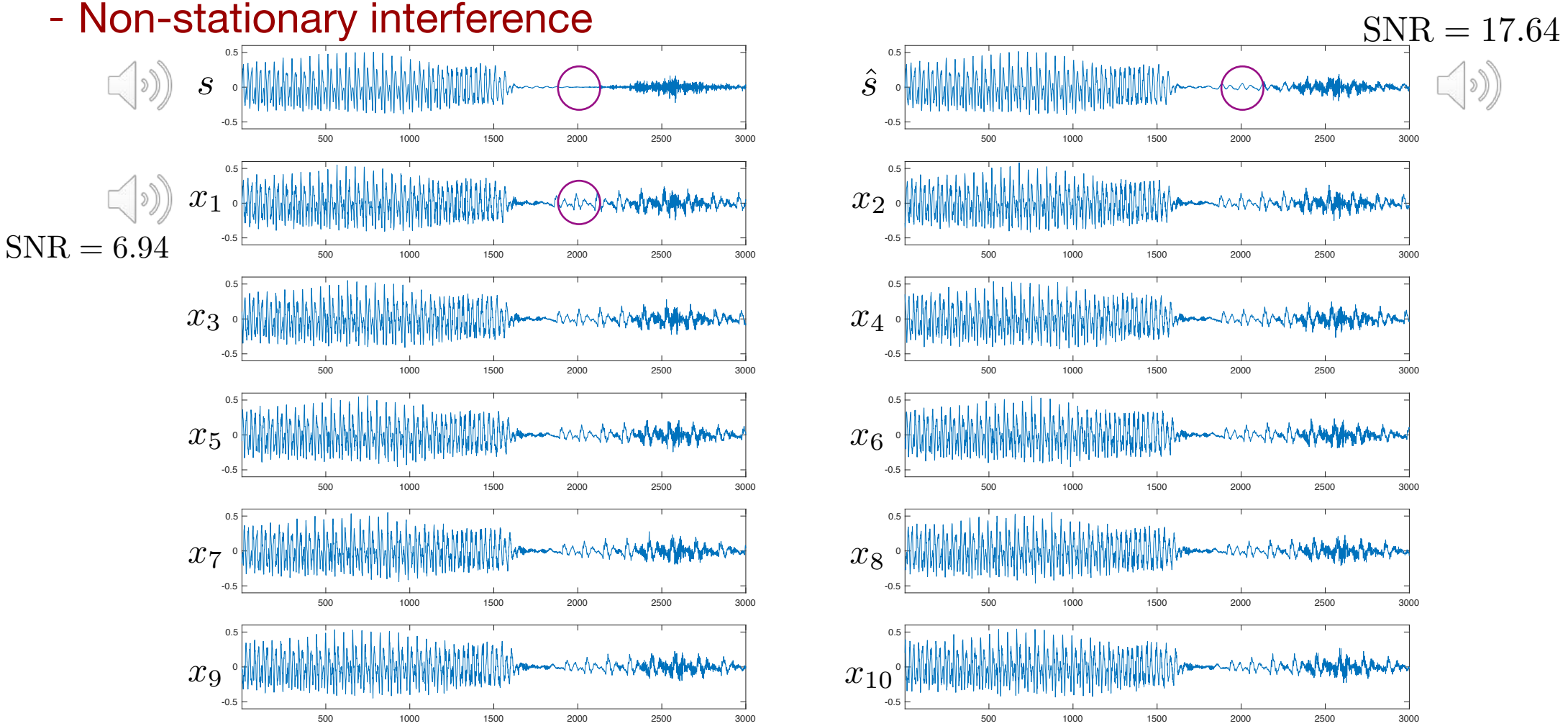
- We've got another interfering source coming from a different direction
- Since we know the proper delay τ for the angle $\theta = \frac{\pi}{4}$
  - But we don't care about the other angles
  - We can do delay-and-sum with θ





Delay-and-Sum Beamforming

- Non-stationary interference



Delay-and-Sum Beamforming

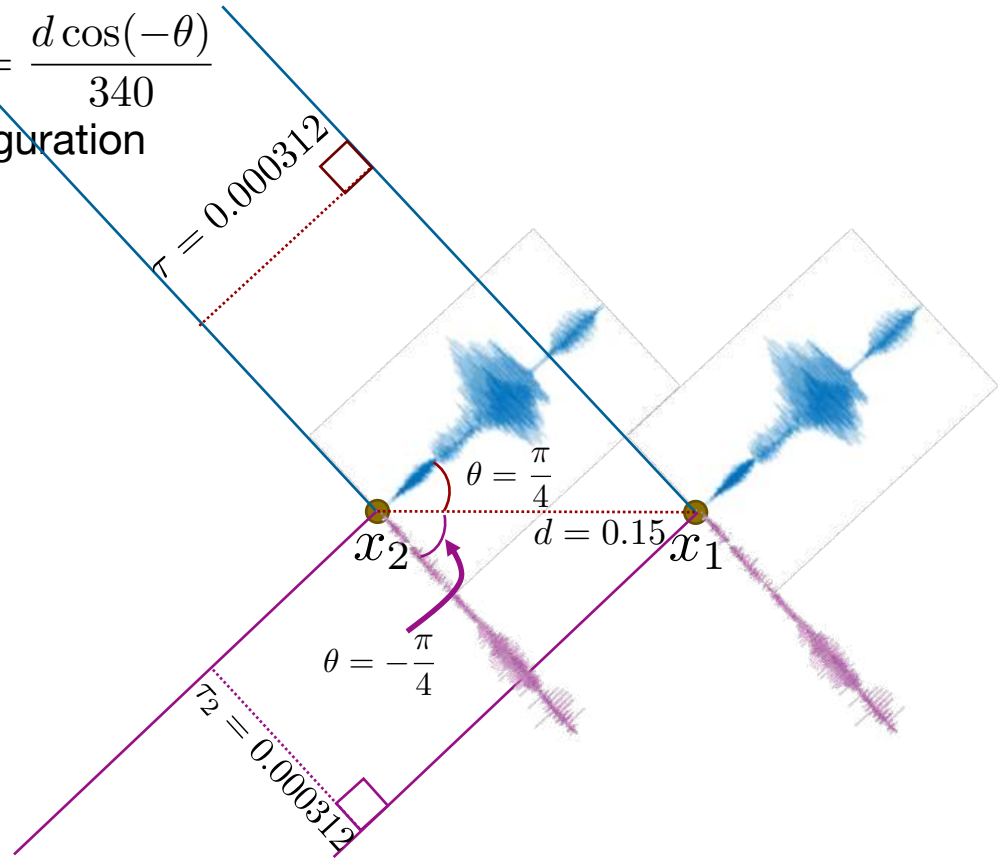
- Drawbacks

- There is a confusion of directionality
  - A delay can mean two different directions $\tau = \frac{d\cos(\theta)}{340} = \frac{d\cos(-\theta)}{340}$
  - Needs more than two mics at least with a triangular configuration
- Prefers high sampling rates
  - The maximum possible delay (when $d = 0.15$):

    $$\tau_{\max} = \frac{d\cos(0)}{340} = 0.000441\text{sec}$$

  - In samples? $\tau_{\max} \cdot [\text{sampling rate}]$
  - To see at least one sample delay
    - $\tau_{\max} \cdot [\text{sampling rate}] > 1$
    - $[\text{sampling rate}] > 1/\tau_{\max} = 1/0.000441 \approx 2268Hz$
  - So what?
    - What if your device is small, say $d = 0.02$
    - Then, $\tau_{\max} = \frac{d}{340} = 0.0000588$

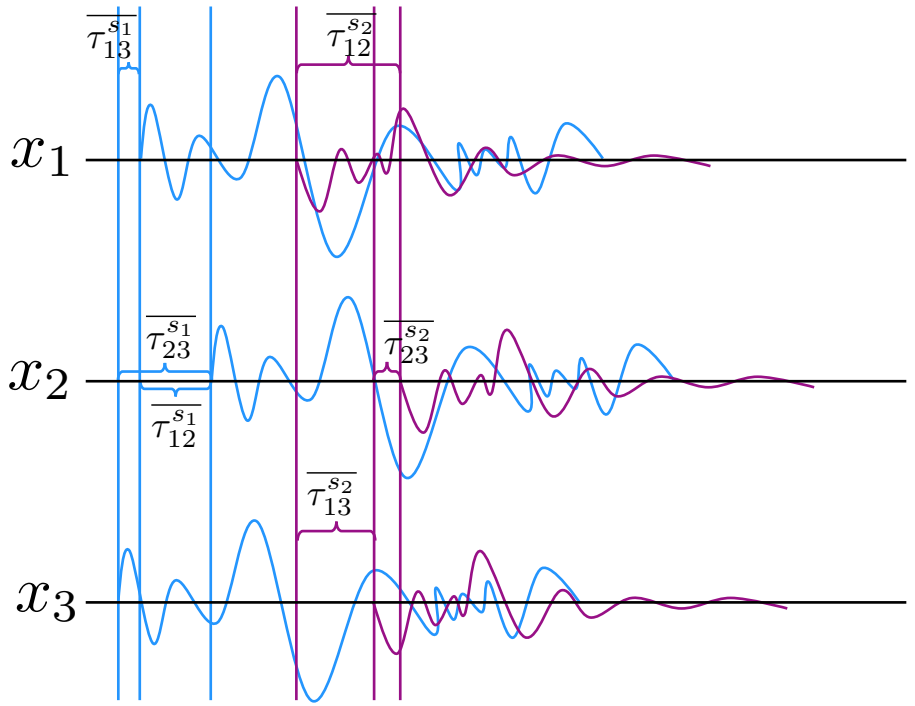
      $[\text{sampling rate}] > 1/\tau_{\max} = 1/0.0000588 \approx 17007Hz$

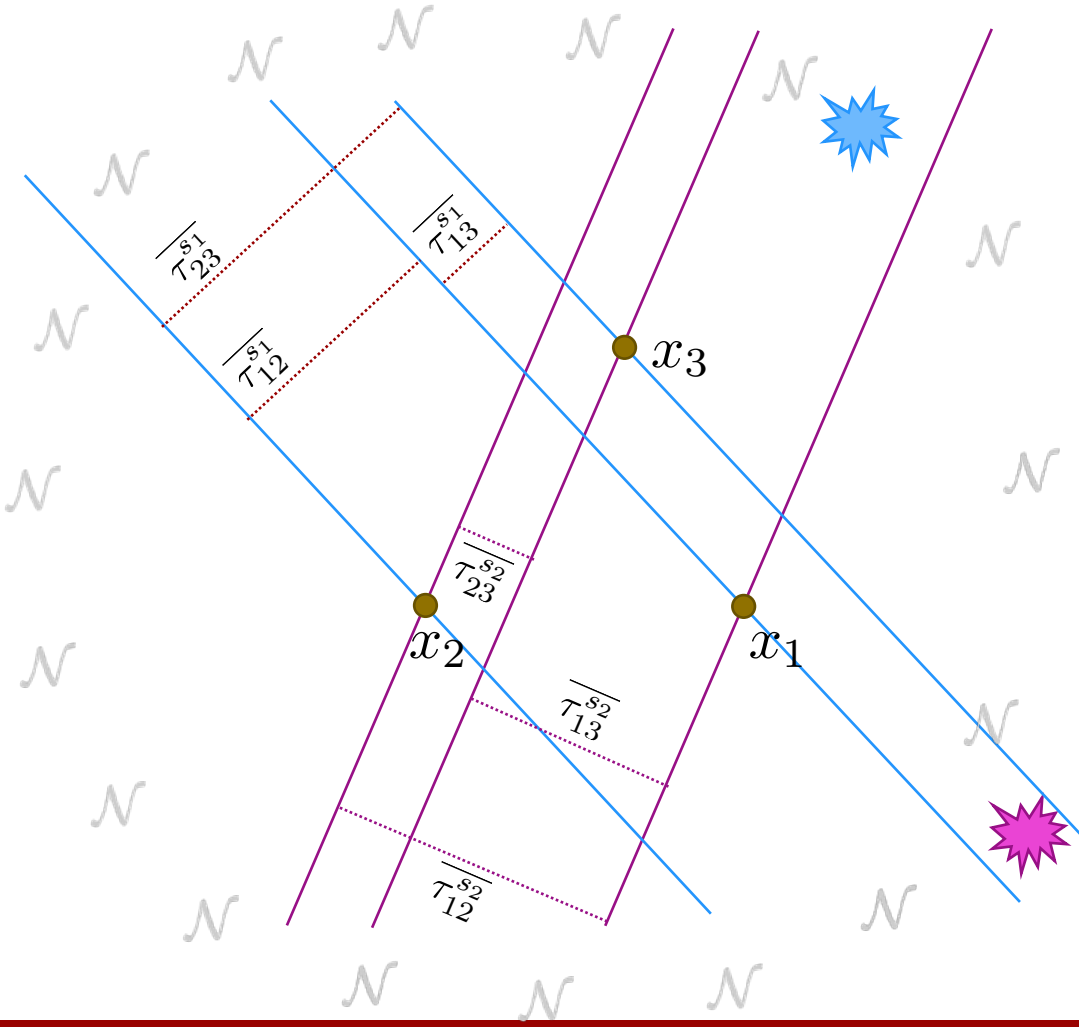


Direction of Arrival

- Beamscan

- Where is the source coming from?



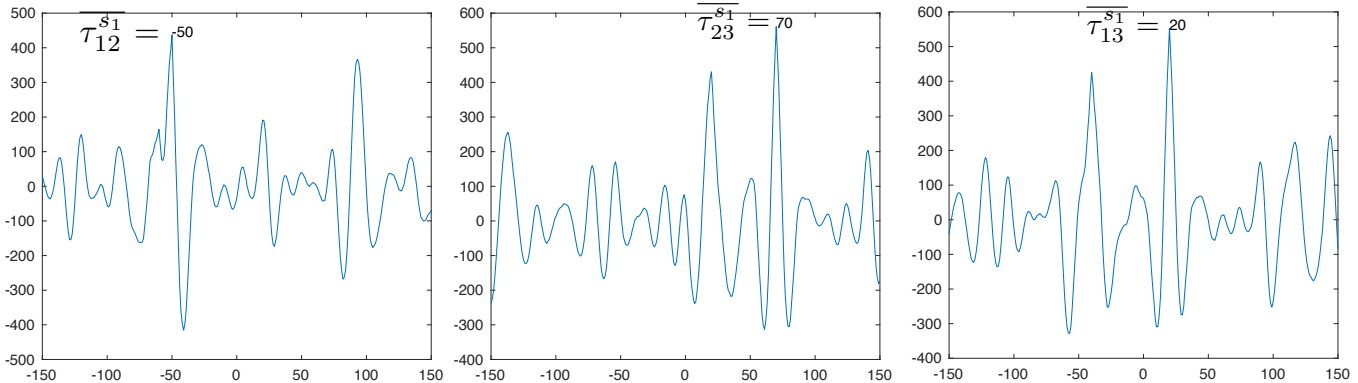


- How do we find out these delays from the data?

Direction of Arrival

- Beamscan

- Scan all the delays!
  - Shifting the signal sample-by-sample
  - Calculate the inner product
  - This is nothing but cross-correlation
- If the shift is with a matching delay, the inner product will create a peak

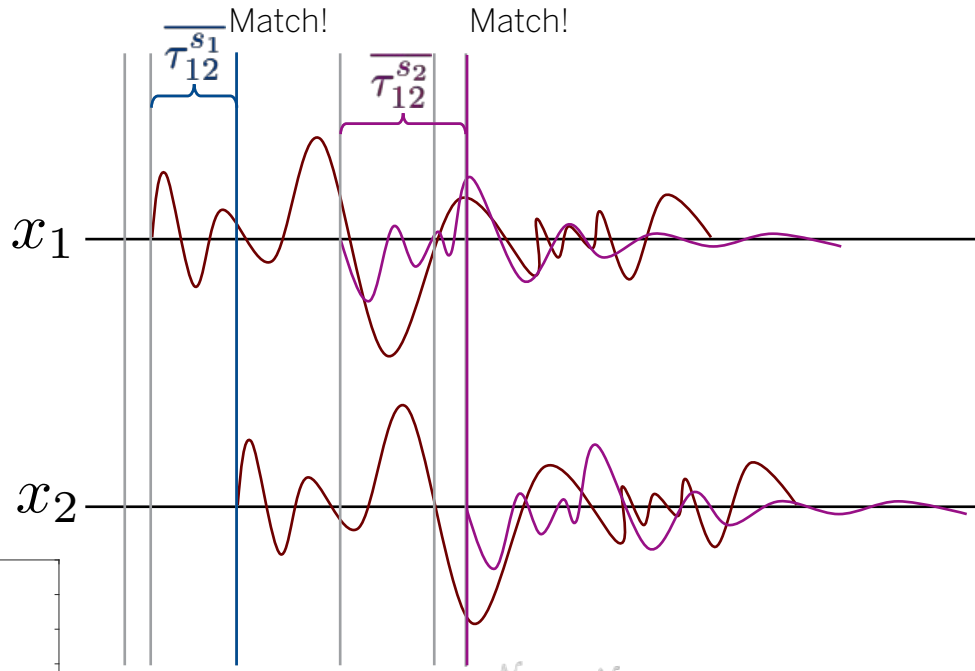


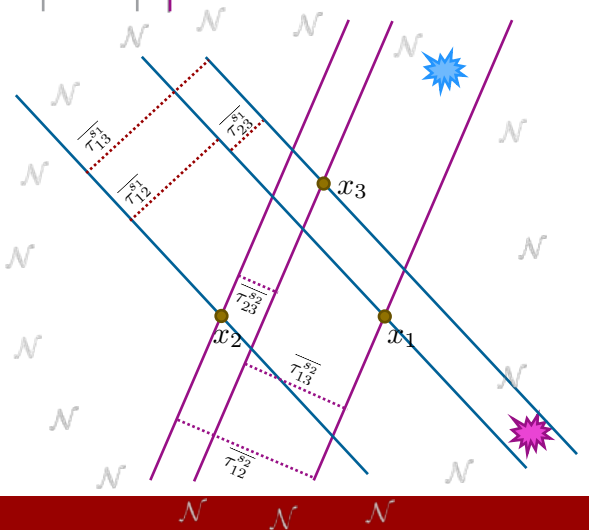
$x_1 \times x_2$ $x_2 \times x_3$ $x_1 \times x_3$

- Using them I can do delay-and-sum

Input SNR: 1.27 dB

Output SNR: 6.66 dB

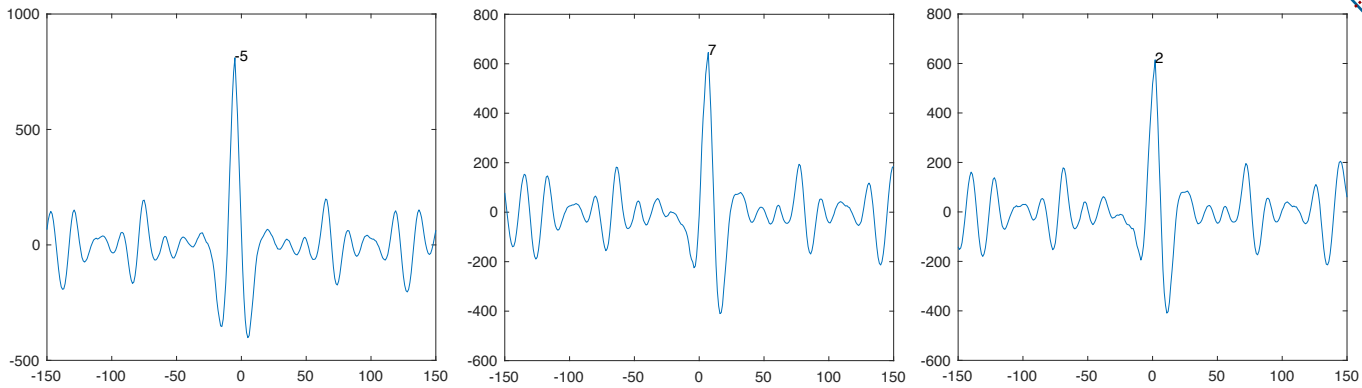




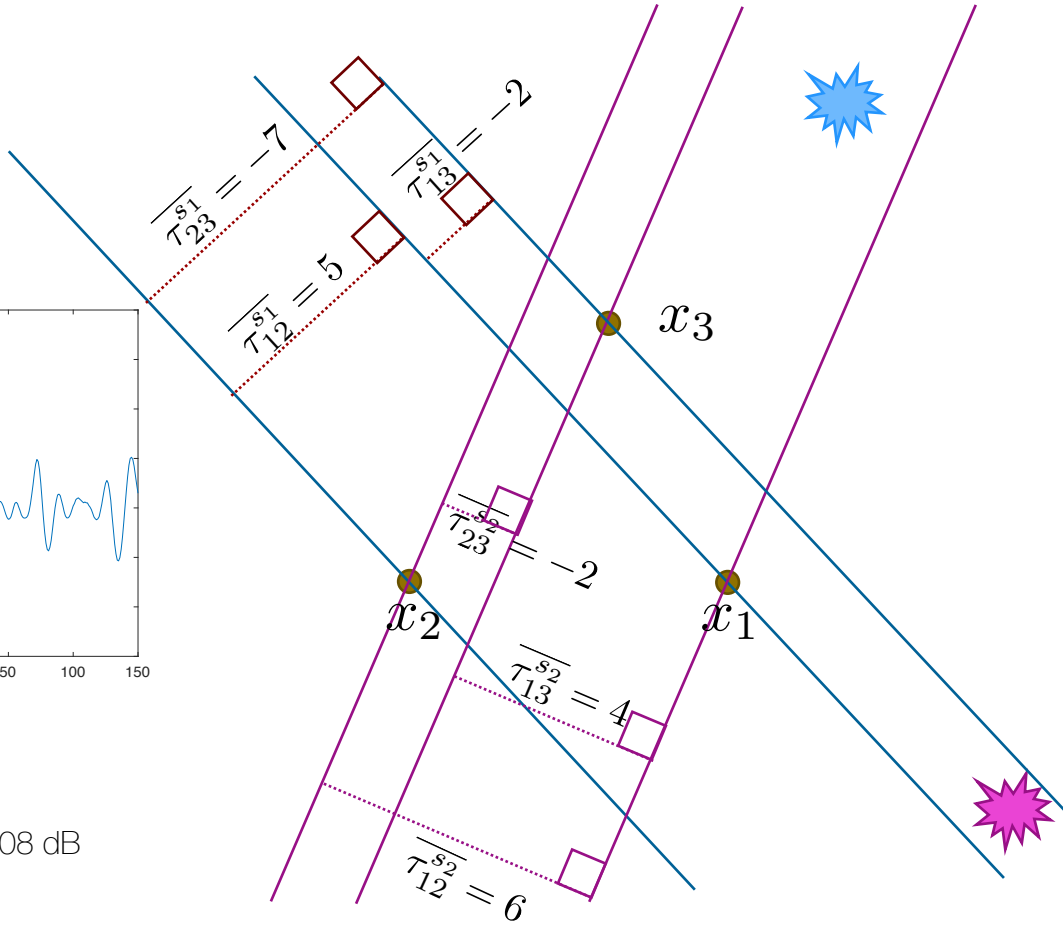
Direction of Arrival

- Beamscan

- 70 samples? Distance between mics?
  - 70/16000*340=1.49m
- A more realistic mic configuration
  - About 15cm at most



Input SNR: 1.27 dB Output SNR: 4.08 dB

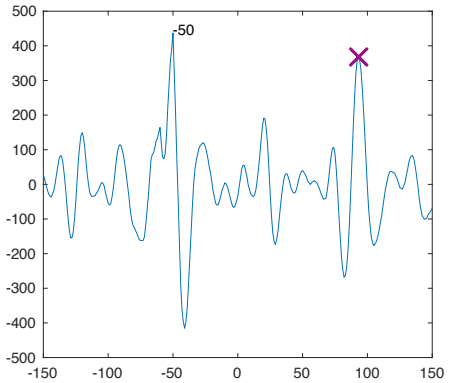


  - Why less improvement?
    - Too small delay to cancel out the interference

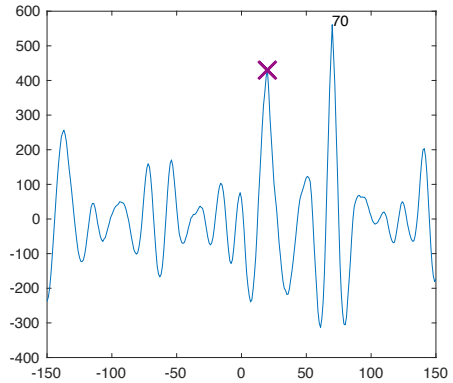
Direction of Arrival

- Beamscan

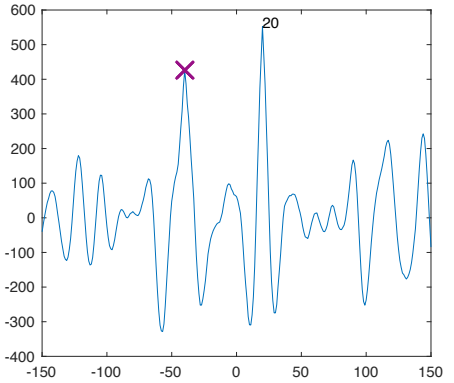
- The other source?
- In the larger array, there is a salient second peaks
- In the smaller array, there's a lack of resolution
  - Need higher sampling rates



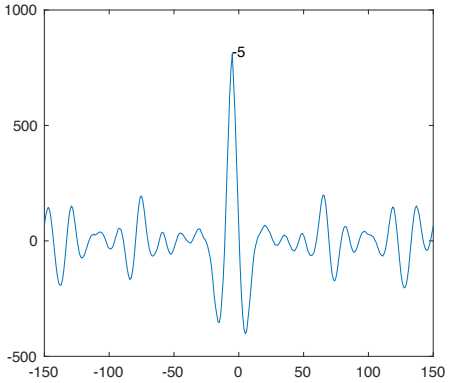
$x_1 \times x_2$

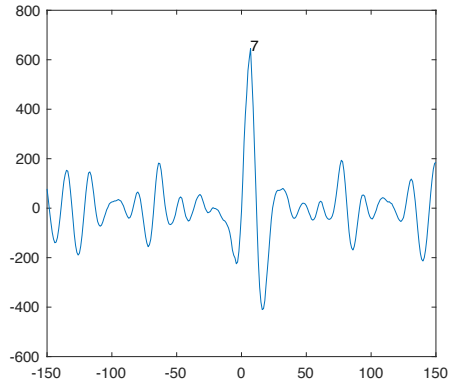


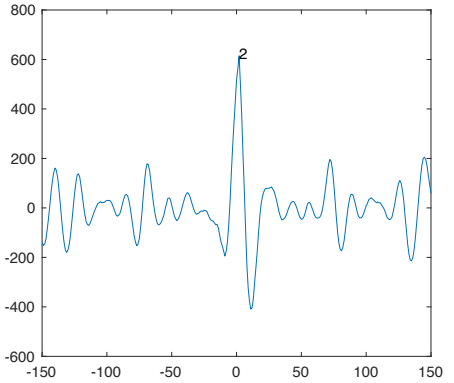
$x_2 \times x_3$



$x_1 \times x_3$







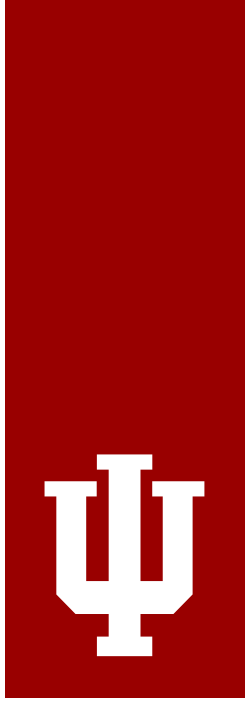
Array Processing

- When does it work?

- Things that make array processing difficult
  - Ambient noise
  - Reverberation
  - Heterogeneousity of the microphones
  - Near-field assumption
  - DoA on small array
  - Source with high frequency components
  - Directionality of the sensors
  - …

Reading

- Tashev, Ivan J., “Sound Capture and Processing : Practical Approaches” (IUCAT)
  - https://eds-b-ebscohost-com.proxyiub.uits.iu.edu/eds/detail/detail?vid=0&sid=2eb653b9-fc69-4d19-9030-7ae99bed0acd%40sessionmgr101&bdata=JnNpdGU9ZWRzLWxpdmUmc2NvcGU9c2l0ZQ%3d%3d#AN=323354&db=edsebk
- Jacob Benesty, Jingdong Chen, Yiteng Huang, “Microphone Array Signal Processing” (IUCAT)
  - http://kg6ek7cq2b.search.serialssolutions.com.proxyiub.uits.iu.edu/?genre=book&atitle=&title=Microphone%20Array%20Signal%20Processing&isbn=9783540786115&volume=00001&issue=&date=20080101&au=&spage=&pages=&sid=EBSCO:eBook%20Index:229117



Thank You!