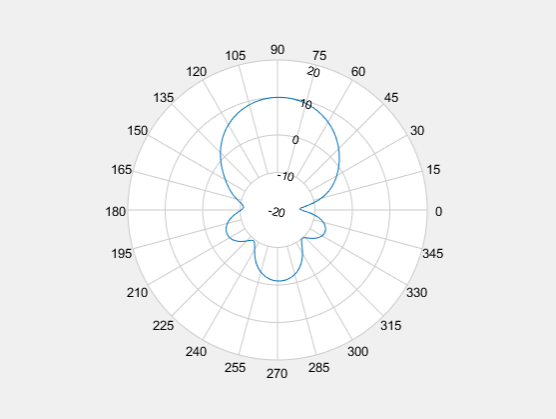
Lokalizacija vira zvoka z mikrofonsko anteno (beamforming)

December 2025

Jure Murovec



- Beamforming: Metoda oblikovanja snopa.
- Akustična kamera, slušni aparati, monitoring hrupa v okolju, sonar, itd.
- Elektromagnetno valovanje: Radar, telekomunikacije, itd.

https://www.youtube.com/watch?v=F6BWItMjTms&ab_channel=gfaitechGmbH

https://https://www.youtube.com/watch?v=6lxt9KeEoSA&ab_channel=CAssoc1

Kako lahko sploh lokaliziramo vir zvoka?

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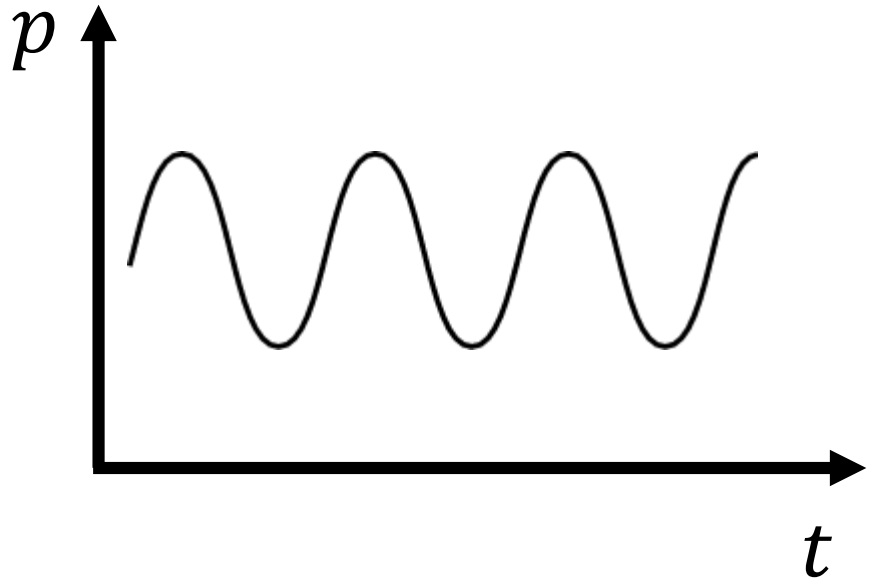
- En mikrofon → Zvočni tlak v točki merjenja



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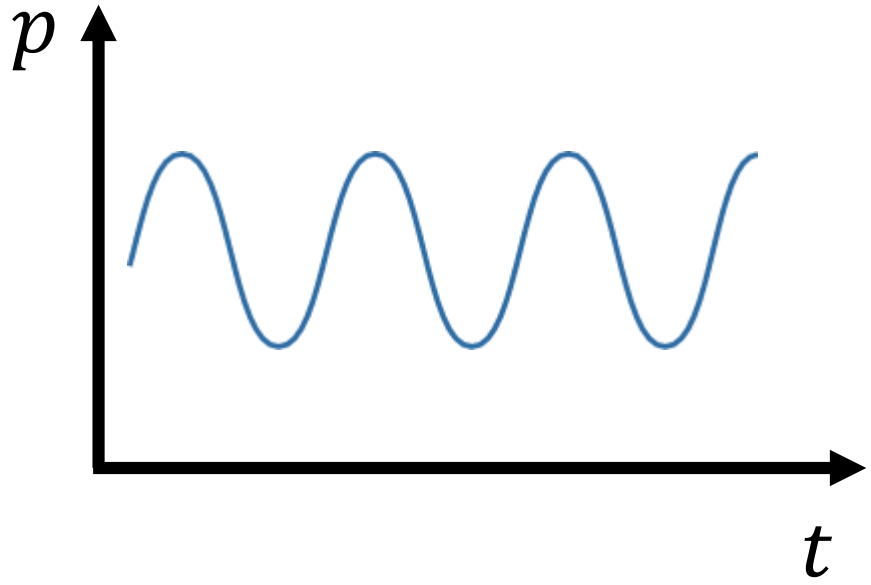
- En mikrofon → Zvočni tlak v točki merjenja



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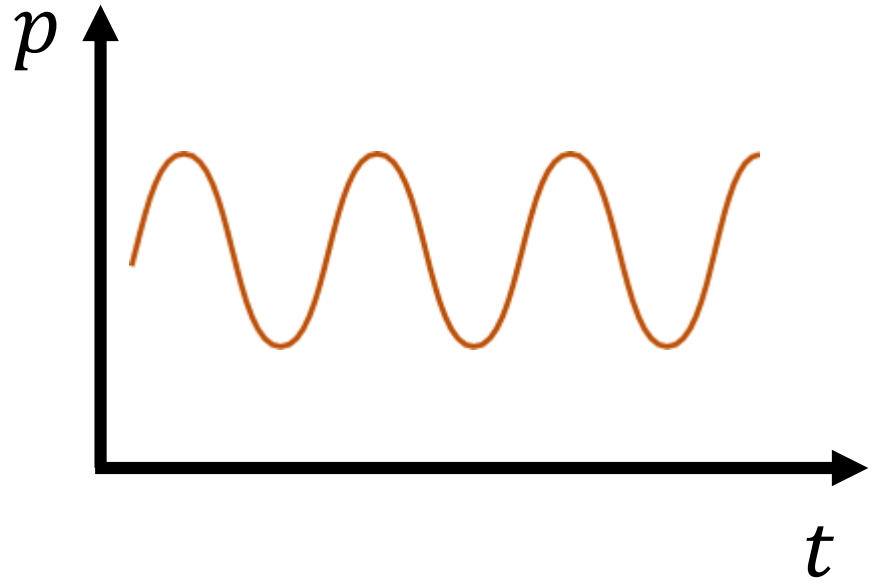

Kako lahko sploh lokaliziramo vir zvoka?

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- Mikrofonska antena

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- En mikrofon → Zvočni tlak v točki merjenja

- Mikrofonska antena = uporaba večih zaznaval

Metode lokalizacije

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- TDE (Time Difference Estimation)

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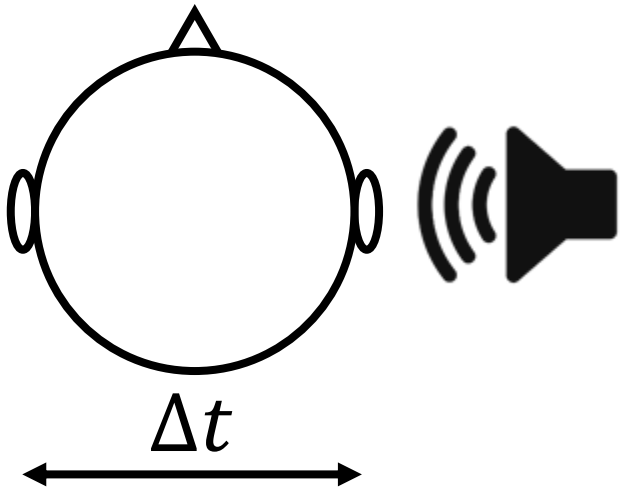
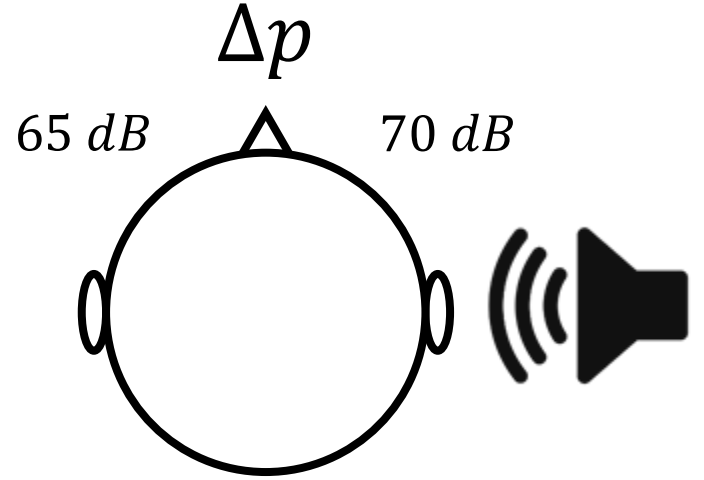


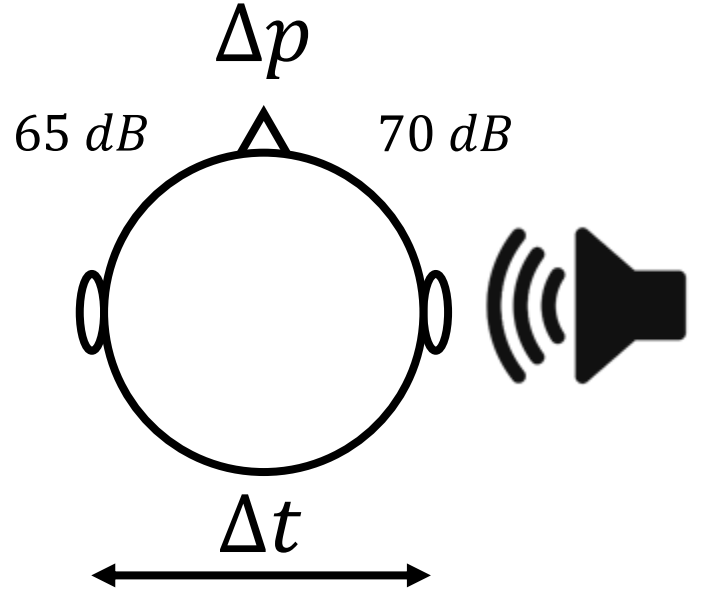
Metode lokalizacije

- TDE (Time Difference Estimation)
- ILD (Interaural Level Difference)



Metode lokalizacije

- TDE (Time Difference Estimation)
- ILD (Interaural Level Difference)
- HRTF (Head Related Transfer Function)
  - TDE + ILD + absorpcija,odboji (uhlji, glava, telo)



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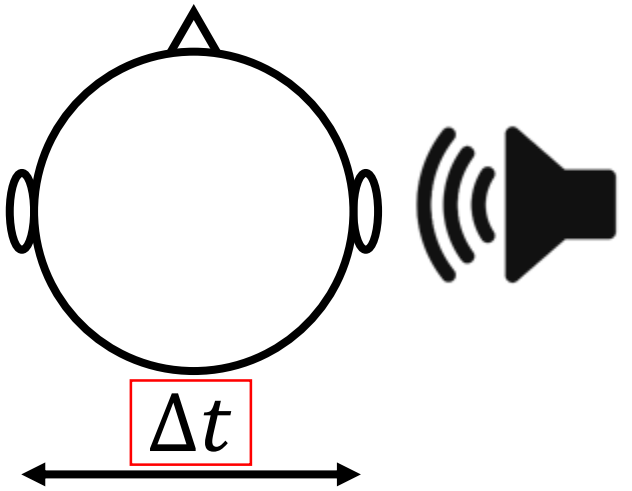
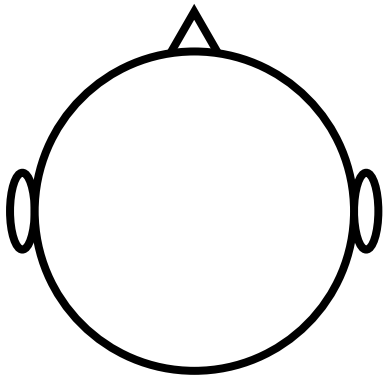
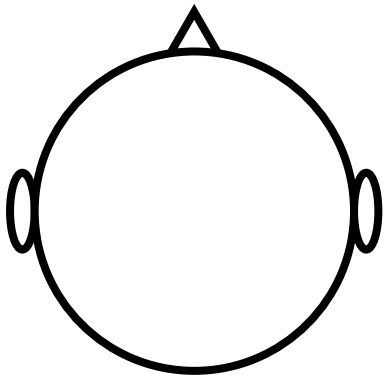
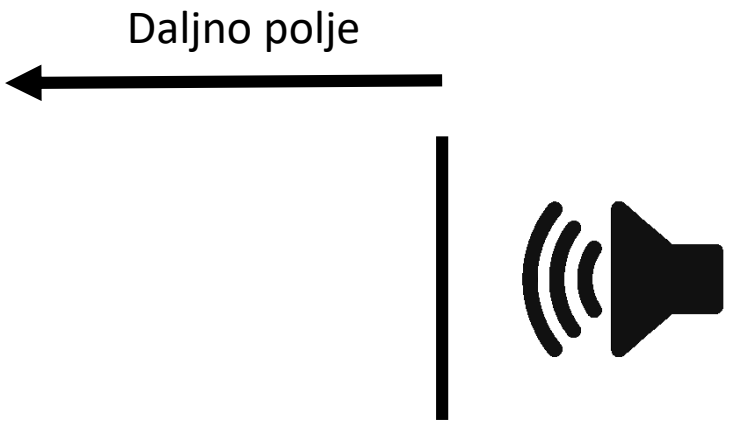
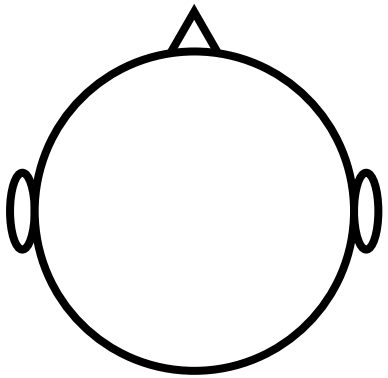
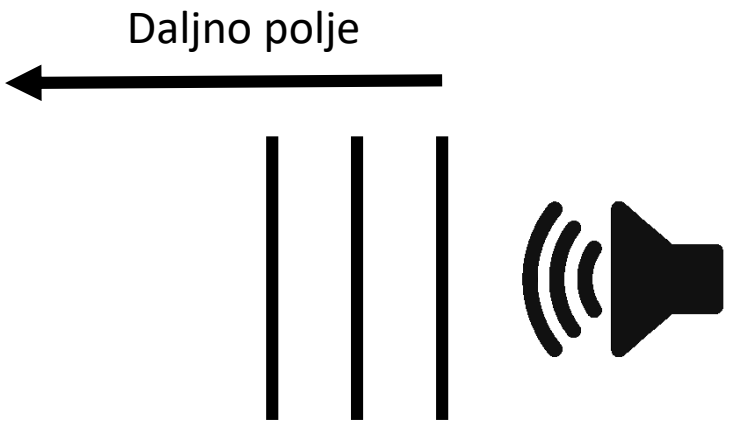







Daljno polje

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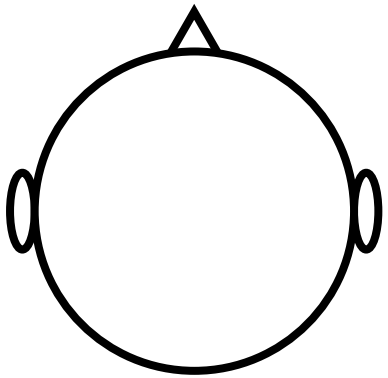

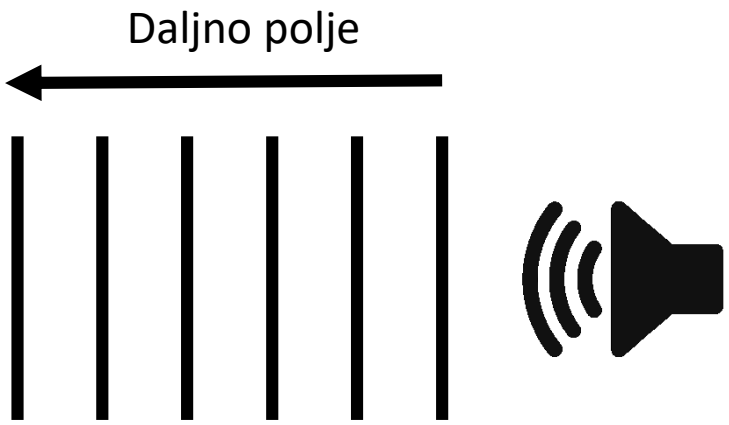
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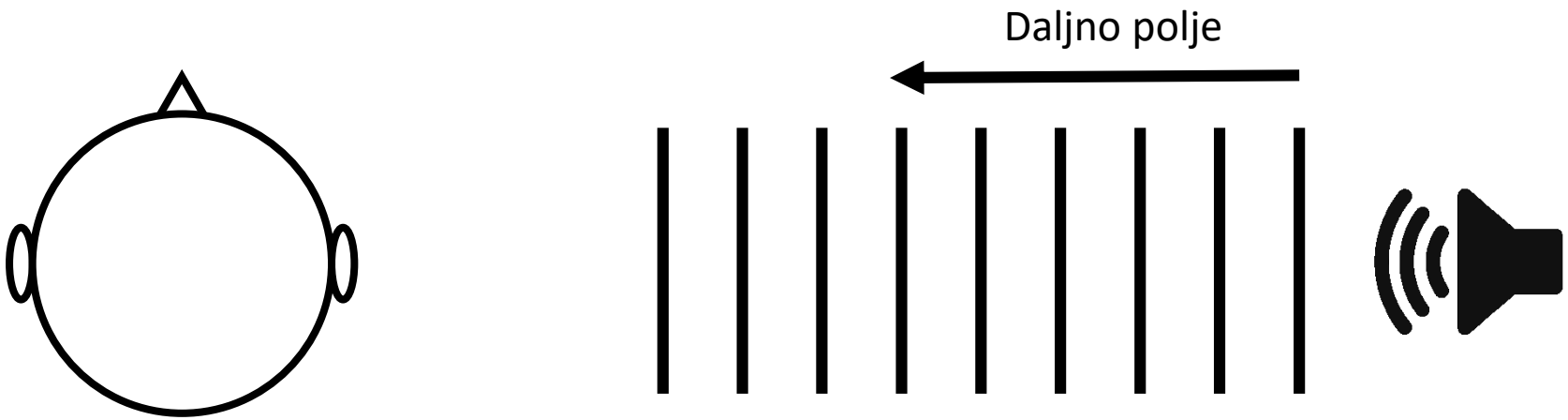
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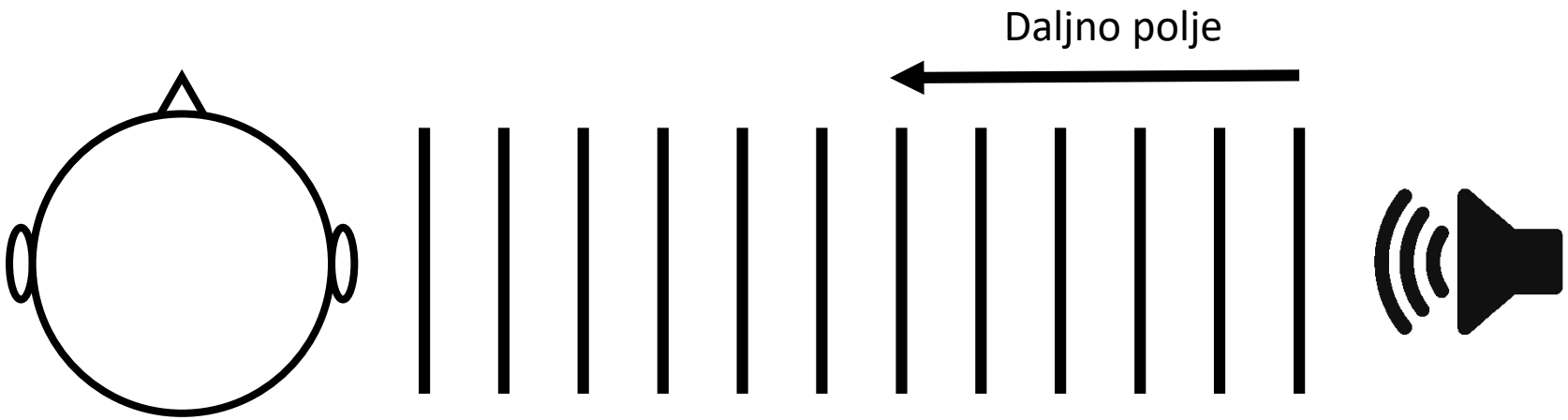
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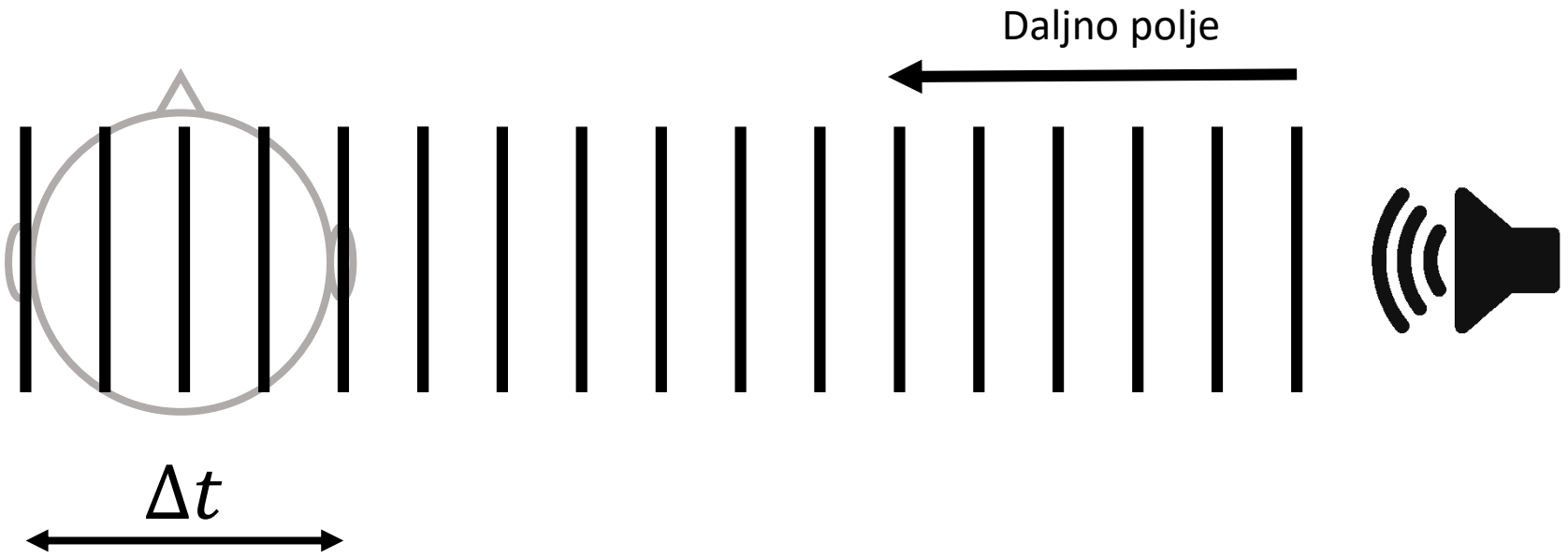
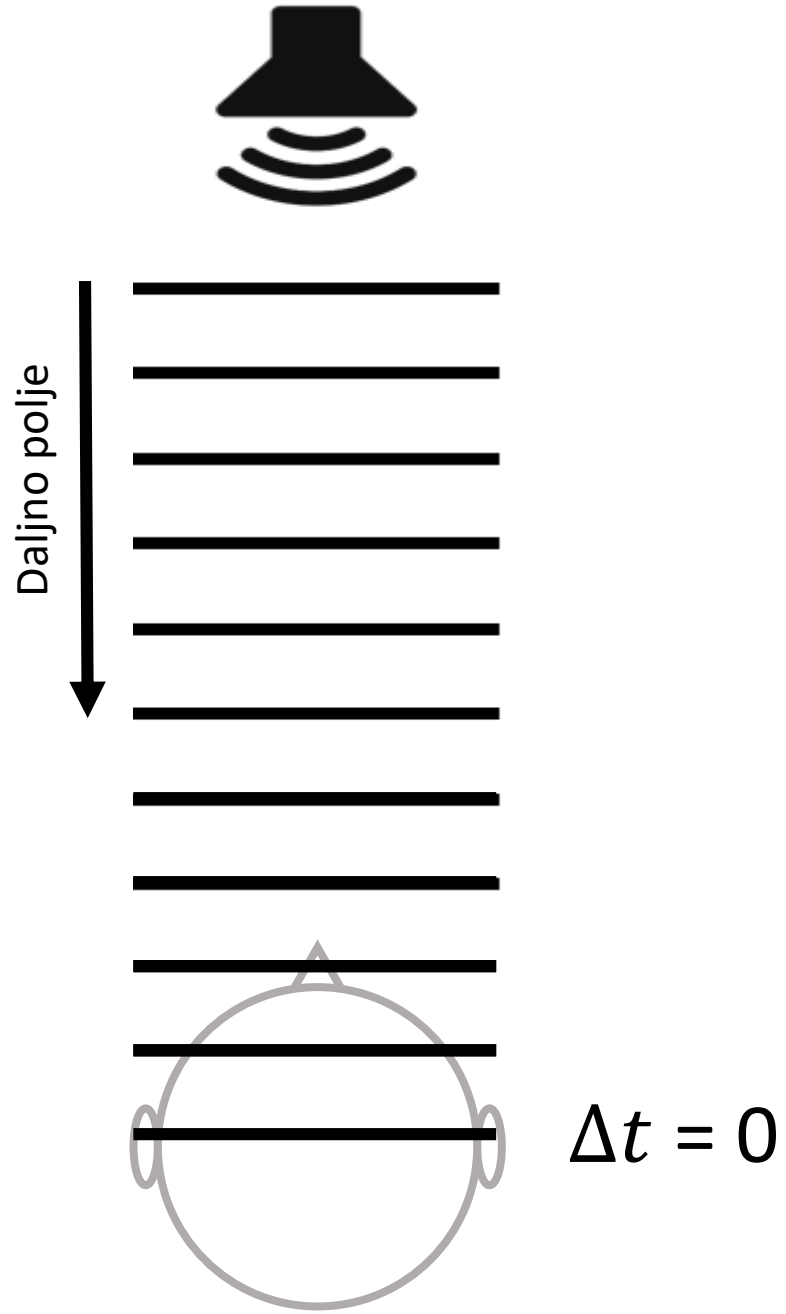
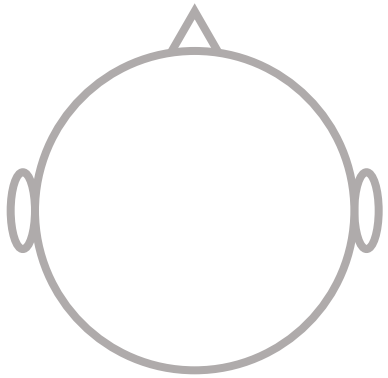
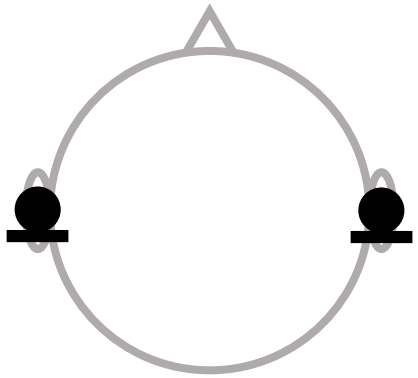
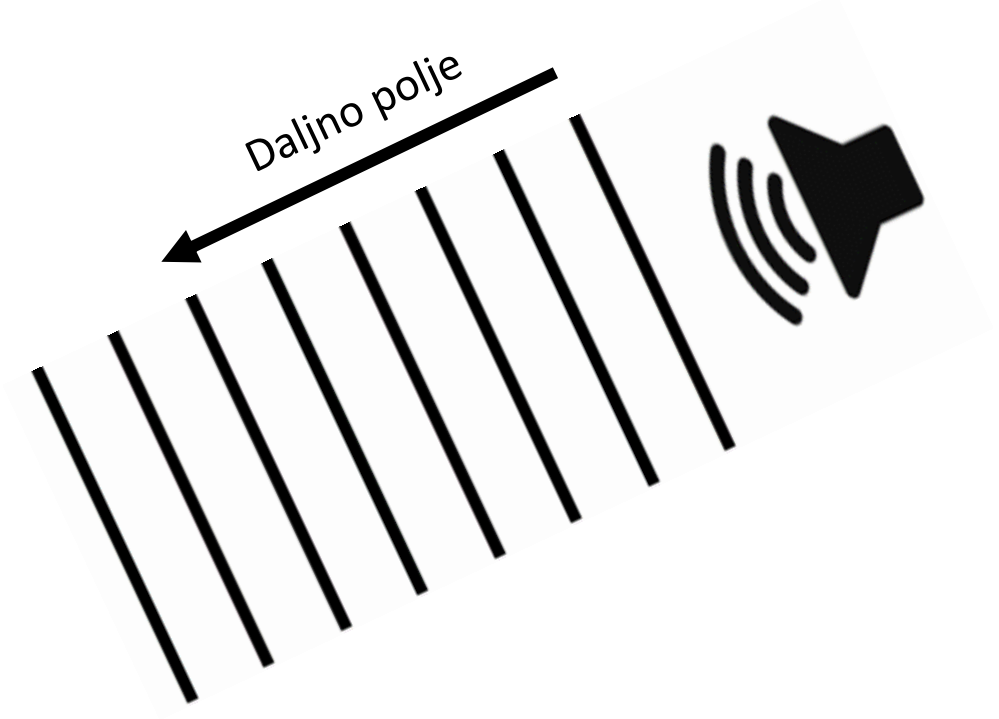

Daljno polje
Δt


Daljno polje
$\Delta t = 0$





(laptop, mobitel)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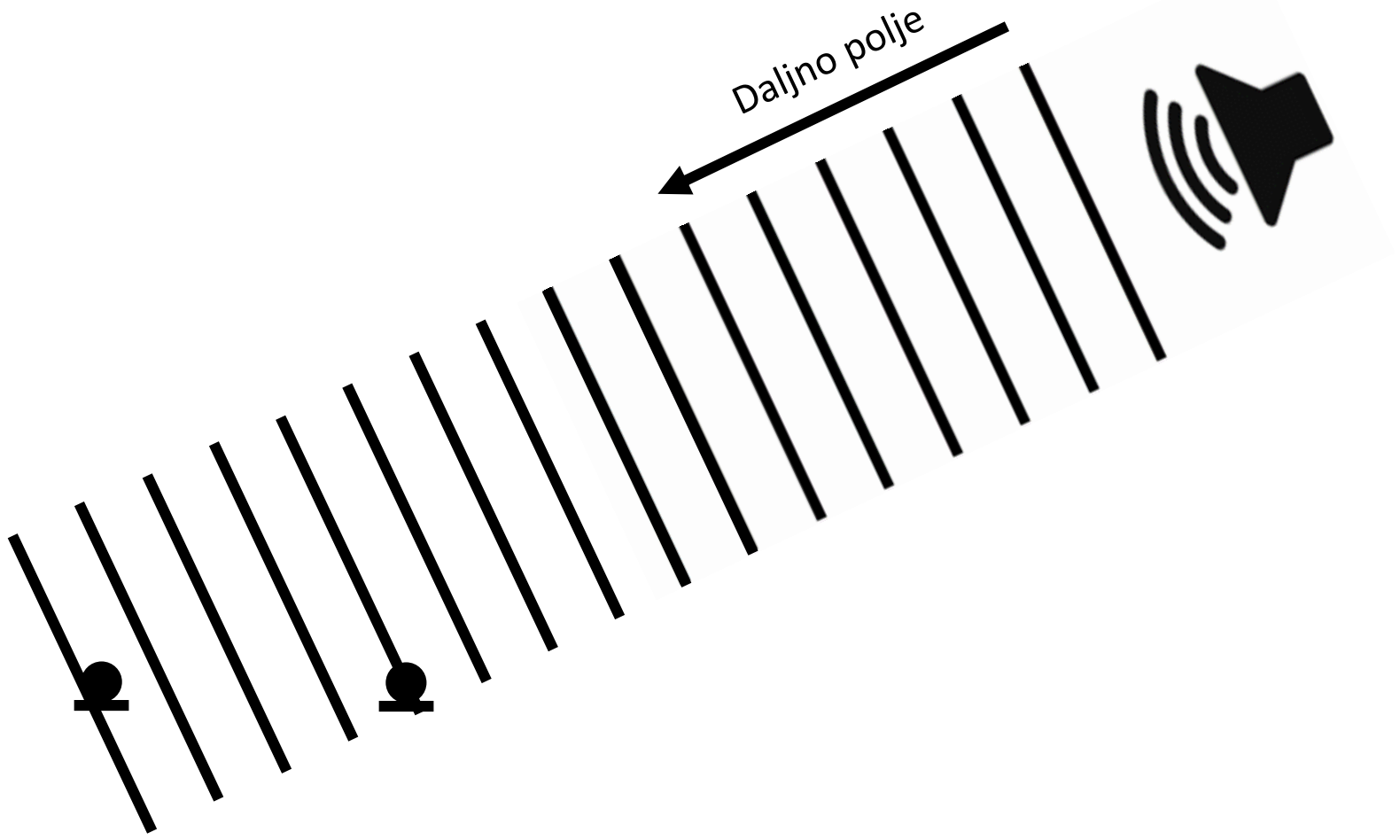
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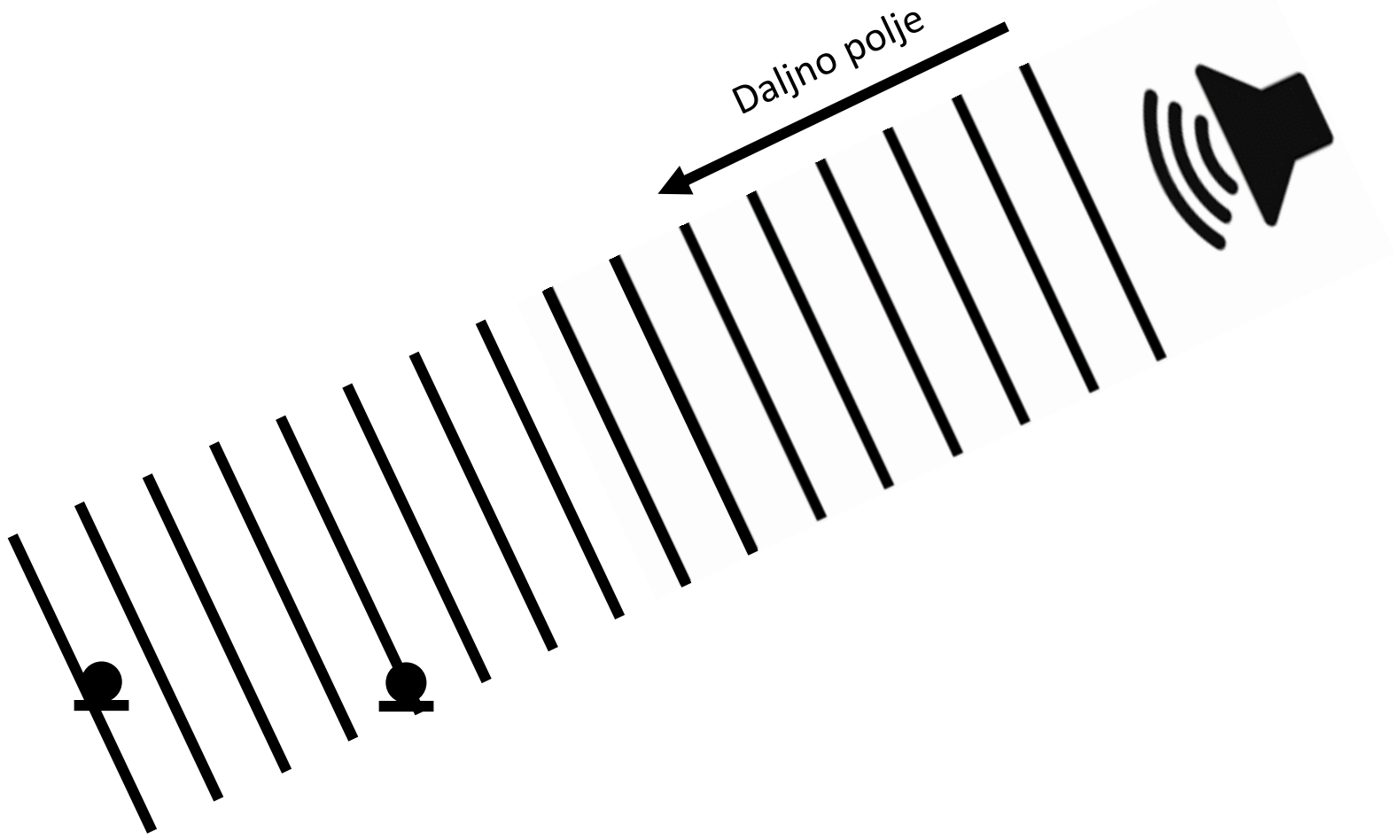
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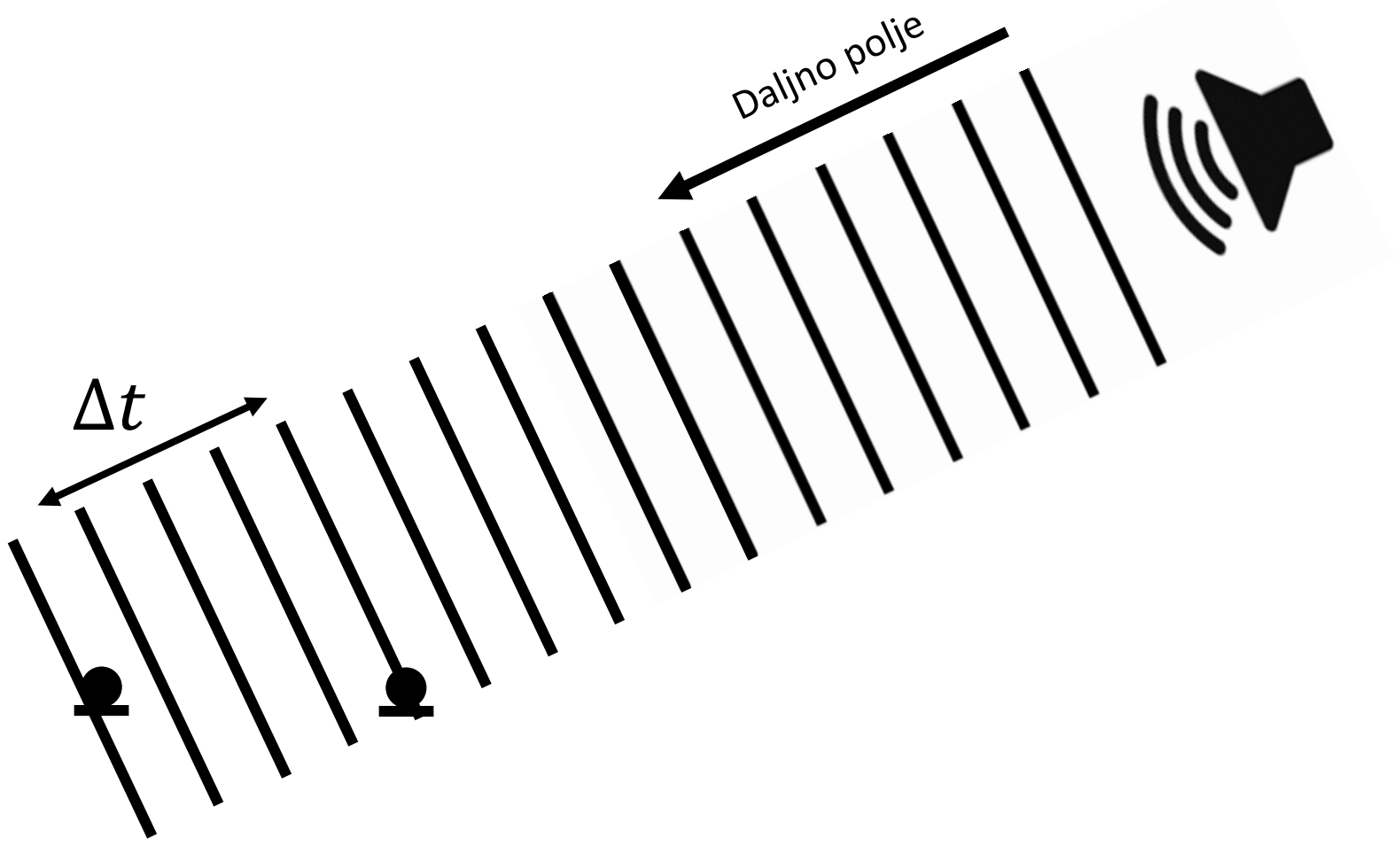
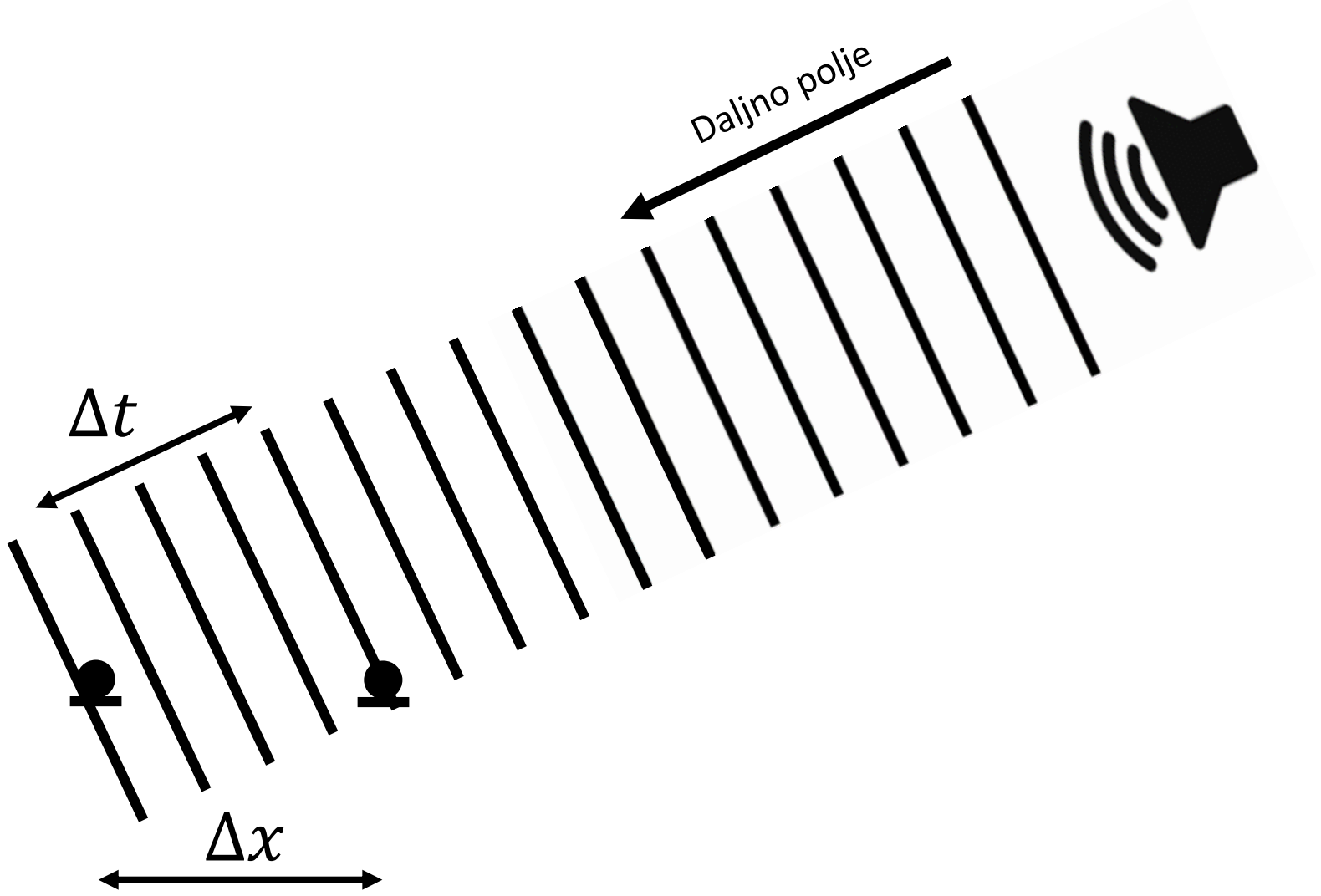
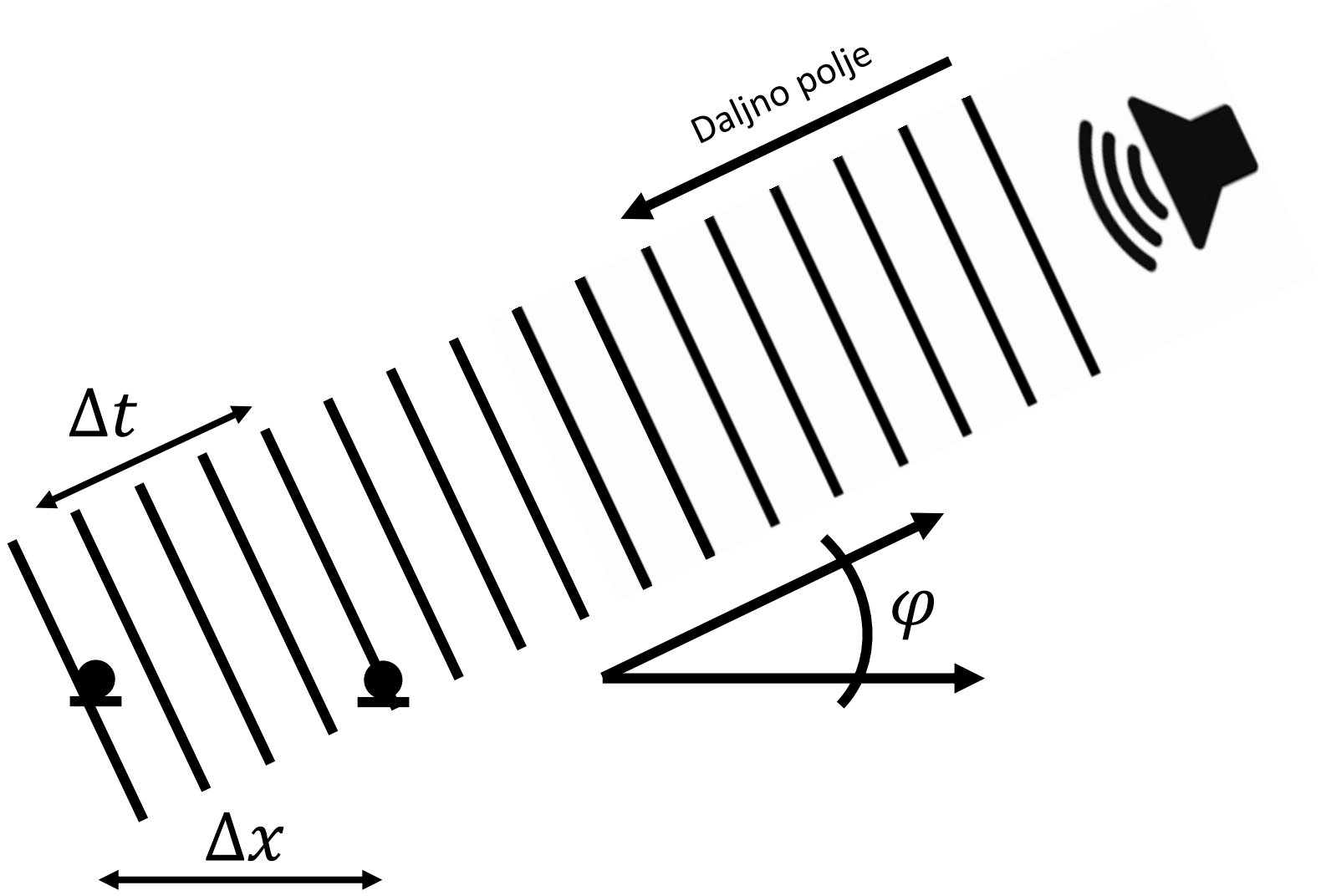
$\Delta t =$



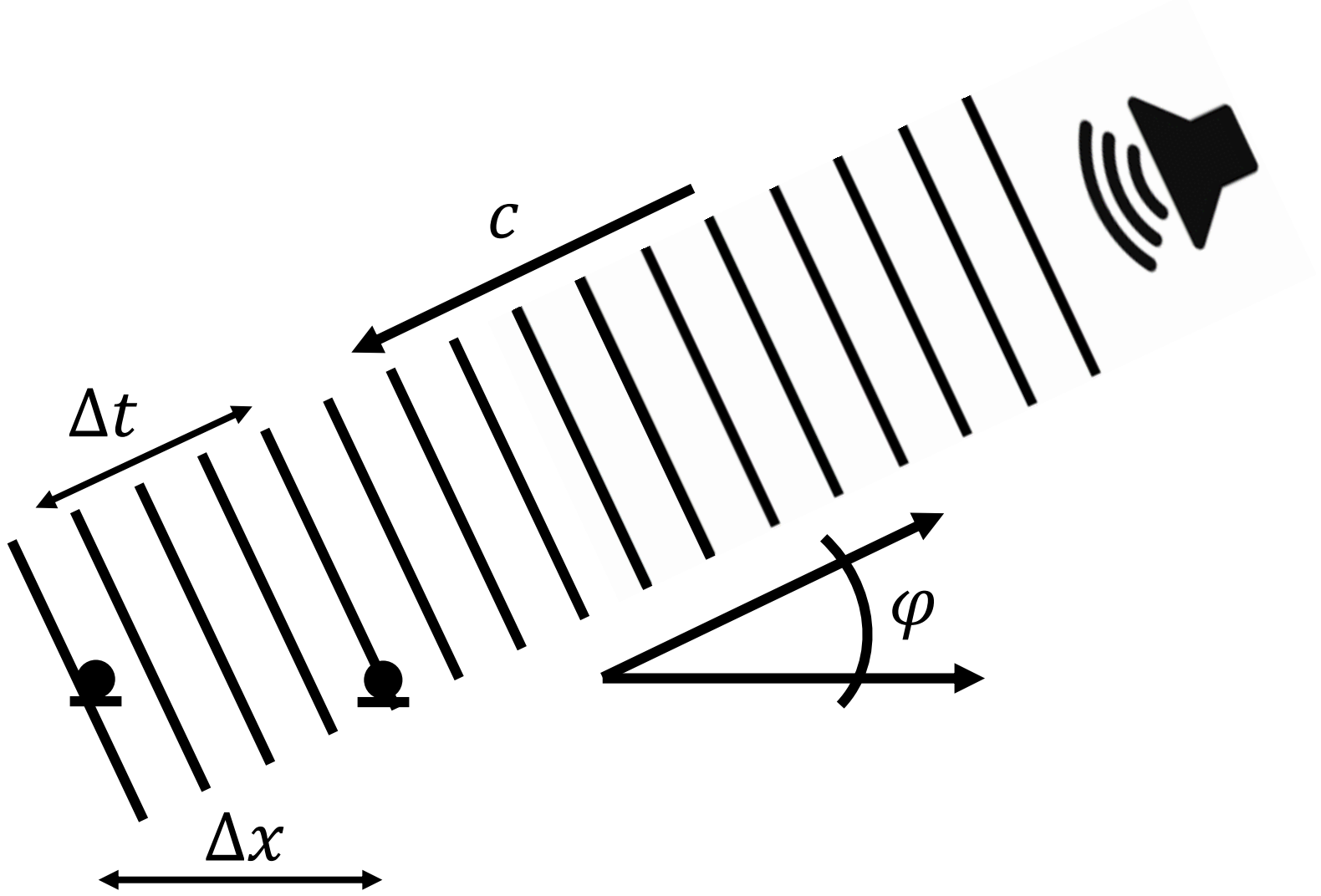
$$\Delta t = \frac{\Delta x \cdot}{\qquad\qquad}$$



$$\Delta t = \frac{\Delta x \ \cdot \cos \varphi}{}$$



$$\Delta t = \frac{\Delta x \ \cdot \cos \varphi}{c}$$



$$\Delta t = \frac{\Delta x \ \cdot \cos \varphi}{c}$$

Analogno-digitalna pretvorba

$$\Delta t = \frac{\Delta x \cdot \cos\varphi}{c}$$

http://gradiva.txt.si/av-komunikacije/zvok-2/analogno-digitalna-pretvorba-zvoka/

Analogno-digitalna pretvorba

$$\Delta t = \frac{\Delta x \cdot \cos\varphi}{c}$$

$$\Delta t \rightarrow \Delta N,$$

$$\Delta N = f_0 \cdot \Delta t$$

http://gradiva.txt.si/av-komunikacije/zvok-2/analogno-digitalna-pretvorba-zvoka/

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http://gradiva.txt.si/av-komunikacije/zvok-2/analogno-digitalna-pretvorba-zvoka/

Analogno-digitalna pretvorba

$$\Delta t = \frac{\Delta x \ \cdot \cos\varphi}{c} \quad \Rightarrow \quad \Delta t \rightarrow \Delta N, \quad \Delta N = f_0 \cdot \Delta t \quad \Rightarrow \quad \Delta N = \frac{\Delta x \ \cdot \cos\varphi \cdot f_0}{c}$$

http://gradiva.txt.si/av-komunikacije/zvok-2/analogno-digitalna-pretvorba-zvoka/

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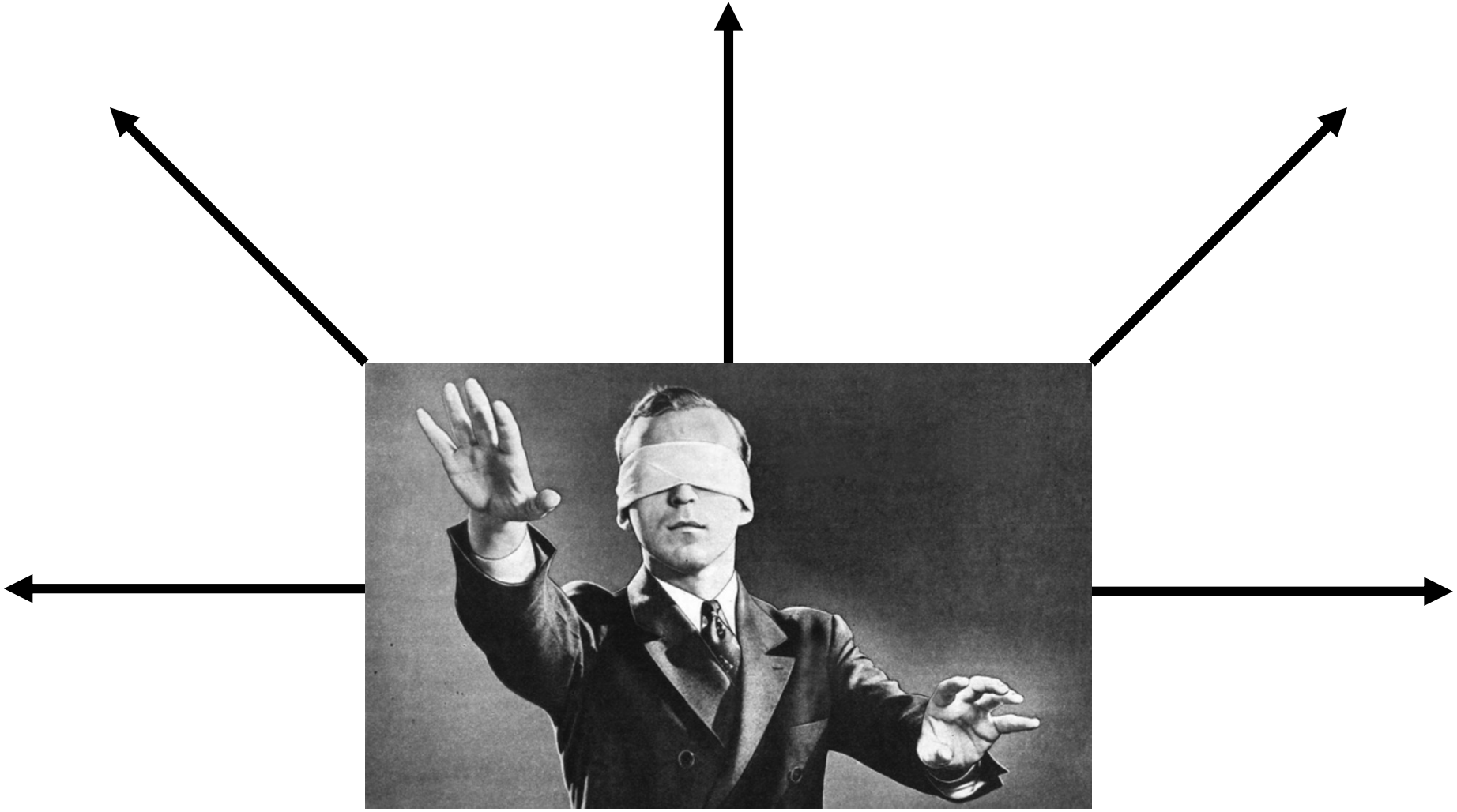
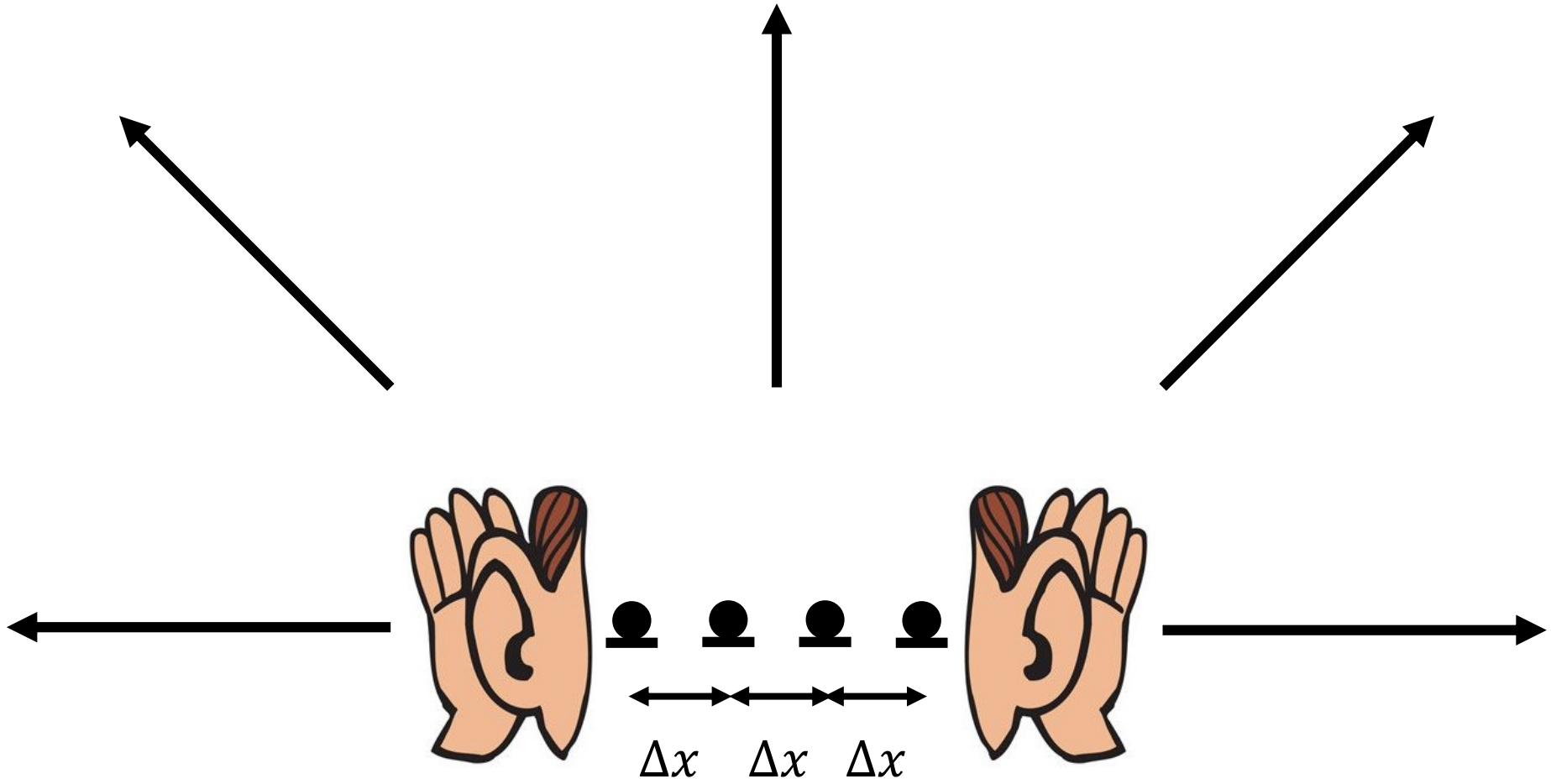
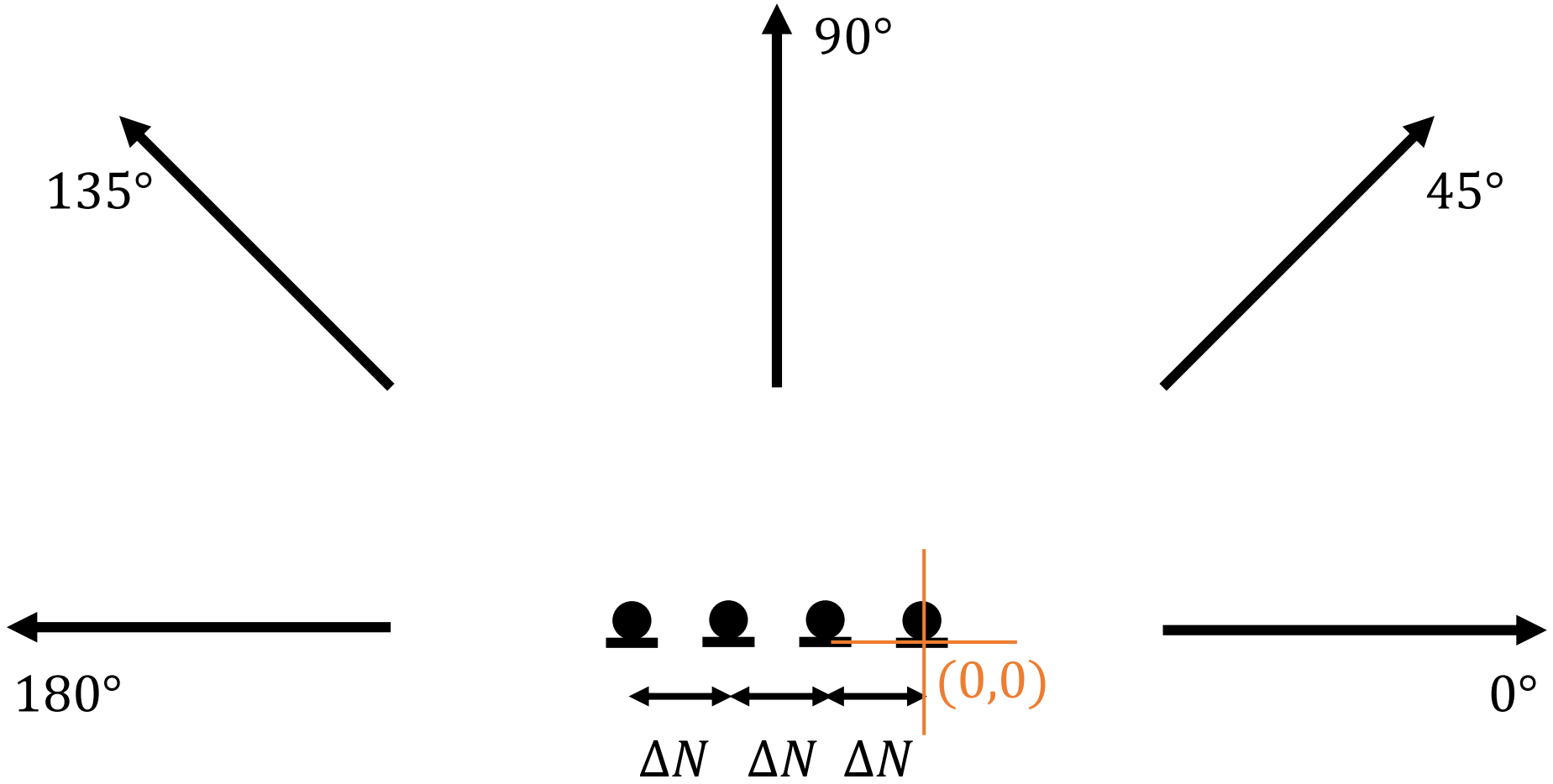
Zaokroževanje!!!

http://gradiva.txt.si/av-komunikacije/zvok-2/analogno-digitalna-pretvorba-zvoka/




Δx Δx Δx

- Mikrofonska antena posluša na ta način, da zajete signale ustrezno zamakne in jih nato sešteje. To ponovi za vsako opazovano smer.



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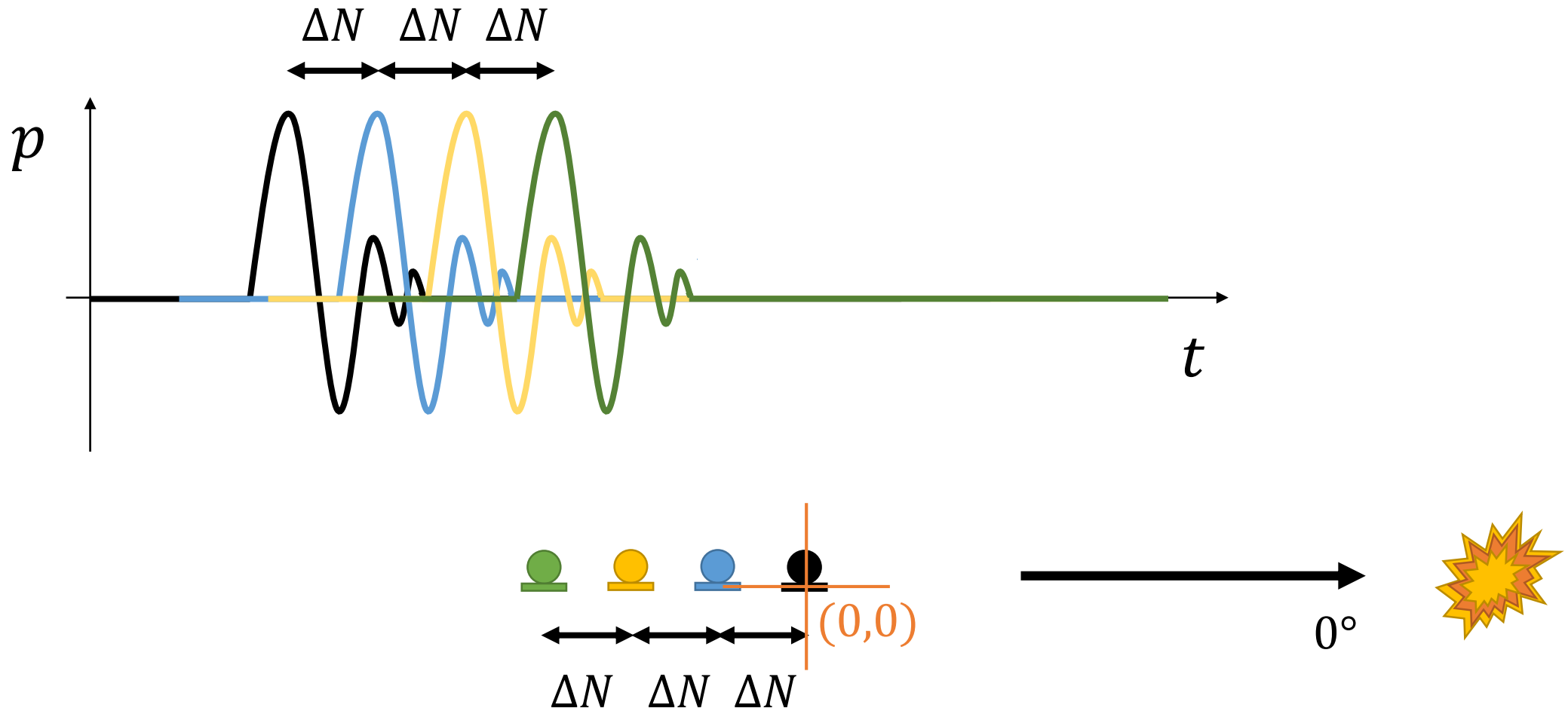
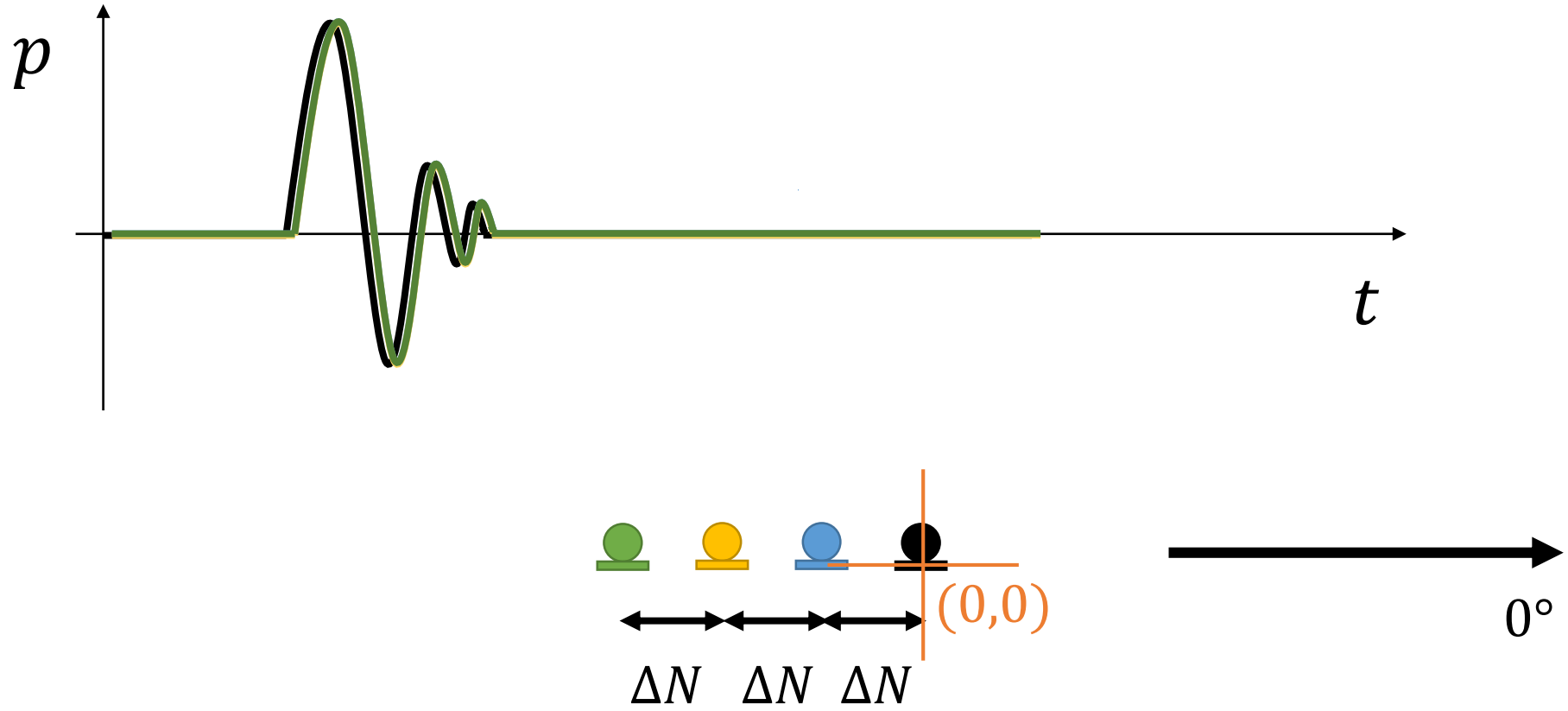
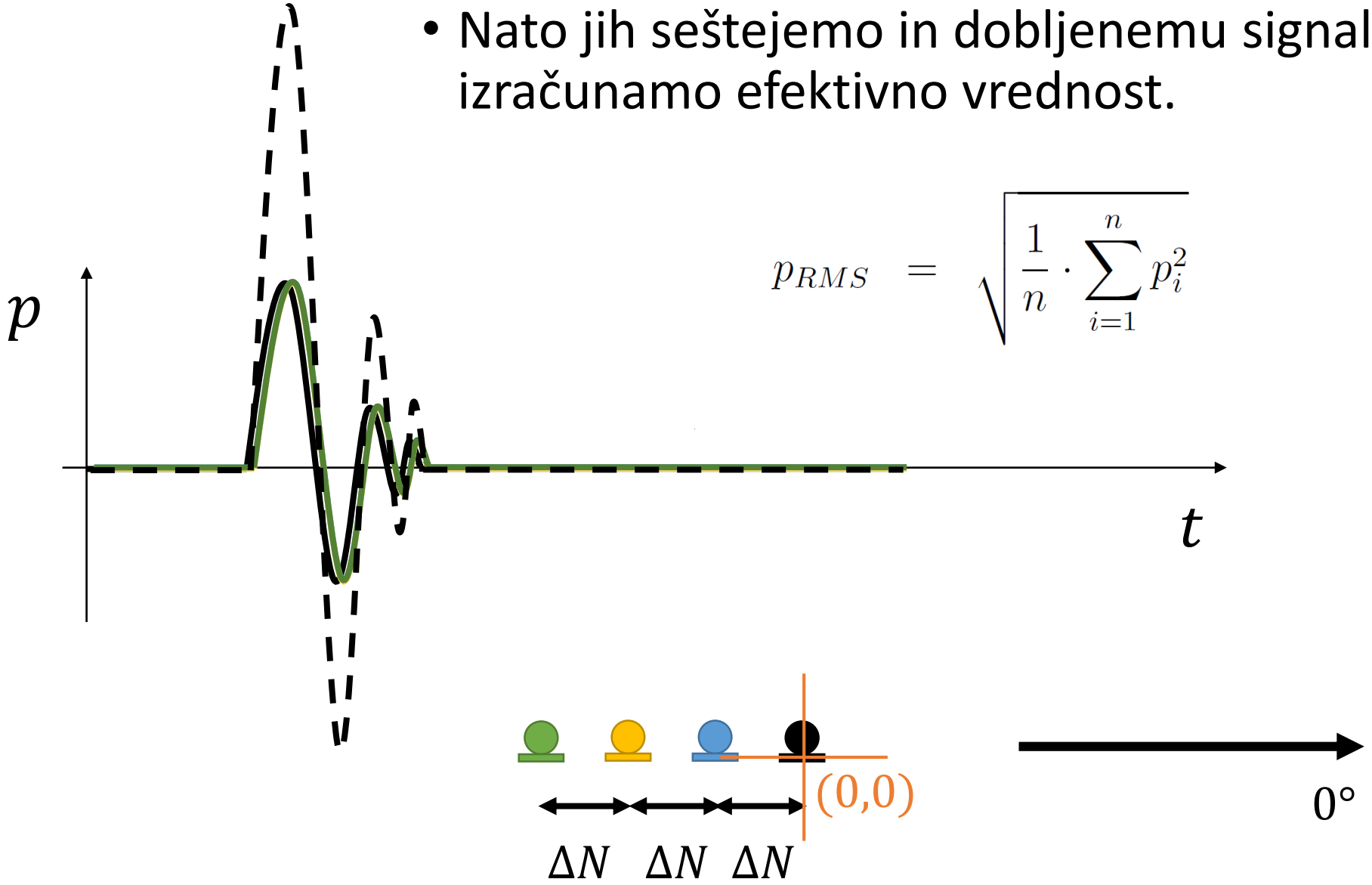


- Signale najprej zamaknemo glede na izračunan ΔN.

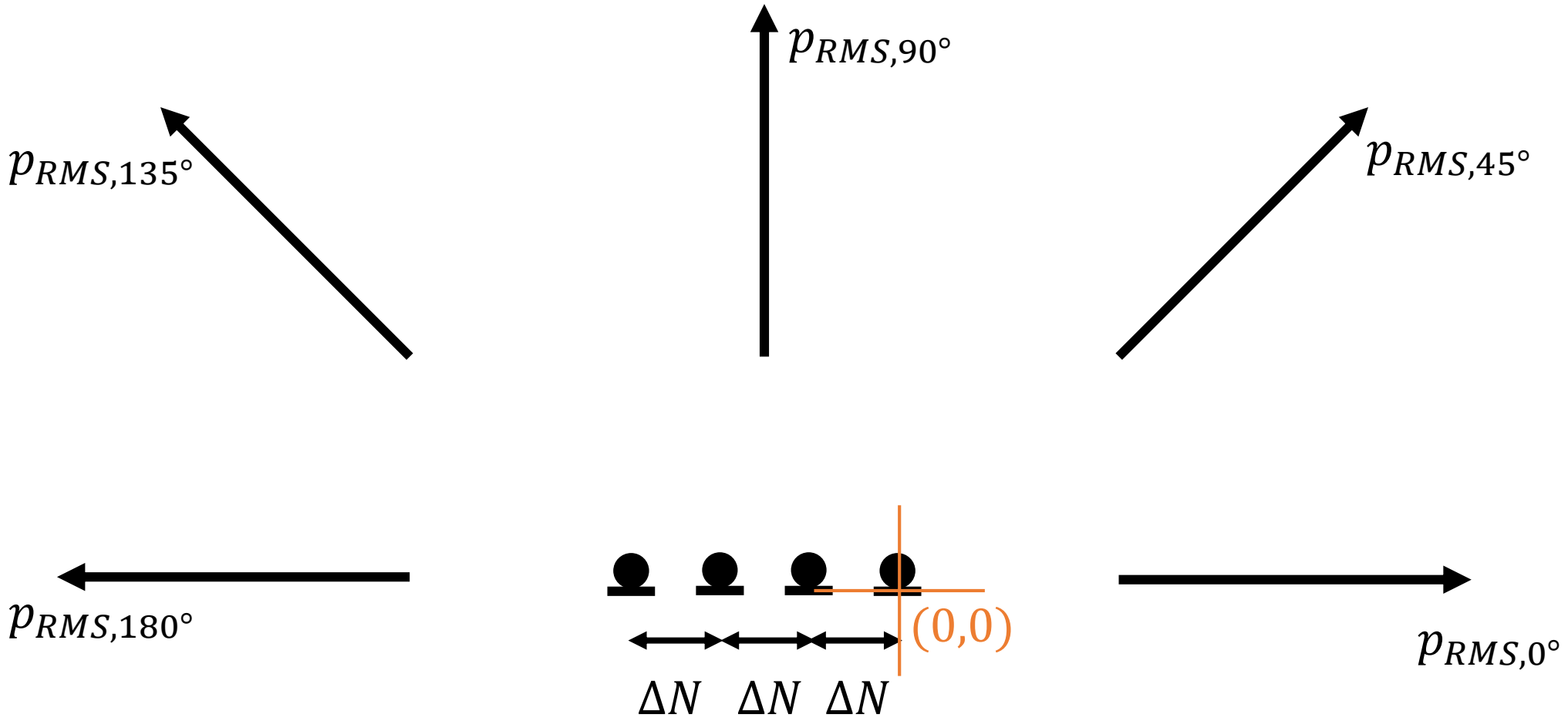


- Nato jih seštejemo in dobljenemu signalu (- - -) izračunamo efektivno vrednost.

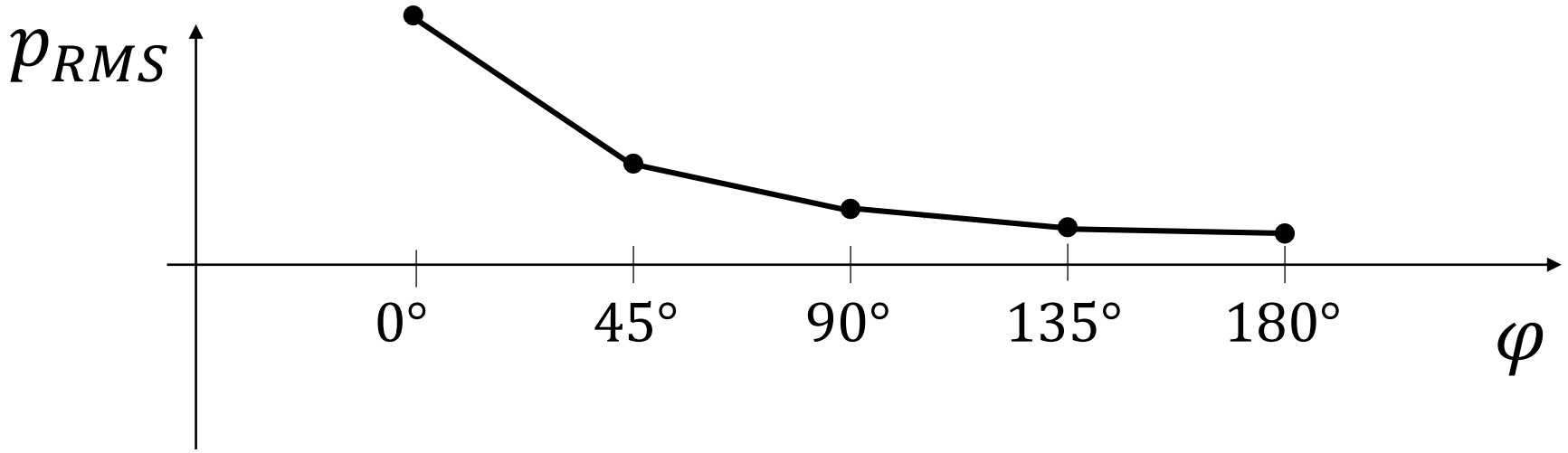
$$p_{RMS} = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} p_i^2}$$

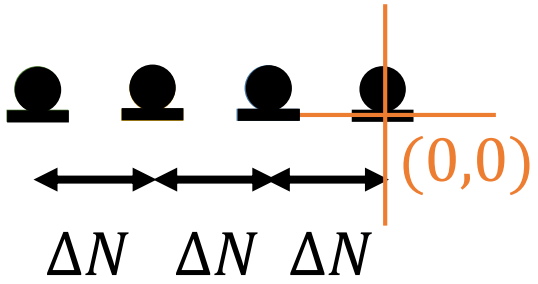


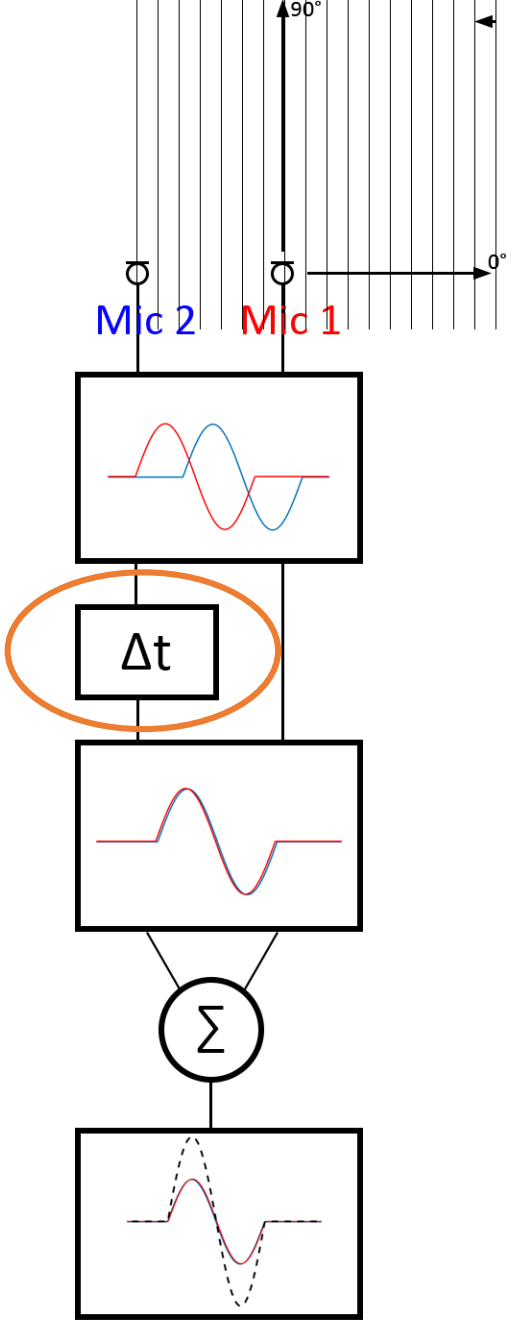
- To naredimo za vsako od opazovanih oziroma “poslušanih” smeri.



- Izračunane efektivne vrednosti nato primerjamo med sabo. Največja vrednost nam nakazuje, iz katere smeri so se signali po zamikanju najbolj poravnali.

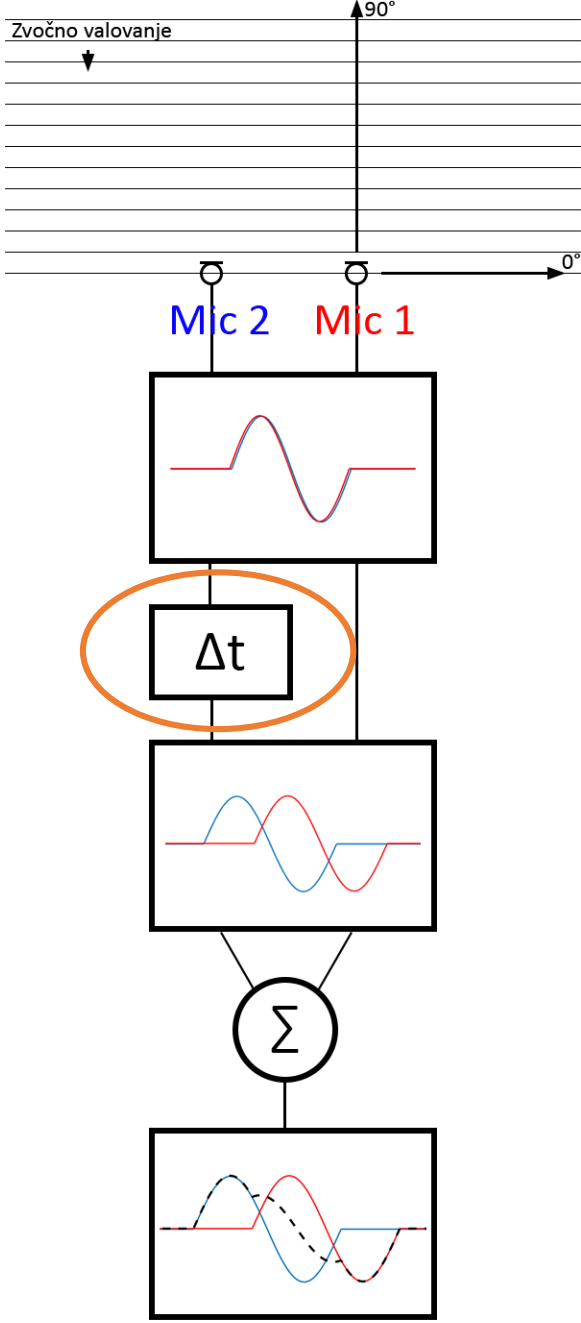




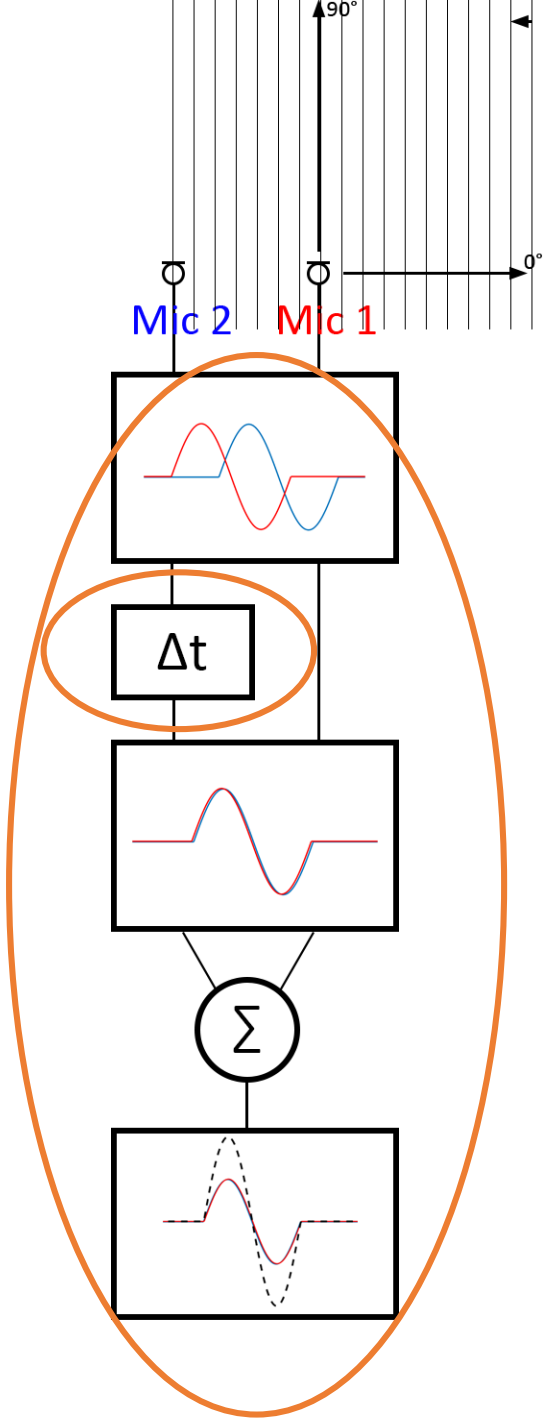


← 0°

90° ↓



- Antena v obeh primerih posluša proti 0°, saj Signal_2 (Mic 2) zamakne za Δt.

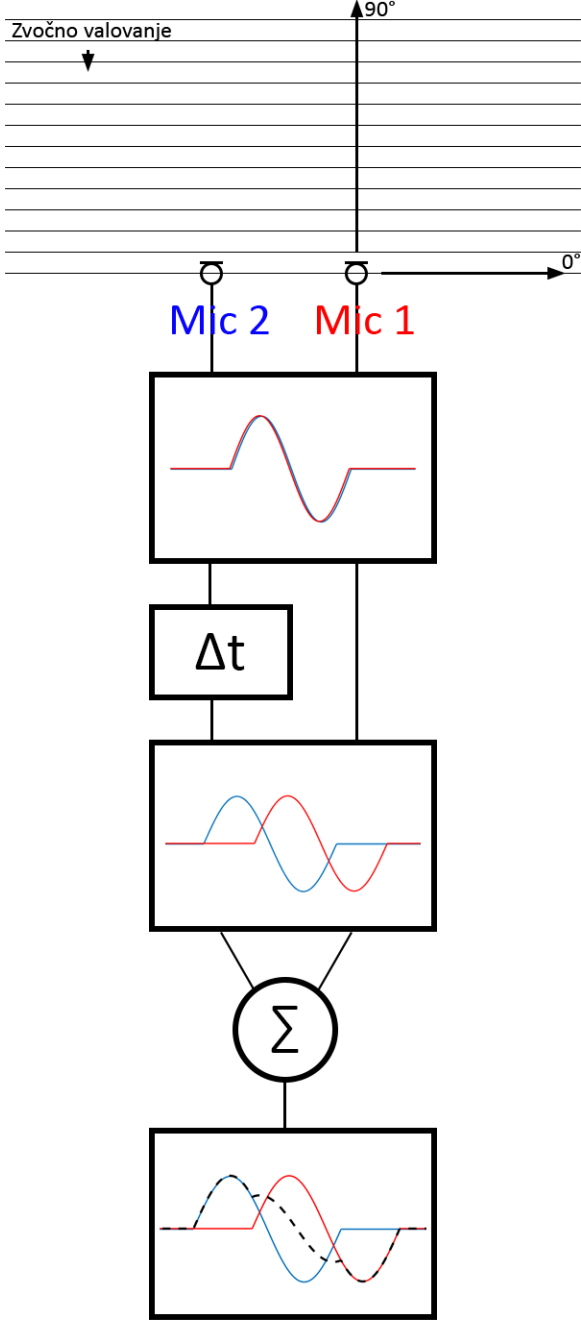


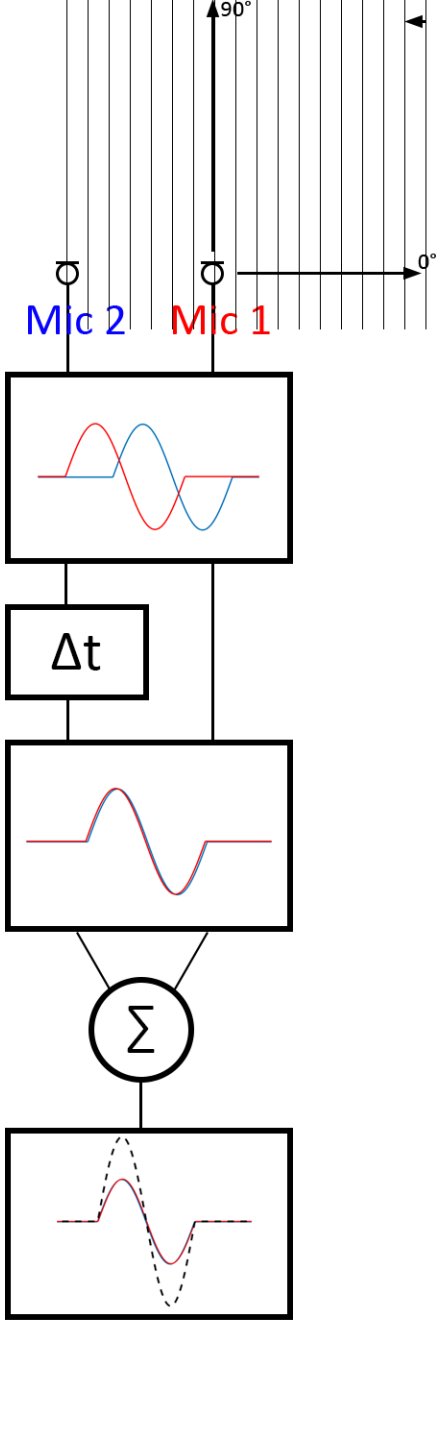
← 0°

90° ↓

- Antena v obeh primerih posluša proti 0°, saj Signal_2 (Mic 2) zamakne za Δt.

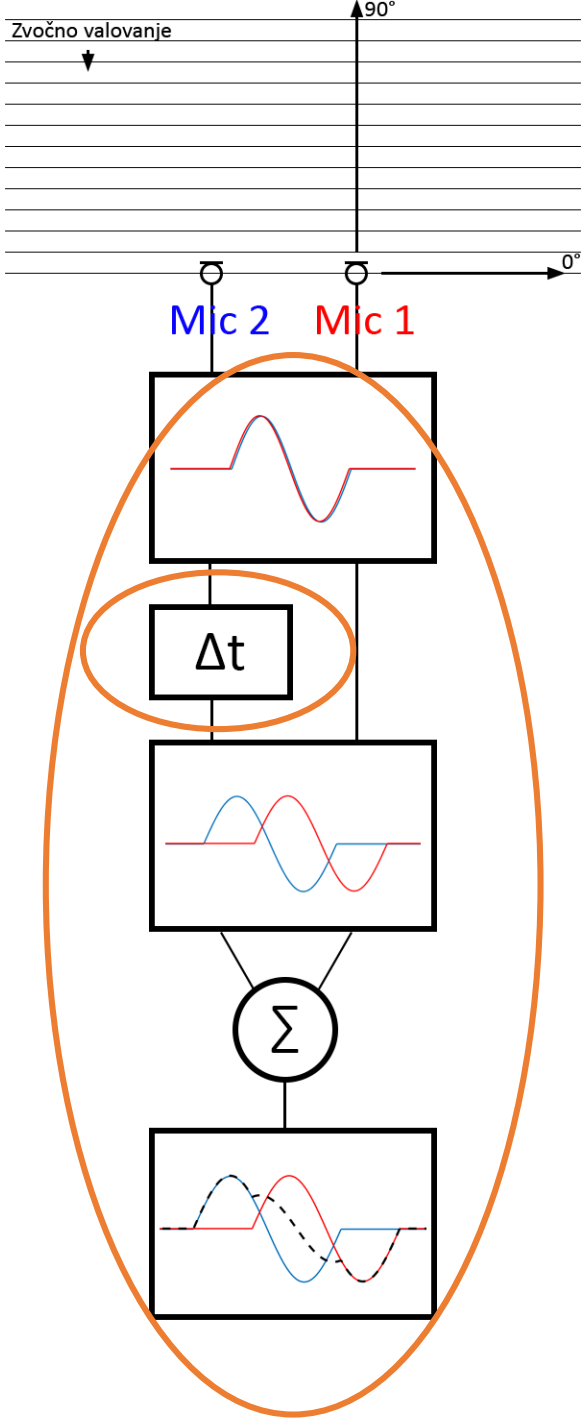
- V primeru, ko zvok dejansko prihaja iz smeri 0°, zamik povzroči, da se signala poravnata.





← 0°

90° ↓

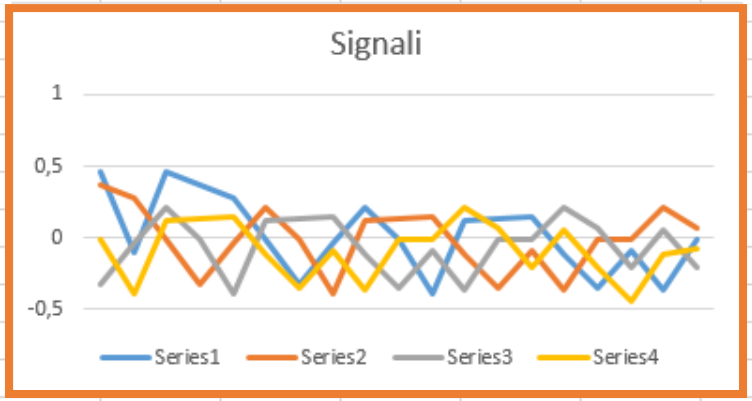


- Antena v obeh primerih posluša proti 0°, saj Signal_2 (Mic 2) zamakne za Δt.
- V primeru, ko zvok dejansko prihaja iz smeri 0°, zamik povzroči, da se signala poravnata.
- V primeru, ko zvok prihaja iz druge smeri (90°), zamik ni koristen in signala se pred seštevanjem NE poravnata. Rezultat je nižja efektivna vrednost seštetega signala.

Lokalizacija na primeru simuliranih signalov

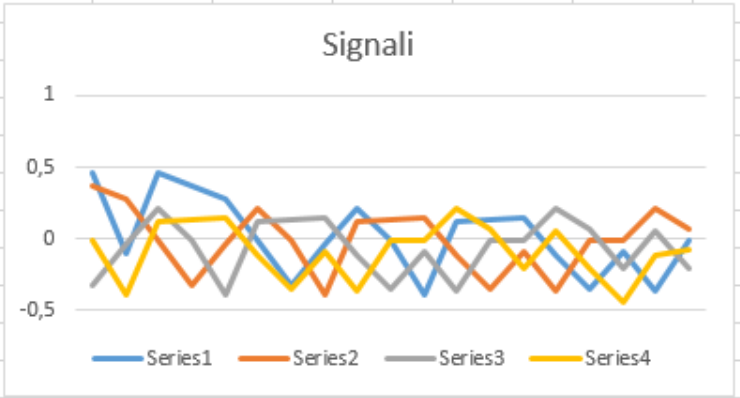
Primer računanja v MS Excel

	Signal_1	Signal_2	Signal_3	Signal_4
2				
3	0,446683	0,358082	-0,08797	0,462434
4	-0,08311	0,156856	0,456122	0,374583
5	-0,17599	-0,20581	-0,10235	0,283846
6	0,358082	-0,08797	0,462434	-0,01495
7	0,156856	0,456122	0,374583	-0,32232
8	-0,20581	-0,10235	0,283846	-0,03038
9	-0,08797	0,462434	-0,01495	0,213794
10	0,456122	0,374583	-0,32232	-0,0127
11	-0,10235	0,283846	-0,03038	-0,39564
12	0,462434	-0,01495	0,213794	0,118543
13	0,374583	-0,32232	-0,0127	0,132761
14	0,283846	-0,03038	-0,39564	0,152377
15	-0,01495	0,213794	0,118543	-0,11398
16	-0,32232	-0,0127	0,132761	-0,34842
17	-0,03038	-0,39564	0,152377	-0,08845
18	0,213794	0,118543	-0,11398	-0,35955
19	-0,0127	0,132761	-0,34842	-0,00871
20	-0,39564	0,152377	-0,08845	-0,00659
21	0,118543	-0,11398	-0,35955	0,217304
22	0,132761	-0,34842	-0,00871	0,06426
23	0,152377	-0,08845	-0,00659	-0,21076
24	-0,11398	-0,35955	0,217304	0,057375
25	-0,34842	-0,00871	0,06426	-0,21005
26	-0,08845	-0,00659	-0,21076	-0,44881
27	-0,35955	0,217304	0,057375	-0,11916
28	-0,00871	0,06426	-0,21005	-0,07495
29	-0,00659	-0,21076	-0,44881	0,48902
30	0,217304	0,057375	0,085108	0,175441
31	0,06426	-0,21005	0,365075	-0,3515
32	-0,21076	-0,44881	-0,2123	0,351368
33	0,057375	-0,4225	-0,14821	0,231879
34	-0,21005	-0,47032	-0,18231	-0,23217
35	-0,44881	-0,25333	-0,11245	-0,44588



	Signal_1	Signal_2	Signal_3	Signal_4
1				
2				
3	0,446683	0,358082	-0,08797	0,462434
4	-0,08311	0,156856	0,456122	0,374583
5	-0,17599	-0,20581	-0,10235	0,283846
6	0,358082	-0,08797	0,462434	-0,01495
7	0,156856	0,456122	0,374583	-0,32232
8	-0,20581	-0,10235	0,283846	-0,03038
9	-0,08797	0,462434	-0,01495	0,213794
10	0,456122	0,374583	-0,32232	-0,0127
11	-0,10235	0,283846	-0,03038	-0,39564
12	0,462434	-0,01495	0,213794	0,118543
13	0,374583	-0,32232	-0,0127	0,132761
14	0,283846	-0,03038	-0,39564	0,152377
15	-0,01495	0,213794	0,118543	-0,11398
16	-0,32232	-0,0127	0,132761	-0,34842
17	-0,03038	-0,39564	0,152377	-0,08845
18	0,213794	0,118543	-0,11398	-0,35955
19	-0,0127	0,132761	-0,34842	-0,00871
20	-0,39564	0,152377	-0,08845	-0,00659
21	0,118543	-0,11398	-0,35955	0,217304
22	0,132761	-0,34842	-0,00871	0,06426
23	0,152377	-0,08845	-0,00659	-0,21076
24	-0,11398	-0,35955	0,217304	0,057375
25	-0,34842	-0,00871	0,06426	-0,21005
26	-0,08845	-0,00659	-0,21076	-0,44881
27	-0,35955	0,217304	0,057375	-0,11916
28	-0,00871	0,06426	-0,21005	-0,07495
29	-0,00659	-0,21076	-0,44881	0,48902
30	0,217304	0,057375	0,085108	0,175441
31	0,06426	-0,21005	0,365075	-0,3515
32	-0,21076	-0,44881	-0,2123	0,351368
33	0,057375	-0,4225	-0,14821	0,231879
34	-0,21005	-0,47032	-0,18231	-0,23217
35	-0,44881	-0,25333	-0,11245	-0,44588

E	F	G	H	I	J	K
0°	30°	60°	90°	120°	150°	180°
dN = 7	dN = 6	dN = 3	dN = 0	dN = -3	dN = -6	dN = -7

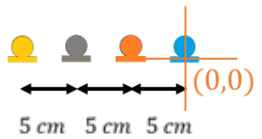


$$p_{RMS} = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} p_i^2}$$

$$\Delta N = \frac{\Delta x \cdot \cos\varphi \cdot f_0}{c}$$

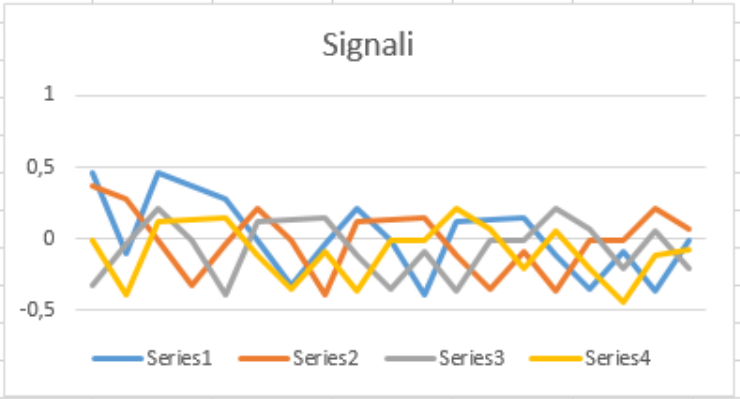
$$f_0 = 48\,000 \text{ Hz}$$

$$c = 343 \text{ m/s}$$



	A	B	C	D	E	F	G	H	I	J	K
1	Signal_1	Signal_2	Signal_3	Signal_4	0°	30°	60°	90°	120°	150°	180°
2					dN = 7	dN = 6	dN = 3	dN = 0	dN = -3	dN = -6	dN = -7
3	0,446683	0,358082	-0,08797	0,462434							
4	-0,08311	0,156856	0,456122	0,374583							
5	-0,17599	-0,20581	-0,10235	0,283846							
6	0,358082	-0,08797	0,462434	-0,01495							
7	0,156856	0,456122	0,374583	-0,32232							
8	-0,20581	-0,10235	0,283846	-0,03038							
9	-0,08797	0,462434	-0,01495	0,213794							
10	0,456122	0,374583	-0,32232	-0,0127	1,031017						
11	-0,10235	0,283846	-0,03038	-0,39564	-0,1233						
12	0,462434	-0,01495	0,213794	0,118543	-0,98817						
13	0,374583	-0,32232	-0,0127	0,132761	-0,17184						
14	0,283846	-0,03038	-0,39564	0,152377	-0,30803						
15	-0,01495	0,213794	0,118543	-0,11398	0,488291						
16	-0,32232	-0,0127	0,132761	-0,34842	0,068176						
17	-0,03038	-0,39564	0,152377	-0,08845	-0,07371						
18	0,213794	0,118543	-0,11398	-0,35955	0,431818						
19	-0,0127	0,132761	-0,34842	-0,00871	0,616315						
20	-0,39564	0,152377	-0,08845	-0,00659	0,352164						
21	0,118543	-0,11398	-0,35955	0,217304	-0,48607						
22	0,132761	-0,34842	-0,00871	0,06426							
23	0,152377	-0,08845	-0,00659	-0,21076							
24	-0,11398	-0,35955	0,217304	0,057375							
25	-0,34842	-0,00871	0,06426	-0,21005							
26	-0,08845	-0,00659	-0,21076	-0,44881							
27	-0,35955	0,217304	0,057375	-0,11916							
28	-0,00871	0,06426	-0,21005	-0,07495							
29	-0,00659	-0,21076	-0,44881	0,48902							
30	0,217304	0,057375	0,085108	0,175441							
31	0,06426	-0,21005	0,365075	-0,3515							
32	-0,21076	-0,44881	-0,2123	0,351368							
33	0,057375	-0,4225	-0,14821	0,231879							
34	-0,21005	-0,47032	-0,18231	-0,23217							
35	-0,44881	-0,25333	-0,11245	-0,44588							

=A3+B10+C17+D24

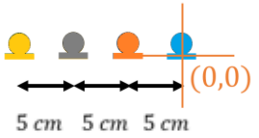


$$p_{RMS} = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} p_i^2}$$

$$\Delta N = \frac{\Delta x \cdot \cos\varphi \cdot f_0}{c}$$

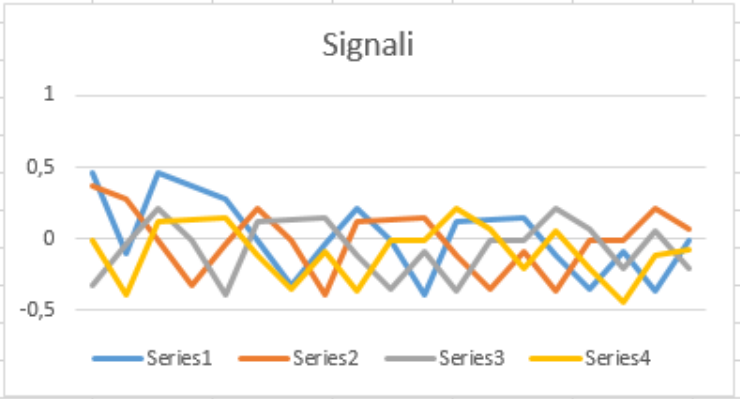
$f_0 = 48\,000$ Hz

c = 343 m/s



	A	B	C	D	E	F	G	H	I	J	K
1	Signal_1	Signal_2	Signal_3	Signal_4	0°	30°	60°	90°	120°	150°	180°
2					dN = 7	dN = 6	dN = 3	dN = 0	dN = -3	dN = -6	dN = -7
3	0,446683	0,358082	-0,08797	0,462434							
4	-0,08311	0,156856	0,456122	0,374583							
5	-0,17599	-0,20581	-0,10235	0,283846							
6	0,358082	-0,08797	0,462434	-0,01495							
7	0,156856	0,456122	0,374583	-0,32232							
8	-0,20581	-0,10235	0,283846	-0,03038							
9	-0,08797	0,462434	-0,01495	0,213794							
10	0,456122	0,374583	-0,32232	-0,0127	1,031017	1,244964					
11	-0,10235	0,283846	-0,03038	-0,39564	-0,1233	0,488491					
12	0,462434	-0,01495	0,213794	0,118543	-0,98817	0,049471					
13	0,374583	-0,32232	-0,0127	0,132761	-0,17184	0,286524					
14	0,283846	-0,03038	-0,39564	0,152377	-0,30803	-0,72394					
15	-0,01495	0,213794	0,118543	-0,11398	0,488291	-0,77345					
16	-0,32232	-0,0127	0,132761	-0,34842	0,068176	-0,35289					
17	-0,03038	-0,39564	0,152377	-0,08845	-0,07371	0,359761					
18	0,213794	0,118543	-0,11398	-0,35955	0,431818	-0,01556					
19	-0,0127	0,132761	-0,34842	-0,00871	0,616315	0,973722					
20	-0,39564	0,152377	-0,08845	-0,00659	0,352164	0,220107					
21	0,118543	-0,11398	-0,35955	0,217304	-0,48607	0,57683					
22	0,132761	-0,34842	-0,00871	0,06426							
23	0,152377	-0,08845	-0,00659	-0,21076							
24	-0,11398	-0,35955	0,217304	0,057375							
25	-0,34842	-0,00871	0,06426	-0,21005							
26	-0,08845	-0,00659	-0,21076	-0,44881							
27	-0,35955	0,217304	0,057375	-0,11916							
28	-0,00871	0,06426	-0,21005	-0,07495							
29	-0,00659	-0,21076	-0,44881	0,48902							
30	0,217304	0,057375	0,085108	0,175441							
31	0,06426	-0,21005	0,365075	-0,3515							
32	-0,21076	-0,44881	-0,2123	0,351368							
33	0,057375	-0,4225	-0,14821	0,231879							
34	-0,21005	-0,47032	-0,18231	-0,23217							
35	-0,44881	-0,25333	-0,11245	-0,44588							

=A3+B9+C15+D21

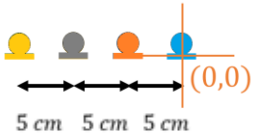


$$p_{RMS} = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} p_i^2}$$

$$\Delta N = \frac{\Delta x \cdot \cos\varphi \cdot f_0}{c}$$

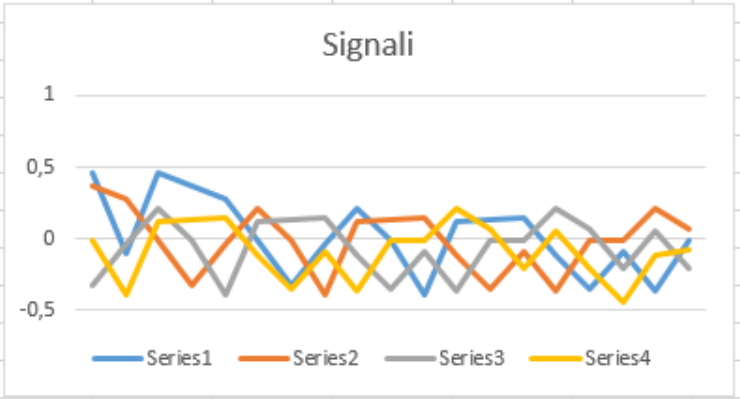
$f_0 = 48\,000$ Hz

c = 343 m/s



	A	B	C	D	E	F	G	H	I	J	K
1	Signal_1	Signal_2	Signal_3	Signal_4	0°	30°	60°	90°	120°	150°	180°
2					dN = 7	dN = 6	dN = 3	dN = 0	dN = -3	dN = -6	dN = -7
3	0,446683	0,358082	-0,08797	0,462434							
4	-0,08311	0,156856	0,456122	0,374583							
5	-0,17599	-0,20581	-0,10235	0,283846							
6	0,358082	-0,08797	0,462434	-0,01495							
7	0,156856	0,456122	0,374583	-0,32232							
8	-0,20581	-0,10235	0,283846	-0,03038							
9	-0,08797	0,462434	-0,01495	0,213794							
10	0,456122	0,374583	-0,32232	-0,0127	1,031017	1,244964	0,462304	1,179227	1,849737	0,779822	-0,36951
11	-0,10235	0,283846	-0,03038	-0,39564	-0,1233	0,488491	0,183453	0,904448	1,498331	0,172325	0,114323
12	0,462434	-0,01495	0,213794	0,118543	-0,98817	0,049471	-0,15634	-0,20031	1,135383	0,010207	0,541949
13	0,374583	-0,32232	-0,0127	0,132761	-0,17184	0,286524	0,920326	0,717595	-0,0598	0,203403	-0,23483
14	0,283846	-0,03038	-0,39564	0,152377	-0,30803	-0,72394	0,170313	0,665242	-1,28927	-0,55068	-0,84065
15	-0,01495	0,213794	0,118543	-0,11398	0,488291	-0,77345	-0,40606	-0,0547	-0,12151	-0,36209	-0,26685
16	-0,32232	-0,0127	0,132761	-0,34842	0,068176	-0,35289	-0,34393	0,573306	0,855175	-0,1412	0,475407
17	-0,03038	-0,39564	0,152377	-0,08845	-0,07371	0,359761	0,257857	0,495686	-0,0508	-0,23707	-0,15562
18	0,213794	0,118543	-0,11398	-0,35955	0,431818	-0,01556	0,013056	-0,24452	-1,58255	-0,3383	-0,72909
19	-0,0127	0,132761	-0,34842	-0,00871	0,616315	0,973722	0,779548	0,779822	0,474171	-0,13769	-0,1791
20	-0,39564	0,152377	-0,08845	-0,00659	0,352164	0,220107	0,077717	0,172325	0,531045	-0,16011	0,051562
21	0,118543	-0,11398	-0,35955	0,217304	-0,48607	0,57683	-0,411	0,010207	0,609507	-0,15343	-0,59172
22	0,132761	-0,34842	-0,00871	0,06426							
23	0,152377	-0,08845	-0,00659	-0,21076							
24	-0,11398	-0,35955	0,217304	0,057375							
25	-0,34842	-0,00871	0,06426	-0,21005							
26	-0,08845	-0,00659	-0,21076	-0,44881							
27	-0,35955	0,217304	0,057375	-0,11916							
28	-0,00871	0,06426	-0,21005	-0,07495							
29	-0,00659	-0,21076	-0,44881	0,48902							
30	0,217304	0,057375	0,085108	0,175441							
31	0,06426	-0,21005	0,365075	-0,3515							
32	-0,21076	-0,44881	-0,2123	0,351368							
33	0,057375	-0,4225	-0,14821	0,231879							
34	-0,21005	-0,47032	-0,18231	-0,23217							
35	-0,44881	-0,25333	-0,11245	-0,44588							

=A24+B17+C10+D3

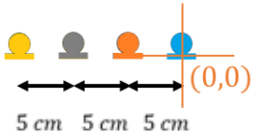


$$p_{RMS} = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} p_i^2}$$

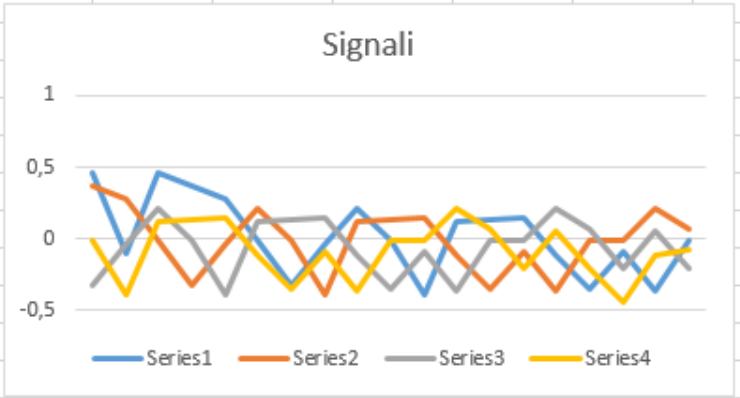
$$\Delta N = \frac{\Delta x \cdot \cos\varphi \cdot f_0}{c}$$

$f_0 = 48\,000$ Hz

c = 343 m/s



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Signal_1**	**Signal_2**	**Signal_3**	**Signal_4**	**0°**	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**								
2					**dN = 7**	**dN = 6**	**dN = 3**	**dN = 0**	**dN = -3**	**dN = -6**	**dN = -7**								
3	0,446683	0,358082	-0,08797	0,462434															
4	-0,08311	0,156856	0,456122	0,374583															
5	-0,17599	-0,20581	-0,10235	0,283846															
6	0,358082	-0,08797	0,462434	-0,01495															
7	0,156856	0,456122	0,374583	-0,32232															
8	-0,20581	-0,10235	0,283846	-0,03038															
9	-0,08797	0,462434	-0,01495	0,213794								**0°**	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**	
10	0,456122	0,374583	-0,32232	-0,0127	1,031017	1,244964	0,462304	1,179227	1,849737	0,779822	-0,36951	1,062997	1,549936	0,213725	1,390577	3,421527	0,608122	0,136534	
11	-0,10235	0,283846	-0,03038	-0,39564	-0,1233	0,488491	0,183453	0,904448	1,498331	0,172325	0,114323	0,015203	0,238624	0,033655	0,818027	2,244995	0,029696	0,01307	
12	0,462434	-0,01495	0,213794	0,118543	-0,98817	0,049471	-0,15634	-0,20031	1,135383	0,010207	0,541949	0,976483	0,002447	0,024443	0,040125	1,289094	0,000104	0,293709	
13	0,374583	-0,32232	-0,0127	0,132761	-0,17184	0,286524	0,920326	0,717595	-0,0598	0,203403	-0,23483	0,02953	0,082096	0,847001	0,514942	0,003576	0,041373	0,055144	
14	0,283846	-0,03038	-0,39564	0,152377	-0,30803	-0,72394	0,170313	0,665242	-1,28927	-0,55068	-0,84065	0,094881	0,524088	0,029007	0,442547	1,662223	0,303251	0,706689	
15	-0,01495	0,213794	0,118543	-0,11398	0,488291	-0,77345	-0,40606	-0,0547	-0,12151	-0,36209	-0,26685	0,238428	0,598224	0,164882	0,002992	0,014765	0,131109	0,071209	
16	-0,32232	-0,0127	0,132761	-0,34842	0,068176	-0,35289	-0,34393	0,573306	0,855175	-0,1412	0,475407	0,004648	0,12453	0,11829	0,32868	0,731324	0,019938	0,226012	
17	-0,03038	-0,39564	0,152377	-0,08845	-0,07371	0,359761	0,257857	0,495686	-0,0508	-0,23707	-0,15562	0,005433	0,129428	0,06649	0,245705	0,002581	0,056203	0,024217	
18	0,213794	0,118543	-0,11398	-0,35955	0,431818	-0,01556	0,013056	-0,24452	-1,58255	-0,3383	-0,72909	0,186467	0,000242	0,00017	0,05979	2,504465	0,114449	0,531572	
19	-0,0127	0,132761	-0,34842	-0,00871	0,616315	0,973722	0,779548	0,779822	0,474171	-0,13769	-0,1791	0,379844	0,948134	0,607695	0,608122	0,224839	0,018959	0,032076	
20	-0,39564	0,152377	-0,08845	-0,00659	0,352164	0,220107	0,077717	0,172325	0,531045	-0,16011	0,051562	0,12402	0,048447	0,00604	0,029696	0,282008	0,025636	0,002659	
21	0,118543	-0,11398	-0,35955	0,217304	-0,48607	0,57683	-0,411	0,010207	0,609507	-0,15343	-0,59172	0,236266	0,332733	0,168924	0,000104	0,371499	0,02354	0,350137	
22	0,132761	-0,34842	-0,00871	0,06426															
23	0,152377	-0,08845	-0,00659	-0,21076							**p_RMS**	**0,528693**	**0,61772**	**0,435921**	**0,611099**	**1,030893**	**0,338179**	**0,451205**	
24	-0,11398	-0,35955	0,217304	0,057375															
25	-0,34842	-0,00871	0,06426	-0,21005															
26	-0,08845	-0,00659	-0,21076	-0,44881															
27	-0,35955	0,217304	0,057375	-0,11916															
28	-0,00871	0,06426	-0,21005	-0,07495															
29	-0,00659	-0,21076	-0,44881	0,48902															
30	0,217304	0,057375	0,085108	0,175441															
31	0,06426	-0,21005	0,365075	-0,3515															
32	-0,21076	-0,44881	-0,2123	0,351368															
33	0,057375	-0,4225	-0,14821	0,231879															
34	-0,21005	-0,47032	-0,18231	-0,23217															
35	-0,44881	-0,25333	-0,11245	-0,44588															

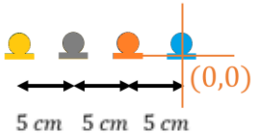


$$p_{RMS} = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} p_i^2}$$

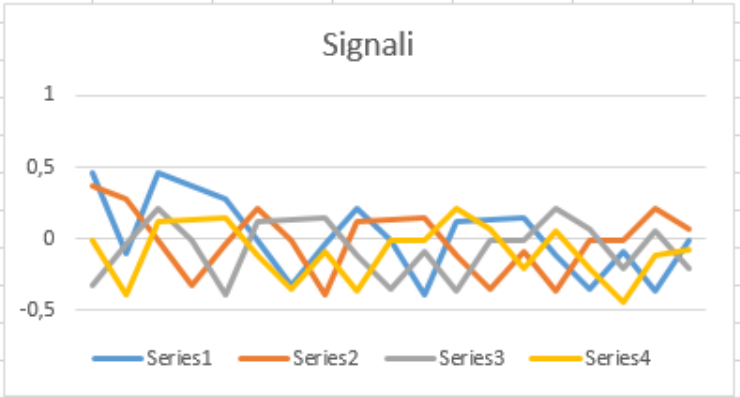
$$\Delta N = \frac{\Delta x \cdot \cos\varphi \cdot f_0}{c}$$

$f_0 = 48\,000$ Hz

c = 343 m/s



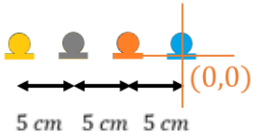
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Signal_1**	**Signal_2**	**Signal_3**	**Signal_4**	**0°**	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**								
2					**dN = 7**	**dN = 6**	**dN = 3**	**dN = 0**	**dN = -3**	**dN = -6**	**dN = -7**								
3	0,446683	0,358082	-0,08797	0,462434															
4	-0,08311	0,156856	0,456122	0,374583															
5	-0,17599	-0,20581	-0,10235	0,283846															
6	0,358082	-0,08797	0,462434	-0,01495															
7	0,156856	0,456122	0,374583	-0,32232															
8	-0,20581	-0,10235	0,283846	-0,03038															
9	-0,08797	0,462434	-0,01495	0,213794								**0°**	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**	
10	0,456122	0,374583	-0,32232	-0,0127	1,031017	1,244964	0,462304	1,179227	1,849737	0,779822	-0,36951	1,062997	1,549936	0,213725	1,390577	3,421527	0,608122	0,136534	
11	-0,10235	0,283846	-0,03038	-0,39564	-0,1233	0,488491	0,183453	0,904448	1,498331	0,172325	0,114323	0,015203	0,238624	0,033655	0,818027	2,244995	0,029696	0,01307	
12	0,462434	-0,01495	0,213794	0,118543	-0,98817	0,049471	-0,15634	-0,20031	1,135383	0,010207	0,541949	0,976483	0,002447	0,024443	0,040125	1,289094	0,000104	0,293709	
13	0,374583	-0,32232	-0,0127	0,132761	-0,17184	0,286524	0,920326	0,717595	-0,0598	0,203403	-0,23483	0,02953	0,082096	0,847001	0,514942	0,003576	0,041373	0,055144	
14	0,283846	-0,03038	-0,39564	0,152377	-0,30803	-0,72394	0,170313	0,665242	-1,28927	-0,55068	-0,84065	0,094881	0,524088	0,029007	0,442547	1,662223	0,303251	0,706689	
15	-0,01495	0,213794	0,118543	-0,11398	0,488291	-0,77345	-0,40606	-0,0547	-0,12151	-0,36209	-0,26685	0,238428	0,598224	0,164882	0,002992	0,014765	0,131109	0,071209	
16	-0,32232	-0,0127	0,132761	-0,34842	0,068176	-0,35289	-0,34393	0,573306	0,855175	-0,1412	0,475407	0,004648	0,12453	0,11829	0,32868	0,731324	0,019938	0,226012	
17	-0,03038	-0,39564	0,152377	-0,08845	-0,07371	0,359761	0,257857	0,495686	-0,0508	-0,23707	-0,15562	0,005433	0,129428	0,06649	0,245705	0,002581	0,056203	0,024217	
18	0,213794	0,118543	-0,11398	-0,35955	0,431818	-0,01556	0,013056	-0,24452	-1,58255	-0,3383	-0,72909	0,186467	0,000242	0,00017	0,05979	2,504465	0,114449	0,531572	
19	-0,0127	0,132761	-0,34842	-0,00871	0,616315	0,973722	0,779548	0,779822	0,474171	-0,13769	-0,1791	0,379844	0,948134	0,607695	0,608122	0,224839	0,018959	0,032076	
20	-0,39564	0,152377	-0,08845	-0,00659	0,352164	0,220107	0,077717	0,172325	0,531045	-0,16011	0,051562	0,12402	0,048447	0,00604	0,029696	0,282008	0,025636	0,002659	
21	0,118543	-0,11398	-0,35955	0,217304	-0,48607	0,57683	-0,411	0,010207	0,609507	-0,15343	-0,59172	0,236266	0,332733	0,168924	0,000104	0,371499	0,02354	0,350137	
22	0,132761	-0,34842	-0,00871	0,06426															
23	0,152377	-0,08845	-0,00659	-0,21076							**p_RMS**	**0,528693**	**0,61772**	**0,435921**	**0,611099**	**1,030893**	**0,338179**	**0,451205**	
24	-0,11398	-0,35955	0,217304	0,057375															
25	-0,34842	-0,00871	0,06426	-0,21005															
26	-0,08845	-0,00659	-0,21076	-0,44881															
27	-0,35955	0,217304	0,057375	-0,11916															
28	-0,00871	0,06426	-0,21005	-0,07495															
29	-0,00659	-0,21076	-0,44881	0,48902															
30	0,217304	0,057375	0,085108	0,175441															
31	0,06426	-0,21005	0,365075	-0,3515															
32	-0,21076	-0,44881	-0,2123	0,351368															
33	0,057375	-0,4225	-0,14821	0,231879															
34	-0,21005	-0,47032	-0,18231	-0,23217															
35	-0,44881	-0,25333	-0,11245	-0,44588															



$$p_{RMS} = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} p_i^2}$$

$$\Delta N = \frac{\Delta x \cdot \cos\varphi \cdot f_0}{c}$$

$$f_0 = 48\,000 \text{ Hz}$$
$$c = 343 \text{ m/s}$$



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Signal_1**	**Signal_2**	**Signal_3**	**Signal_4**	**0°**	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**								
2					**dN = 7**	**dN = 6**	**dN = 3**	**dN = 0**	**dN = -3**	**dN = -6**	**dN = -7**								
3	0,446683	0,358082	-0,08797	0,462434															
4	-0,08311	0,156856	0,456122	0,374583															
5	-0,17599	-0,20581	-0,10235	0,283846															
6	0,358082	-0,08797	0,462434	-0,01495															
7	0,156856	0,456122	0,374583	-0,32232															
8	-0,20581	-0,10235	0,283846	-0,03038															
9	-0,08797	0,462434	-0,01495	0,213794								**0°**	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**	
10	0,456122	0,374583	-0,32232	-0,0127	1,031017	1,244964	0,462304	1,179227	1,849737	0,779822	-0,36951	1,062997	1,549936	0,213725	1,390577	3,421527	0,608122	0,136534	
11	-0,10235	0,283846	-0,03038	-0,39564	-0,1233	0,488491	0,183453	0,904448	1,498331	0,172325	0,114323	0,015203	0,238624	0,033655	0,818027	2,244995	0,029696	0,01307	
12	0,462434	-0,01495	0,213794	0,118543	-0,98817	0,049471	-0,15634	-0,20031	1,135383	0,010207	0,541949	0,976483	0,002447	0,024443	0,040125	1,289094	0,000104	0,293709	
13	0,374583	-0,32232	-0,0127	0,132761	-0,17184	0,286524	0,920326	0,717595	-0,0598	0,203403	-0,23483	0,02953	0,082096	0,847001	0,514942	0,003576	0,041373	0,055144	
14	0,283846	-0,03038	-0,39564	0,152377	-0,30803	-0,72394	0,170313	0,665242	-1,28927	-0,55068	-0,84065	0,094881	0,524088	0,029007	0,442547	1,662223	0,303251	0,706689	
15	-0,01495	0,213794	0,118543	-0,11398	0,488291	-0,77345	-0,40606	-0,0547	-0,12151	-0,36209	-0,26685	0,238428	0,598224	0,164882	0,002992	0,014765	0,131109	0,071209	
16	-0,32232	-0,0127	0,132761	-0,34842	0,068176	-0,35289	-0,34393	0,573306	0,855175	-0,1412	0,475407	0,004648	0,12453	0,11829	0,32868	0,731324	0,019938	0,226012	
17	-0,03038	-0,39564	0,152377	-0,08845	-0,07371	0,359761	0,257857	0,495686	-0,0508	-0,23707	-0,15562	0,005433	0,129428	0,06649	0,245705	0,002581	0,056203	0,024217	
18	0,213794	0,118543	-0,11398	-0,35955	0,431818	-0,01556	0,013056	-0,24452	-1,58255	-0,3383	-0,72909	0,186467	0,000242	0,00017	0,05979	2,504465	0,114449	0,531572	
19	-0,0127	0,132761	-0,34842	-0,00871	0,616315	0,973722	0,779548	0,779822	0,474171	-0,13769	-0,1791	0,379844	0,948134	0,607695	0,608122	0,224839	0,018959	0,032076	
20	-0,39564	0,152377	-0,08845	-0,00659	0,352164	0,220107	0,077717	0,172325	0,531045	-0,16011	0,051562	0,12402	0,048447	0,00604	0,029696	0,282008	0,025636	0,002659	
21	0,118543	-0,11398	-0,35955	0,217304	-0,48607	0,57683	-0,411	0,010207	0,609507	-0,15343	-0,59172	0,236266	0,332733	0,168924	0,000104	0,371499	0,02354	0,350137	
22	0,132761	-0,34842	-0,00871	0,06426															
23	0,152377	-0,08845	-0,00659	-0,21076							**p_RMS**	**0,528693**	**0,61772**	**0,435921**	**0,611099**	**1,030893**	**0,338179**	**0,451205**	
24	-0,11398	-0,35955	0,217304	0,057375															
25	-0,34842	-0,00871	0,06426	-0,21005															
26	-0,08845	-0,00659	-0,21076	-0,44881															
27	-0,35955	0,217304	0,057375	-0,11916															
28	-0,00871	0,06426	-0,21005	-0,07495															
29	-0,00659	-0,21076	-0,44881	0,48902															
30	0,217304	0,057375	0,085108	0,175441															
31	0,06426	-0,21005	0,365075	-0,3515															
32	-0,21076	-0,44881	-0,2123	0,351368															
33	0,057375	-0,4225	-0,14821	0,231879															
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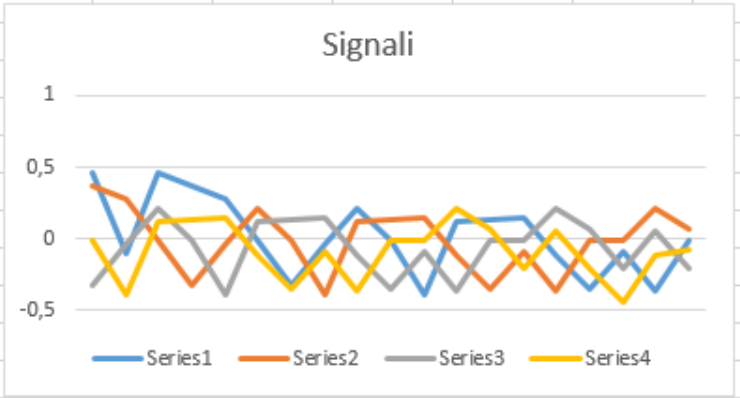
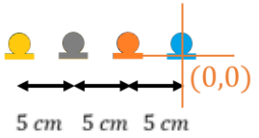
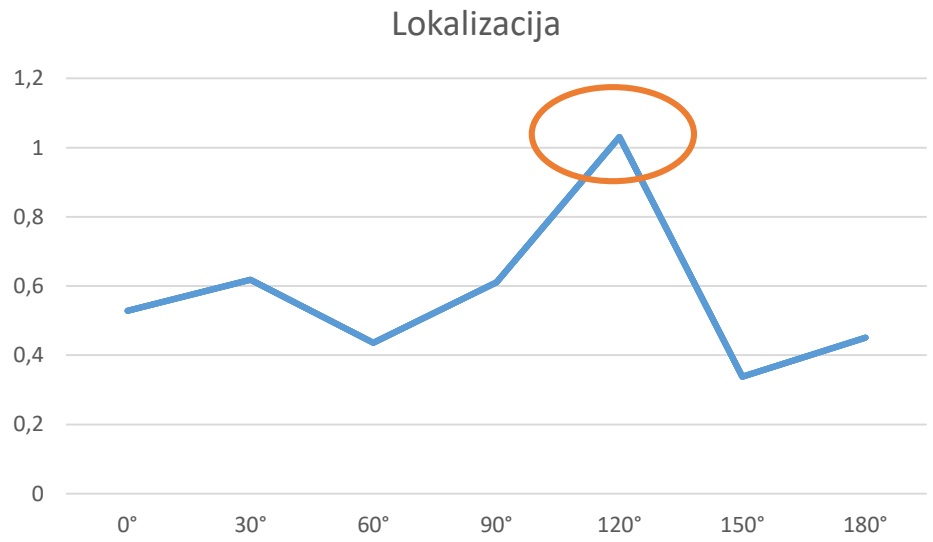


$$p_{RMS} = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} p_i^2}$$

$$\Delta N = \frac{\Delta x \cdot \cos\varphi \cdot f_0}{c}$$

$$f_0 = 48\,000 \text{ Hz}$$
$$c = 343 \text{ m/s}$$




Lokalizacija
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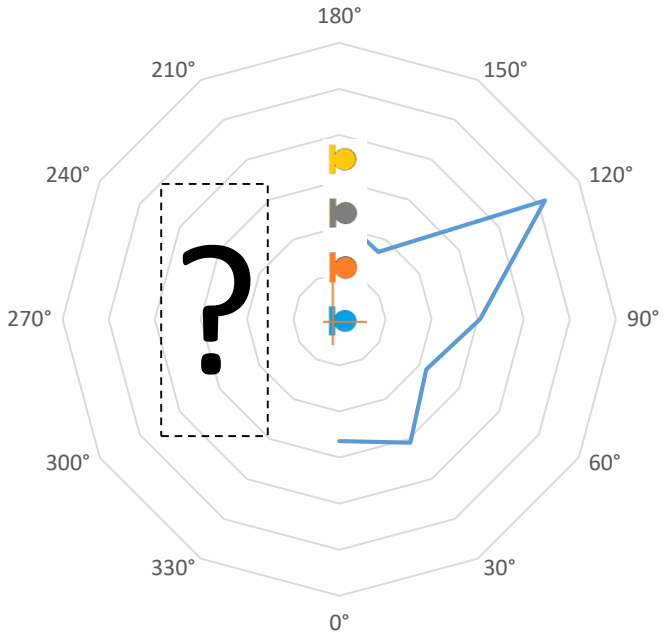
30°
60°
90°
120°
150°
180°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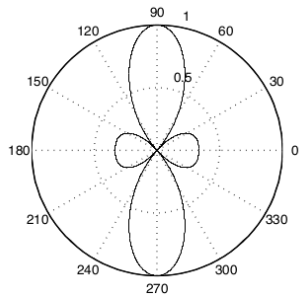
90
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150
30
180
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210
330
240
300
270

Poročilo

- Poročilo naj bo narejeno po istem pricipu kot pri prejšnjih vajah,
- V predlogi so podana vprašanja in naloge, ki jih je potrebno vključiti v poročilo,
- Za vsa morebitna vprašanja sem dosegljiv na:

jure.murovec@fs.uni-lj.si