

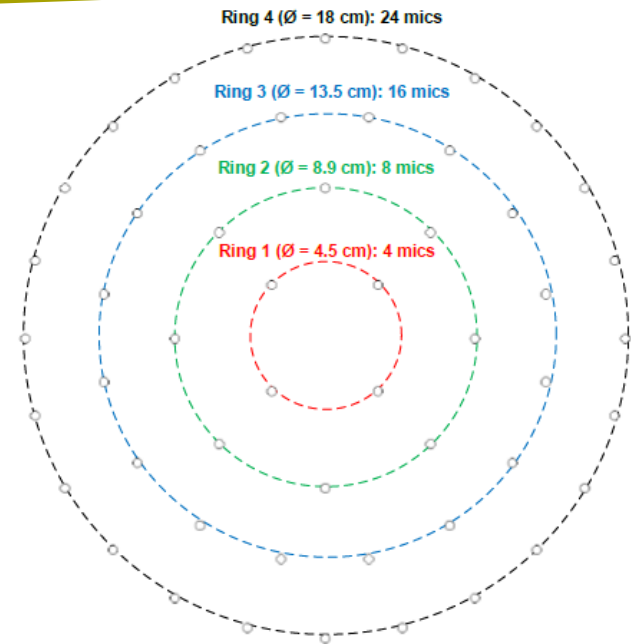
Runtime Reconfigurable Beamforming Architecture for Real-Time Sound-Source Localization

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Description and Requirements



Up to 64 Orientations

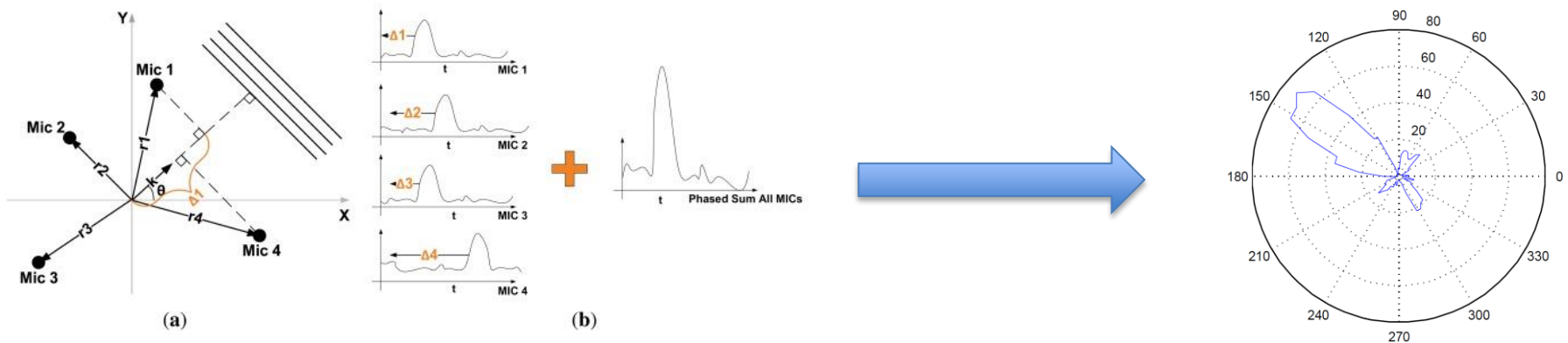


Up to 52 MEMS Microphones

- Scalable architecture able to support a variable high number of digital I/O from the external sensor array.
- Real-time (< 100ms) sound source detection.
- Power efficient.

Sound-Source location

- Use of Delay-and Sum beamforming to detect sound sources.
- The polar steered response power (P-SRP) is displayed in a polar map.
- The main peak determines the sound-source direction.



Time delay per MIC
and orientation:

$$\Delta_m(\kappa) = \frac{r_m \cdot \kappa}{c}$$

The total output of the
array based on the signal
output of each MIC:

$$O(\kappa, \omega) = \sum_{m=1}^M S_m(\omega) e^{-j\omega \Delta_m(\kappa)}$$

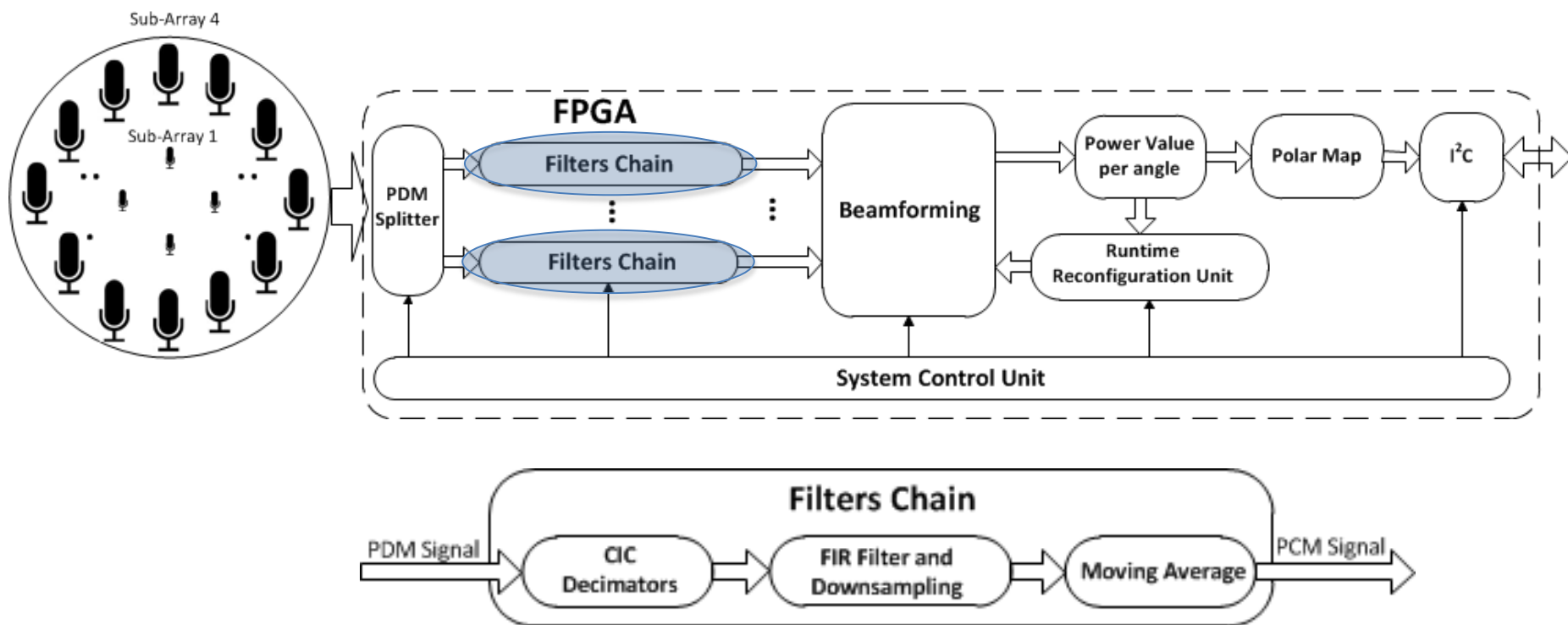
The array's power
output per orientation:

$$P(\kappa, \phi) = |O(\kappa, \phi)|^2$$

Polar steered response power:

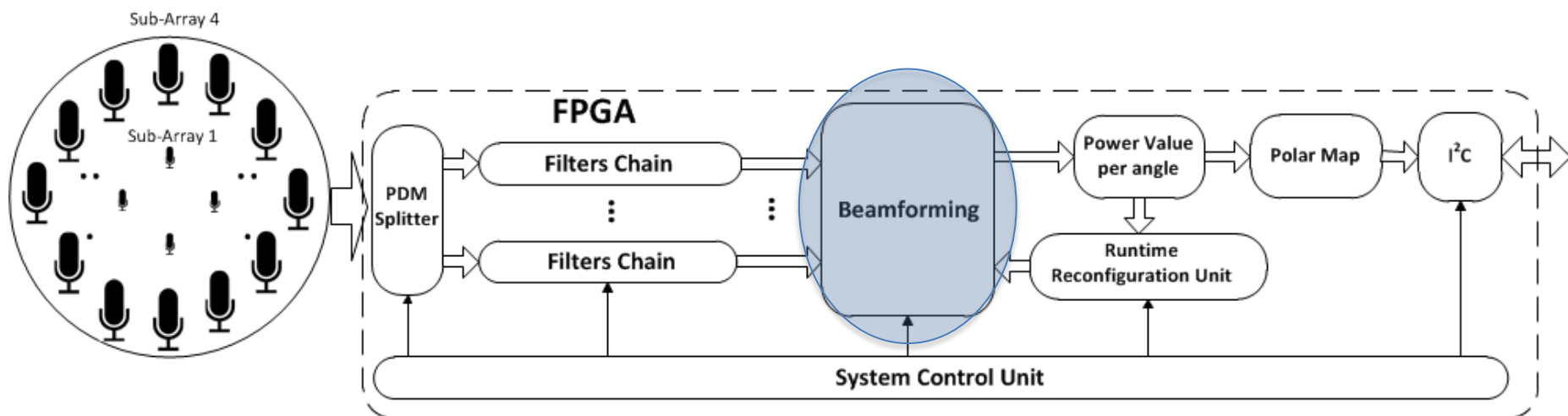
$$P\text{-SRP}(\theta, \phi) = \frac{P(\theta, \phi)}{\max_{\theta \in [0, 2\pi]} P(\theta, \phi)}$$

A Scalable Design (I)

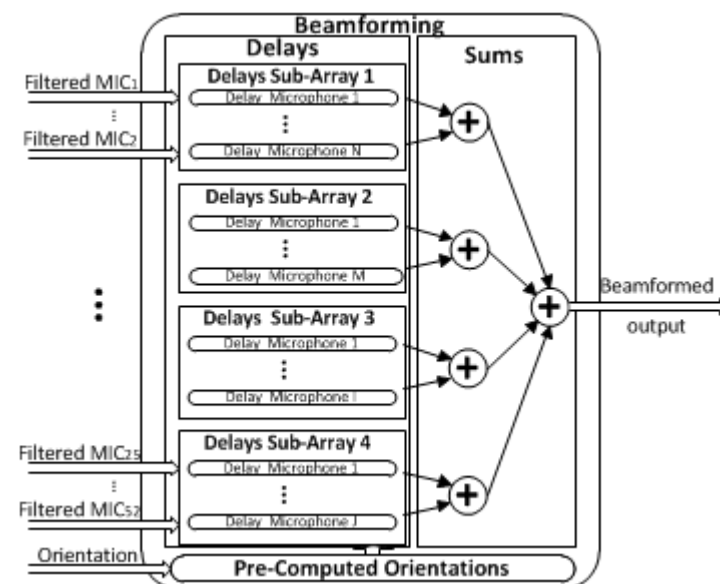


- The PDM signal from the MICs need to be individually filtered.
- The signal also needs to be downsampled to become audio.

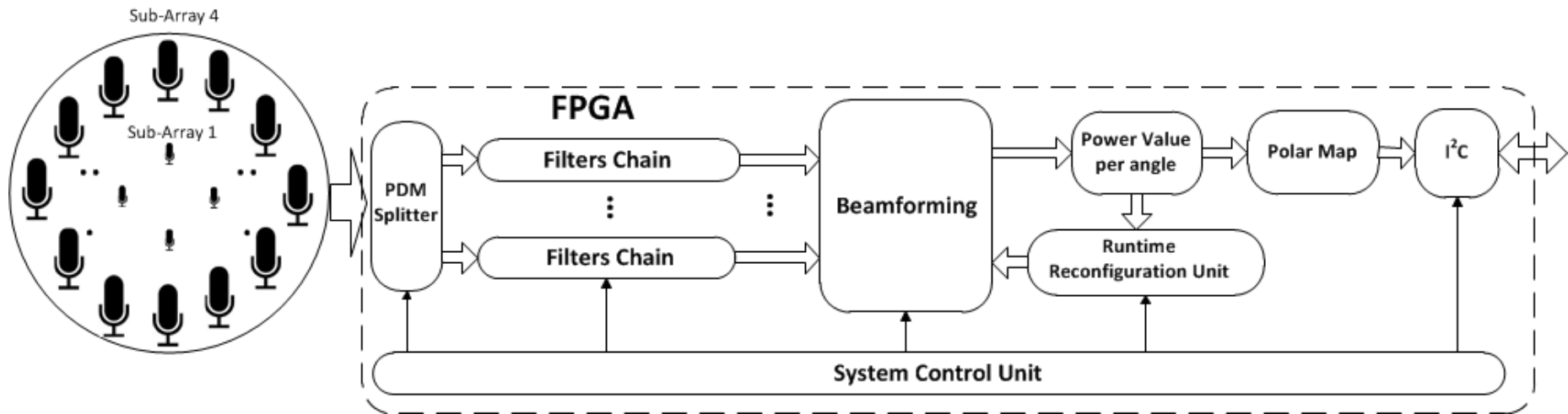
A Scalable Design (II)



- The Delay-and-Sum beamforming is decomposed in sub-arrays.
- Scalable solution which allows to deactivate sub-arrays.



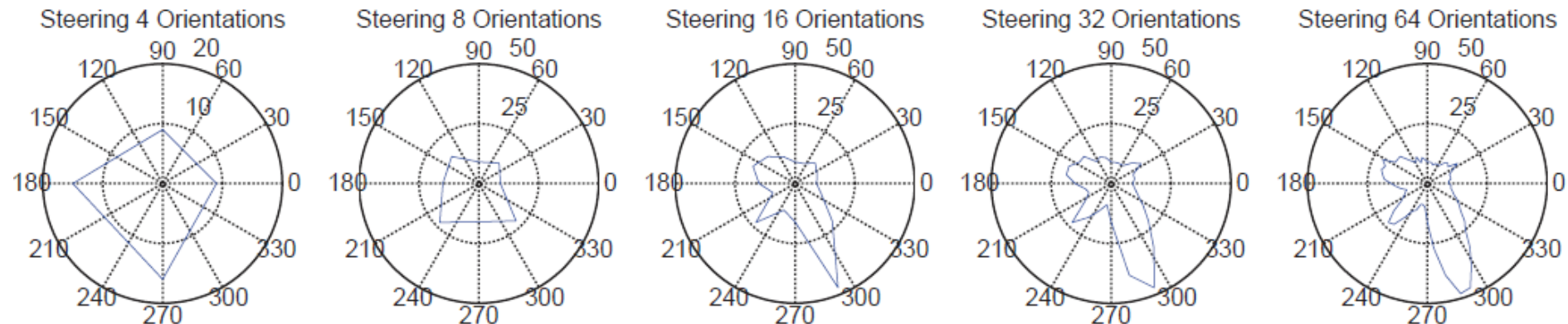
Limitations



- Static behavior: Fixed number of orientations.
- “Slow” response: 400 ms per steering loop.
- Internal memory sharing and buffering.
- BRAMs and DSPs become the limiting resources when scaling the design.

How to reach real-time?

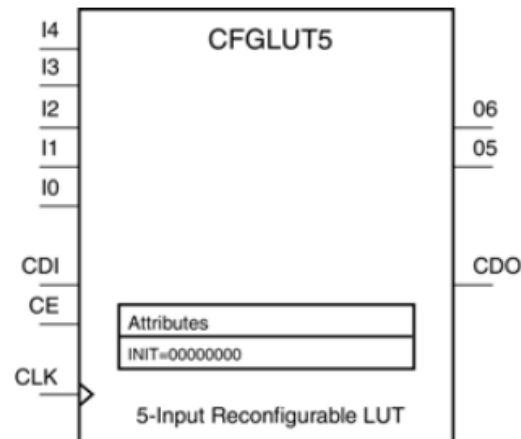
- Reduce the number of explored orientations.
- Unfortunately, it leads to inaccurate results.



- Solution: Dynamic angular resolution
 - Behavior based on the acoustic environment.
 - Real-time response (< 100 ms).

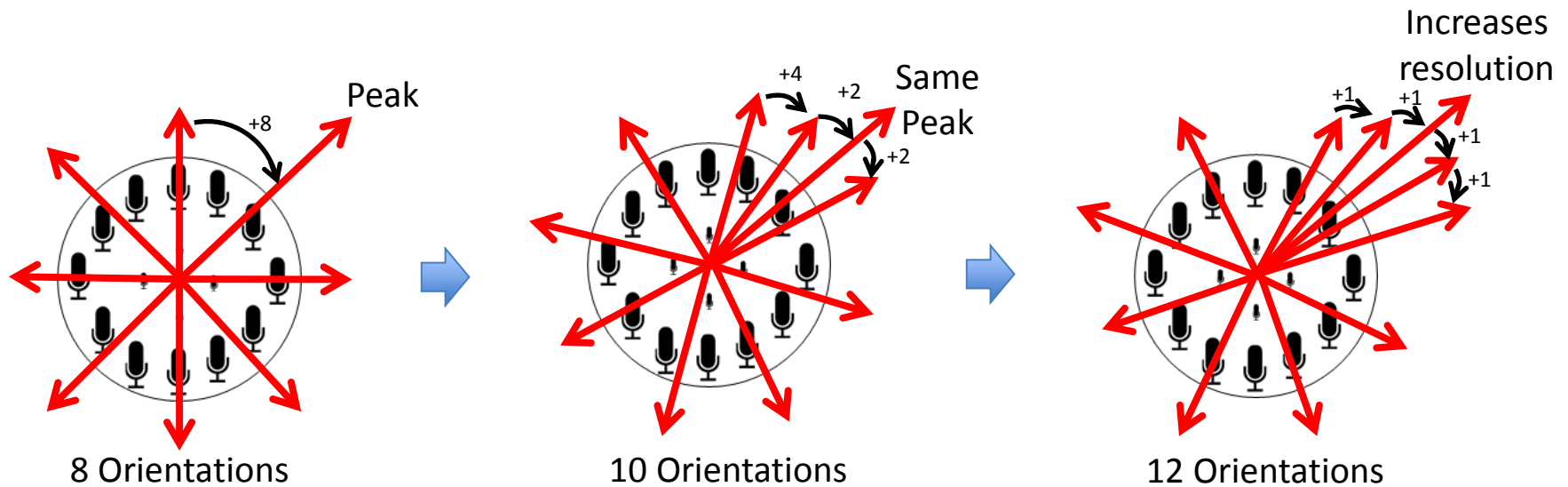
Runtime Reconfiguration (I)

- Use of a fast reconfiguration to reach real-time sound-source detection: CFGLUT5
- 5-input loop-up table (LUT).
- Enables the changing of the logical function of the LUT during circuit operation.



Runtime Reconfiguration (II)

- The use of a fast CFGLUT reconfiguration + different steering strategy leads to a real-time sound-source detection.



Results & Conclusion

Array Configurations	One Orientation	64 Orientations	Average Shift Strategy	Average Reconfigurable Shift Strategy
Sub-array 1 Standalone	6.165	394.560	104.805	73.980
Sub-arrays 1 & 2	6.294	402.753	106.998	75.528
Sub-arrays 1 & 2 & 3	6.421	410.945	109.157	77.052
All Sub-arrays	6.550	419.144	111.350	78.600

- A scalable design allows us to disable not only microphones but also the associated logic.
- The runtime reconfiguration allows to keep accuracy while reaching real-time.
- Only CFLUTs provide runtime reconfiguration in few clock cycles.