

A High-Performance and Ultra Low-Power Processor  
Architecture for Binaural Hearing Aid Systems.

Low-Power Optimization of a VLIW-SIMD  
ASIP for Hearing Aid Devices

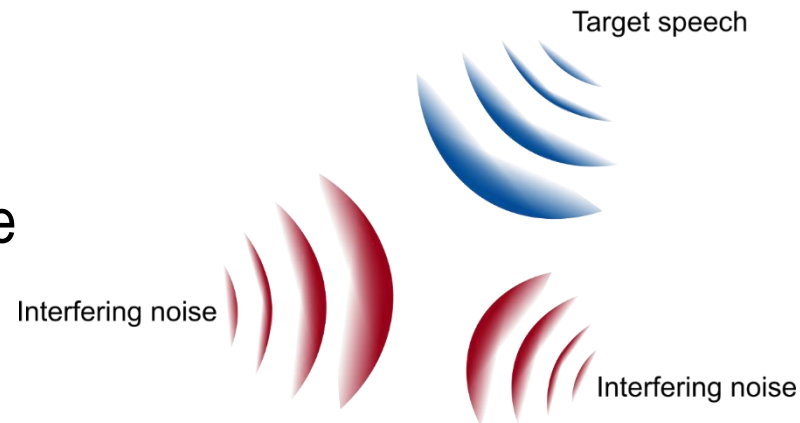
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Institute of Microelectronic Systems

Tensilica Day 2017

- Hearing loss affects about **17%** of the adult human population [1]
- Hearing impaired persons often suffer **from a loss of temporal and spectral perception**
- **Decreased speech intelligibility** in noisy environments
- **Digital hearing aids** support the hearing aid user in many situations

- Objective

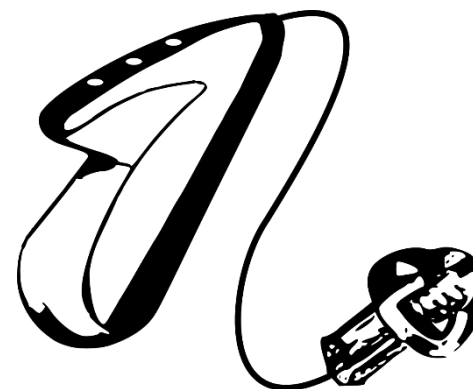
- Increase **signal-to-noise** ratio (SNR)
- Increase **speech intelligibility** in noise
- Increase **benefit** of the hearing aid



[1] National Institutes of Health, Hearing Aids, 2010

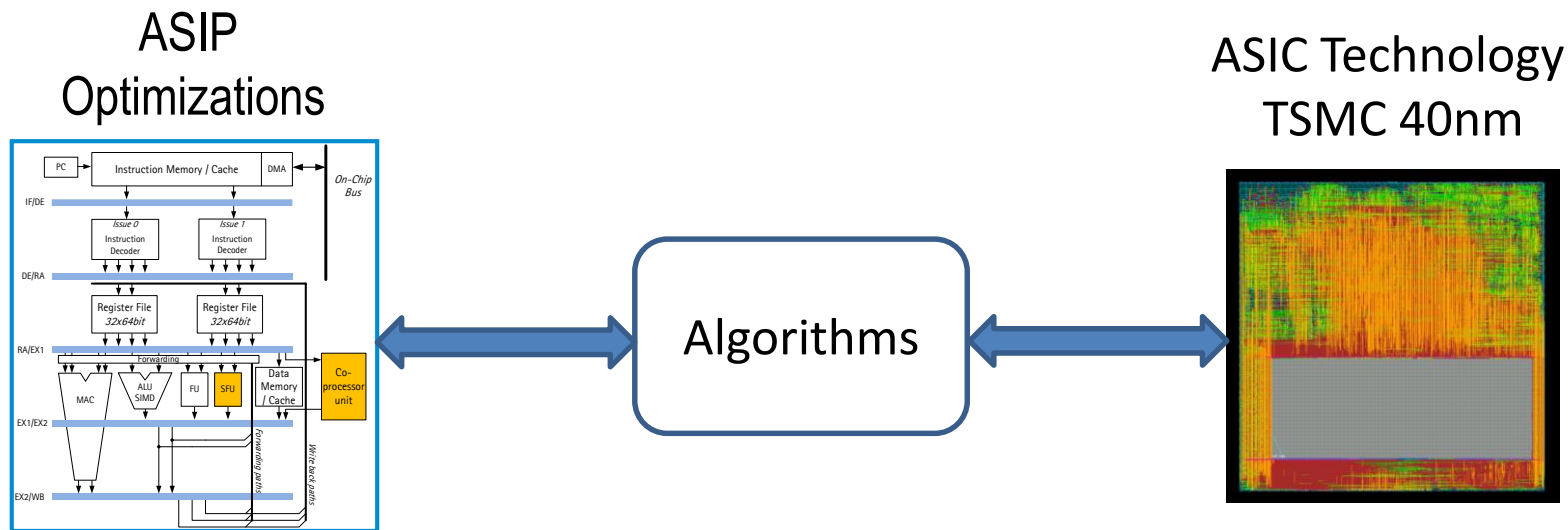
- Hearing aid **requirements**:

- Small and light
- Long battery life
- Availability of many algorithms
- High adaptivity and flexibility
- Many microphones
- Small latency
- High audio quality
- ...

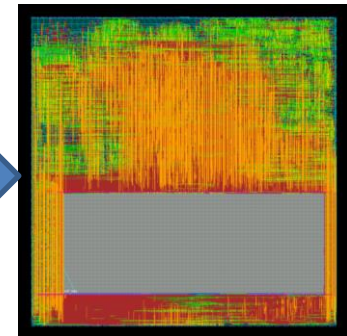


- In reality there is a **trade-off** between these requirements

## Power Evaluation of Hearing Aid ASIP Optimizations based on the Performance of Algorithms



ASIC Technology  
TSMC 40nm



Algorithms

### Application-Specific Evaluation of

- Processing Performance
- Algorithm Benefit
- Power
- Area

- **Algorithms:** 3 Beamformer Algorithms

- Fixed Beamformer
- Adaptive Filter Beamformer
- Adaptive Gain Beamformer

- **Hardware:** 24 optimized ASIP configurations

- 24-bit up to 64-bit data path width
- With and without a hardware Co-Processors
- Register file isolation and dummy registers

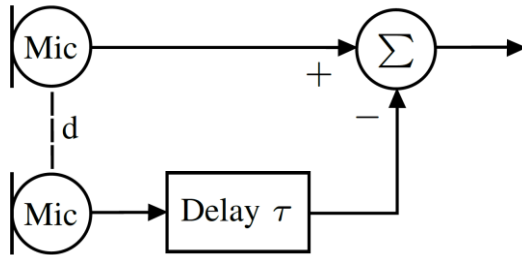
- **Evaluation**

- STOI
- iSNR
- PESQ

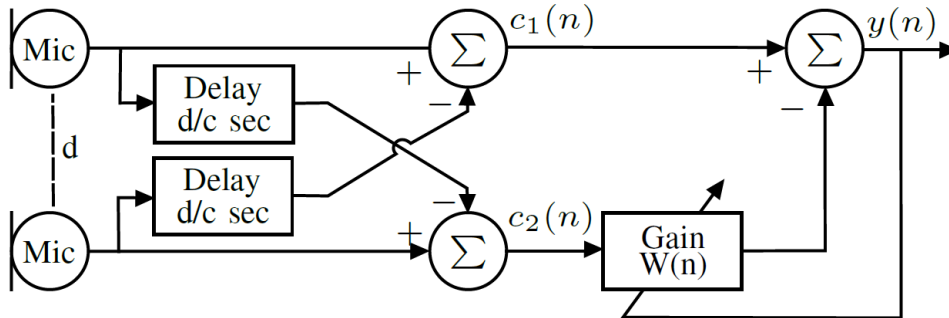


- Power
- Area
- Performance

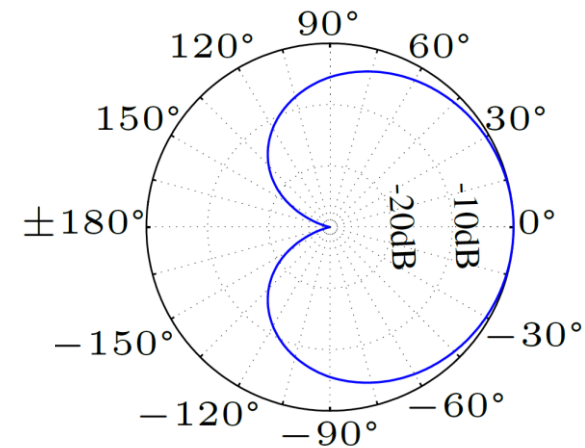
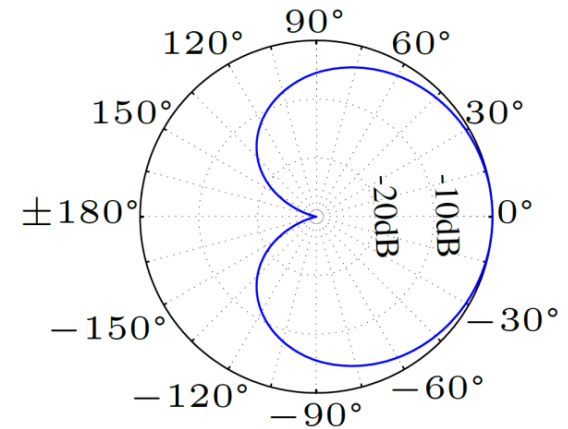
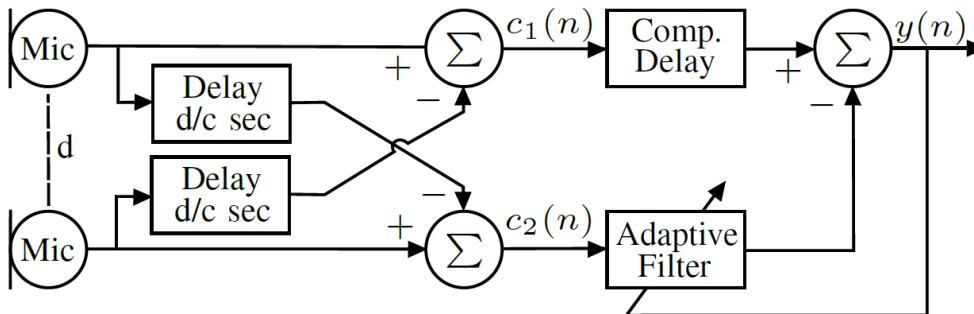
Fixed Beamformer



Adaptive Gain Beamformer

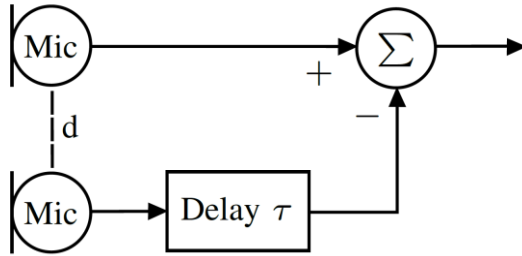


Adaptive Filter Beamformer

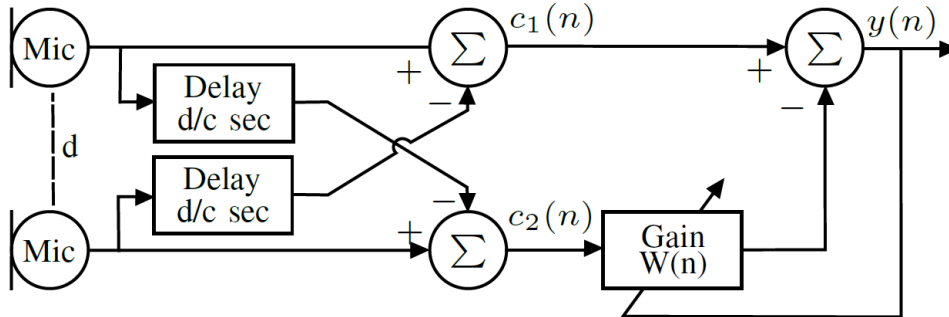


Output Polar Pattern

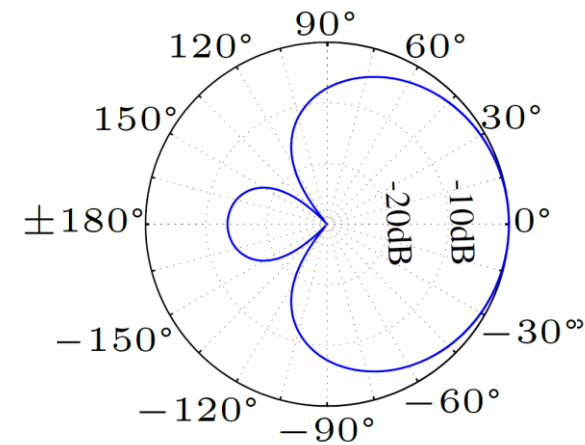
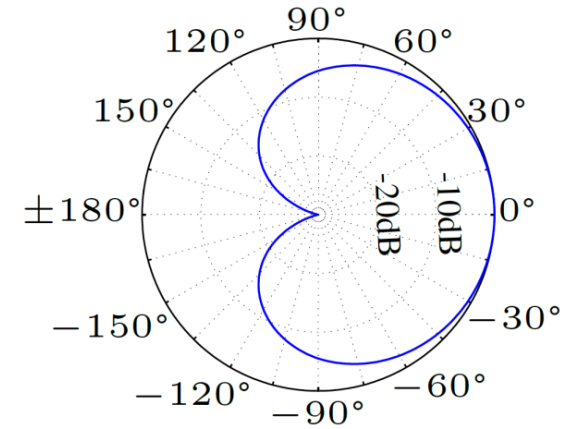
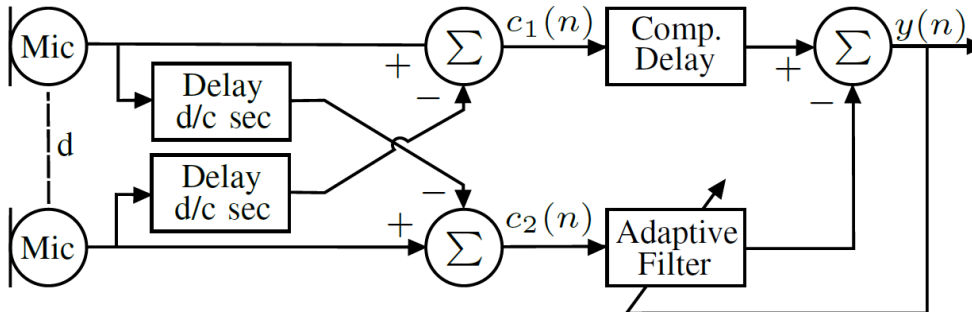
Fixed Beamformer



Adaptive Gain Beamformer

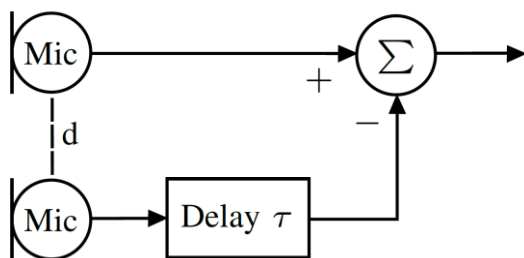


Adaptive Filter Beamformer

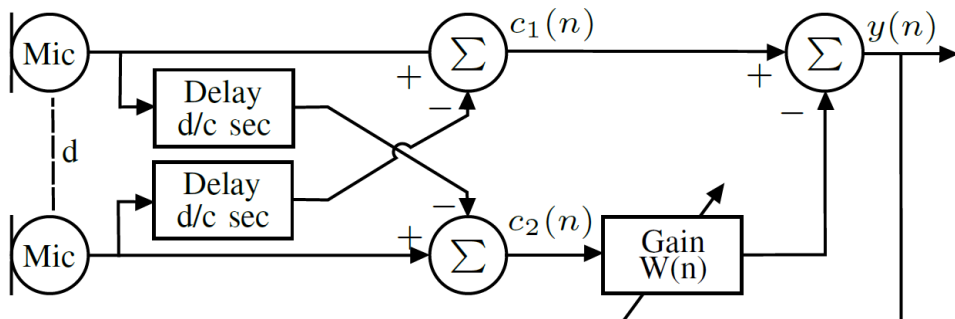


Output Polar Pattern

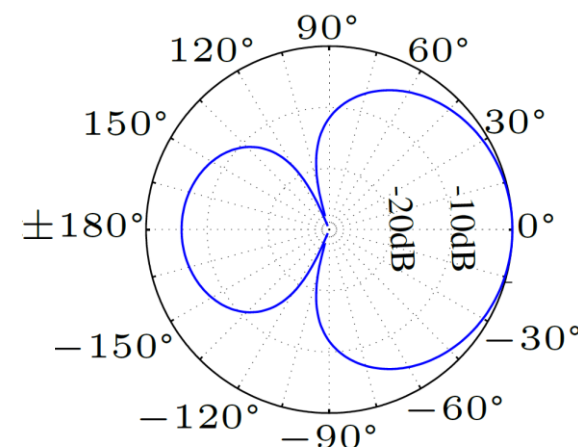
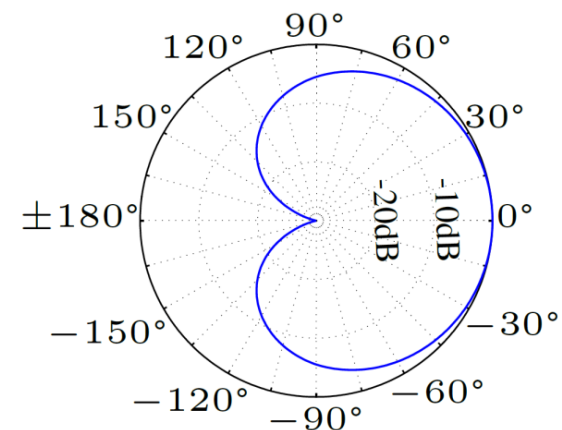
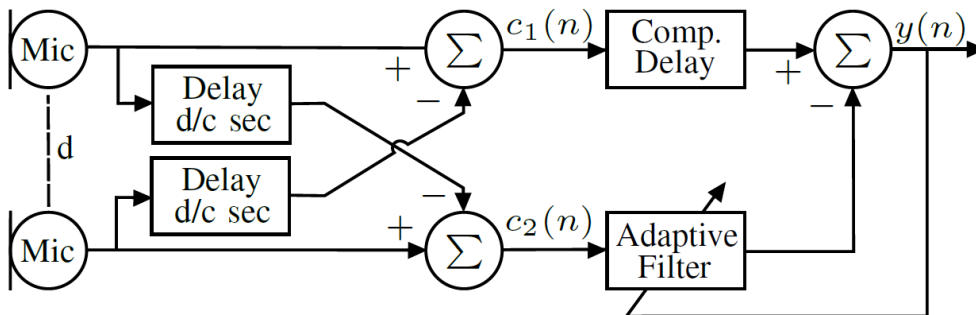
Fixed Beamformer



Adaptive Gain Beamformer



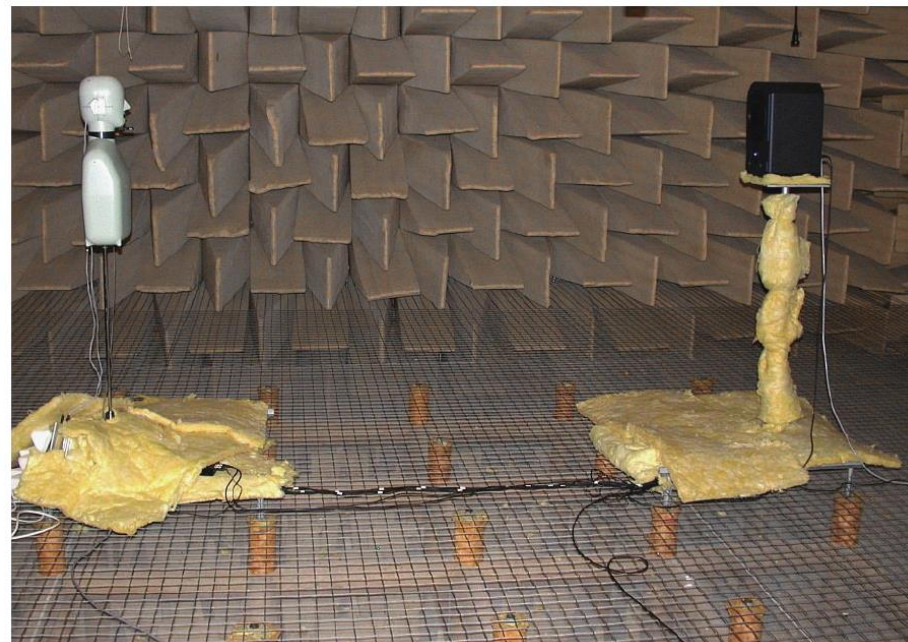
Adaptive Filter Beamformer



Output Polar Pattern



- Requirements:  
Realistic construction of  
simulated sound fields
- Experimental setup:  
HRIR database [1]



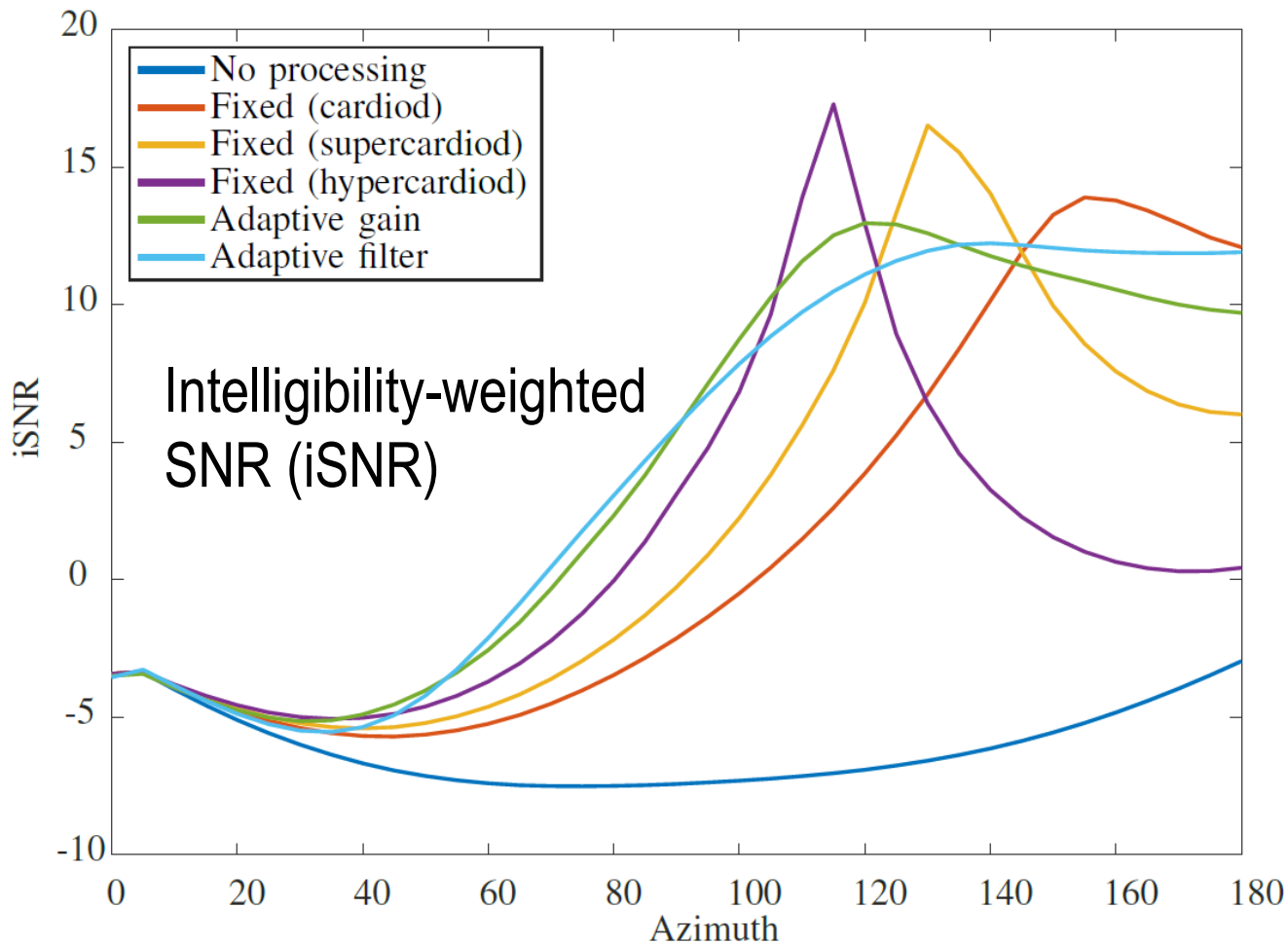
[1] Kayser, H. et al., 2009

Environment: Anechoic chamber

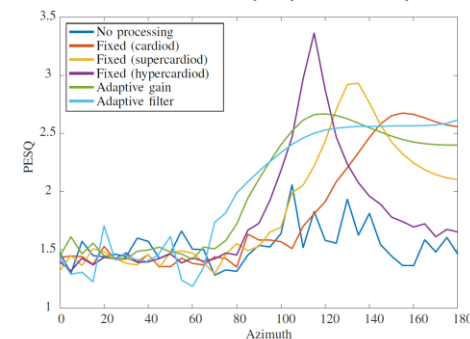
Target source: male speaker

Interfering source: moving babble noise

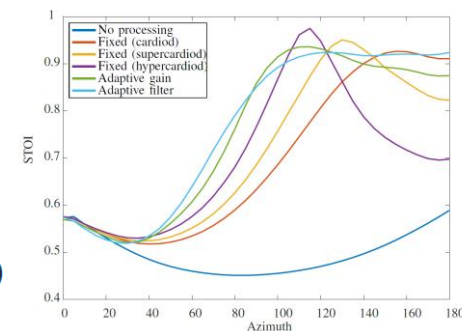
[1] Kayser, H. et al., 2009. Database of multichannel in-ear and behind-the-ear head-related and binaural room impulse responses. EURASIP Journal on Advances in Signal Processing, 2009, p.6.



Perceptual evaluation of speech quality (PESQ)

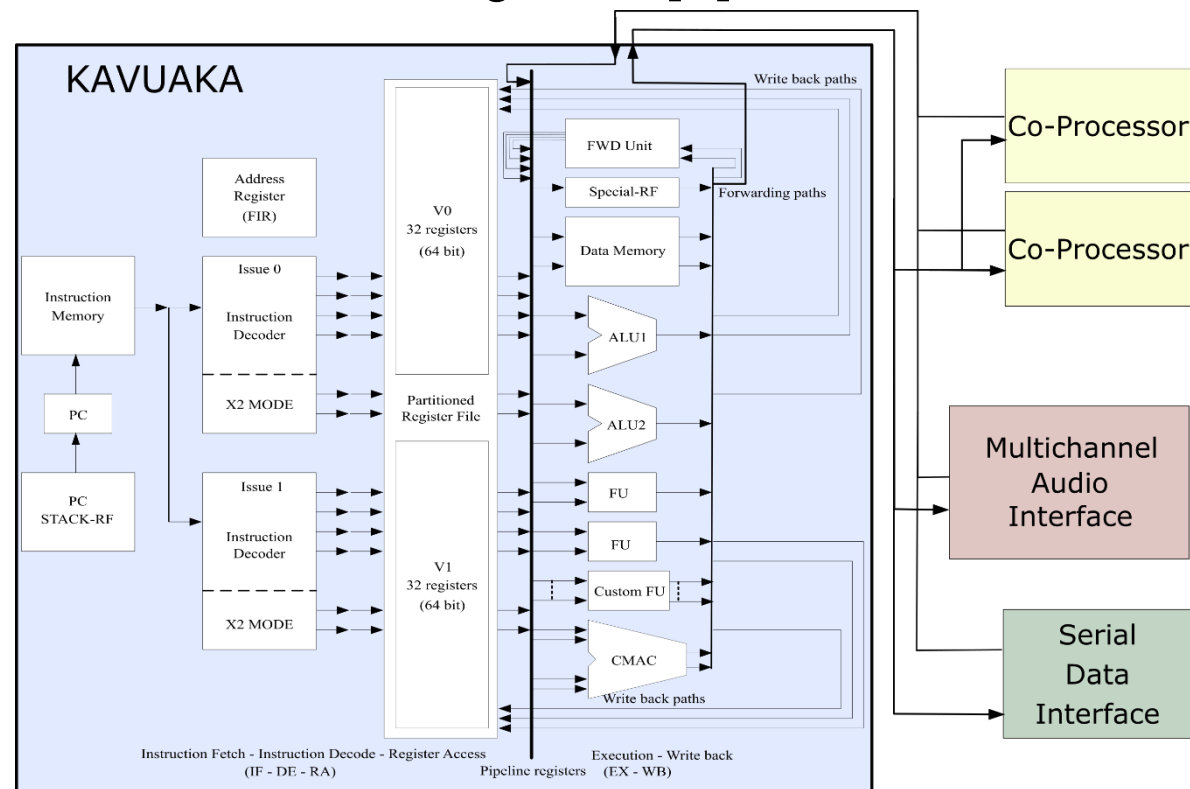


Short-time objective intelligibility (STOI)



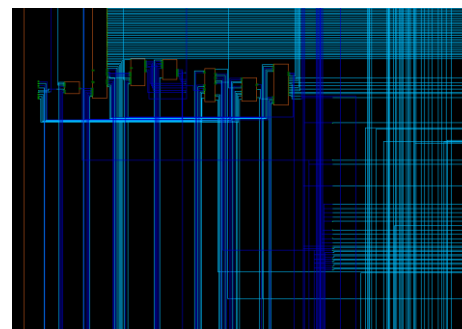
## ■ KAVUAKA VLIW-SIMD ASIP for Hearing Aids [1]

- 2 pipeline stages
- 2 issue slots
- SIMD
- Partitioned register file
- Co-processors
- Multichannel audio interface

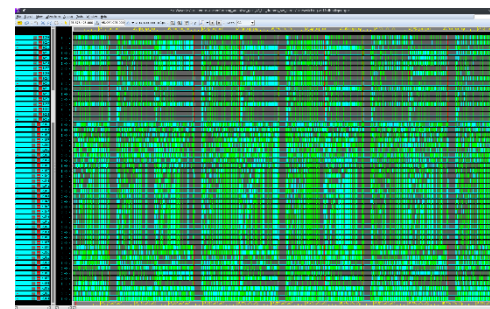


[1] Hartig, J.; Gerlach, L.; Payá-Vayá, G.; Blume, H. (2014): Customizing a VLIW-SIMD Application-Specific Instruction-Set Processor for Hearing Aid Devices, IEEE International Workshop on Signal Processing Systems 2014 (SiPS)

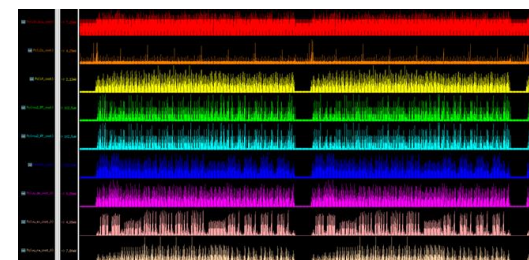
- Evaluation setup:
  - TSMC 40nm Synthesis
  - Netlist simulations of ASIP and co-processors executing the beamformer algorithms
  - Switching activity stored for 700 audio samples, after memories are filled with realistic data
  - Prime Time Signoff Power dynamic power analysis



ASIP  
synthesis

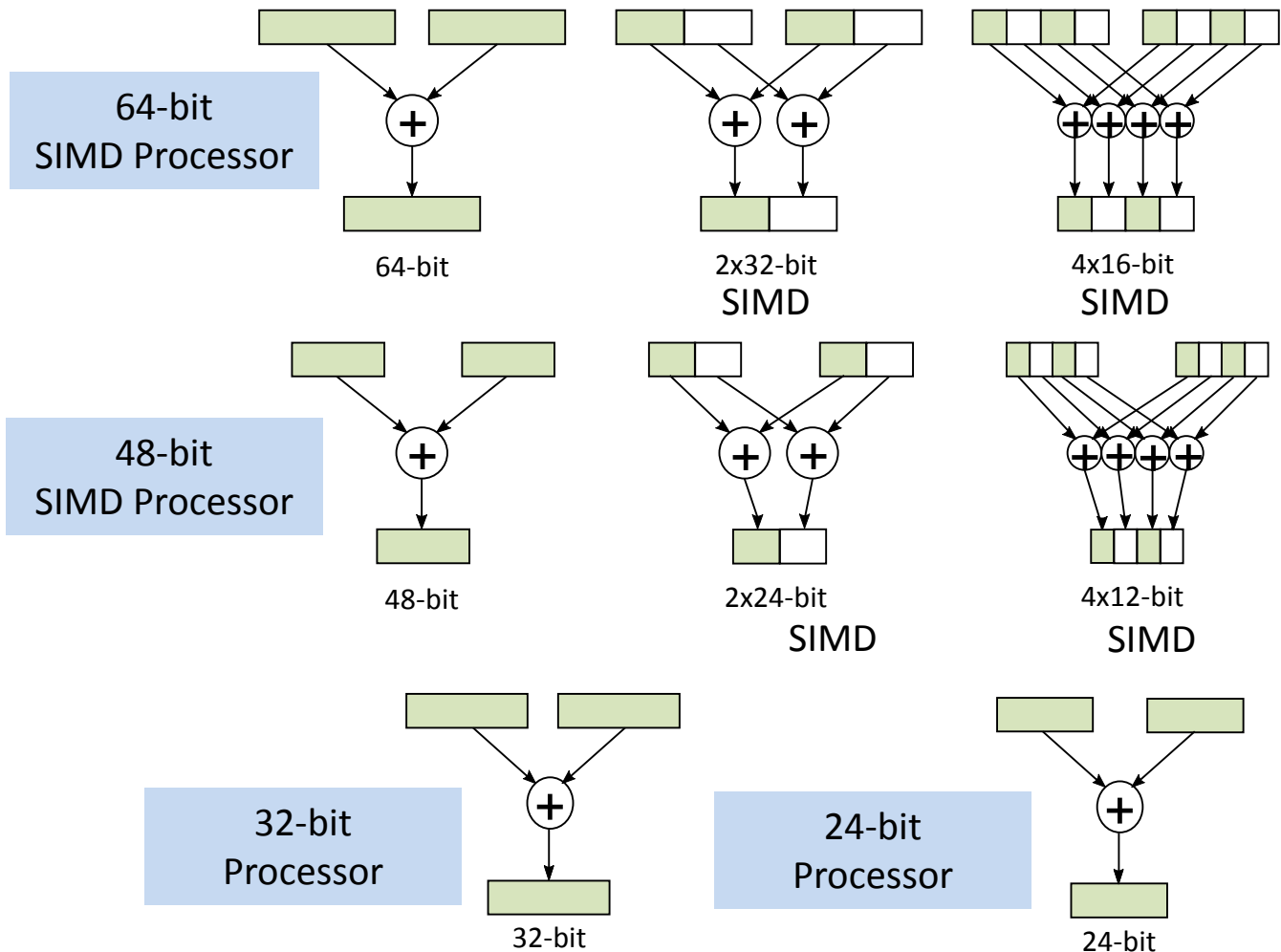


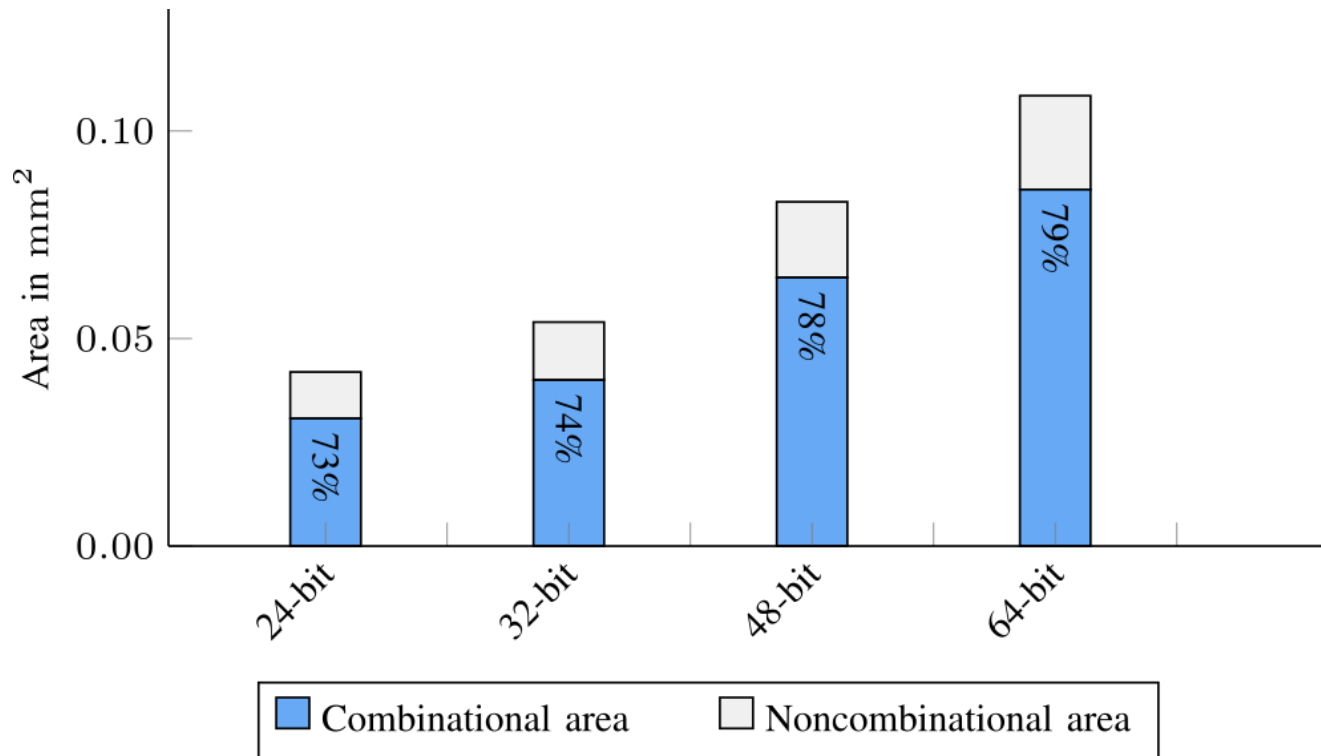
Netlist  
simulations

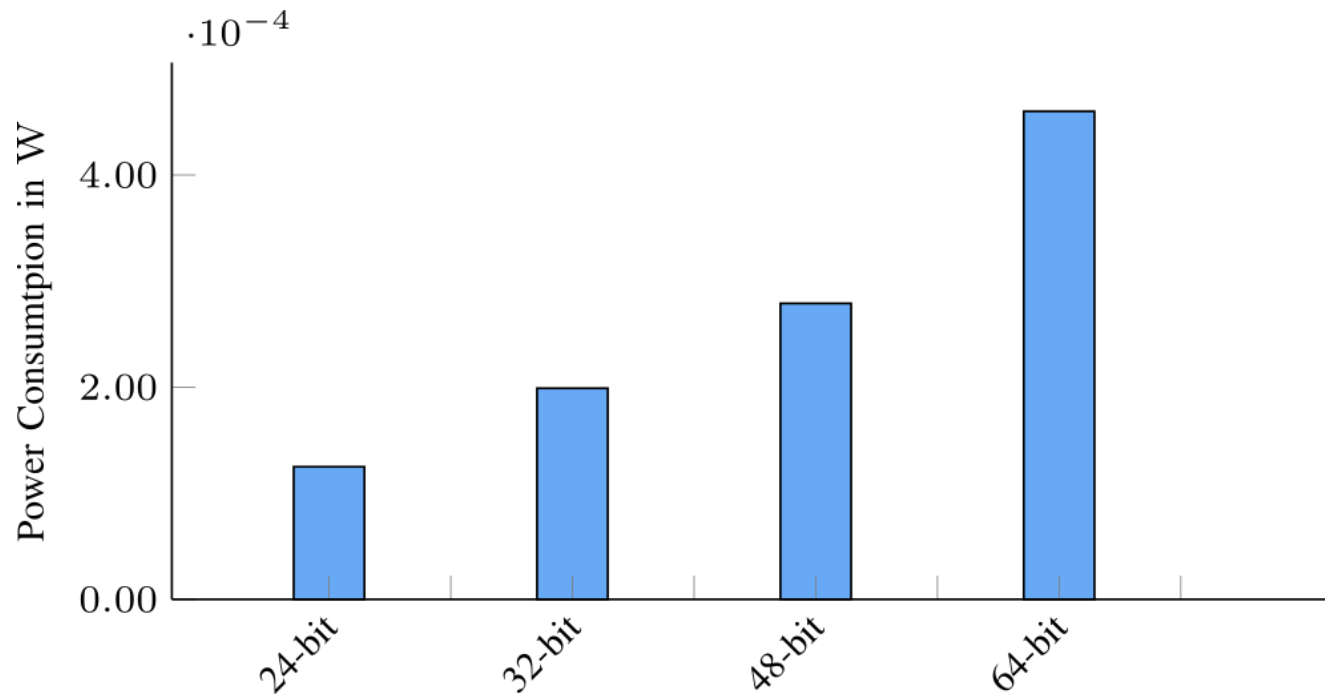


Power  
Analysis

- **Modification of word width**
- Register File
- Function units
- Data bus
- Co-Processors
  
- **SIMD activated /deactivated**





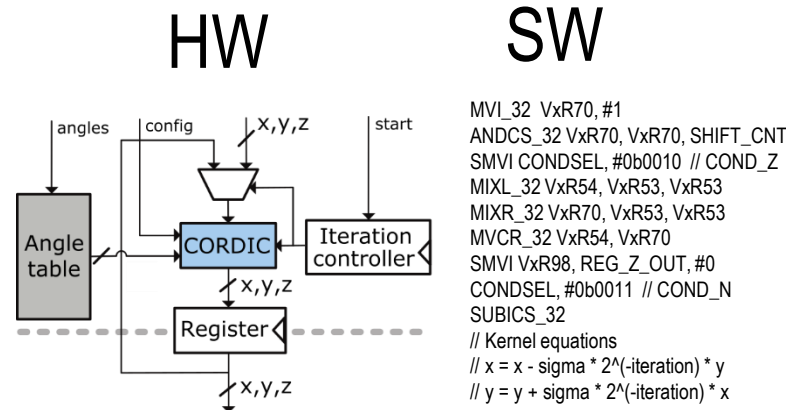


- Adaptive Gain Beamformer requires **division** operation:

- Normalised** least mean squares adaptation

$$W(n) = \frac{\hat{R}_{c_1 c_2}(n)}{\hat{R}_{c_2 c_2}(n)}$$

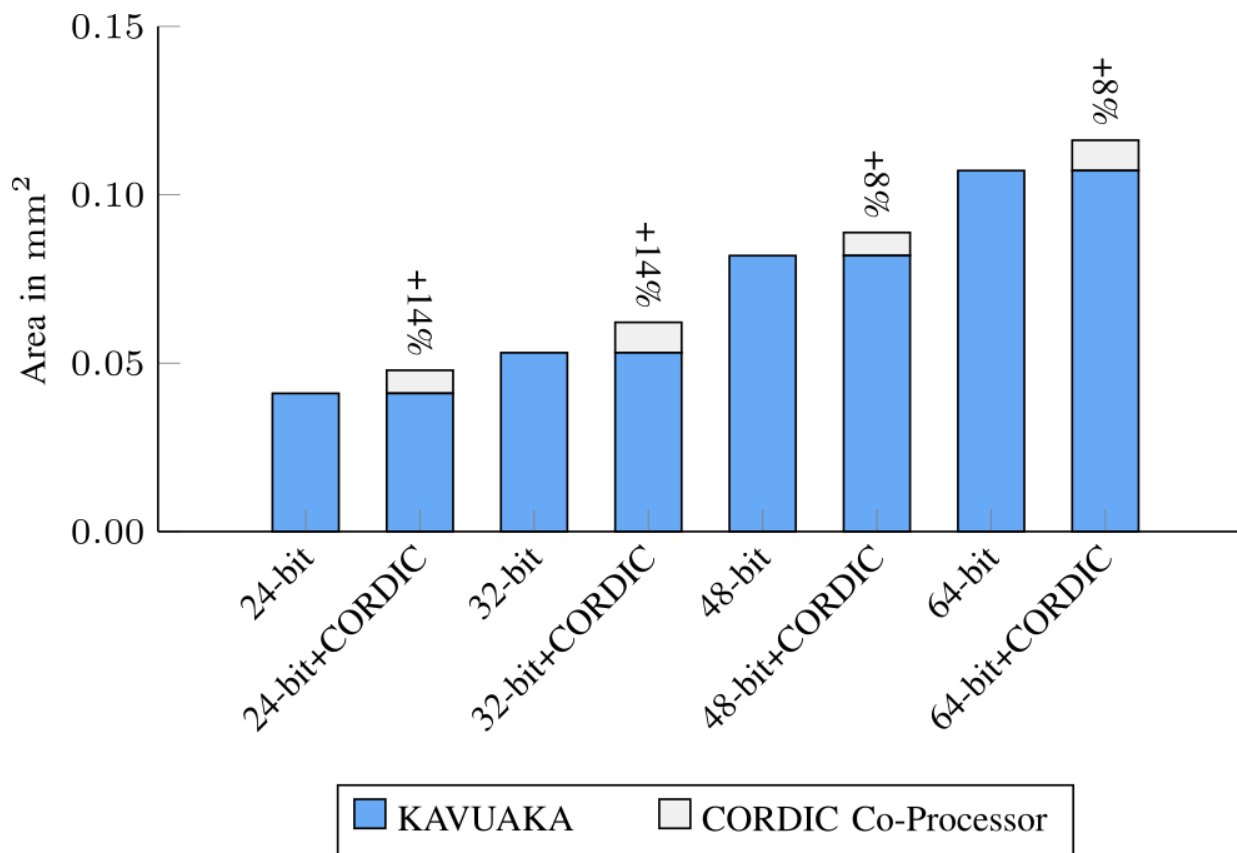
- Implementation:  
CORDIC algorithm

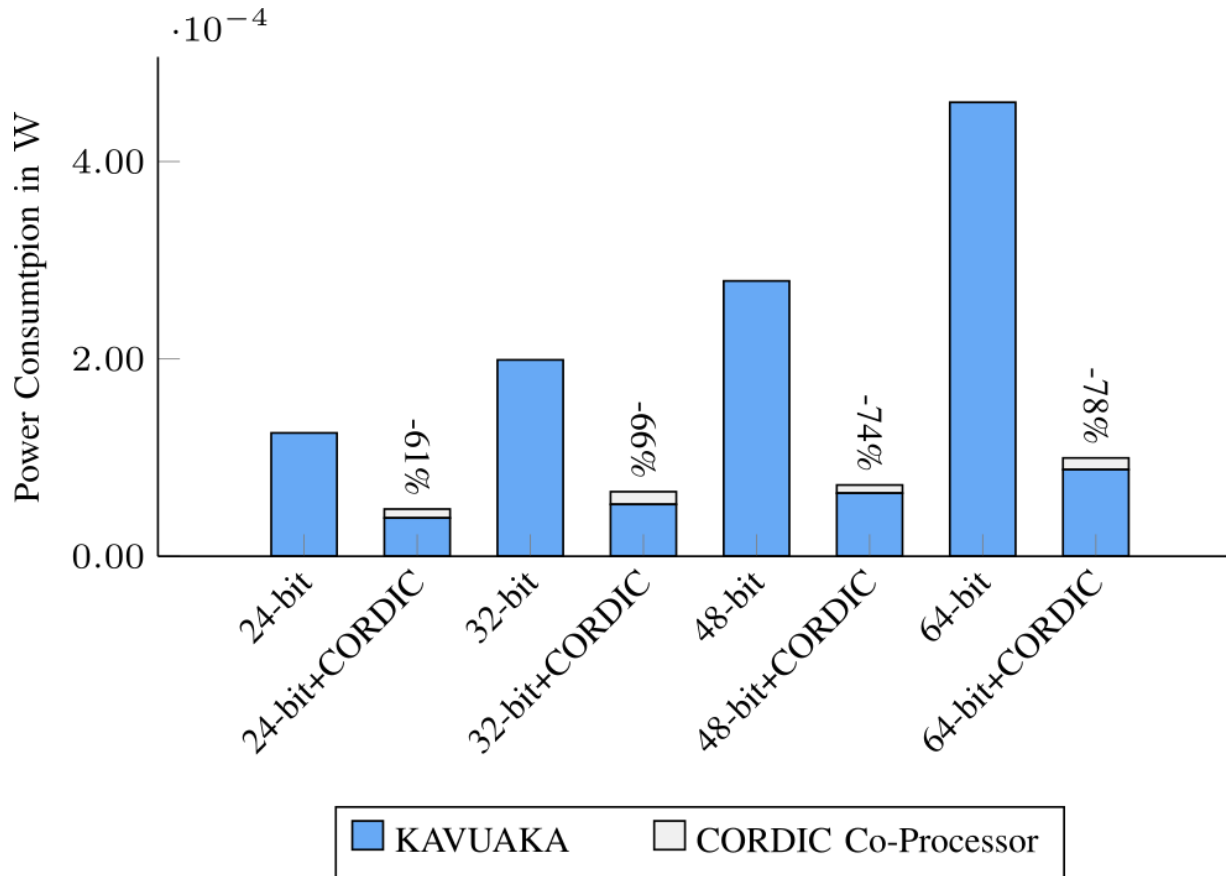


- Performance for 32-bit Fixed Point Division

Processing Cycles	HW-Co-Processor	SW-Library
cycles	113	489
	← 4.3x ←	

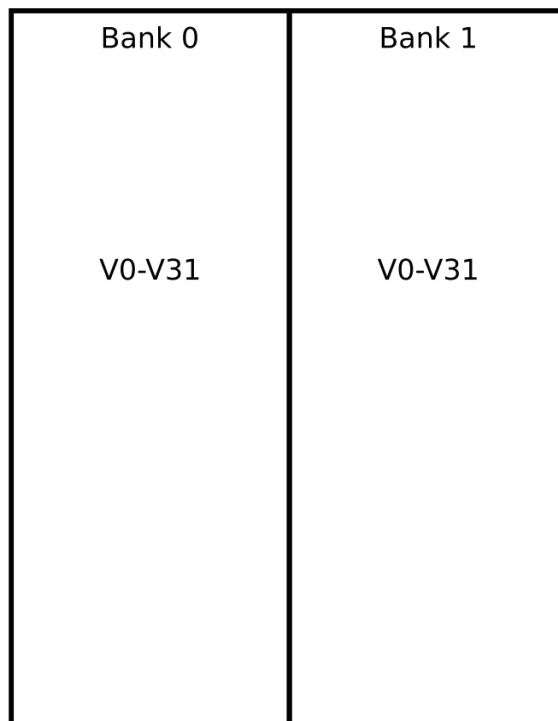


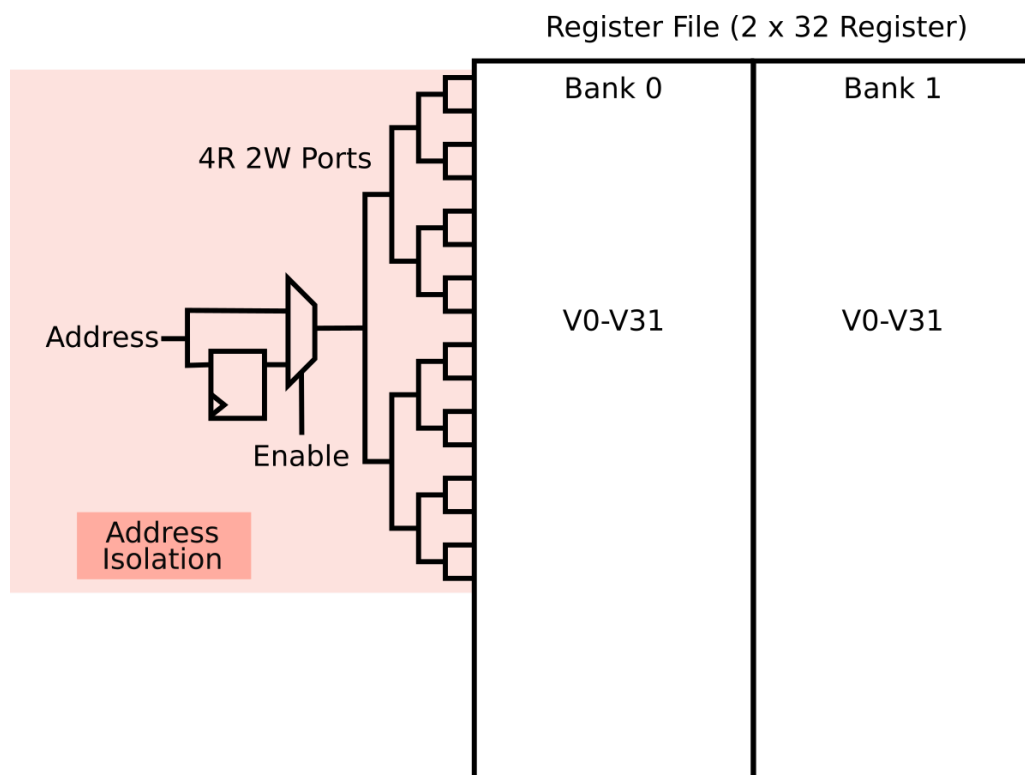


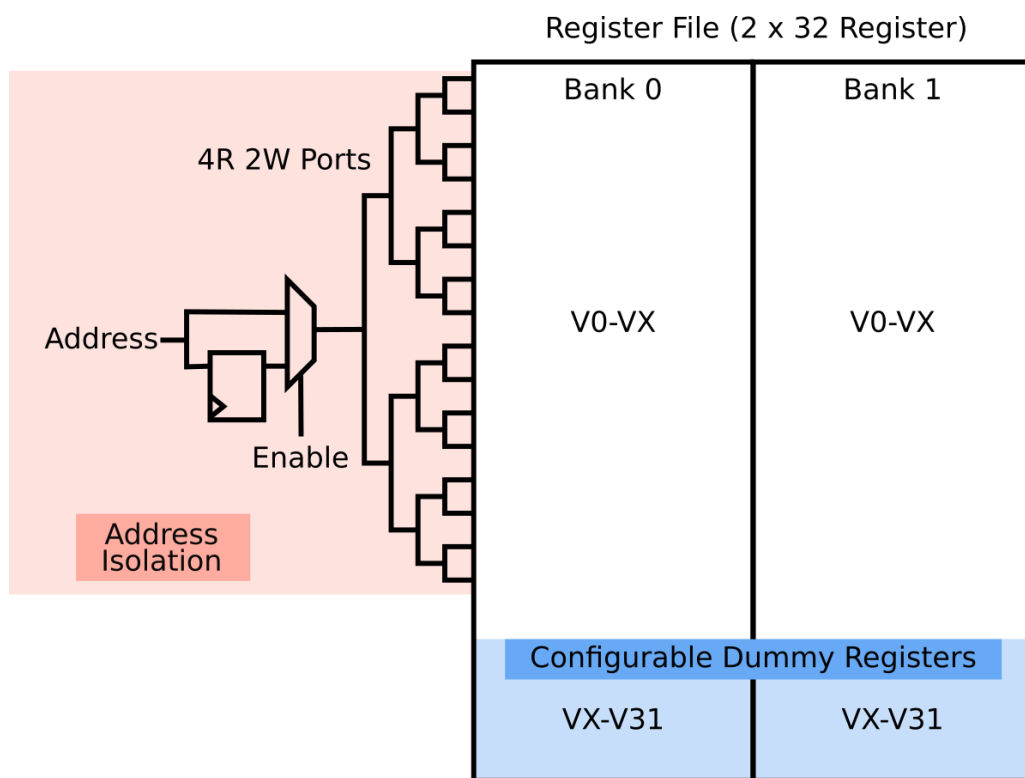


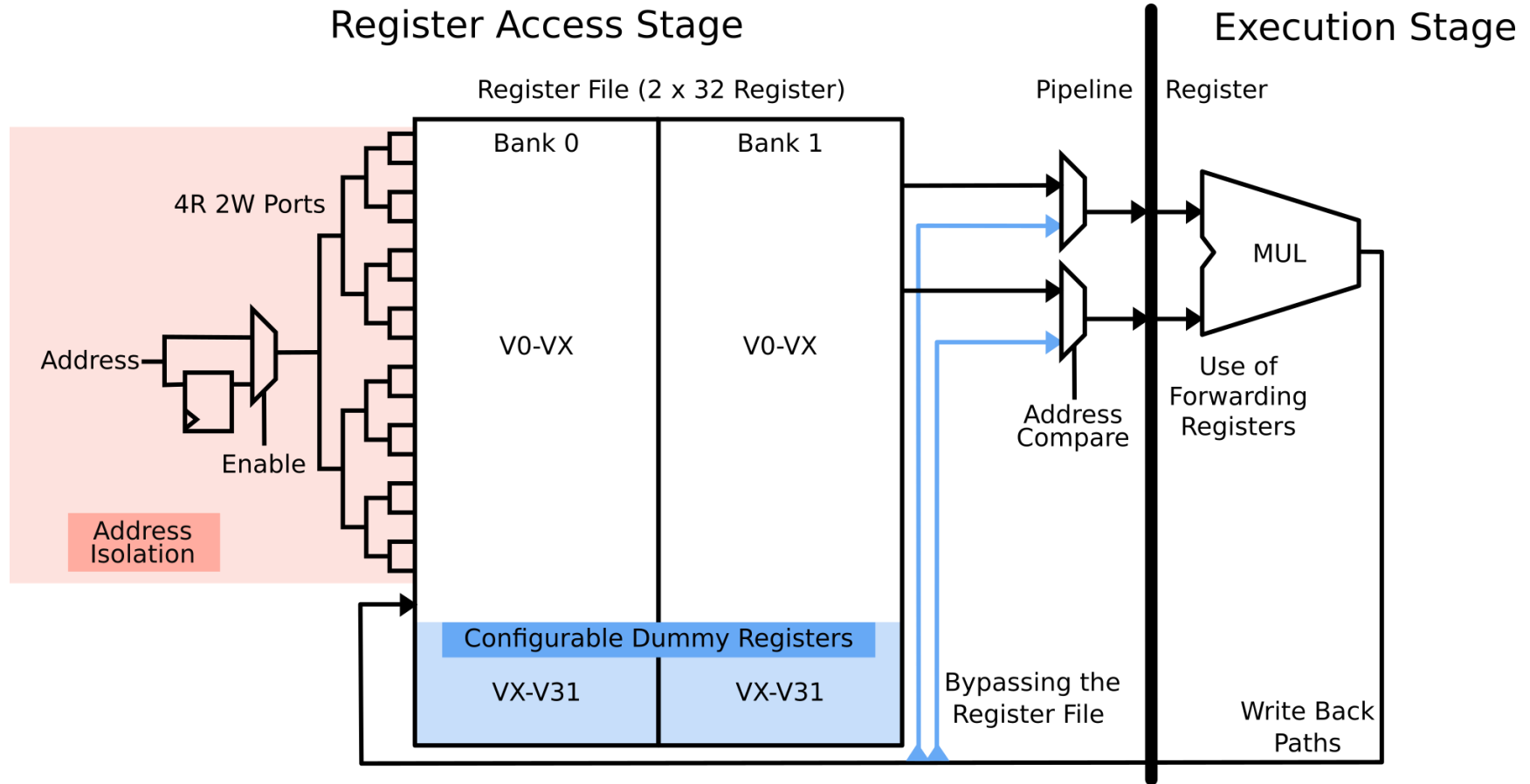
## Adaptive Gain Beamformer

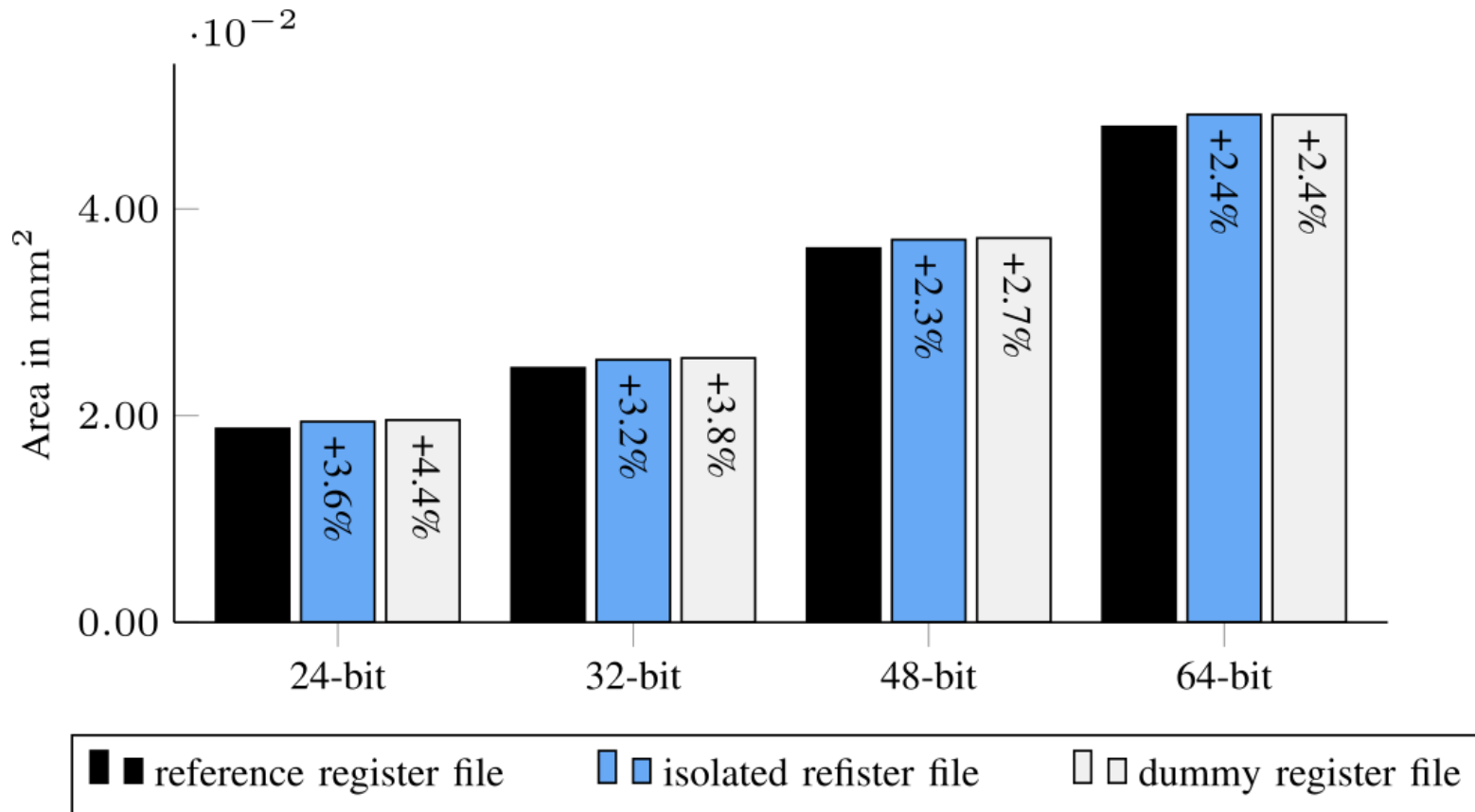
Register File (2 x 32 Register)

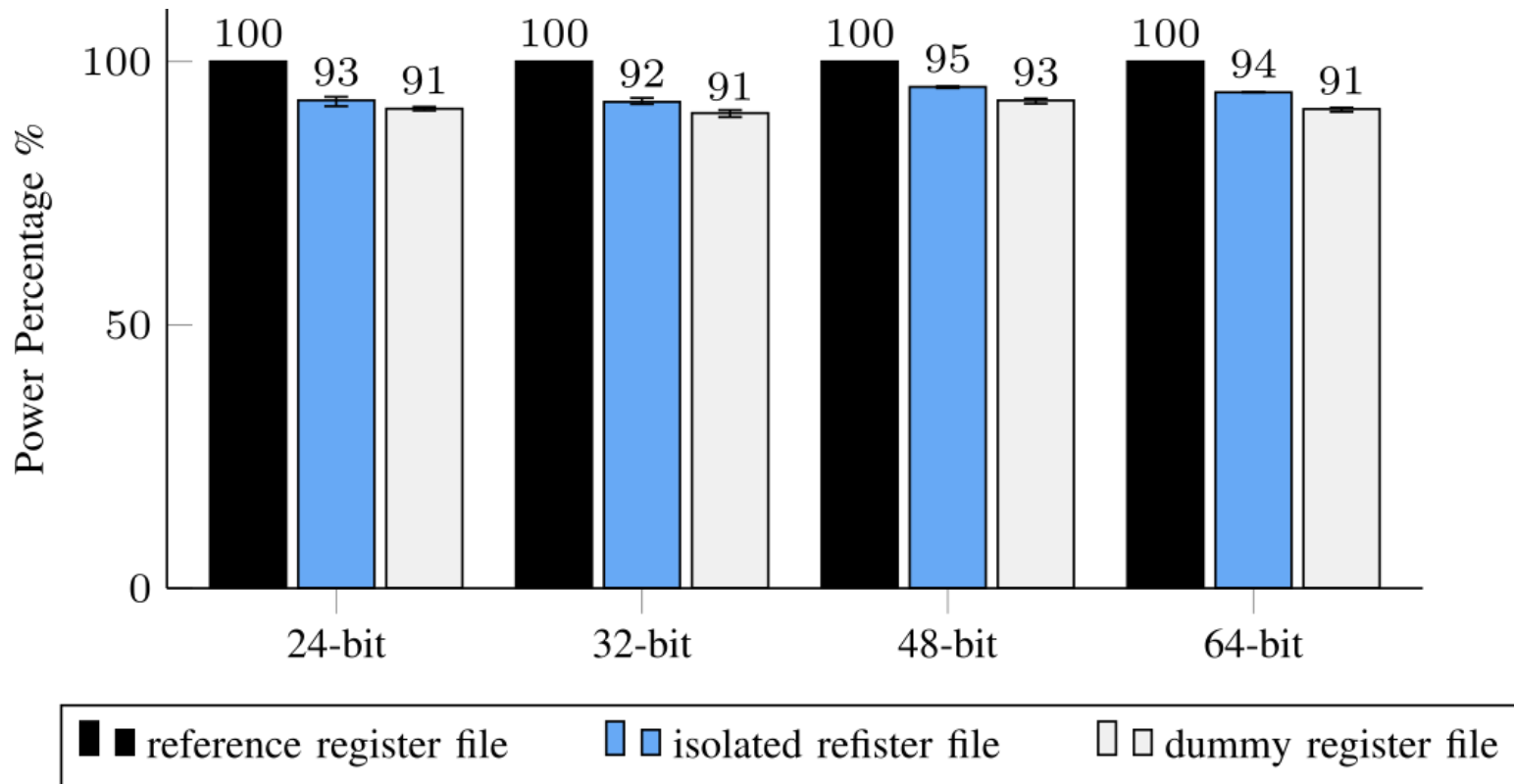




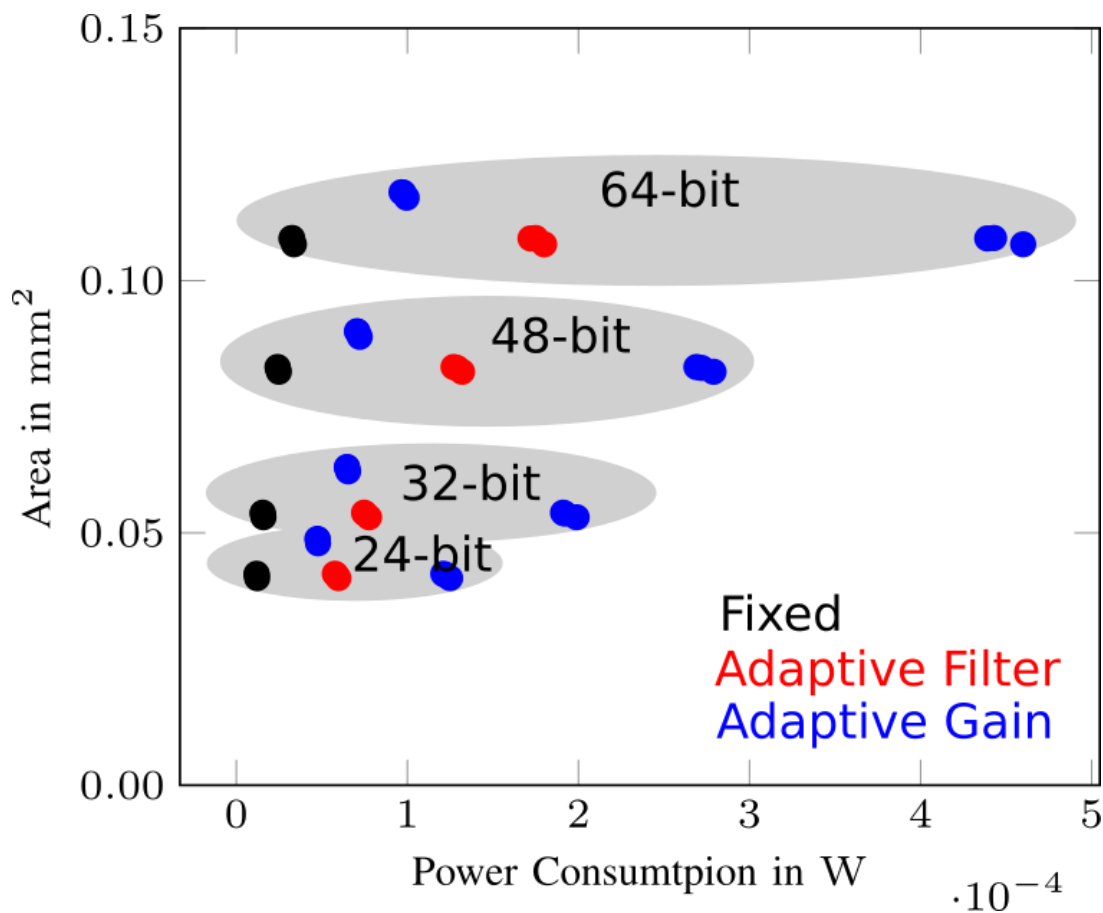


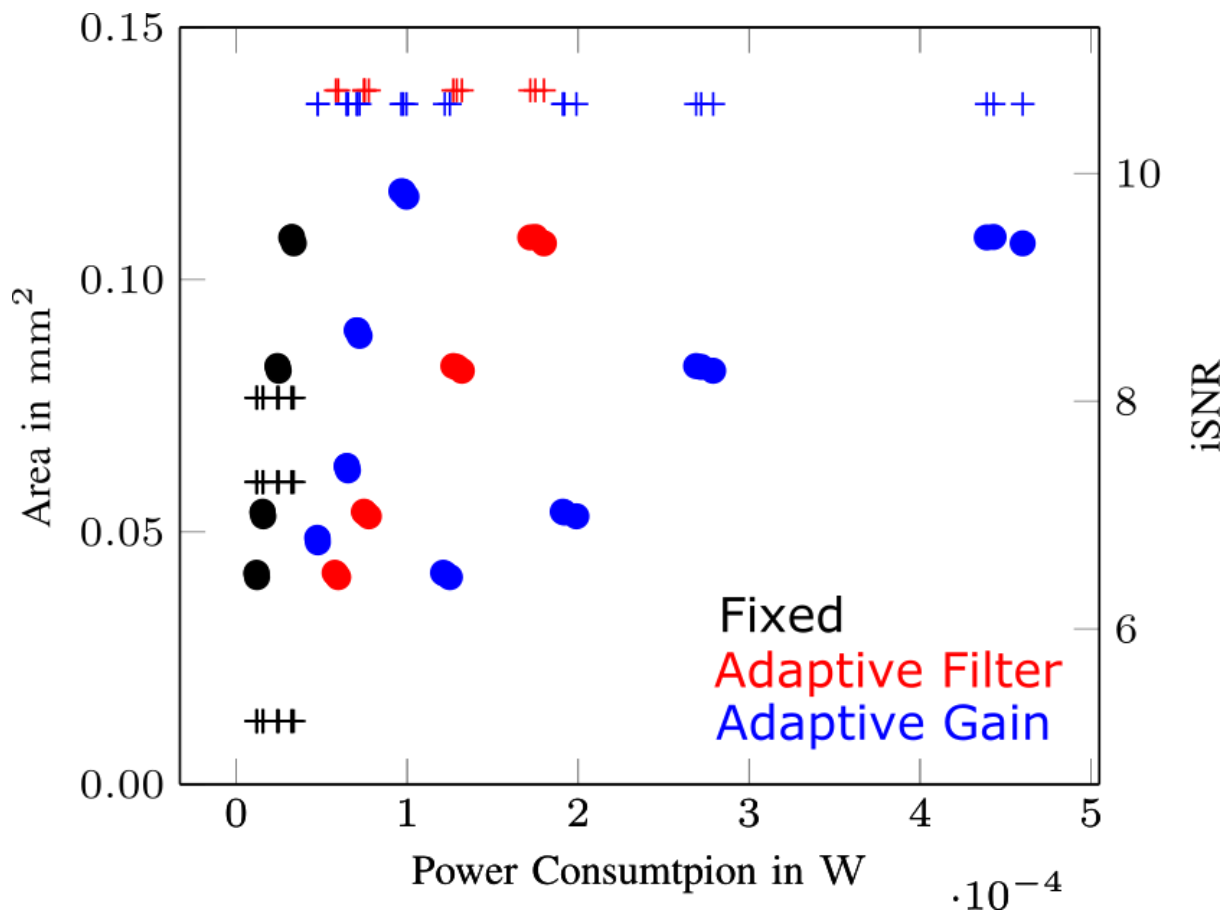


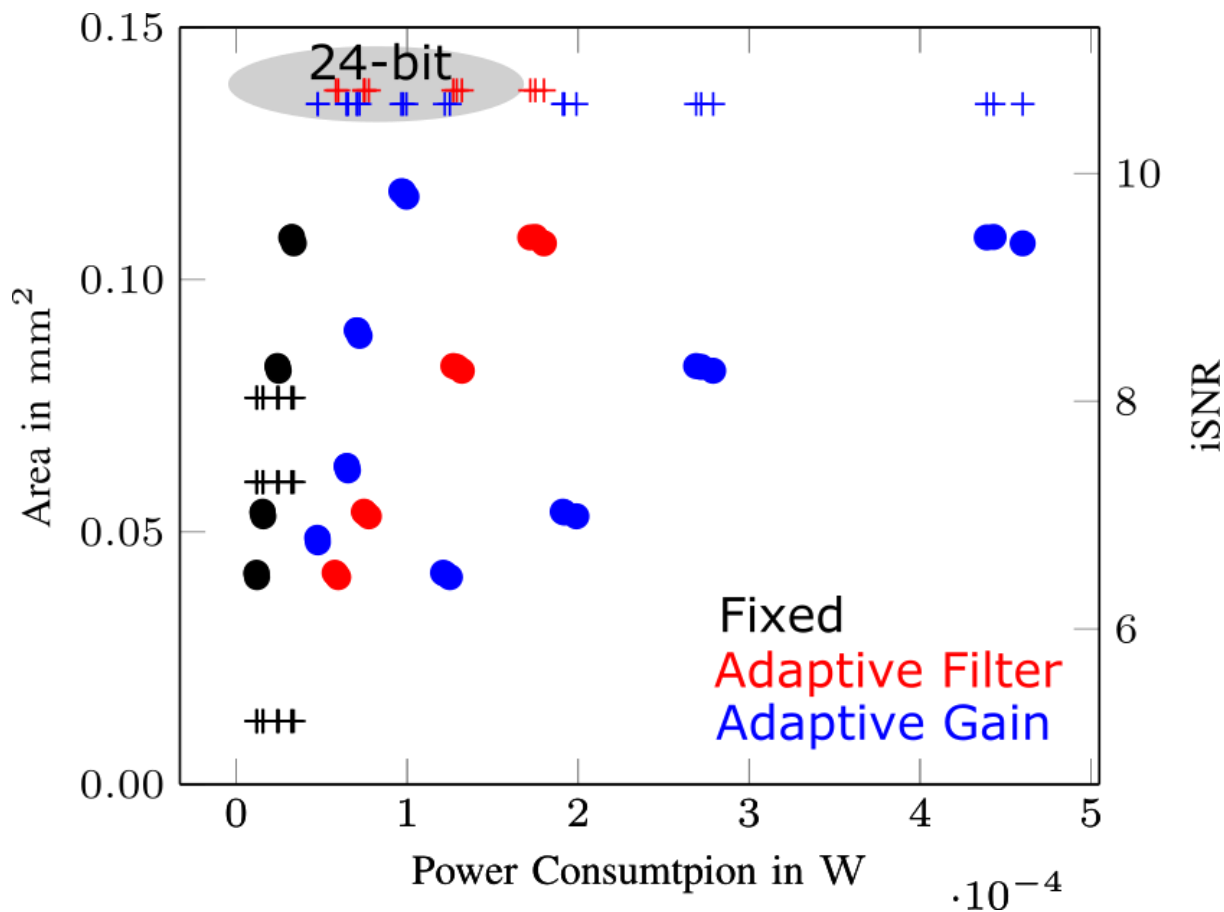












- Low-Power Optimization of a VLIW-SIMD ASIP for Hearing Aid Devices
  - Objective algorithm evaluations
    - PESQ
    - iSNR
    - STOI
  - Hardware evaluations
    - Dynamic power
    - Area
    - Performance
- With the combination of the hardware and algorithm evaluations, the overall benefit of future hearing aid systems can be increased.