Ultra Low-Power ANSI S1.11 Filter Bank for Digital Hearing Aids

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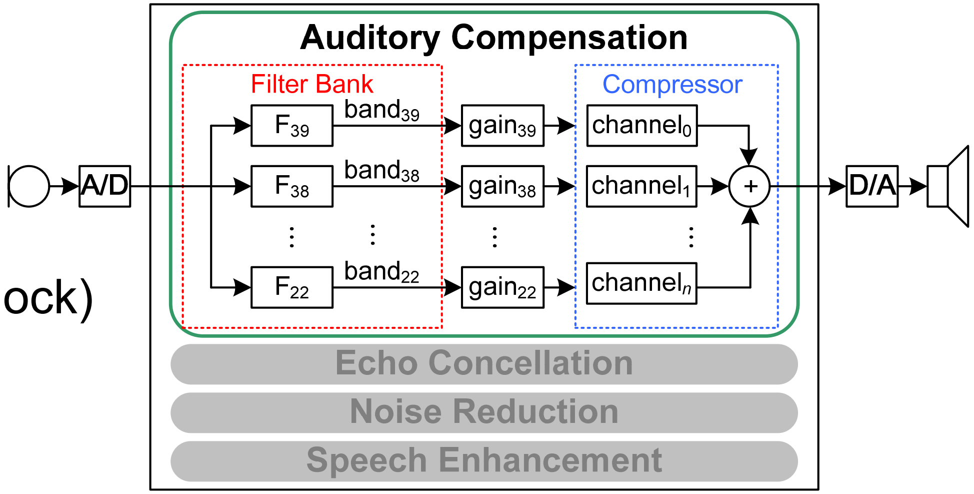
Outline

- Introduction
- Algorithm & architecture
- Implementation results
- Conclusions

Introduction

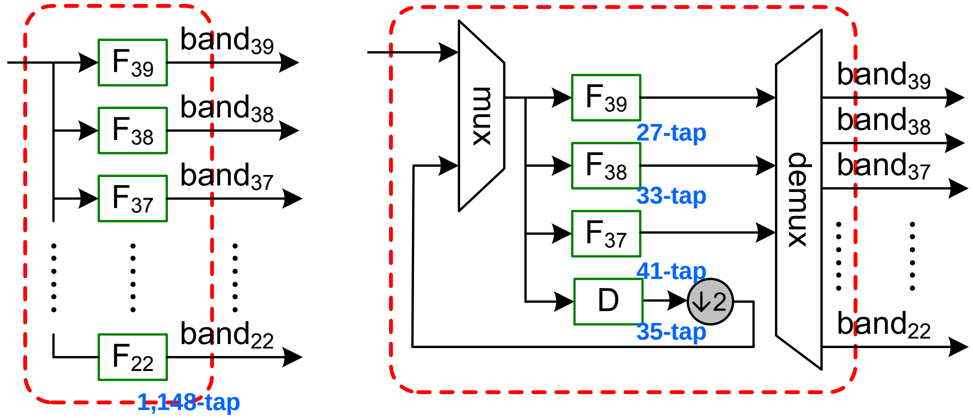


- Digital hearing aid
  - Auditory compensation (main block)
    - Filter bank
    - Dynamic range compression
  - …
- ANSI S1.11 filter bank (standard 1/3-octave bands)
  - Popular in acoustic/speech applications
    - Well match the frequency analysis in human hearing systems
  - But high computation complexity
    (1,488-tap FIR filter required for a straightforward implementation)

So, we designed a low-power ANSI S1.11 filter bank to meet the stringent power constraints of hearing aids

Filter Bank Algorithm Design

- Proposed multirate filter bank
  - ANSI S1.11 1/3-octave class-2 filters
  - 22nd ~ 39th bands (~8980Hz)
  - 24KHz sampling rate



parallel filter bank *multirate filter bank*

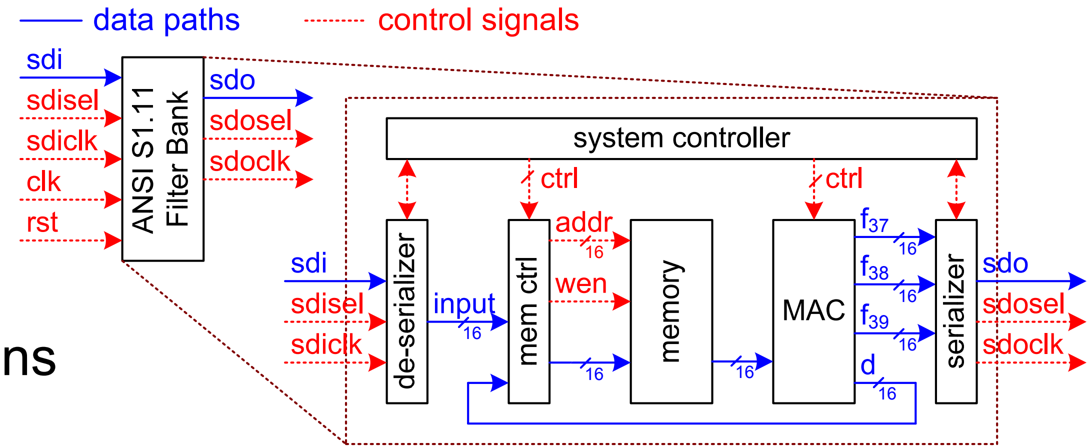
- Computation complexity

		IIR	**FIR**
Parallel	# MPY	192	3,270
	# ADD	165	6,520
Multirate	# MPY	102	**120**
	# ADD	90	**233**

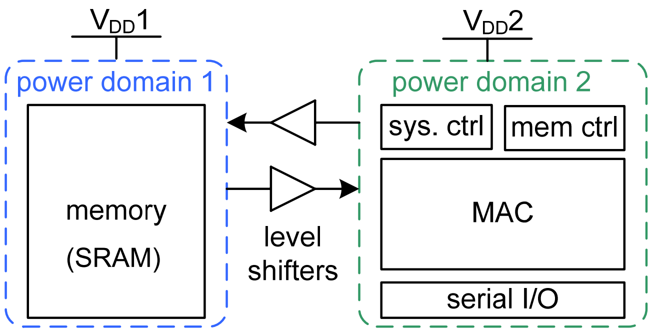
96% reduction

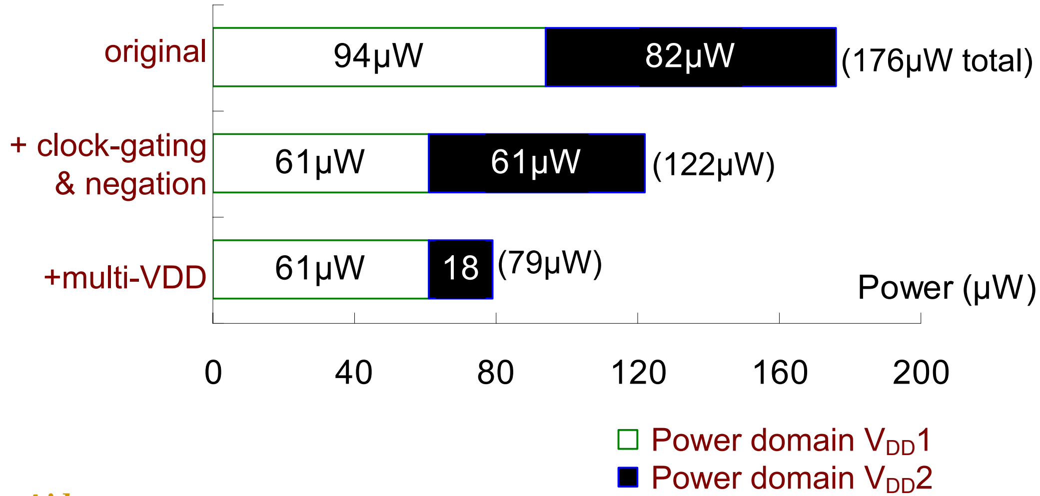
Architecture Design

- Block diagram



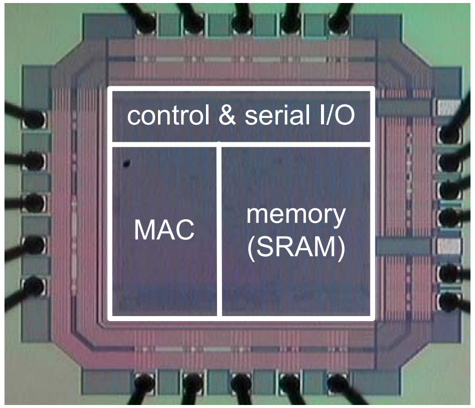
- Low-power optimizations
  - Clock gating
  - Selective coefficient negation
  - Multi-VDD implementation





Results

- Silicon Implementation
  - TSMC 0.13μm CMOS tech.
  - Cell library from Artisan
  - 6MHz clock frequency (for 24KHz sampling rate)



Sub-modules	Gate count
MAC	2,847
memory	5,594
system controller	1,010
memory controller	301
serial I/O	1,103

- Comparison

	# bands	Process (μm)	V_{DD} (V)	Power (μW)	$P_{normailzed}$ *
[5]	7	0.70	1.55	471	7.49
[6]	8	0.18	1.6	316	16.05
[3]	16	0.35	1.1	248	6.85
Proposed	18	0.13	1.2/0.6	79	4.39

$$^{*}P_{normalized} = Power \times \left(\frac{0.13}{Process}\right) \times \left(\frac{1.2}{V_{DD}}\right)^2 \times \left(\frac{1}{\#bands}\right)$$

Conclusions

- An ultra low-power filter bank has been designed & implemented
  - ANSI S1.11 1/3-octave bands
  - Class-2 filter specification
  - 24KHz sampling rate
- It is optimized for low power at the algorithmic, architectural, and circuit levels
  - 96% multiplications saved with multirate algorithm
  - 55% power saved with architectural/circuit level optimizations (from 176 to 79 μW)
- The proposed design is suitable for hearing aids
  - Only 27~64% power of other filter banks (more energy-efficient)
  - The 1/3-octave bands match the human auditory characteristics