Washington University
School of Engineering and Applied Science

Power Consumption of Customized Numerical Representations for Audio Signal Processing

Roger Chamberlain, Yen Hsiang Chew,
Varuna DeAlwis, Eric Hemmeter,John Lockwood,
Robert Morley, Ed Richter, Jason White,
and Huakai Zhang

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Outline

- Audio Signal Requirements
- Customized Numerical Representations
- SNR and Dynamic Range
- Design of Computation Structures
- Power Consumption Results
- Summary and Conclusions

Audio Signal Applications

- Music
  - MP3 players
- Speech
  - communications equipment
  - hearing aids (our target application)
- Signal requirements to understand speech
  - ~30 dB SNR over entire dynamic range
  - ~100 dB dynamic range
- Power consumption critical for all of above

Customized Numerical Representations

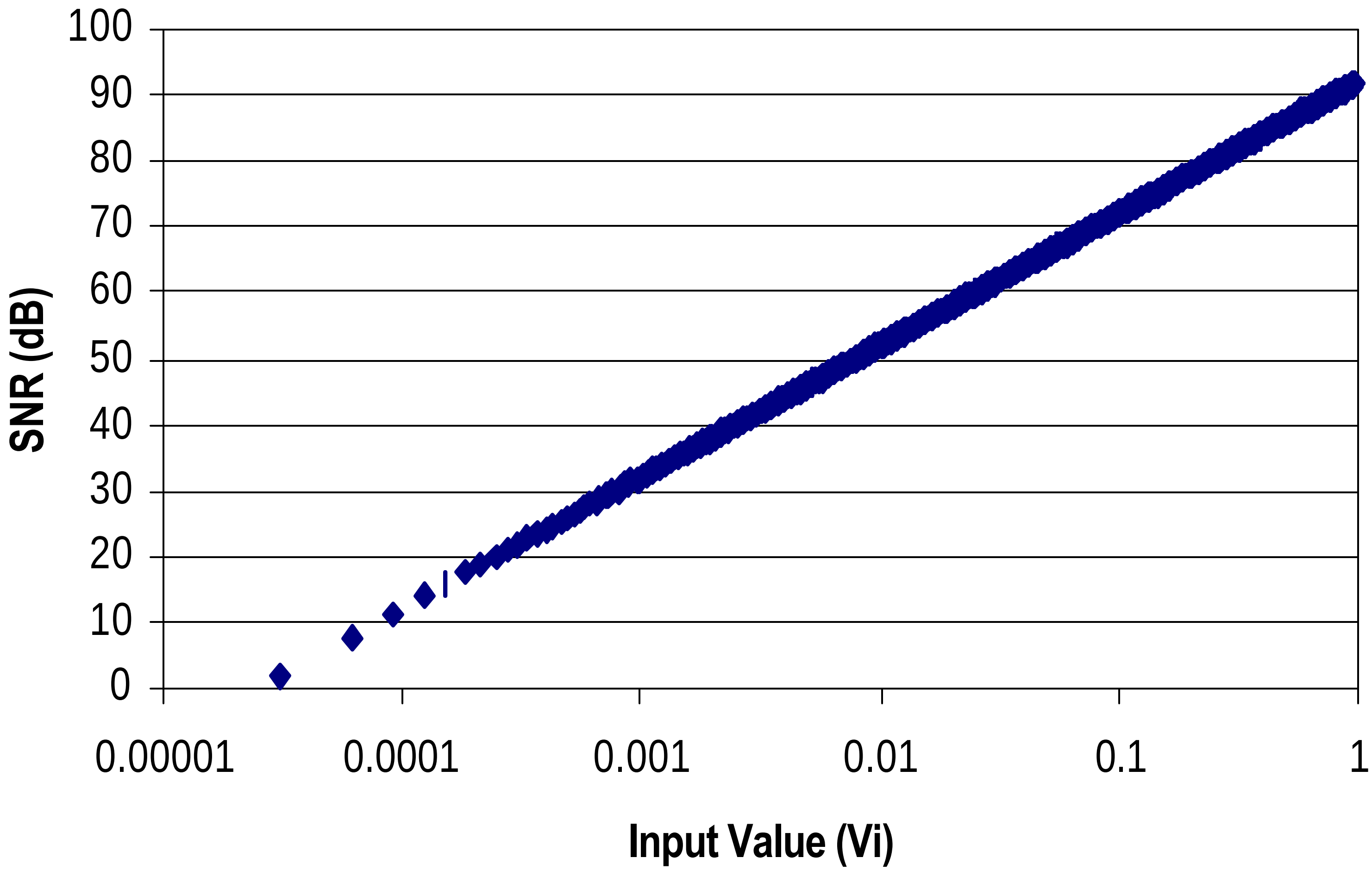
- 16-bit integer is traditional for audio
  - 90 dB dynamic range, SNR from 0 to 90 dB
- Logarithmic representation more closely mimics human perception
  - Loudness response is highly non-linear
  - SNR is relatively constant across dynamic range
- Floating point representations are partially logarithmic and partially linear
  - 32-bit IEEE standard is more than is needed
  - Tailor choice for number of bits in exponent and mantissa to needs of application

SNR and Dynamic Range

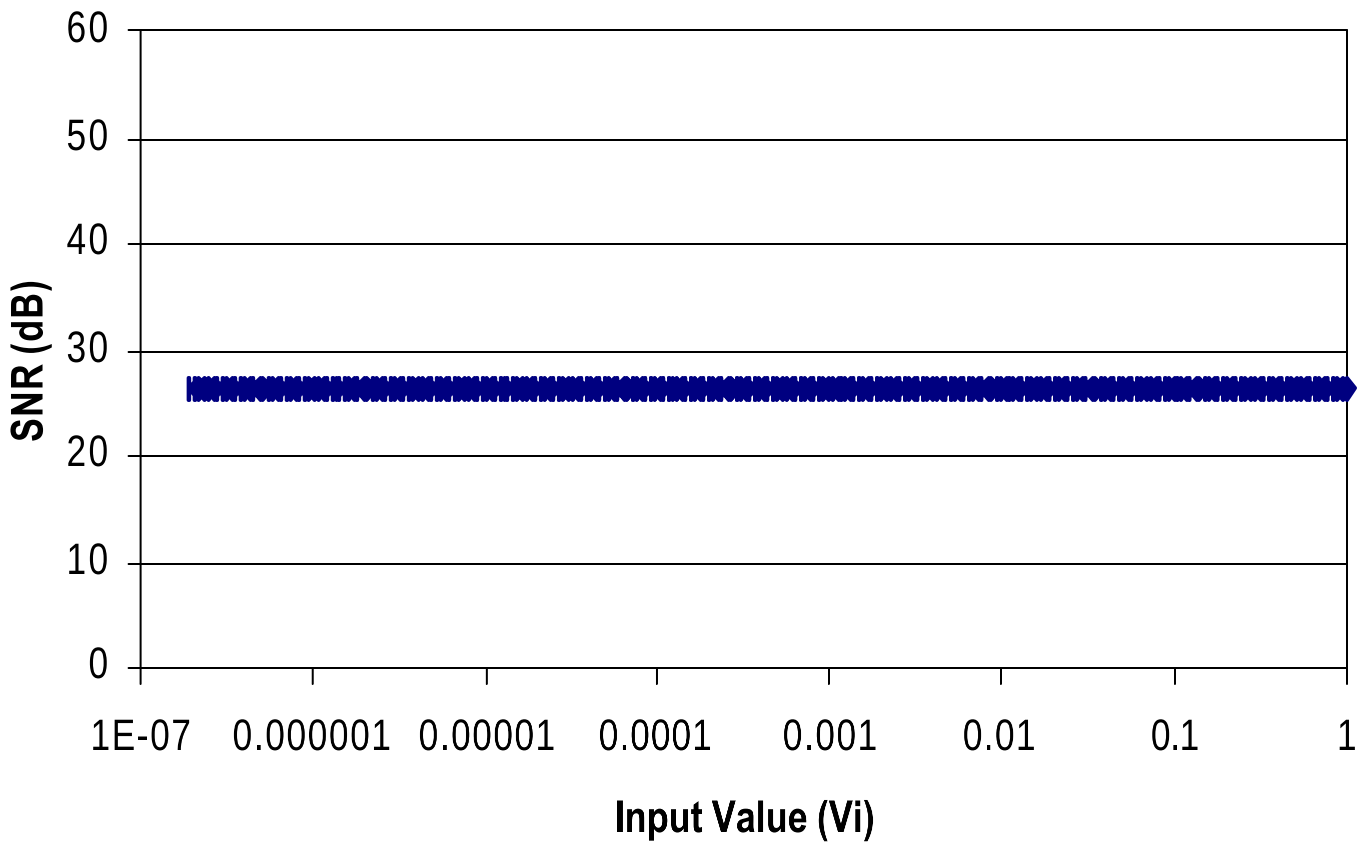
$$\text{SNR (dB)} = 20 \cdot \log_{10}\left(\frac{\dfrac{V_i}{2\sqrt{2}}}{\dfrac{V_{i+1} - V_i}{\sqrt{12}}} \right)$$

$$\text{Dynamic Range (dB)} = 20 \cdot \log_{10}\left(\frac{V_{\max}}{V_{\min}} \right)$$

16-bit Integer SNR

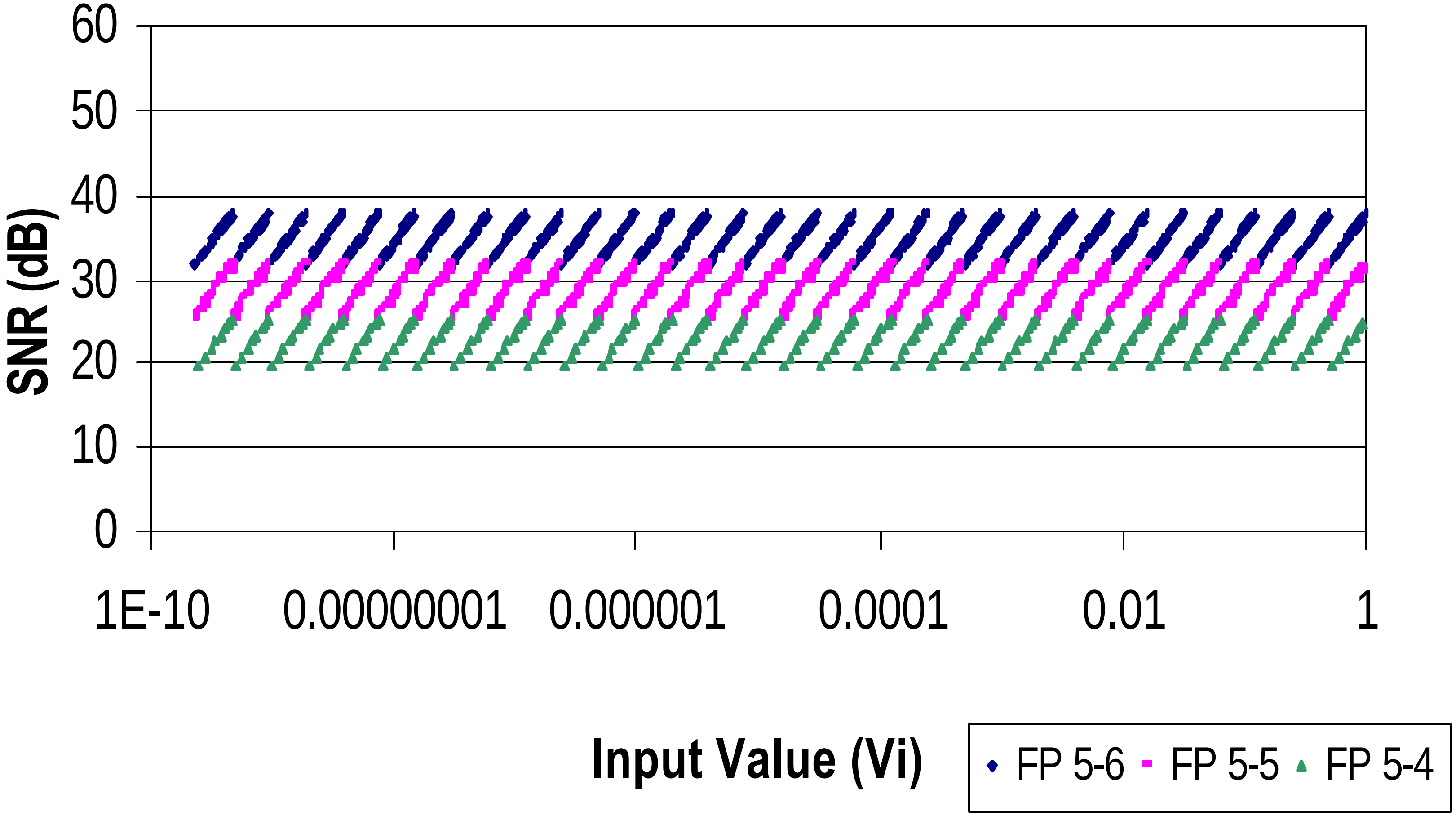


9-bit Logarithmic SNR

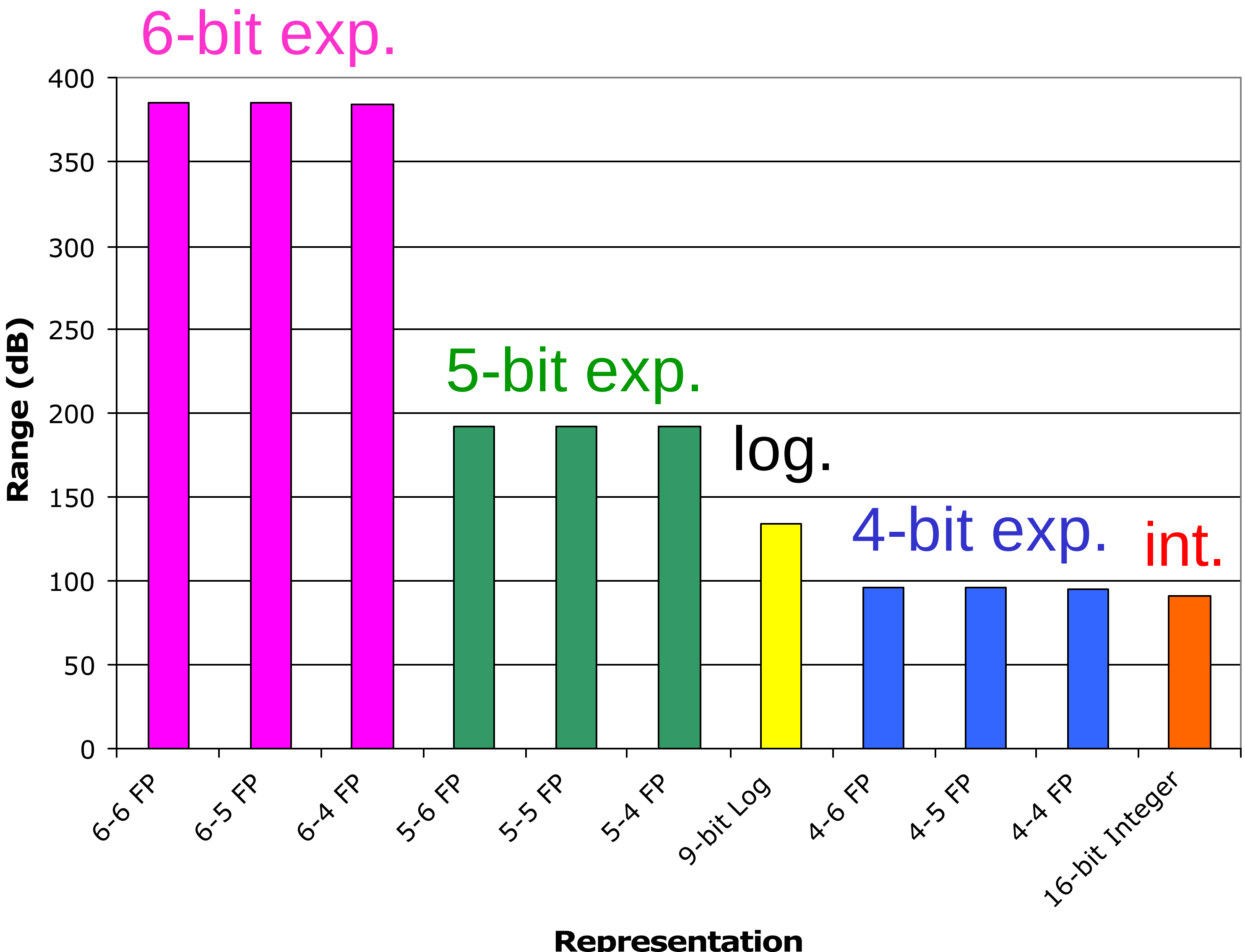


Floating Point SNR

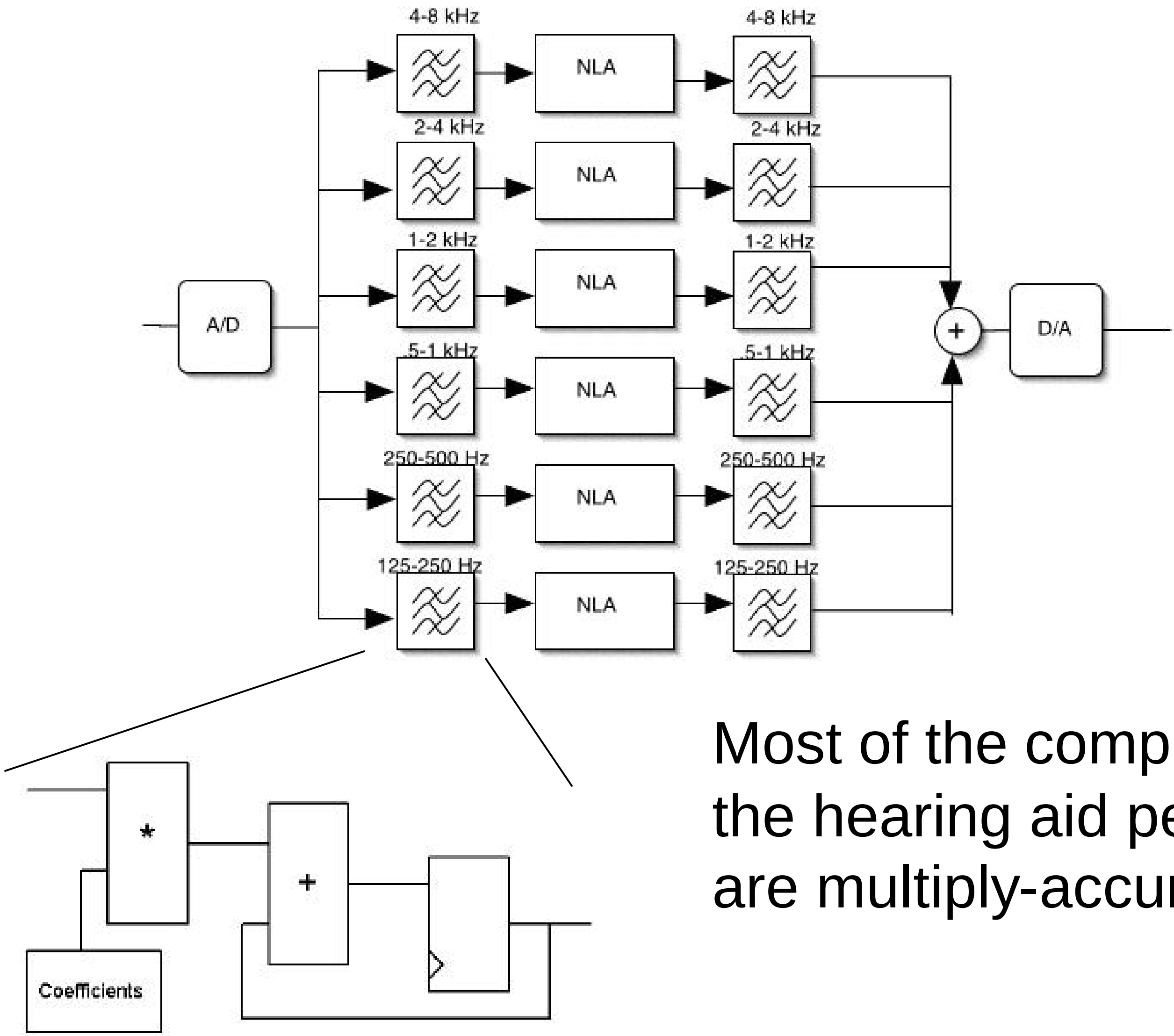
5-bit exponent – 4, 5, and 6-bit mantissa



Dynamic Range



Hearing Aid Architecture

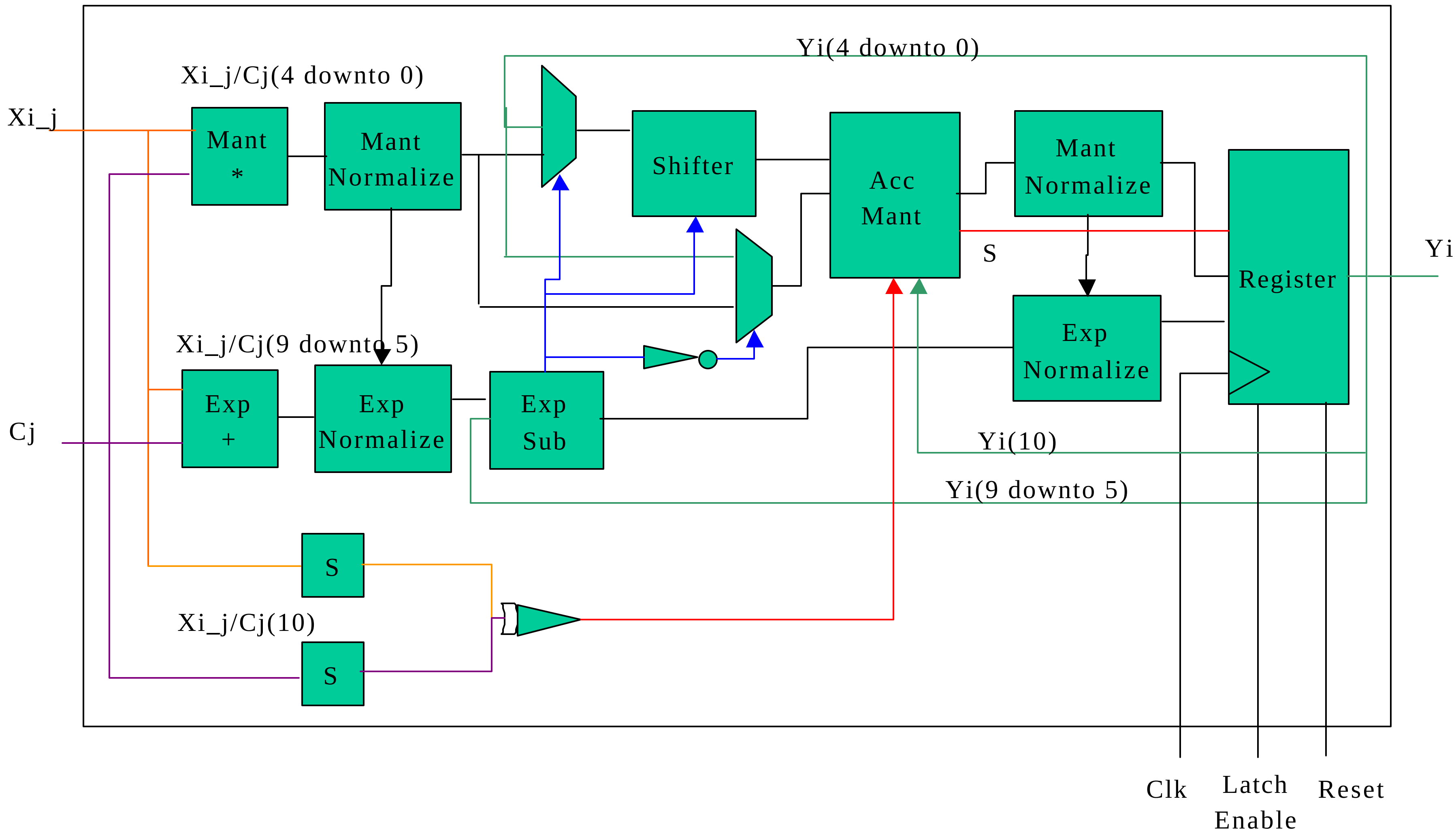


Most of the computations the hearing aid performs are multiply-accumulates.

Floating Point MAC Design

- Traditional structure for floating point hardware computations
- Perl script generates synthesizable VHDL code for specific exponent and mantissa size
- Small size of mantissa implies lower power multiplier hardware

Floating Point MAC



Logarithmic MAC Design

- Multiply function provided by an adder:

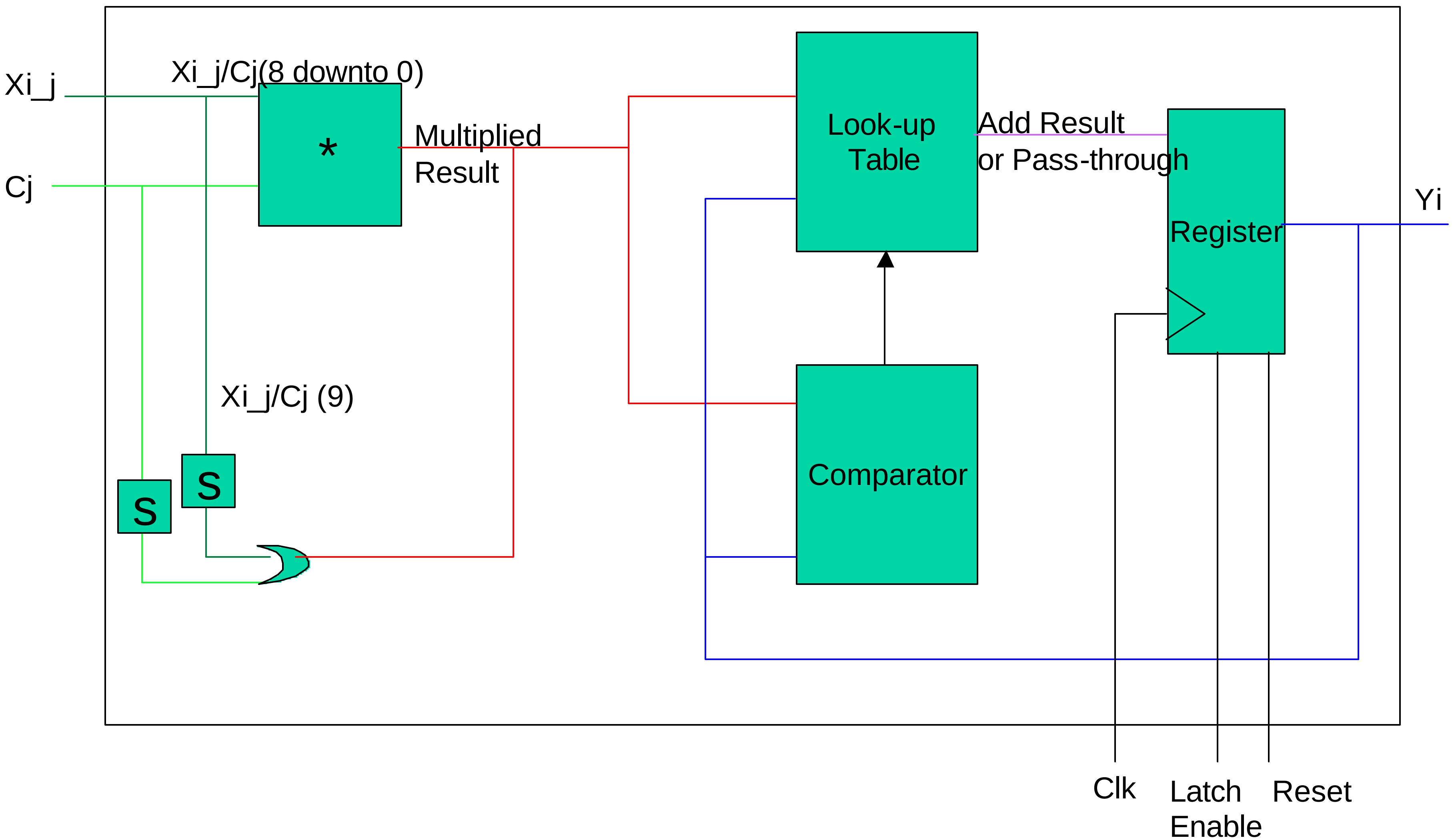
$$\log(A \times B) = \log(A) + \log(B)$$

- Addition function exploits the following relationship:

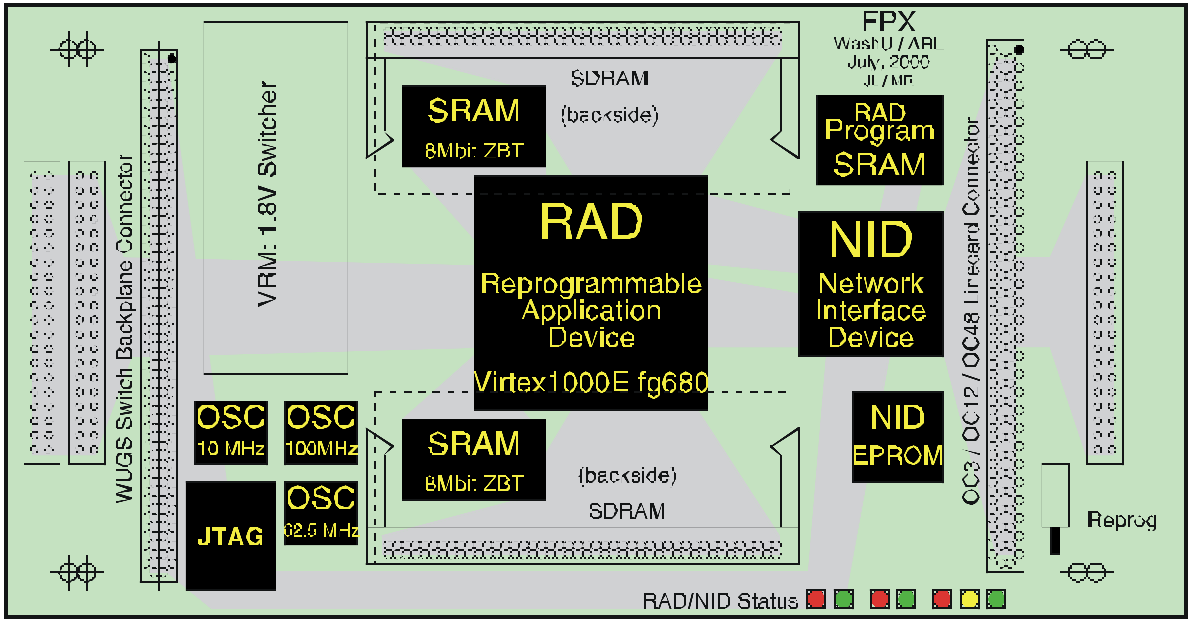
$$\log(A + B) = \log(A) + \log\left(1 + \frac{B}{A}\right)$$

- Last term implemented via a lookup table

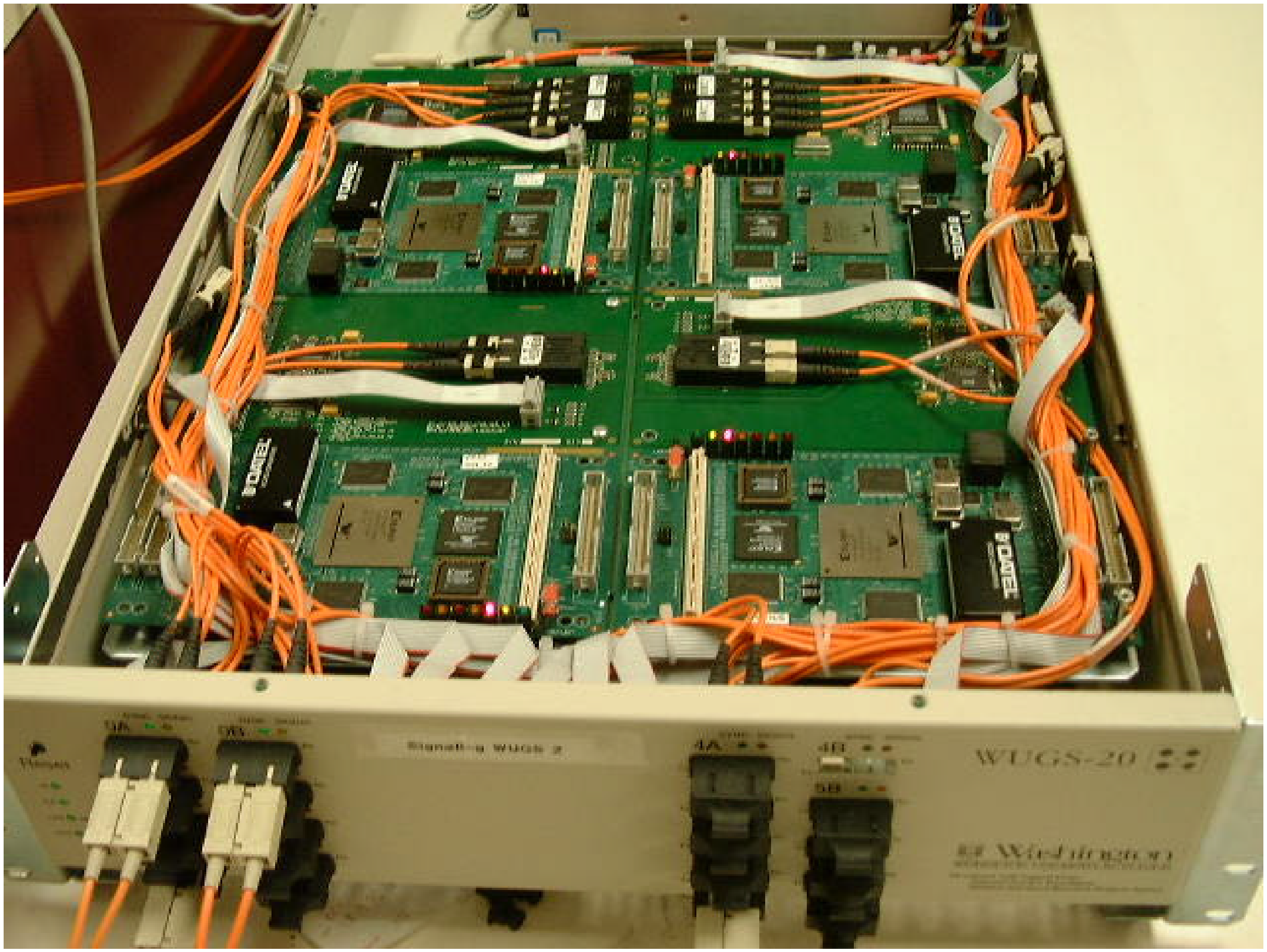
9-bit Logarithmic MAC



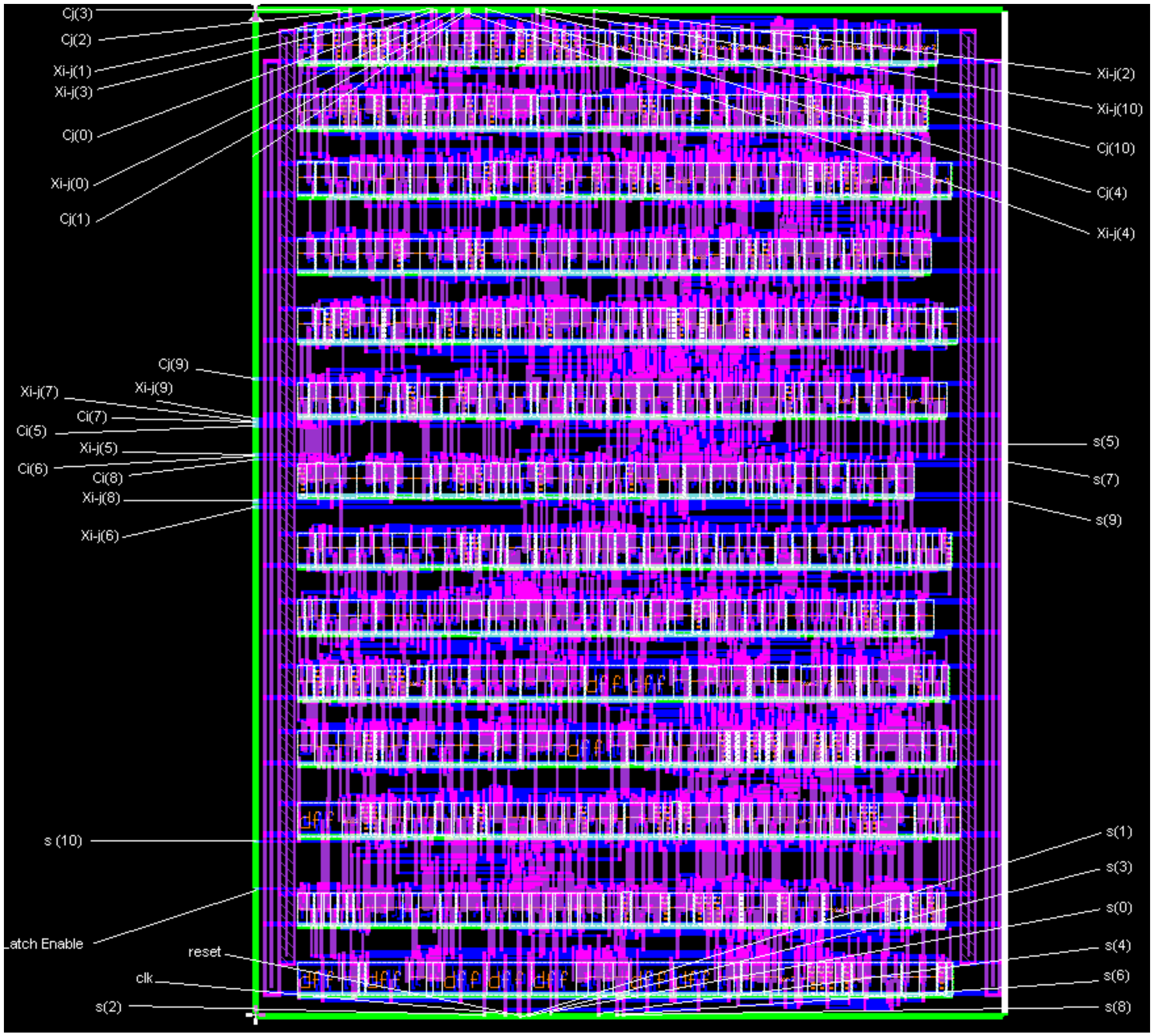
Verification Via FPX Platform



FPX Platform



Layout

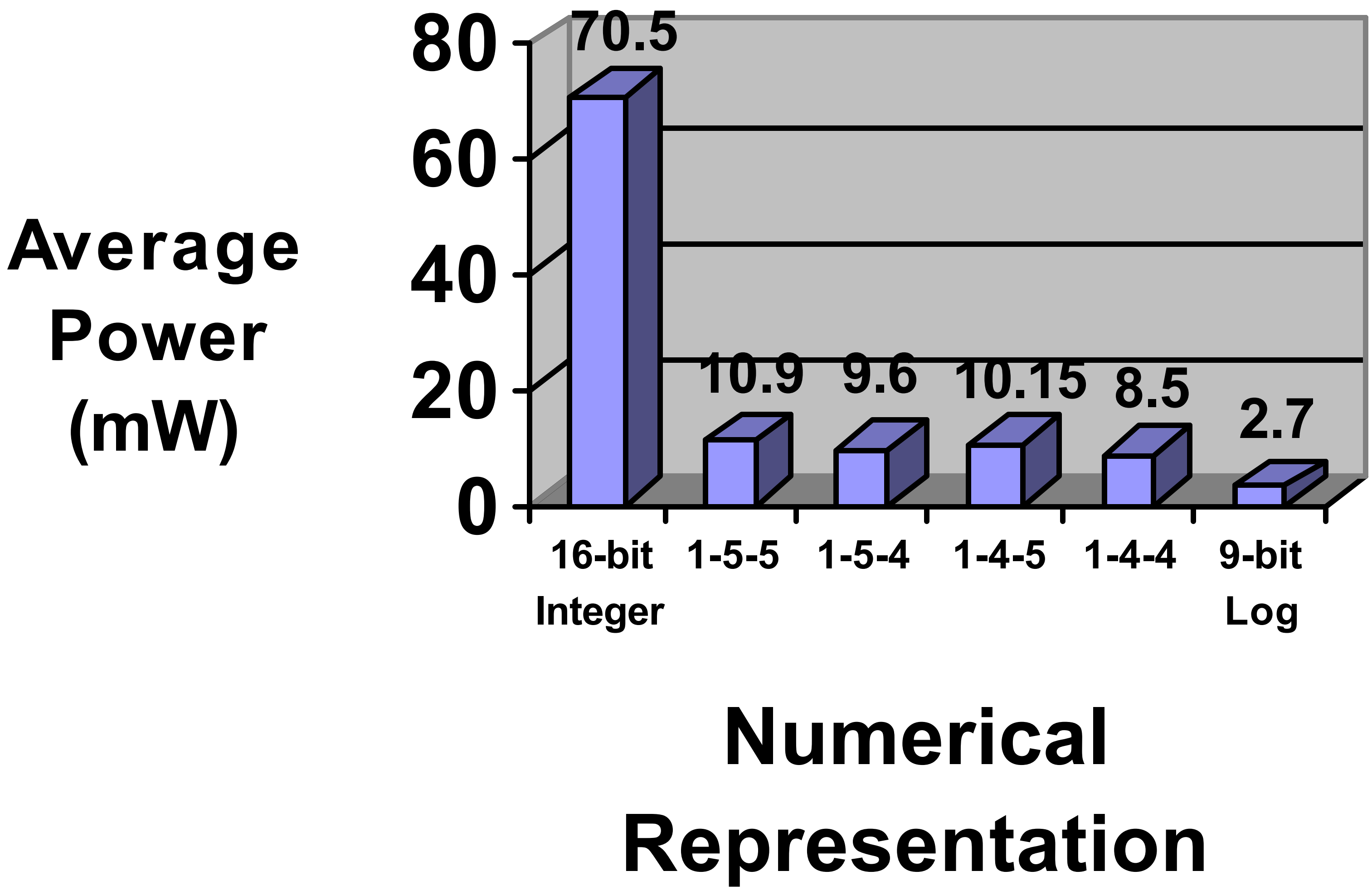


- AMI 0.5 ìm process
- ADK library from Mentor Graphics HEP
- 5-5 floating point MAC is shown

Power Estimation via Simulation

- Simulate using Mentor Graphics MACH-PA
  - Spice-level simulation tool
  - Driven by extracted layout
- Focus on Multiply-Accumulate units
  - Random input vectors
  - Simulation provides current usage
- $P = IV$ provides power results

Power Consumption



Summary and Conclusions

- Customizing a numerical representation to the specific needs of an application can have tangible benefits
- Several 9 or 10-bit representations have improved SNR and dynamic range for audio speech applications relative to traditional 16-bit integers
- Both customized floating point and logarithmic representations have been considered
- Power savings are significant

For Further Information

http://www.ccrc.wustl.edu/hearingaid

or

hearingaid@ccrc.wustl.edu