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

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

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

16-bit Integer SNR

[Graph showing the relationship between SNR (dB) and input value (Vi)]
9-bit Logarithmic SNR

Floating Point SNR

5-bit exponent — 4, 5, and 6-bit mantissa
Dynamic Range

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
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
 Verification Via FPX Platform

FPX Platform
Layout

- AMI 0.5 $\mu$m 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
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