Log-Domain Circuits for Auditory Signal Processing

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Log-Domain Circuits for Auditory Signal Processing

- Introduction
- An Auditory Signal Processing System
- Common circuits: Filtering, Normalization, and Smoothing
- Energy Envelope Measurement: Rectification
- Energy Envelope Measurement: Peak-Peak Detection
- Experimental Results
- Conclusion

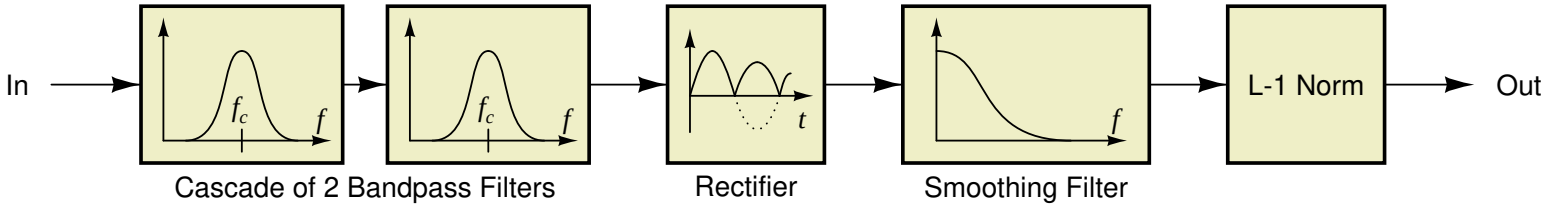
Introduction

System implementation:

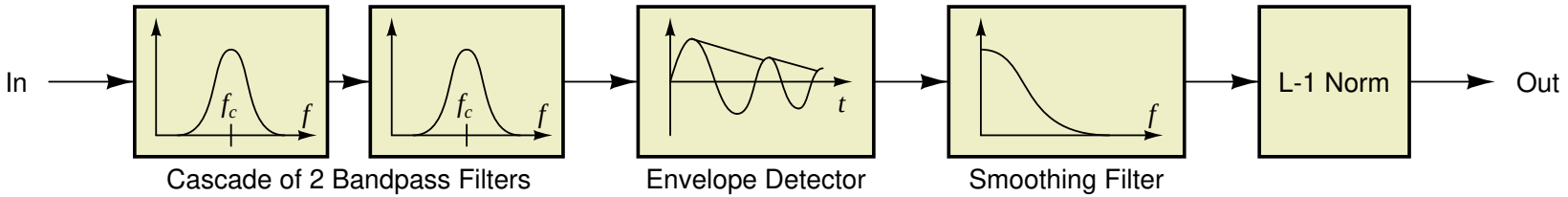
- 16-channel bandpass filterbank with short-term energy envelope measurement
- Current-mode design
- *Log-domain filters* based on *translinear circuits*
- BiCMOS design for greatest dynamic range and linearity with high integration density
- Log-domain structures for energy envelope computation and normalization function

Two models for a filterbank with energy envelope measurement

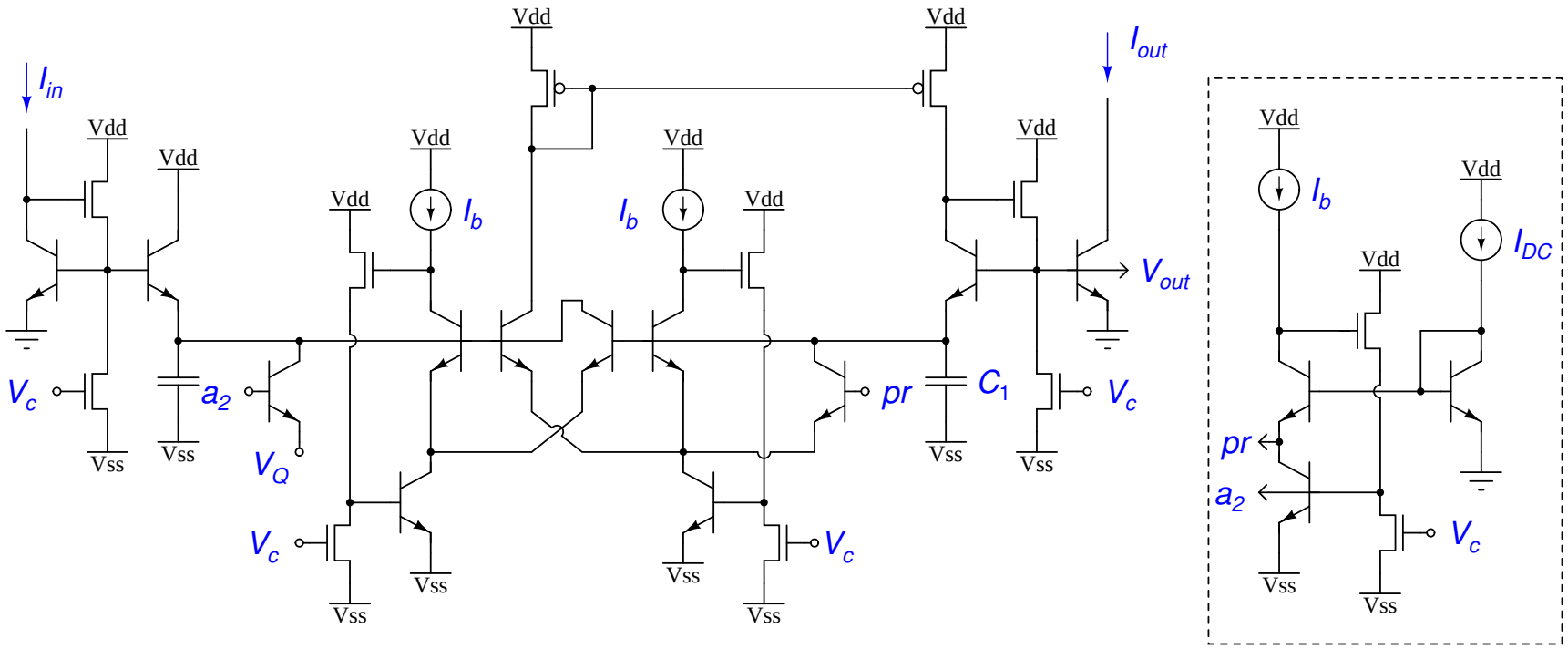
Full-Wave Rectification and Smoothing



Peak Detection and Smoothing

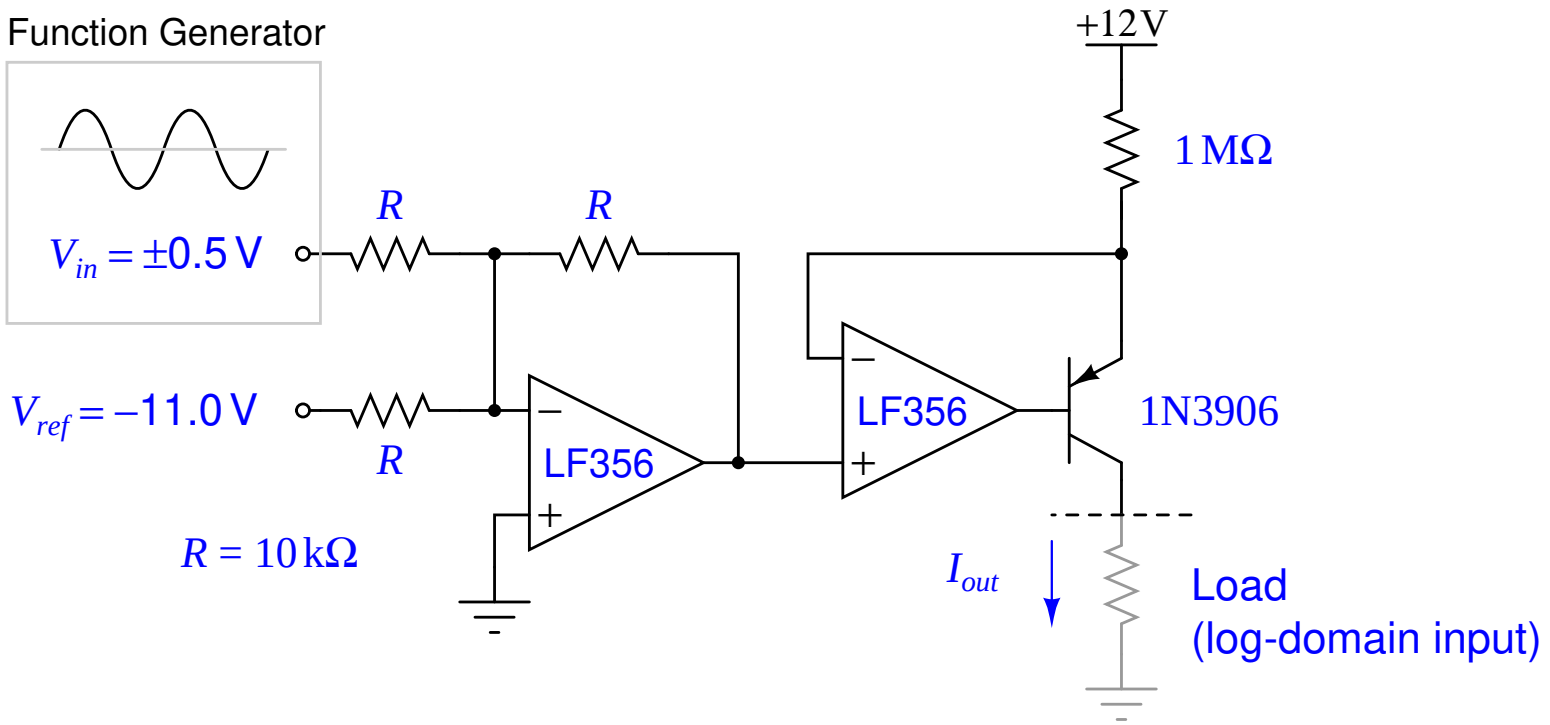


Yet Another Log-domain Bandpass Filter



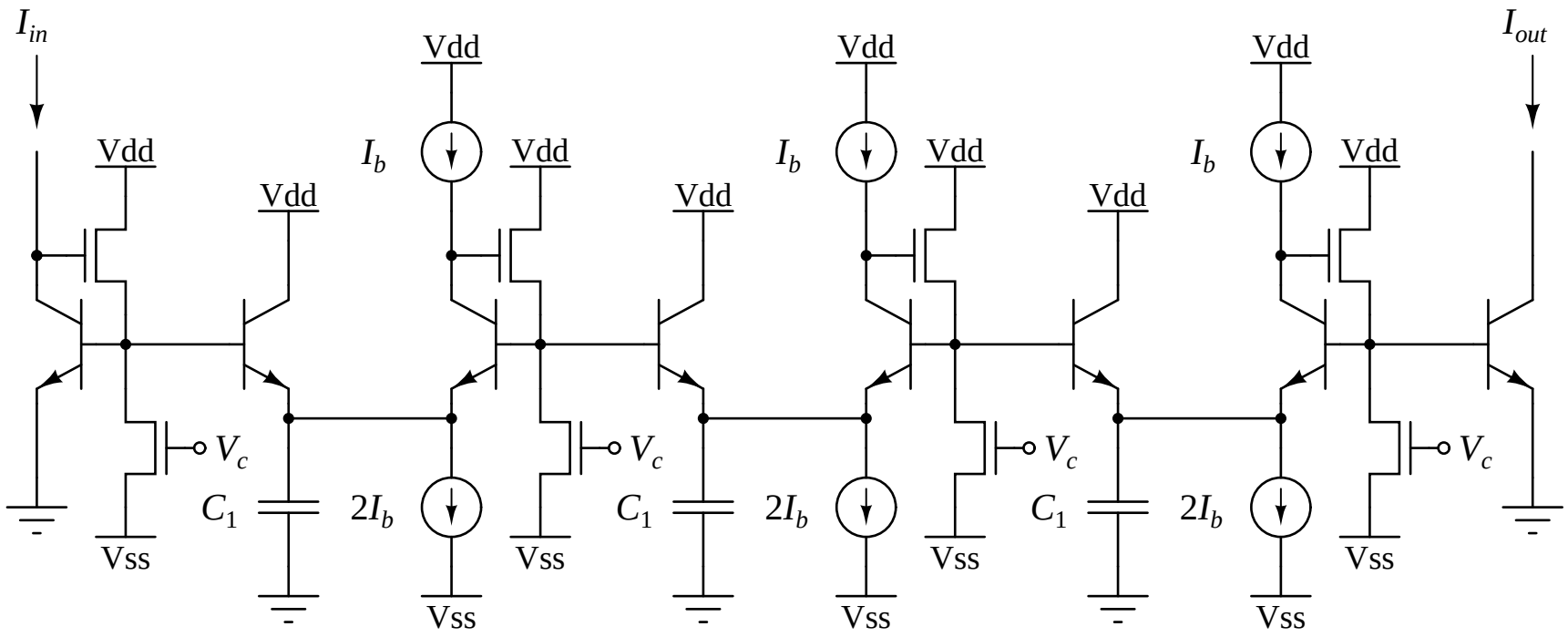
$$I_{out} = I_{in}\left(\frac{\tau s}{1+(1/Q)\tau s+\tau^2 s^2}\right)+I_{DC} \qquad \textbf{where} \qquad \tau = \left(\frac{V_t C_1}{I_b}\right) \qquad \textbf{and} \qquad Q = e^{V_Q/V_t}$$

System Signal Input



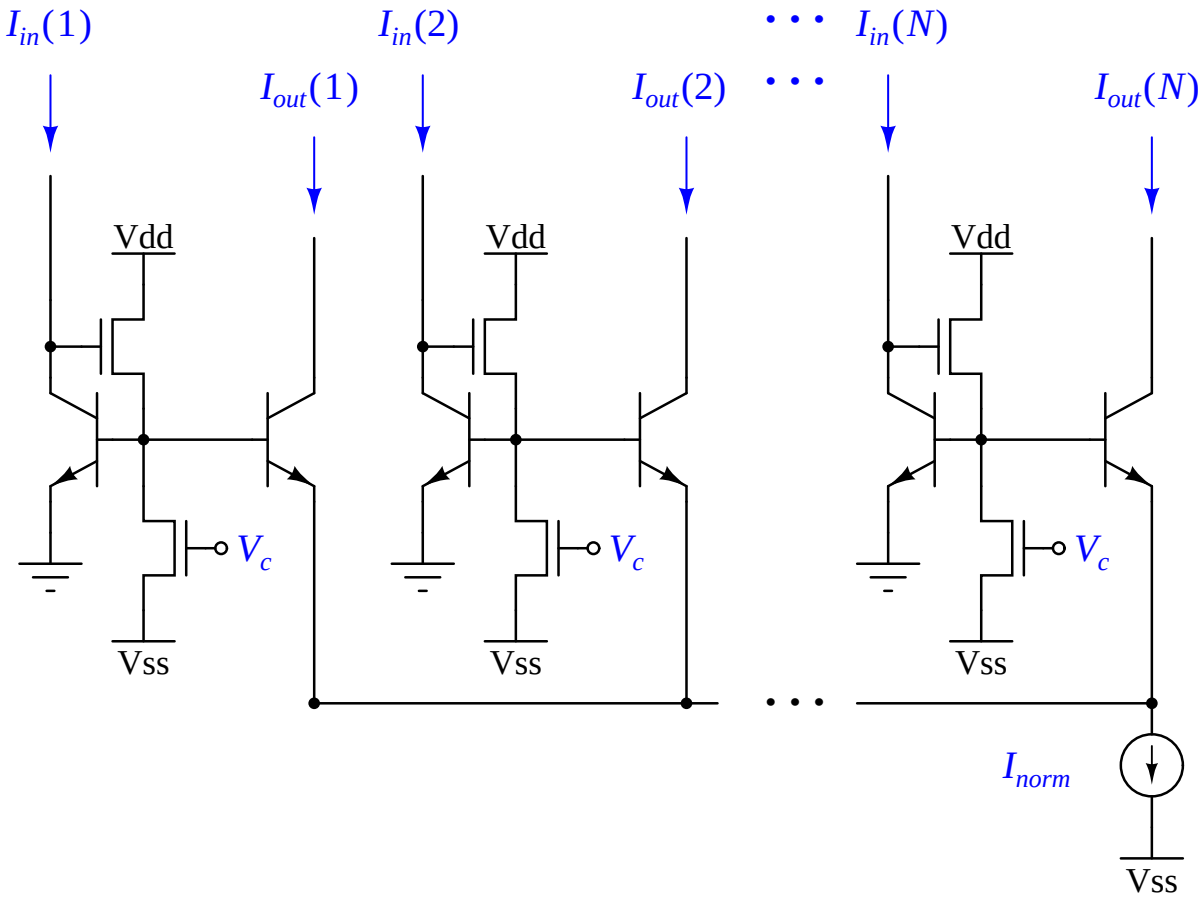
$$I_{out} = (12 + V_{ref} + V_{in})\ \textbf{µA}$$

Smoothing Filter



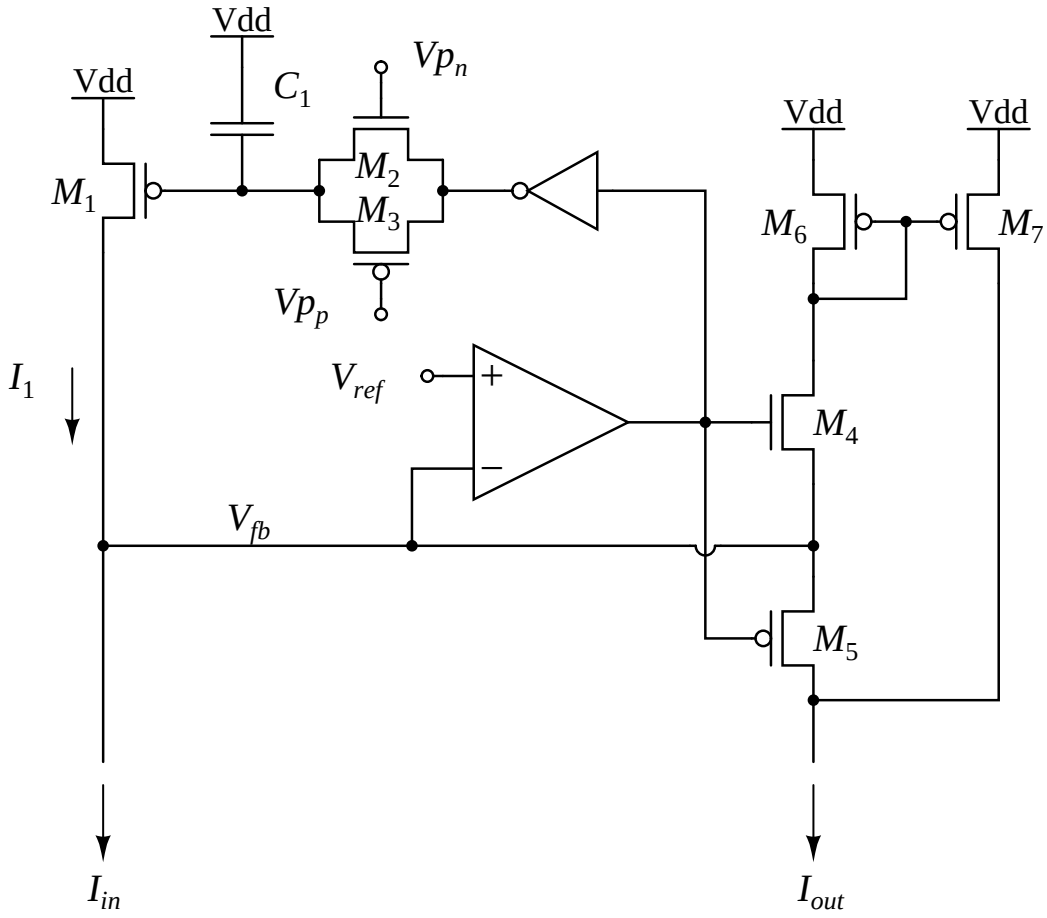
$$I_{out} = I_{in}\left(\frac{1}{1+\tau s}\right) \qquad \textbf{where} \qquad \tau = \left(\frac{V_t C_1}{I_b}\right)$$

L-1 Normalization Circuit (Gilbert Normalizer)



$$I_{out}(i) = I_{norm} \frac{I_{in}(i)}{\sum_{j=1}^{N} I_{in}(j)}$$

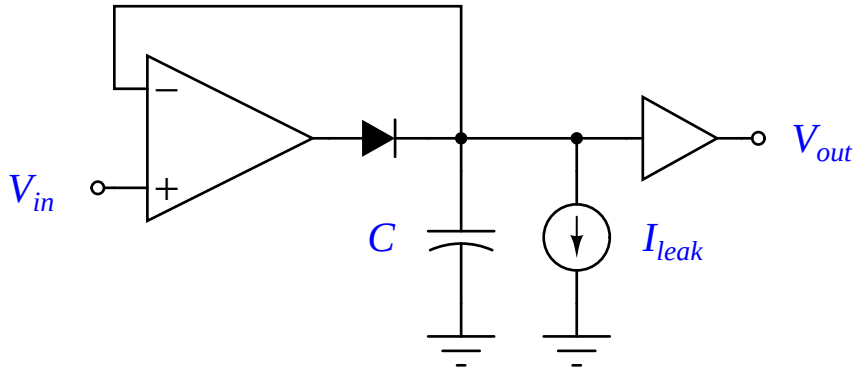
A Current-Mode Rectifier



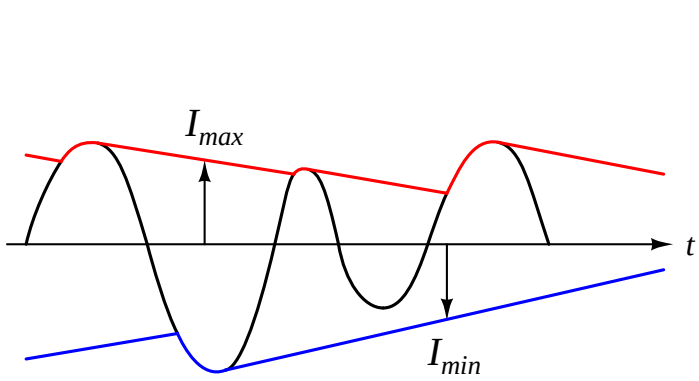
$$I_{out}(i) = |I_{in} - I_1| \qquad I_1 = \langle I_{in} \rangle$$

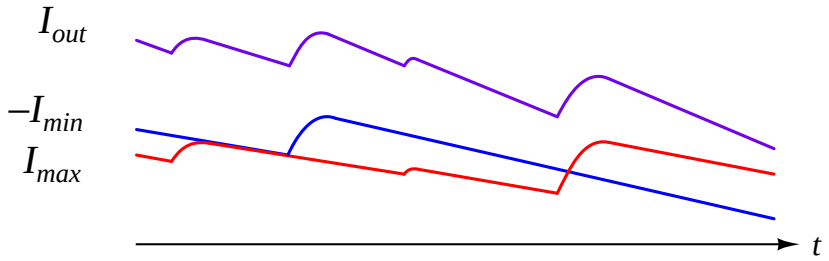
The Envelope (Peak) Detector

Simple Op-Amp Peak Detector



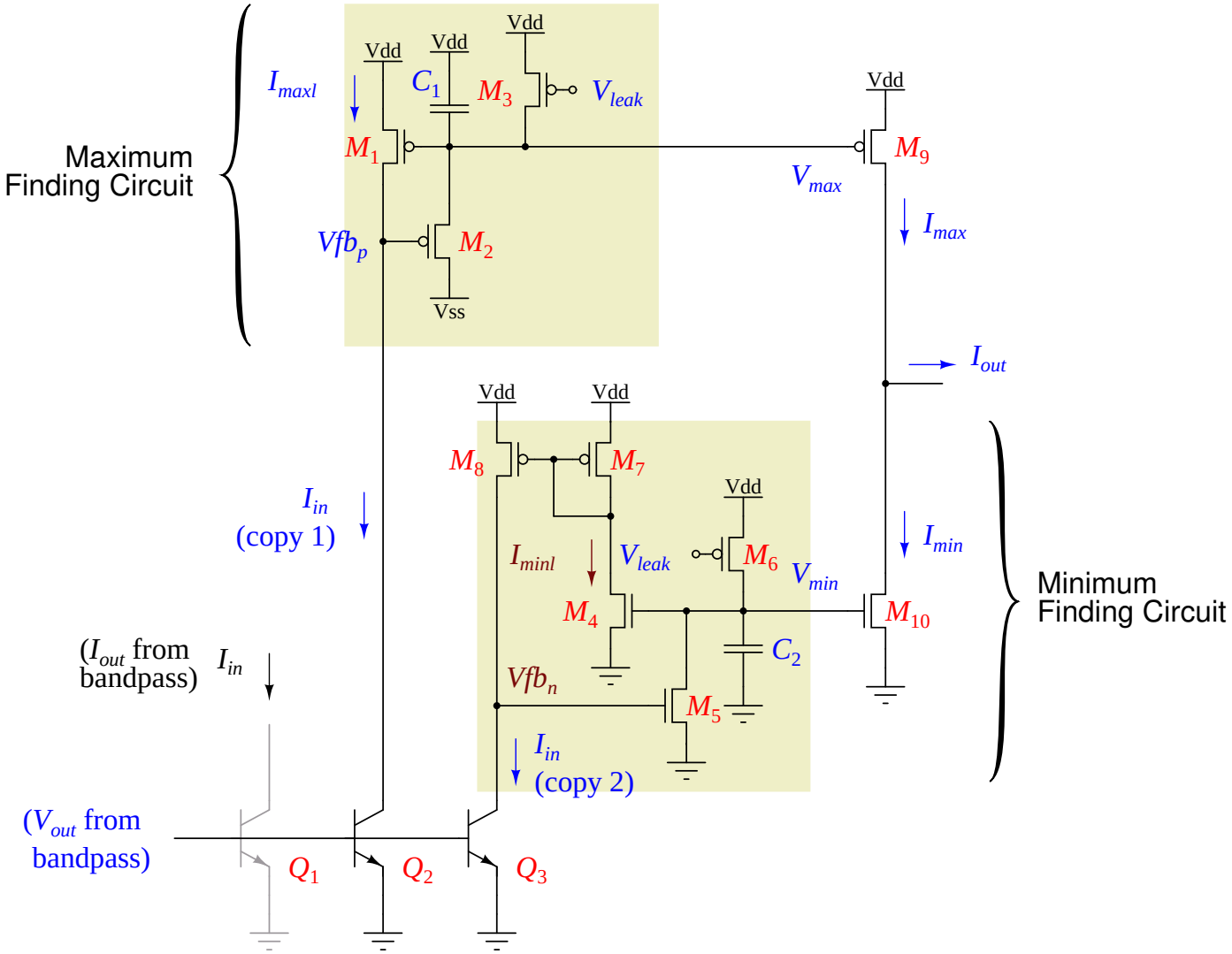
Behavior of a Peak-to-Peak Detector



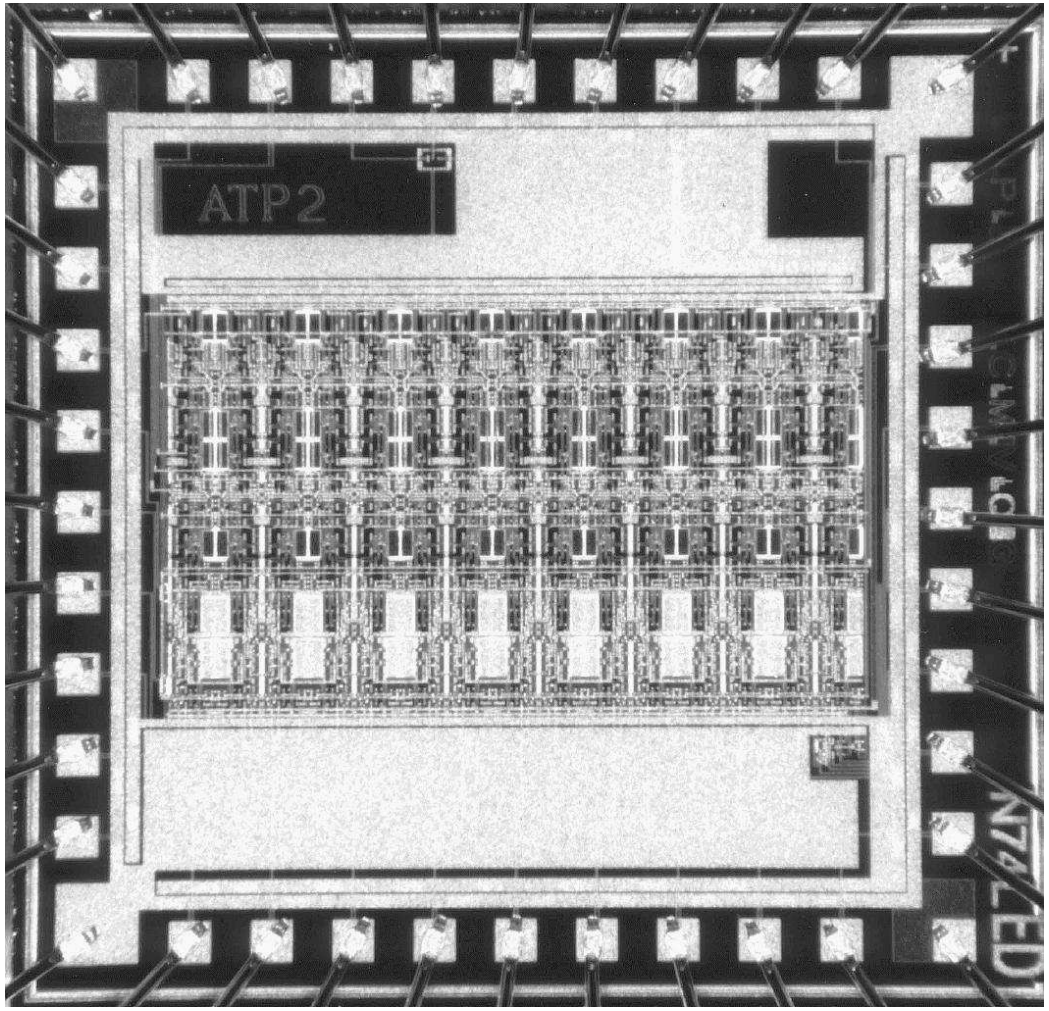


$$I_{out} = I_{max} - I_{min}$$

The Envelope Detector

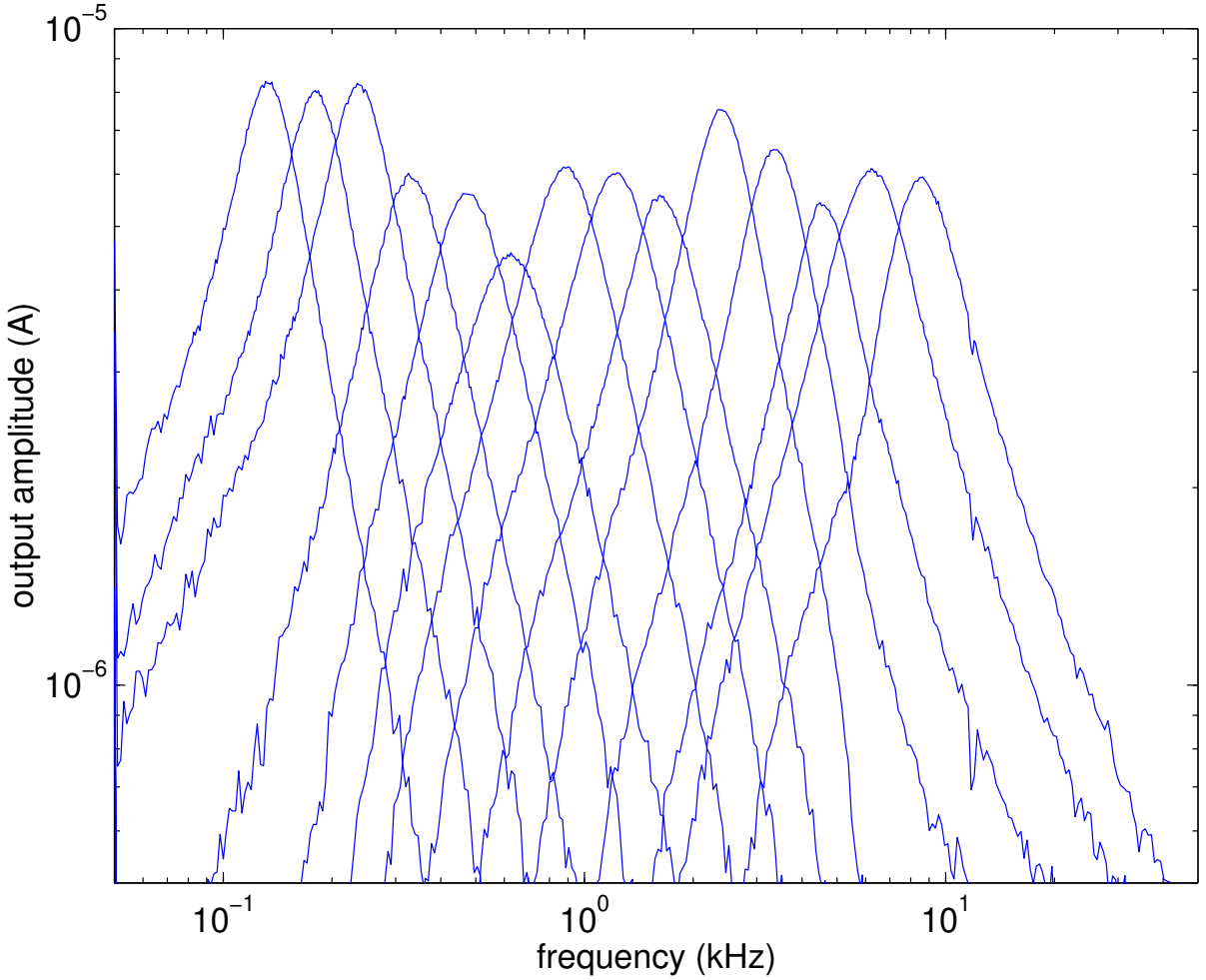


Log-Domain Frontend Filterbank—Photograph



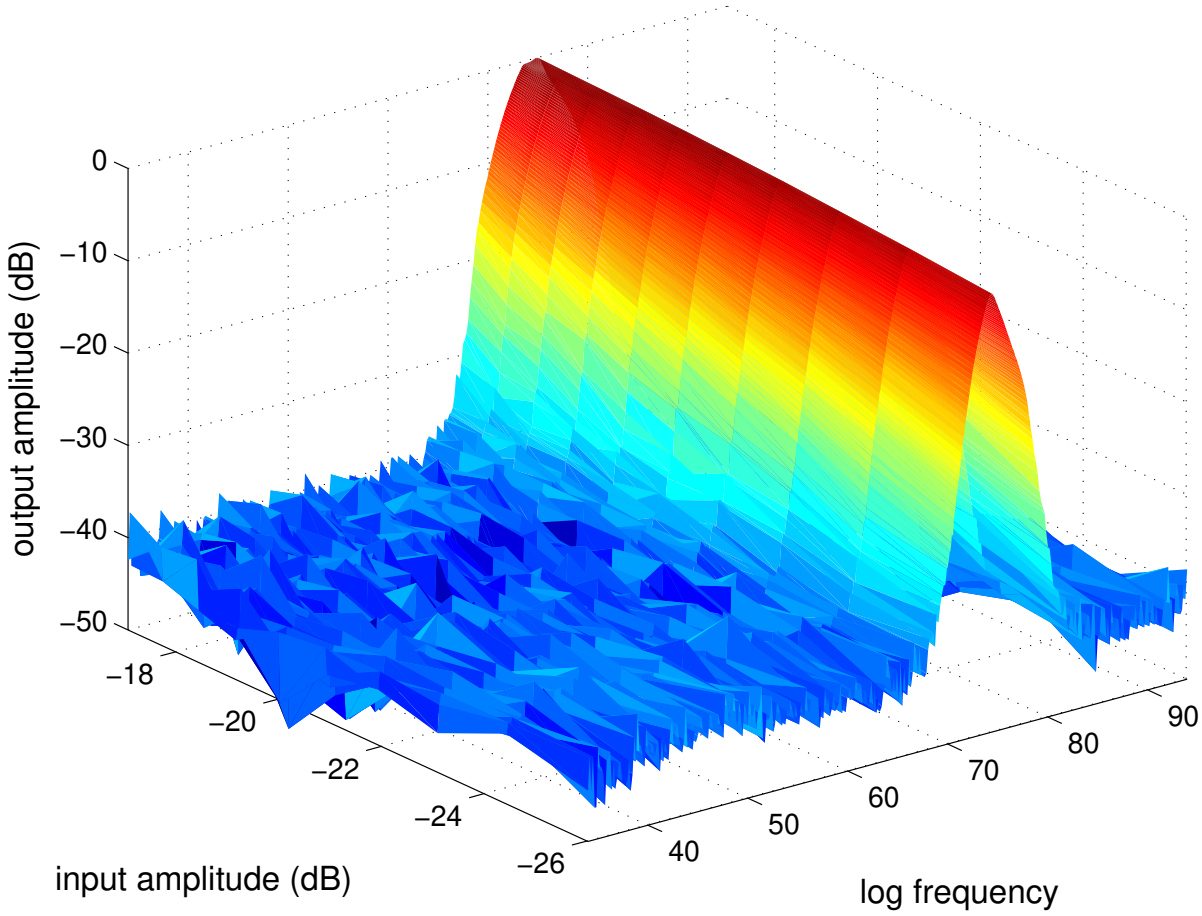
The fifteen-channel bandpass filterbank fabricated in 1.2 µm technology inside a 2.2 mm $\times$ 2.2 mm padframe.

Measured filter characteristics using the peak detector



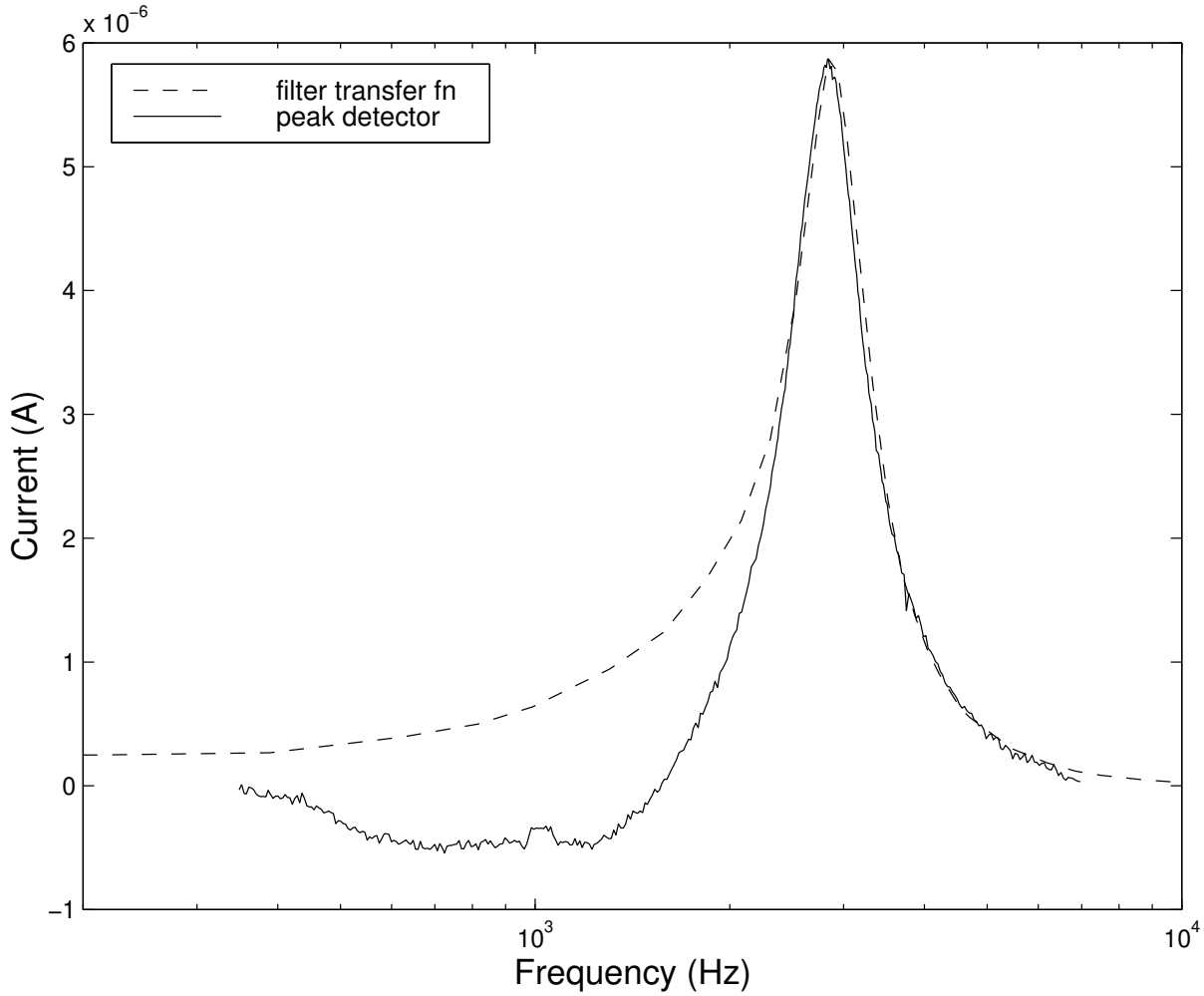
Measured output of the envelope detector of all filter outputs, showing mismatch between channels.

Measured filter characteristics using the peak detector



Measured output of the envelope detector for one filter channel over frequency and input amplitude.

Measured filter characteristics using the peak detector



Comparison between filter characteristic measured as signal gain at the filter output (dotted line) and as a current from the peak detector (solid line).

Conclusion

We have developed, tested, and characterized efficient architectures and circuits for current-mode acoustic signal processing in analog VLSI hardware.

- Log-domain bandpass filterbank
- Energy envelope measurement using:
  - Signal rectification
  - Peak-peak detection
  - Log-domain smoothing filter
- L-1 Normalization