Butterworth Bandpass Filter Design – Verilog Implementation

This document describes the design and implementation of a Butterworth bandpass filter for human voice audio signals, with coefficients converted to Q1.15 format for Verilog/DSP hardware.

Filter Specifications

- Audio Signal for Human Voice : 300Hz - 3.4kHz
- Passband : 300Hz - 3.4kHz
- Stopband (low): 0 - 200Hz
- Stopband (higher): 4kHz - Nyquist rate (8kHz)
- Passband Ripple: ~1dB

Filter Order Clarification

The filter was designed as a 2nd-order lowpass prototype. After applying the lowpass-to-bandpass transformation, the result is a 4th-order bandpass filter, implemented as two cascaded biquads. Each SOS row corresponds to one biquad stage.

Key Parameters

Center Frequency = sqrt(low freq * high freq)
= sqrt(300 Hz * 3400 Hz)
= sqrt(1,020,000) ≈ 1.01 kHz

Bandwidth = High freq - Low freq
= 3400 Hz - 300 Hz = 3100 Hz

Butterworth Coefficients

Floating Point:

```
[[ 0.60319724  1.20639449  0.60319724  1.0  1.34230451  0.51638013]
 [ 1.0       -2.0       1.0         1.0 -1.66756167  0.71766256]]
```

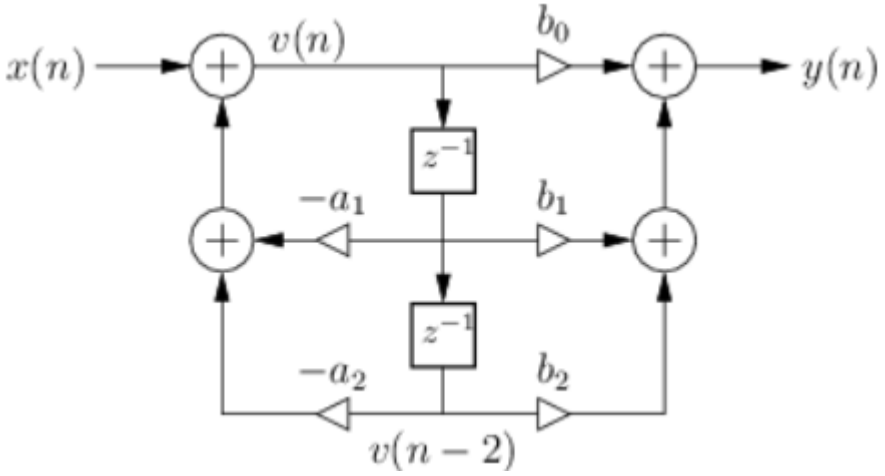
Q1.15 Coefficients:

```
[[ 19766  32767  19766  32767  32767  16921]
 [ 32767 -32768  32767  32767 -32768  23516]]
```

Implementation in Verilog

Each SOS row is implemented as a Direct Form II Transposed biquad block. The two rows are cascaded to realize the complete 4th-order bandpass filter.

Diagram (Direct Form II Transposed Structure)



$$
\begin{aligned}
v(n) &= x(n) - a_1 v(n-1) - a_2 v(n-2) \\
y(n) &= b_0 v(n) + b_1 v(n-1) + b_2 v(n-2)
\end{aligned}
$$