SignalForge Noise Analysis & Filter Design Report

Source File: demo_pure_tone_1k.wav

Sampling Rate: 48000.0 Hz

User Specifications

Metric	Specification
Tonal Suppression (dB)	≥ 20.0
SNR Improvement (dB)	Δ ≥ 6.0
FIR Passband Ripple (dB)	≤ 0.10
FIR Stopband Attenuation (dB)	≥ 60.0

These specifications define the target performance for tonal suppression, overall SNR improvement, FIR passband flatness, and stopband attenuation.

Performance & Compliance Summary

Executive Summary

• This report analyzes **demo_pure_tone_1k.wav**.
• Sampling rate: **48000.0 Hz**.
• Tonal components were detected near **785.2, 960.9, 1002.0, 1043.0, 1212.9 Hz**.
• The filter pipeline includes **1** IIR notch filter(s) at 1212.9 Hz.
• A FIR low-pass filter is applied with cutoff **10800.00 Hz** and **101** taps (≈ **2.104 ms** latency).

System Health Check

Status	Comment
Info	No obvious full-scale clipping observed.
Info	DC offset is within normal range.
Info	Signal duration ≈ 3.000 s (sufficient).

These checks provide a quick sanity review of the input signal and analysis conditions, including clipping, DC offset, and duration relative to the sampling rate.

Measurement Notes

Tonal Suppression Measurement:
• Suppression is computed from the Welch PSD of the input and filtered signals at the notch center frequency.
• PSD uses a Hann window and segment length up to 8192 samples; relative metrics are emphasized over absolute calibration.
• Suppression (dB) = PSD_before(f_0) – PSD_after(f_0).

SNR Measurement:
• A smoothed version of the signal (moving-average envelope) is treated as the useful signal component.
• Noise is defined as the deviation from this envelope in the time-domain.
• SNR_before and SNR_after are computed as 10·log10(P_signal / P_noise); improvement is the difference.

FIR Metrics:
• Passband ripple is computed from the magnitude response in the passband region using the designed FIR taps.
• Stopband attenuation is computed as the maximum magnitude in the stopband, expressed as the negative of the maximum in dB.

User Specification Interpretation

Main Tone Protection
• Main Tone Frequency defines a protected signal component. No notch filtering is applied within the specified tolerance range.

Tonal Suppression Target
• Required Suppression specifies a verification target evaluated after filter design. It does not guarantee exact attenuation under all conditions.

SNR Target
• Output SNR is used for post-design evaluation only. The filter design process does not explicitly optimize SNR.

Bandwidth Constraint
• Maximum Bandwidth defines the frequency range to preserve. Frequencies above this limit may be attenuated by the FIR stage.

Filter Design Preferences
• Design preferences influence filter selection but do not override protection, stability, or verification rules.

Performance Gap Analysis

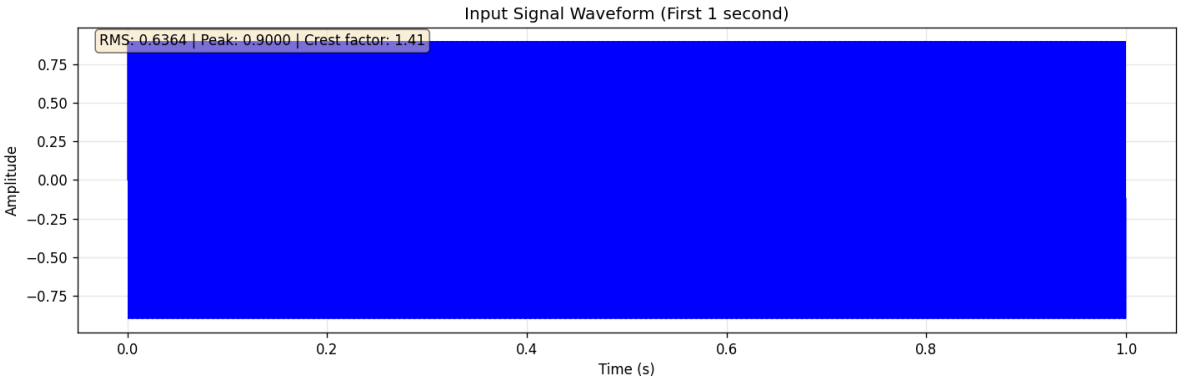
This section provides an engineering interpretation of why certain metrics may not fully meet the requested specifications, based on tonal behavior, filter alignment, and residual noise characteristics.

Engineering Recommendations

• The current filter design meets all user specifications; no corrective actions are required.

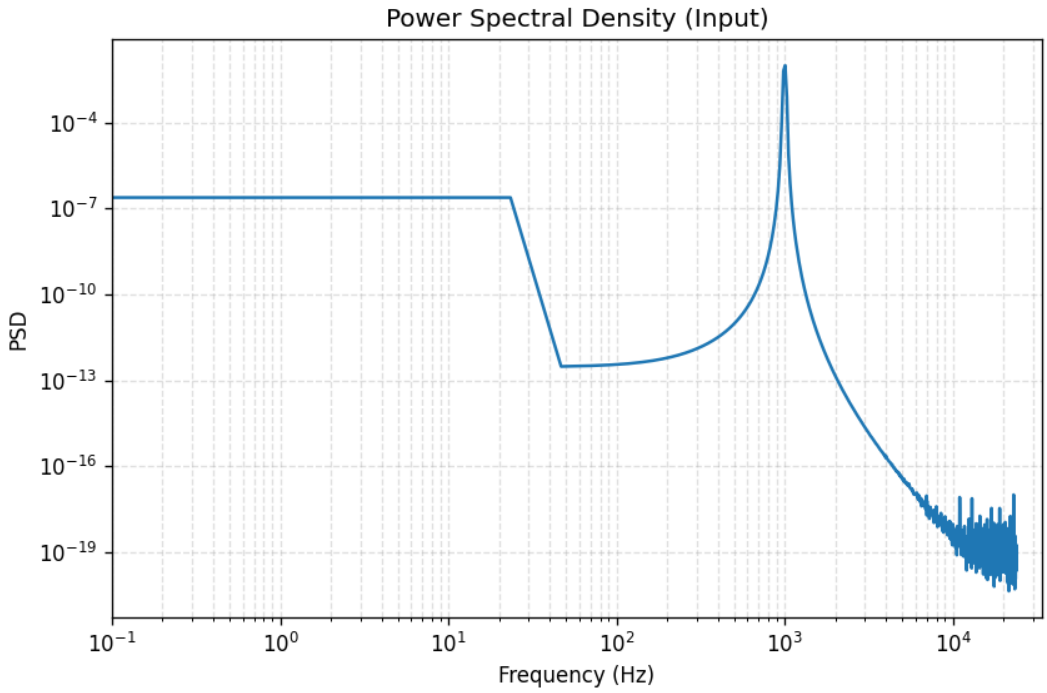
These recommendations provide practical options for further optimizing the filter design with respect to tonal rejection, SNR, and implementation constraints.

Input Signal Waveform



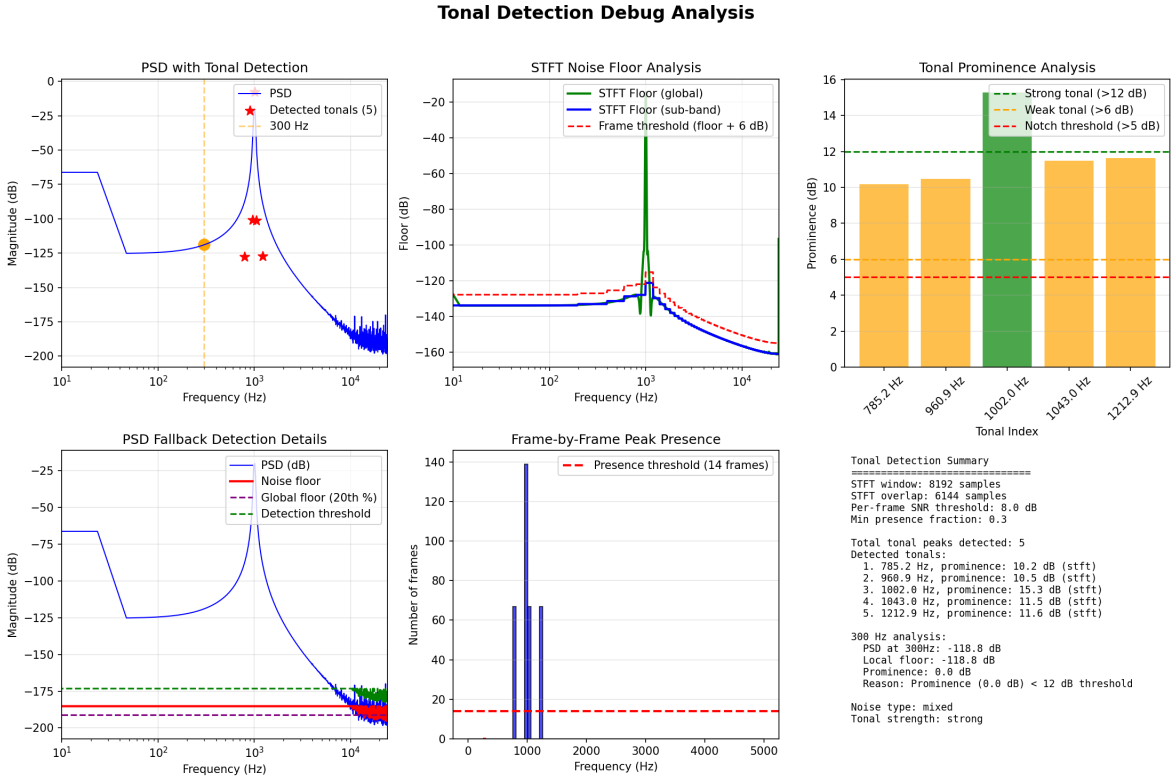
Time-domain representation of the input signal.

Power Spectral Density (Input)



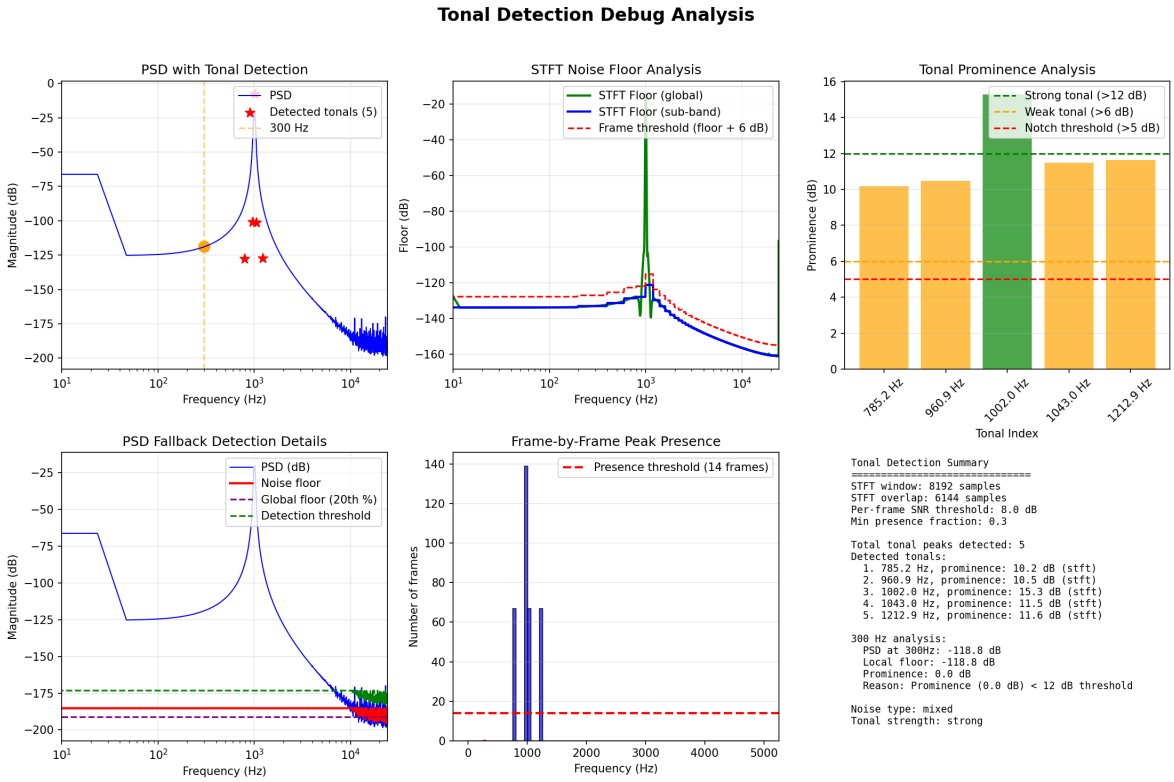
The input spectrum shows broadband noise and tonal components.

Tonal Detection Debug (Overview)



Detailed breakdown of the tonal detection process showing thresholds, noise floors, and candidate evaluations.

Tonal Detection Debug Analysis



Detailed breakdown of the tonal detection process showing thresholds, noise floors, and candidate evaluations.

Detection Summary:

Detected 5 tonal component(s):

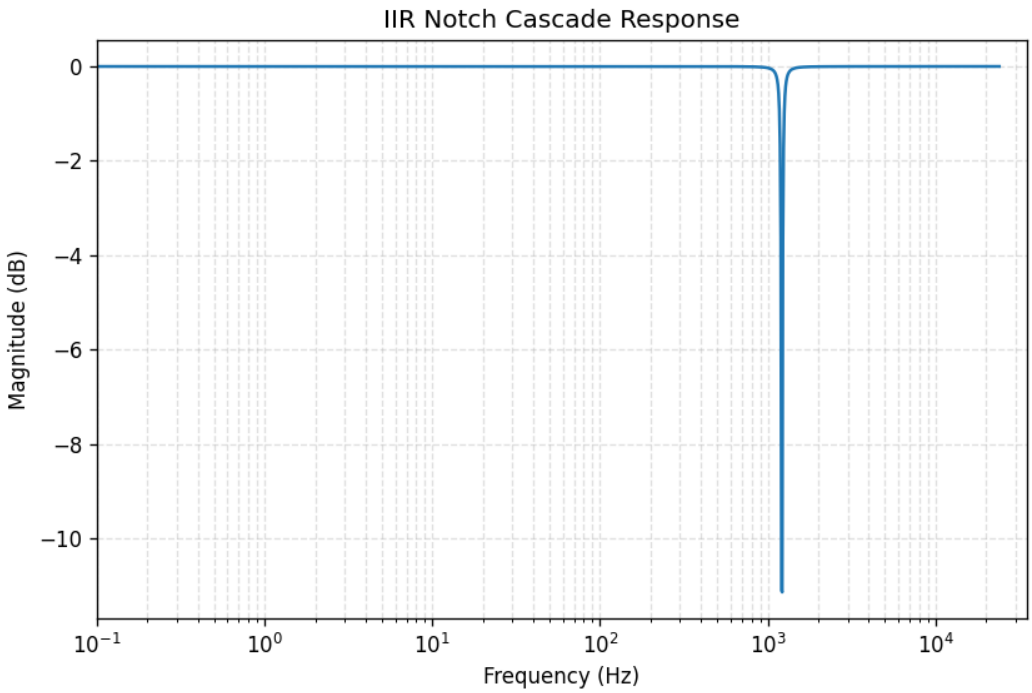
#	Frequency (Hz)	Prominence (dB)	Source	Notch Recommended?
1	785.2	10.2	stft	Yes
2	960.9	10.5	stft	Yes
3	1002.0	15.3	stft	Yes
4	1043.0	11.5	stft	Yes
5	1212.9	11.6	stft	Yes

Detection Parameters:

- STFT window size: 8192 samples
- STFT overlap: 6144 samples
- Per-frame SNR threshold: 8.0 dB
- Minimum presence fraction: 0.3

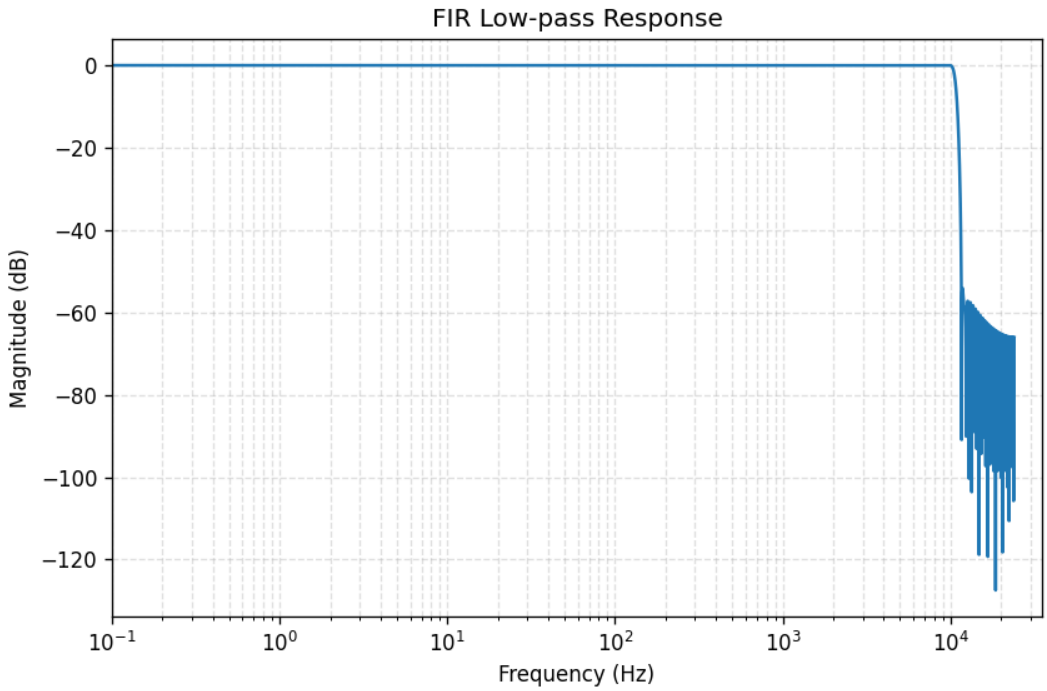
- PSD fallback thresholds: 12 dB (local prominence), 6 dB (global prominence)

IIR Notch Cascade Response



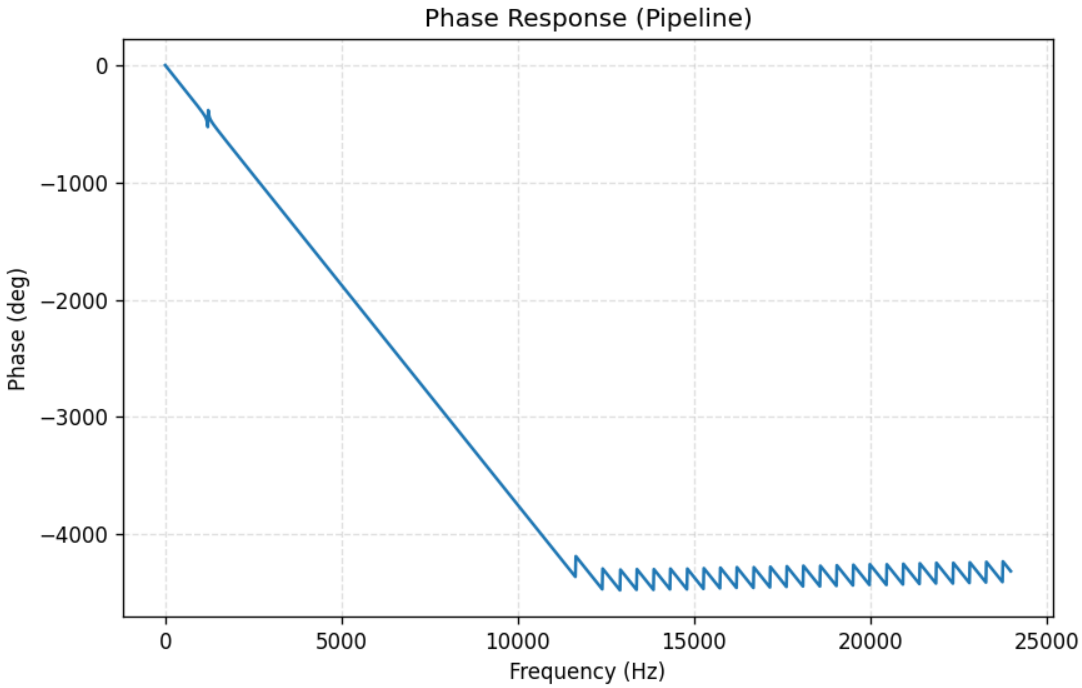
Each notch suppresses a narrow-band interference frequency.

FIR Low-pass Response



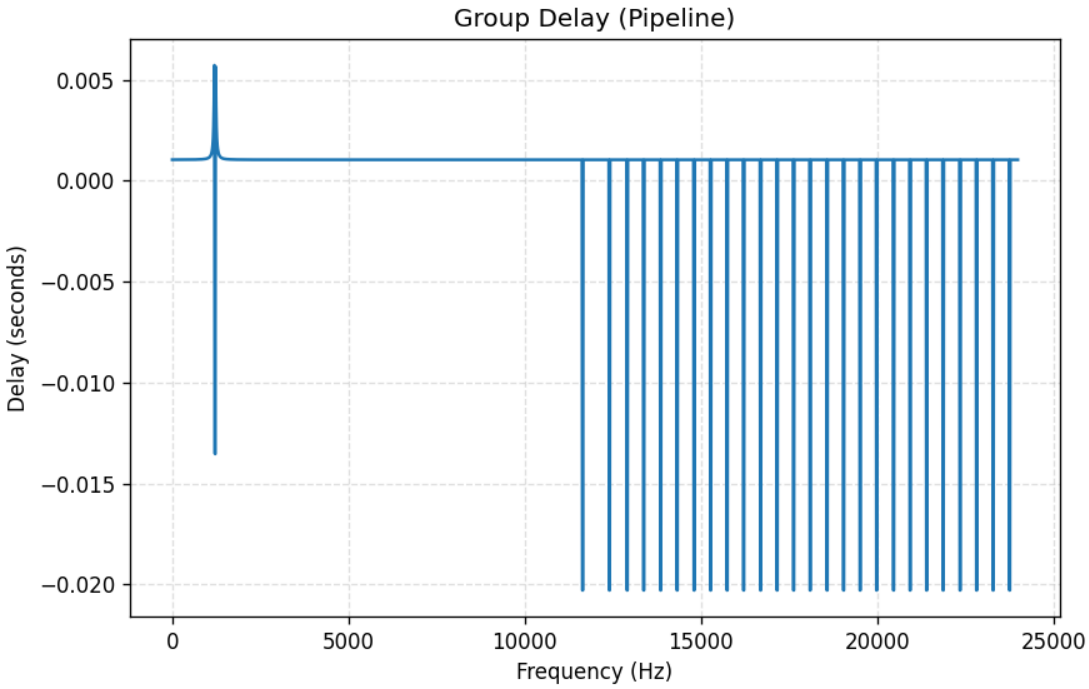
The FIR stage removes high-frequency noise beyond the cutoff.

Phase Response (Pipeline)



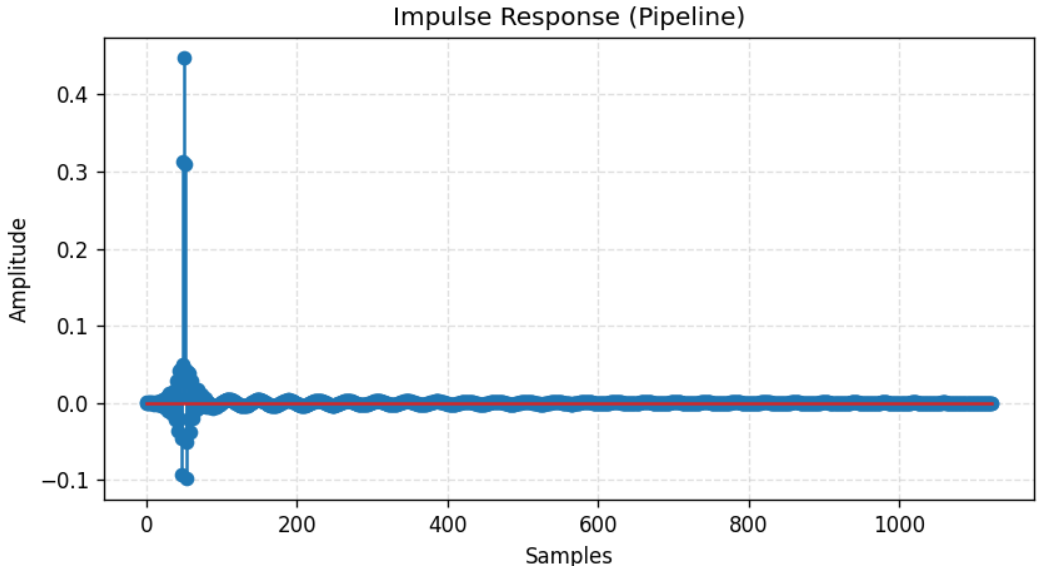
Phase remains approximately linear across most of the passband.

Group Delay (Pipeline)



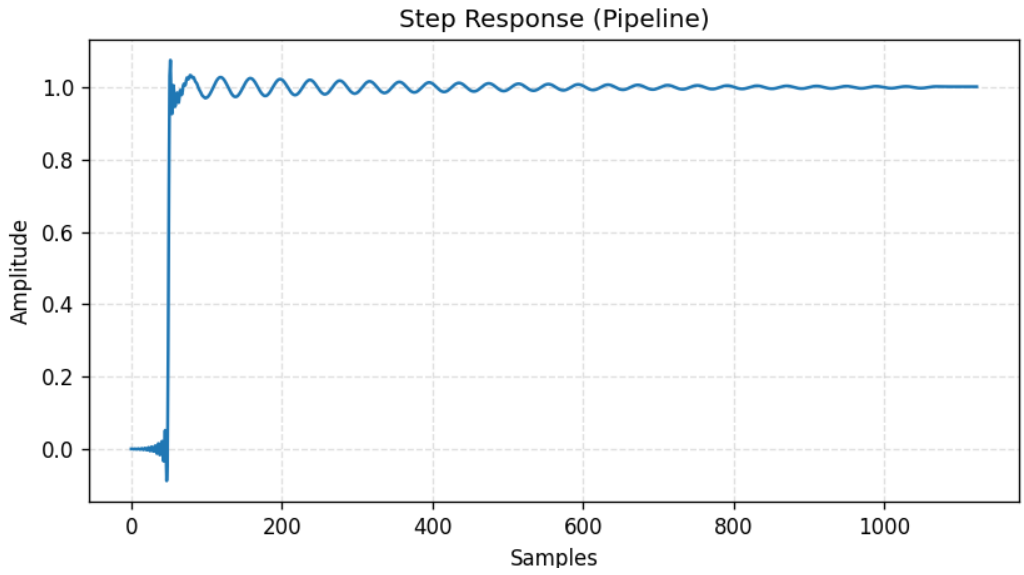
Group delay spikes indicate the frequency of notch filters.

Impulse Response (Pipeline)



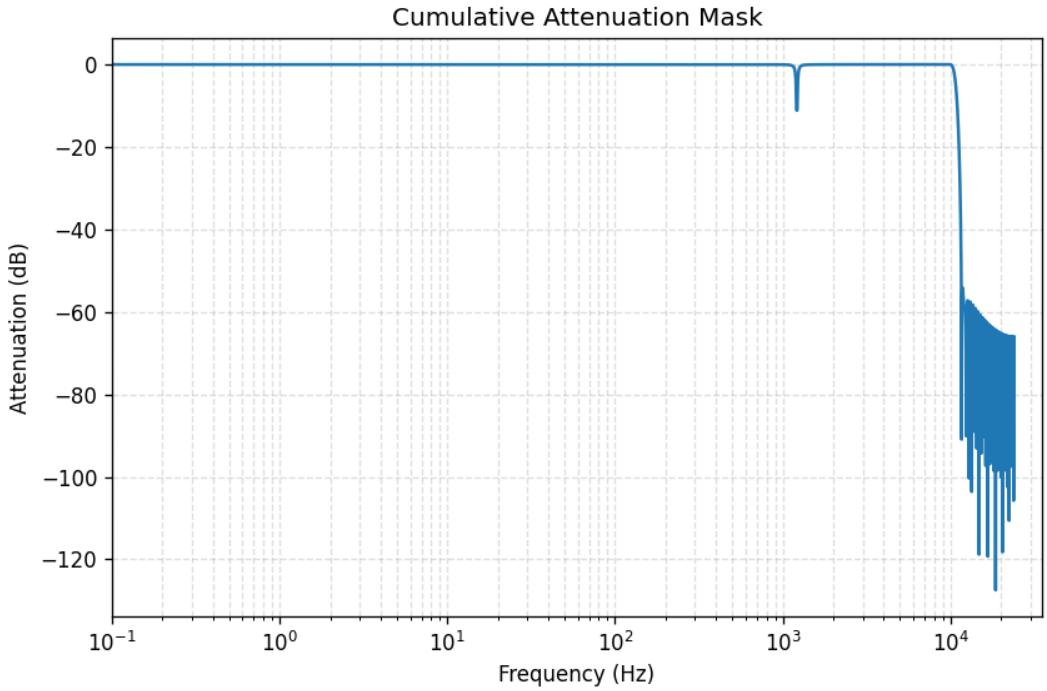
Impulse response reveals filter stability and temporal spread.

Step Response (Pipeline)



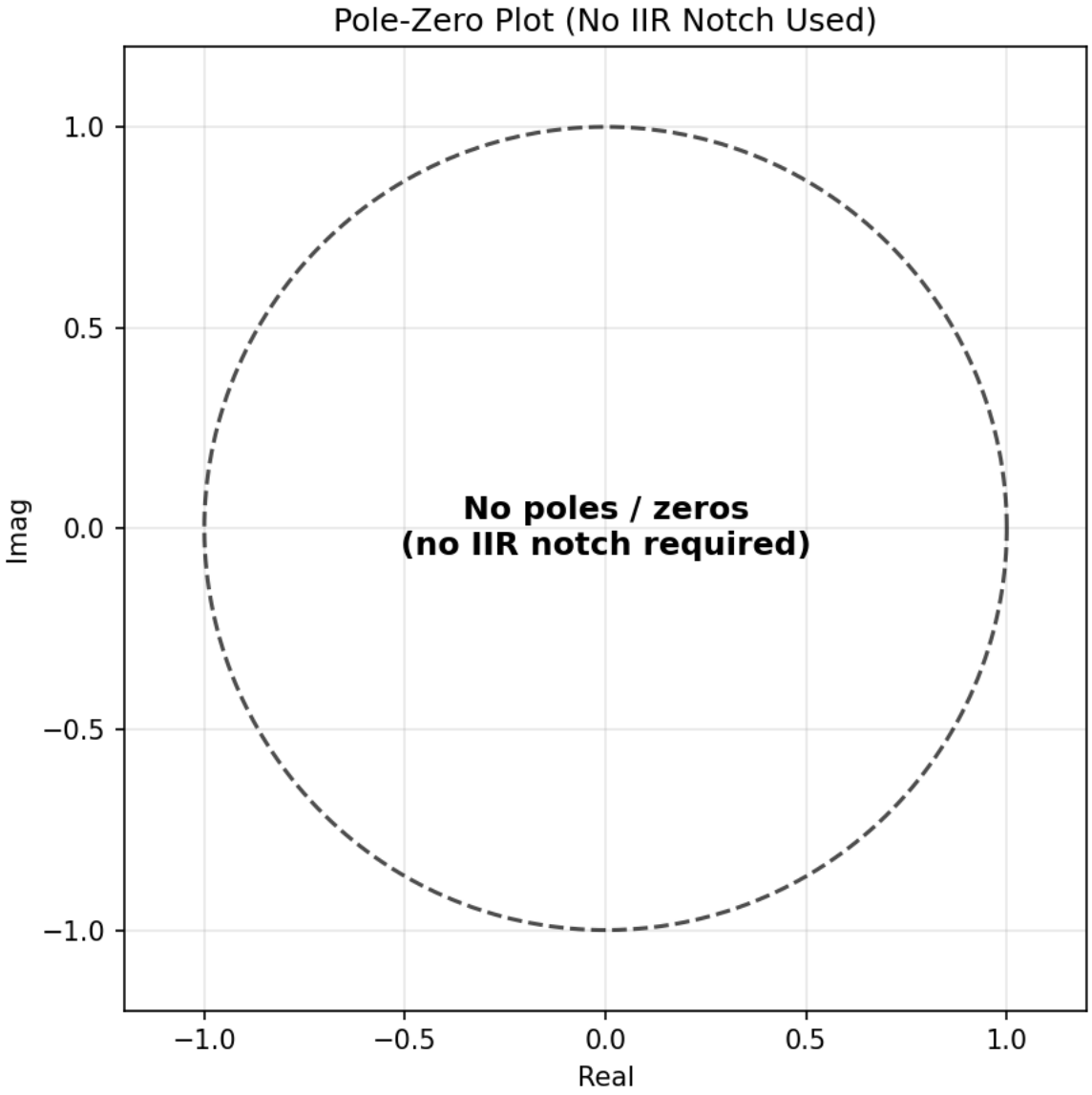
Step response highlights settling behavior and overshoot control.

Cumulative Attenuation Mask



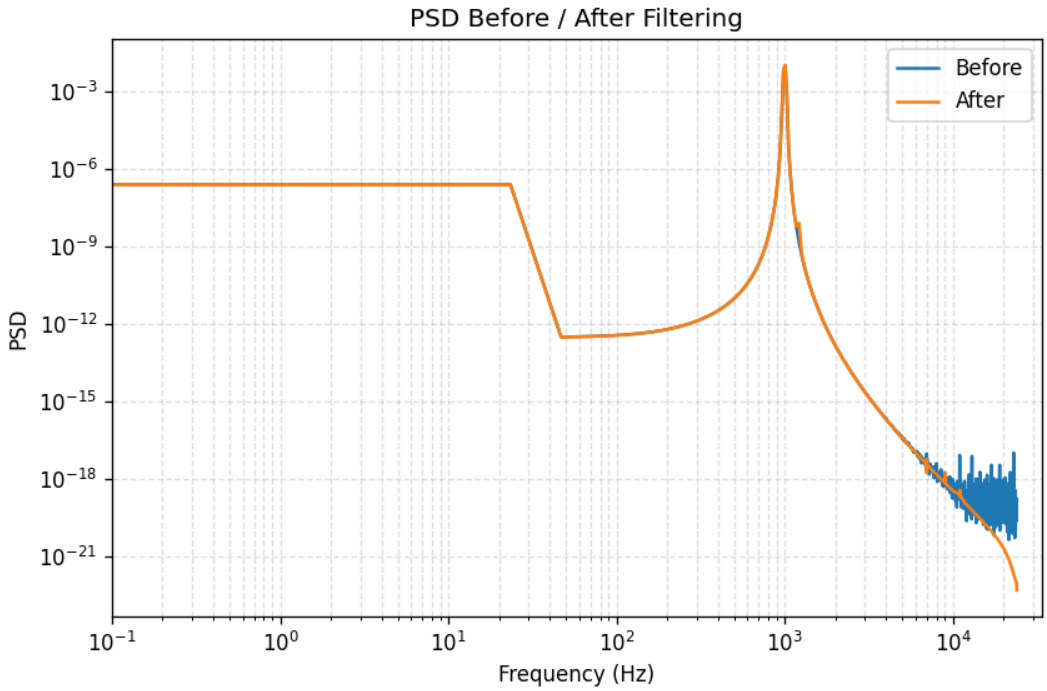
Shows total attenuation of the complete filter pipeline.

Pole-Zero Plot (Overall Pipeline)



Poles and zeros indicate stability and notch sharpness.

PSD Before / After Filtering



Demonstrates the overall improvement after filtering.

Filter Design Summary

Parameter	Value
Source File	demo_pure_tone_1k.wav
Sampling Rate (Hz)	48000.0
FIR Cutoff (Hz)	10800.00
FIR Tap Count	101
IIR Notches	1212.89 Hz (Q=30.0)

This summary captures the key parameters of the automatically designed filter pipeline, including FIR low-pass characteristics and IIR notch frequencies with their Q-factors.

IIR Notch Detail Table

#	Center (Hz)	Q	Approx BW (Hz)
1	1212.89	30.0	40.430

Each notch section is implemented as a biquad (second-order IIR) with a pair of complex-conjugate zeros on the unit circle and poles slightly inside the unit circle to control bandwidth and stability.

Implementation Notes

Pipeline Notes:
• The filter cascade is stable and suitable for real-time use.
• IIR notch sections introduce negligible additional latency.
• FIR stage length is **101** taps, giving approximately **2.104 ms** of group delay at the center of the passband.
• The exported C header and runtime implementation can be integrated into embedded systems, DSPs, or microcontrollers without modification.