

SignalForge Noise Analysis & Filter Design Report

Source File: low_freq_50hz_hum.wav

Sampling Rate: 44100.0 Hz

User Specifications

Metric	Specification
IIR Notch Count	<= 0 count

This table is rendered from design_result.json (verify output). Undefined specifications are shown as N/A.

Performance & Compliance Summary

Metric	Specification	Measured	Margin	Pass?
IIR Notch Count	<= 0 count	0 count	0 count	PASS

All defined user specifications are satisfied by the current filter design.

Executive Summary

- This report analyzes **low_freq_50hz_hum.wav**.
- Sampling rate: **44100.0 Hz**.
- This report was generated strictly under the user-specified constraints: **min_prominence=6.0 dB**, **max_notches=0**.
- Tonal components were detected near **48.4, 86.1, 150.7, 247.6, 253.0, 349.9, 446.8, 452.2, 500.6, 549.1, 597.5, 602.9, 651.4, 699.8, 748.3, 796.7, 802.1, 850.6, 899.0, 904.4, 947.5, 952.8, 995.9, 1001.3, 1049.7, 1098.2, 1103.6, 1146.6, 1152.0, 1195.1, 1200.5, 1248.9, 1297.4, 1302.8, 1399.7, 1405.0, 1448.1, 1496.6, 1501.9, 1545.0, 1550.4, 1598.8, 1604.2, 1647.3, 1652.7, 1695.7, 1701.1, 1749.6, 1798.0, 1803.4, 1894.9, 1900.3, 1948.8, 1997.2, 2002.6, 2051.0, 2099.5, 2104.9, 2147.9, 2153.3, 2196.4, 2201.8, 2250.2, 2298.7, 2304.1, 2347.1, 2352.5, 2395.6, 2401.0, 2449.4, 2497.9, 2503.2, 2551.7, 2600.1, 2648.6, 2697.0, 2702.4, 2750.9, 2799.3, 2804.7, 2847.8, 2896.2, 2901.6, 3003.9, 3052.3, 3095.4, 3100.8, 3149.2, 3197.7, 3203.1, 3251.5, 3300.0, 3348.4, 3396.9, 3402.2, 3450.7, 3499.1, 3547.6, 3601.4, 3698.3, 3752.2, 3800.6, 3849.1, 3897.5, 3902.9, 3951.3, 3999.8, 4048.2, 4102.1, 4199.0, 4247.4, 4252.8, 4301.3, 4349.7, 4398.2, 4446.6, 4452.0, 4500.4, 4548.9, 4597.3, 4602.7, 4651.2, 4699.6, 4748.1, 4801.9, 4898.8, 4952.6, 5001.1, 5049.5, 5098.0, 5151.8, 5200.3, 5248.7, 5302.6, 5351.0, 5399.5, 5447.9, 5501.7, 5550.2, 5598.6, 5652.5, 5700.9, 5749.4, 5797.8, 5851.6, 5900.1, 6002.4, 6050.8, 6099.3, 6147.7, 6201.6, 6250.0, 6298.5, 6352.3, 6400.7, 6449.2, 6497.6, 6551.5, 6599.9, 6648.4, 6702.2, 6750.7, 6799.1, 6847.6, 6901.4, 6949.8, 6998.3, 7052.1, 7100.6, 7149.0, 7251.3, 7299.8, 7348.2, 7402.0, 7450.5, 7498.9, 7547.4, 7601.2, 7649.7, 7698.1, 7752.0, 7800.4, 7848.9, 7951.1, 7999.6, 8048.0, 8101.9, 8198.8, 8247.2, 8252.6, 8301.0,**

8397.9, 8451.8, 8500.2, 8548.7, 8651.0, 8699.4, 8747.9, 8801.7, 8850.1, 8898.6, 8952.4, 9000.9, 9049.3, 9097.8, 9151.6, 9200.1, 9248.5, 9302.3, 9350.8, 9399.2, 9447.7, 9501.5, 9550.0, 9598.4, 9652.3, 9700.7, 9749.2, 9851.4, 9899.9, 9948.3, 10002.2, 10050.6, 10099.1, 10147.5, 10201.4, 10249.8, 10298.3, 10352.1, 10400.5, 10449.0, 10599.7, 10648.2, 10702.0, 10798.9, 10847.4, 10852.7, 10901.2, 10949.6, 10998.1, 11051.9, 11100.4, 11148.8, 11251.1, 11299.5, 11348.0, 11401.8, 11450.3, 11498.7, 11552.6, 11601.0, 11649.5, 11697.9, 11751.7, 11800.2, 11848.6, 11950.9, 11999.4, 12047.8, 12101.7, 12150.1, 12198.6, 12252.4, 12300.8, 12349.3, 12451.6, 12500.0, 12650.8, 12699.2, 12747.7, 12801.5, 12849.9, 12898.4, 12952.2, 13000.7, 13049.1, 13151.4, 13199.9, 13248.3, 13302.1, 13350.6, 13399.0, 13447.5, 13501.3, 13549.8, 13598.2, 13652.1, 13700.5, 13749.0, 13851.2, 13899.7, 13948.1, 14002.0, 14050.4, 14098.9, 14147.3, 14152.7, 14201.1, 14249.6, 14298.0, 14351.9, 14400.3, 14448.8, 14551.1, 14599.5, 14648.0, 14701.8, 14750.2, 14798.7, 14847.1, 14852.5, 14901.0, 14949.4, 14997.9, 15051.7, 15100.2, 15250.9, 15299.3, 15347.8, 15401.6, 15450.1, 15498.5, 15552.4, 15600.8, 15649.3, 15800.0, 15848.4, 15950.7, 15999.2, 16047.6, 16101.5, 16149.9, 16198.4, 16252.2, 16300.6, 16349.1, 16499.8, 16548.3, 16602.1, 16650.5, 16699.0, 16747.4, 16801.3, 16849.7, 16898.2, 16952.0, 17000.5, 17048.9, 17151.2, 17199.6, 17248.1, 17301.9, 17350.4, 17398.8, 17447.3, 17452.7, 17501.1, 17549.6, 17598.0, 17651.8, 17700.3, 17748.7, 17899.5, 17947.9, 18001.8, 18050.2, 18098.7, 18152.5, 18200.9, 18249.4, 18351.7, 18400.1, 18448.6, 18550.9, 18599.3, 18647.8, 18701.6, 18750.0, 18798.5, 18852.3, 18900.8, 18949.2, 19051.5, 19100.0, 19148.4, 19202.2, 19250.7, 19299.1, 19347.6, 19401.4, 19449.9, 19498.3, 19552.1, 19600.6, 19751.3, 19799.8, 19848.2, 19902.1, 19999.0, 20047.4, 20101.2, 20149.7, 20198.1, 20252.0, 20300.4, 20348.9, 20451.2, 20499.6, 20548.1, 20601.9, 20650.3, 20698.8, 20752.6, 20801.1, 20849.5, 20898.0, 20951.8, 21000.3, 21048.7, 21151.0, 21199.4, 21247.9, 21301.7, 21350.2, 21398.6, 21452.5, 21500.9, 21549.4, 21651.6, 21700.1, 21748.5, 21802.4, 21850.8, 21899.3, 21947.7, 22001.6 Hz.

- Note: detection may identify multiple candidates; notch placement is constrained by user settings (e.g., max notch count, prominence thresholds, and protected bands).
- The filter pipeline includes no IIR notch stages.
- A FIR low-pass filter is applied with cutoff **9922.50 Hz** and **101** taps (approx **2.290 ms** latency).
- **All user specifications are satisfied.**

System Health Check

Status	Comment
Info	No obvious full-scale clipping observed.
Info	DC offset is within normal range.
Info	Signal duration >= 10.000 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 selected tonal frequency.
- Suppression (dB) = $10 \cdot \log_{10}(\text{PSD_before}(f_0) / \text{PSD_after}(f_0))$.

SNR Measurement:

- SNR is estimated from PSD statistics, optionally excluding narrow bands around notch frequencies.
- $\text{total_power} = \text{sum}(\text{PSD})$, $\text{noise_power} \approx \text{median}(\text{PSD}) * N_{\text{bins}}$, $\text{signal_power} = \text{total_power} - \text{noise_power}$.
- $\text{SNR(dB)} = 10 * \log_{10}(\text{signal_power} / \text{noise_power})$. If $\text{signal_power} \leq 0$ under this estimator, SNR is reported as N/A.

- Note: For tone-dominant signals or near numerical-noise-floor inputs, broadband SNR may be non-representative; interpret SNR together with tonal suppression and the before/after PSD.

Applicability Note:

- For tone-dominant signals, tonal suppression is the primary performance indicator; broadband SNR metrics may be less representative and are provided for reference only.

FIR Metrics:

- Passband ripple is measured from the magnitude response in a passband region excluding the transition band near cutoff.
- Stopband attenuation is measured from the stopband magnitude response (robust percentile-based estimate).

User Specification Interpretation

General Principle

- All outcomes reported here are produced under the user-specified constraints configured in the SignalForge UI. Detection results may include multiple tonal candidates; the final filter design applies only a constrained subset according to notch budget, thresholds, and protected-band rules.

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

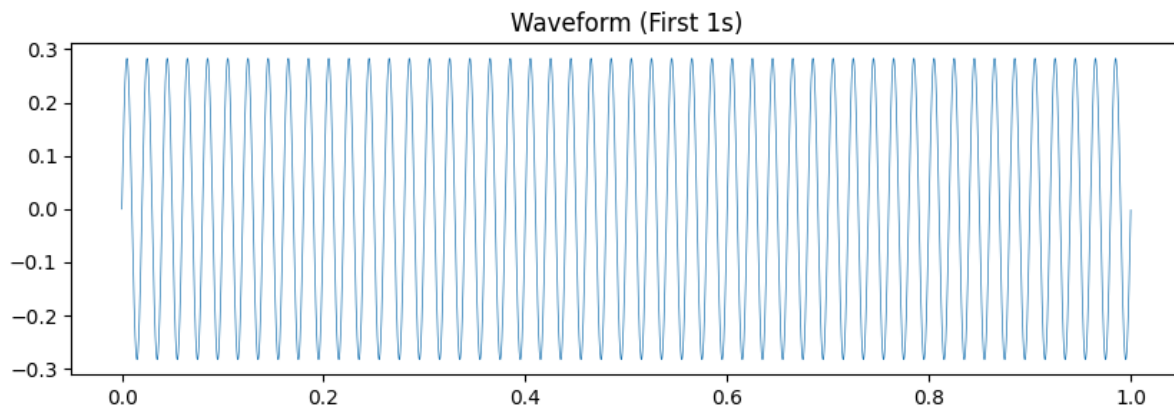
This section provides an engineering interpretation of why certain metrics may not fully meet the requested specifications, based on tonal behavior, filter alignment, and residual noise characteristics.

Engineering Recommendations

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

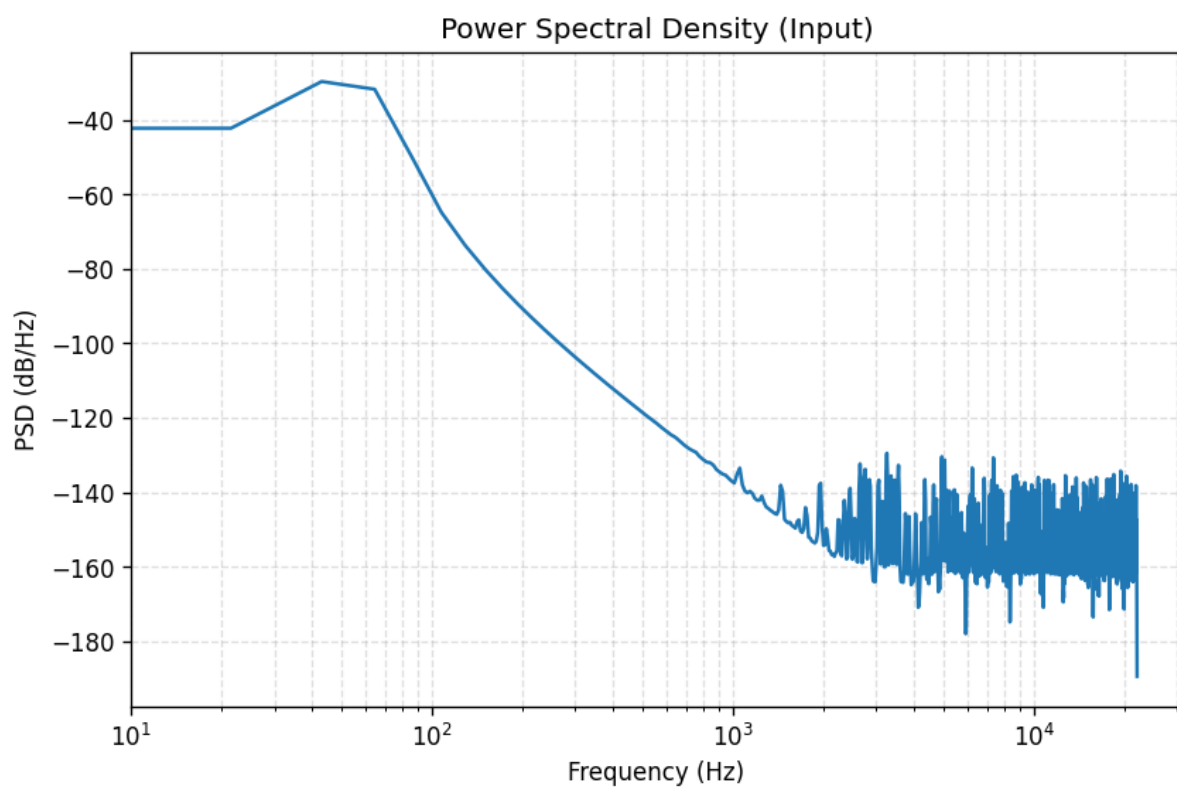
These recommendations provide practical options for further optimizing the filter design with respect to tonal rejection, SNR, and implementation constraints.

Input Signal Waveform



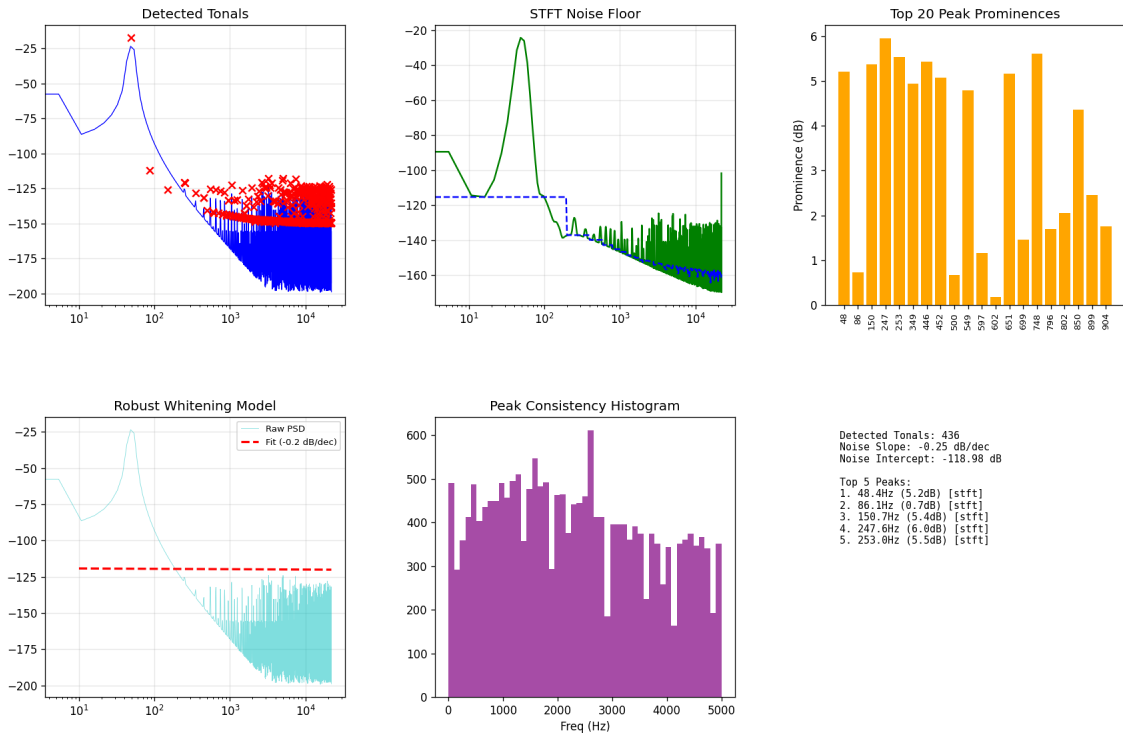
Time-domain representation of the input signal.

Power Spectral Density (Input)



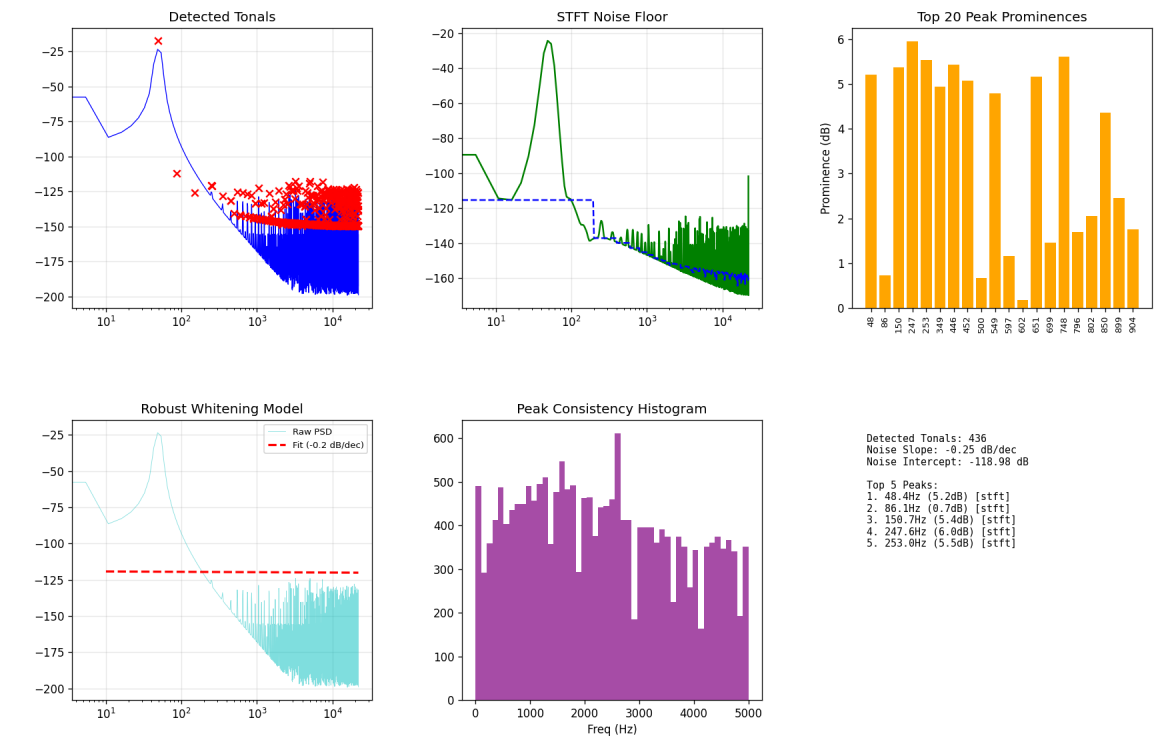
The input spectrum shows broadband noise and tonal components.

Tonal Detection Debug (Overview)



Detailed breakdown of tonal detection showing thresholds and candidate evaluations.

Tonal Detection Debug Analysis



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

Detection Summary:

Detected 436 tonal component(s):

#	Frequency (Hz)	Prominence (dB)	Source	Notch Recommended?
1	48.4	5.2	stft_voting	Yes
2	86.1	0.7	stft_voting	No (below 5 dB threshold)
3	150.7	5.4	stft_voting	Yes
4	247.6	6.0	stft_voting	Yes
5	253.0	5.5	stft_voting	Yes
6	349.9	4.9	stft_voting	No (below 5 dB threshold)
7	446.8	5.4	stft_voting	Yes
8	452.2	5.1	stft_voting	Yes
9	500.6	0.7	stft_voting	No (below 5 dB threshold)
10	549.1	4.8	stft_voting	No (below 5 dB threshold)
11	597.5	1.2	stft_voting	No (below 5 dB threshold)

12	602.9	0.2	stft_voting	No (below 5 dB threshold)
13	651.4	5.2	stft_voting	Yes
14	699.8	1.5	stft_voting	No (below 5 dB threshold)
15	748.3	5.6	stft_voting	Yes
16	796.7	1.7	stft_voting	No (below 5 dB threshold)
17	802.1	2.0	stft_voting	No (below 5 dB threshold)
18	850.6	4.4	stft_voting	No (below 5 dB threshold)
19	899.0	2.5	stft_voting	No (below 5 dB threshold)
20	904.4	1.8	stft_voting	No (below 5 dB threshold)
21	947.5	5.1	stft_voting	Yes
22	952.8	5.1	stft_voting	Yes
23	995.9	2.6	stft_voting	No (below 5 dB threshold)
24	1001.3	2.6	stft_voting	No (below 5 dB threshold)
25	1049.7	3.7	stft_voting	No (below 5 dB threshold)
26	1098.2	3.2	stft_voting	No (below 5 dB threshold)
27	1103.6	2.7	stft_voting	No (below 5 dB threshold)
28	1146.6	5.2	stft_voting	Yes
29	1152.0	5.4	stft_voting	Yes
30	1195.1	3.0	stft_voting	No (below 5 dB threshold)
31	1200.5	2.9	stft_voting	No (below 5 dB threshold)
32	1248.9	4.9	stft_voting	No (below 5 dB threshold)
33	1297.4	3.6	stft_voting	No (below 5 dB threshold)
34	1302.8	3.4	stft_voting	No (below 5 dB threshold)
35	1399.7	3.4	stft_voting	No (below 5 dB threshold)
36	1405.0	3.4	stft_voting	No (below 5 dB threshold)
37	1448.1	5.8	stft_voting	Yes
38	1496.6	3.7	stft_voting	No (below 5 dB threshold)
39	1501.9	3.9	stft_voting	No (below 5 dB threshold)
40	1545.0	4.7	stft_voting	No (below 5 dB threshold)
41	1550.4	4.9	stft_voting	No (below 5 dB threshold)
42	1598.8	4.0	stft_voting	No (below 5 dB threshold)
43	1604.2	3.8	stft_voting	No (below 5 dB threshold)
44	1647.3	5.2	stft_voting	Yes
45	1652.7	5.2	stft_voting	Yes
46	1695.7	3.8	stft_voting	No (below 5 dB threshold)

47	1701.1	4.1	stft_voting	No (below 5 dB threshold)
48	1749.6	4.1	stft_voting	No (below 5 dB threshold)
49	1798.0	4.0	stft_voting	No (below 5 dB threshold)
50	1803.4	4.3	stft_voting	No (below 5 dB threshold)
51	1894.9	4.1	stft_voting	No (below 5 dB threshold)
52	1900.3	4.4	stft_voting	No (below 5 dB threshold)
53	1948.8	4.9	stft_voting	No (below 5 dB threshold)
54	1997.2	4.3	stft_voting	No (below 5 dB threshold)
55	2002.6	4.4	stft_voting	No (below 5 dB threshold)
56	2051.0	5.2	stft_voting	Yes
57	2099.5	4.6	stft_voting	No (below 5 dB threshold)
58	2104.9	4.2	stft_voting	No (below 5 dB threshold)
59	2147.9	4.1	stft_voting	No (below 5 dB threshold)
60	2153.3	4.4	stft_voting	No (below 5 dB threshold)
61	2196.4	4.6	stft_voting	No (below 5 dB threshold)
62	2201.8	4.6	stft_voting	No (below 5 dB threshold)
63	2250.2	3.9	stft_voting	No (below 5 dB threshold)
64	2298.7	4.7	stft_voting	No (below 5 dB threshold)
65	2304.1	4.6	stft_voting	No (below 5 dB threshold)
66	2347.1	6.4	stft_voting	Yes
67	2352.5	6.4	stft_voting	Yes
68	2395.6	4.6	stft_voting	No (below 5 dB threshold)
69	2401.0	4.7	stft_voting	No (below 5 dB threshold)
70	2449.4	4.1	stft_voting	No (below 5 dB threshold)
71	2497.9	4.9	stft_voting	No (below 5 dB threshold)
72	2503.2	5.0	stft_voting	Yes
73	2551.7	5.5	stft_voting	Yes
74	2600.1	5.2	stft_voting	Yes
75	2648.6	5.1	stft_voting	Yes
76	2697.0	5.5	stft_voting	Yes
77	2702.4	4.8	stft_voting	No (below 5 dB threshold)
78	2750.9	4.4	stft_voting	No (below 5 dB threshold)
79	2799.3	4.7	stft_voting	No (below 5 dB threshold)
80	2804.7	3.8	stft_voting	No (below 5 dB threshold)
81	2847.8	6.3	stft_voting	Yes

82	2896.2	5.3	stft_voting	Yes
83	2901.6	4.3	stft_voting	No (below 5 dB threshold)
84	3003.9	5.4	stft_voting	Yes
85	3052.3	6.4	stft_voting	Yes
86	3095.4	3.7	stft_voting	No (below 5 dB threshold)
87	3100.8	4.7	stft_voting	No (below 5 dB threshold)
88	3149.2	4.3	stft_voting	No (below 5 dB threshold)
89	3197.7	5.2	stft_voting	Yes
90	3203.1	6.3	stft_voting	Yes
91	3251.5	5.3	stft_voting	Yes
92	3300.0	5.3	stft_voting	Yes
93	3348.4	5.4	stft_voting	Yes
94	3396.9	5.5	stft_voting	Yes
95	3402.2	5.3	stft_voting	Yes
96	3450.7	4.2	stft_voting	No (below 5 dB threshold)
97	3499.1	5.3	stft_voting	Yes
98	3547.6	6.5	stft_voting	Yes
99	3601.4	5.5	stft_voting	Yes
100	3698.3	5.5	stft_voting	Yes
101	3752.2	6.2	stft_voting	Yes
102	3800.6	5.4	stft_voting	Yes
103	3849.1	4.5	stft_voting	No (below 5 dB threshold)
104	3897.5	5.5	stft_voting	Yes
105	3902.9	5.4	stft_voting	Yes
106	3951.3	5.1	stft_voting	Yes
107	3999.8	5.5	stft_voting	Yes
108	4048.2	5.6	stft_voting	Yes
109	4102.1	5.4	stft_voting	Yes
110	4199.0	5.5	stft_voting	Yes
111	4247.4	6.4	stft_voting	Yes
112	4252.8	6.5	stft_voting	Yes
113	4301.3	5.3	stft_voting	Yes
114	4349.7	3.7	stft_voting	No (below 5 dB threshold)
115	4398.2	5.5	stft_voting	Yes
116	4446.6	5.2	stft_voting	Yes

117	4452.0	5.4	stft_voting	Yes
118	4500.4	5.7	stft_voting	Yes
119	4548.9	4.7	stft_voting	No (below 5 dB threshold)
120	4597.3	5.2	stft_voting	Yes
121	4602.7	5.6	stft_voting	Yes
122	4651.2	4.8	stft_voting	No (below 5 dB threshold)
123	4699.6	5.3	stft_voting	Yes
124	4748.1	5.8	stft_voting	Yes
125	4801.9	5.6	stft_voting	Yes
126	4898.8	5.5	stft_voting	Yes
127	4952.6	6.8	stft_voting	Yes
128	5001.1	5.5	stft_voting	Yes
129	5049.5	3.9	stft_voting	No (below 5 dB threshold)
130	5098.0	5.4	stft_voting	Yes
131	5151.8	5.7	stft_voting	Yes
132	5200.3	5.3	stft_voting	Yes
133	5248.7	5.0	stft_voting	No (below 5 dB threshold)
134	5302.6	5.1	stft_voting	Yes
135	5351.0	4.6	stft_voting	No (below 5 dB threshold)
136	5399.5	5.2	stft_voting	Yes
137	5447.9	6.0	stft_voting	Yes
138	5501.7	5.4	stft_voting	Yes
139	5550.2	3.6	stft_voting	No (below 5 dB threshold)
140	5598.6	5.4	stft_voting	Yes
141	5652.5	6.6	stft_voting	Yes
142	5700.9	5.4	stft_voting	Yes
143	5749.4	4.1	stft_voting	No (below 5 dB threshold)
144	5797.8	5.1	stft_voting	Yes
145	5851.6	5.5	stft_voting	Yes
146	5900.1	5.1	stft_voting	Yes
147	6002.4	4.7	stft_voting	No (below 5 dB threshold)
148	6050.8	4.4	stft_voting	No (below 5 dB threshold)
149	6099.3	5.1	stft_voting	Yes
150	6147.7	6.3	stft_voting	Yes
151	6201.6	5.2	stft_voting	Yes

152	6250.0	3.4	stft_voting	No (below 5 dB threshold)
153	6298.5	5.2	stft_voting	Yes
154	6352.3	6.4	stft_voting	Yes
155	6400.7	5.1	stft_voting	Yes
156	6449.2	4.5	stft_voting	No (below 5 dB threshold)
157	6497.6	5.0	stft_voting	No (below 5 dB threshold)
158	6551.5	5.2	stft_voting	Yes
159	6599.9	4.4	stft_voting	No (below 5 dB threshold)
160	6648.4	5.4	stft_voting	Yes
161	6702.2	5.0	stft_voting	Yes
162	6750.7	4.1	stft_voting	No (below 5 dB threshold)
163	6799.1	5.0	stft_voting	No (below 5 dB threshold)
164	6847.6	6.5	stft_voting	Yes
165	6901.4	5.2	stft_voting	Yes
166	6949.8	3.8	stft_voting	No (below 5 dB threshold)
167	6998.3	5.1	stft_voting	Yes
168	7052.1	5.6	stft_voting	Yes
169	7100.6	4.8	stft_voting	No (below 5 dB threshold)
170	7149.0	4.6	stft_voting	No (below 5 dB threshold)
171	7251.3	5.0	stft_voting	No (below 5 dB threshold)
172	7299.8	4.8	stft_voting	No (below 5 dB threshold)
173	7348.2	5.7	stft_voting	Yes
174	7402.0	4.9	stft_voting	No (below 5 dB threshold)
175	7450.5	3.9	stft_voting	No (below 5 dB threshold)
176	7498.9	5.0	stft_voting	Yes
177	7547.4	6.8	stft_voting	Yes
178	7601.2	5.1	stft_voting	Yes
179	7649.7	3.7	stft_voting	No (below 5 dB threshold)
180	7698.1	5.2	stft_voting	Yes
181	7752.0	5.9	stft_voting	Yes
182	7800.4	4.5	stft_voting	No (below 5 dB threshold)
183	7848.9	4.8	stft_voting	No (below 5 dB threshold)
184	7951.1	4.8	stft_voting	No (below 5 dB threshold)
185	7999.6	4.5	stft_voting	No (below 5 dB threshold)
186	8048.0	6.0	stft_voting	Yes

187	8101.9	5.3	stft_voting	Yes
188	8198.8	5.0	stft_voting	No (below 5 dB threshold)
189	8247.2	6.5	stft_voting	Yes
190	8252.6	6.5	stft_voting	Yes
191	8301.0	4.8	stft_voting	No (below 5 dB threshold)
192	8397.9	5.3	stft_voting	Yes
193	8451.8	5.6	stft_voting	Yes
194	8500.2	4.4	stft_voting	No (below 5 dB threshold)
195	8548.7	5.0	stft_voting	Yes
196	8651.0	4.6	stft_voting	No (below 5 dB threshold)
197	8699.4	4.4	stft_voting	No (below 5 dB threshold)
198	8747.9	6.1	stft_voting	Yes
199	8801.7	4.9	stft_voting	No (below 5 dB threshold)
200	8850.1	3.5	stft_voting	No (below 5 dB threshold)
201	8898.6	4.6	stft_voting	No (below 5 dB threshold)
202	8952.4	6.5	stft_voting	Yes
203	9000.9	4.5	stft_voting	No (below 5 dB threshold)
204	9049.3	4.2	stft_voting	No (below 5 dB threshold)
205	9097.8	5.4	stft_voting	Yes
206	9151.6	5.4	stft_voting	Yes
207	9200.1	4.4	stft_voting	No (below 5 dB threshold)
208	9248.5	5.2	stft_voting	Yes
209	9302.3	5.3	stft_voting	Yes
210	9350.8	4.4	stft_voting	No (below 5 dB threshold)
211	9399.2	4.5	stft_voting	No (below 5 dB threshold)
212	9447.7	6.3	stft_voting	Yes
213	9501.5	5.1	stft_voting	Yes
214	9550.0	3.5	stft_voting	No (below 5 dB threshold)
215	9598.4	5.1	stft_voting	Yes
216	9652.3	6.2	stft_voting	Yes
217	9700.7	4.5	stft_voting	No (below 5 dB threshold)
218	9749.2	4.4	stft_voting	No (below 5 dB threshold)
219	9851.4	5.2	stft_voting	Yes
220	9899.9	4.4	stft_voting	No (below 5 dB threshold)
221	9948.3	5.5	stft_voting	Yes

222	10002.2	5.5	stft_voting	Yes
223	10050.6	4.1	stft_voting	No (below 5 dB threshold)
224	10099.1	4.6	stft_voting	No (below 5 dB threshold)
225	10147.5	6.6	stft_voting	Yes
226	10201.4	5.0	stft_voting	Yes
227	10249.8	3.6	stft_voting	No (below 5 dB threshold)
228	10298.3	5.5	stft_voting	Yes
229	10352.1	6.0	stft_voting	Yes
230	10400.5	4.5	stft_voting	No (below 5 dB threshold)
231	10449.0	4.6	stft_voting	No (below 5 dB threshold)
232	10599.7	4.2	stft_voting	No (below 5 dB threshold)
233	10648.2	5.7	stft_voting	Yes
234	10702.0	5.7	stft_voting	Yes
235	10798.9	4.7	stft_voting	No (below 5 dB threshold)
236	10847.4	6.8	stft_voting	Yes
237	10852.7	6.8	stft_voting	Yes
238	10901.2	4.8	stft_voting	No (below 5 dB threshold)
239	10949.6	3.8	stft_voting	No (below 5 dB threshold)
240	10998.1	5.8	stft_voting	Yes
241	11051.9	5.8	stft_voting	Yes
242	11100.4	4.3	stft_voting	No (below 5 dB threshold)
243	11148.8	4.9	stft_voting	No (below 5 dB threshold)
244	11251.1	4.7	stft_voting	No (below 5 dB threshold)
245	11299.5	4.2	stft_voting	No (below 5 dB threshold)
246	11348.0	5.9	stft_voting	Yes
247	11401.8	5.6	stft_voting	Yes
248	11450.3	3.7	stft_voting	No (below 5 dB threshold)
249	11498.7	4.9	stft_voting	No (below 5 dB threshold)
250	11552.6	6.7	stft_voting	Yes
251	11601.0	4.6	stft_voting	No (below 5 dB threshold)
252	11649.5	4.0	stft_voting	No (below 5 dB threshold)
253	11697.9	5.7	stft_voting	Yes
254	11751.7	5.6	stft_voting	Yes
255	11800.2	4.2	stft_voting	No (below 5 dB threshold)
256	11848.6	5.1	stft_voting	Yes

257	11950.9	4.5	stft_voting	No (below 5 dB threshold)
258	11999.4	4.3	stft_voting	No (below 5 dB threshold)
259	12047.8	6.1	stft_voting	Yes
260	12101.7	5.4	stft_voting	Yes
261	12150.1	3.5	stft_voting	No (below 5 dB threshold)
262	12198.6	5.1	stft_voting	Yes
263	12252.4	6.5	stft_voting	Yes
264	12300.8	4.5	stft_voting	No (below 5 dB threshold)
265	12349.3	4.2	stft_voting	No (below 5 dB threshold)
266	12451.6	5.4	stft_voting	Yes
267	12500.0	4.9	stft_voting	No (below 5 dB threshold)
268	12650.8	4.3	stft_voting	No (below 5 dB threshold)
269	12699.2	4.4	stft_voting	No (below 5 dB threshold)
270	12747.7	6.4	stft_voting	Yes
271	12801.5	5.2	stft_voting	Yes
272	12849.9	3.5	stft_voting	No (below 5 dB threshold)
273	12898.4	5.3	stft_voting	Yes
274	12952.2	6.2	stft_voting	Yes
275	13000.7	4.3	stft_voting	No (below 5 dB threshold)
276	13049.1	4.4	stft_voting	No (below 5 dB threshold)
277	13151.4	5.2	stft_voting	Yes
278	13199.9	4.1	stft_voting	No (below 5 dB threshold)
279	13248.3	5.5	stft_voting	Yes
280	13302.1	5.8	stft_voting	Yes
281	13350.6	4.1	stft_voting	No (below 5 dB threshold)
282	13399.0	4.5	stft_voting	No (below 5 dB threshold)
283	13447.5	6.6	stft_voting	Yes
284	13501.3	4.9	stft_voting	No (below 5 dB threshold)
285	13549.8	3.6	stft_voting	No (below 5 dB threshold)
286	13598.2	5.6	stft_voting	Yes
287	13652.1	6.0	stft_voting	Yes
288	13700.5	4.2	stft_voting	No (below 5 dB threshold)
289	13749.0	4.7	stft_voting	No (below 5 dB threshold)
290	13851.2	4.9	stft_voting	No (below 5 dB threshold)
291	13899.7	4.1	stft_voting	No (below 5 dB threshold)

292	13948.1	5.8	stft_voting	Yes
293	14002.0	5.8	stft_voting	Yes
294	14050.4	3.9	stft_voting	No (below 5 dB threshold)
295	14098.9	4.7	stft_voting	No (below 5 dB threshold)
296	14147.3	6.6	stft_voting	Yes
297	14152.7	6.7	stft_voting	Yes
298	14201.1	4.8	stft_voting	No (below 5 dB threshold)
299	14249.6	3.9	stft_voting	No (below 5 dB threshold)
300	14298.0	5.8	stft_voting	Yes
301	14351.9	5.8	stft_voting	Yes
302	14400.3	4.2	stft_voting	No (below 5 dB threshold)
303	14448.8	4.8	stft_voting	No (below 5 dB threshold)
304	14551.1	4.7	stft_voting	No (below 5 dB threshold)
305	14599.5	4.1	stft_voting	No (below 5 dB threshold)
306	14648.0	6.0	stft_voting	Yes
307	14701.8	5.5	stft_voting	Yes
308	14750.2	3.7	stft_voting	No (below 5 dB threshold)
309	14798.7	4.8	stft_voting	No (below 5 dB threshold)
310	14847.1	6.5	stft_voting	Yes
311	14852.5	6.5	stft_voting	Yes
312	14901.0	4.5	stft_voting	No (below 5 dB threshold)
313	14949.4	4.1	stft_voting	No (below 5 dB threshold)
314	14997.9	5.8	stft_voting	Yes
315	15051.7	5.5	stft_voting	Yes
316	15100.2	4.0	stft_voting	No (below 5 dB threshold)
317	15250.9	4.4	stft_voting	No (below 5 dB threshold)
318	15299.3	4.3	stft_voting	No (below 5 dB threshold)
319	15347.8	6.2	stft_voting	Yes
320	15401.6	5.4	stft_voting	Yes
321	15450.1	3.4	stft_voting	No (below 5 dB threshold)
322	15498.5	5.2	stft_voting	Yes
323	15552.4	6.4	stft_voting	Yes
324	15600.8	4.3	stft_voting	No (below 5 dB threshold)
325	15649.3	4.3	stft_voting	No (below 5 dB threshold)
326	15800.0	4.1	stft_voting	No (below 5 dB threshold)

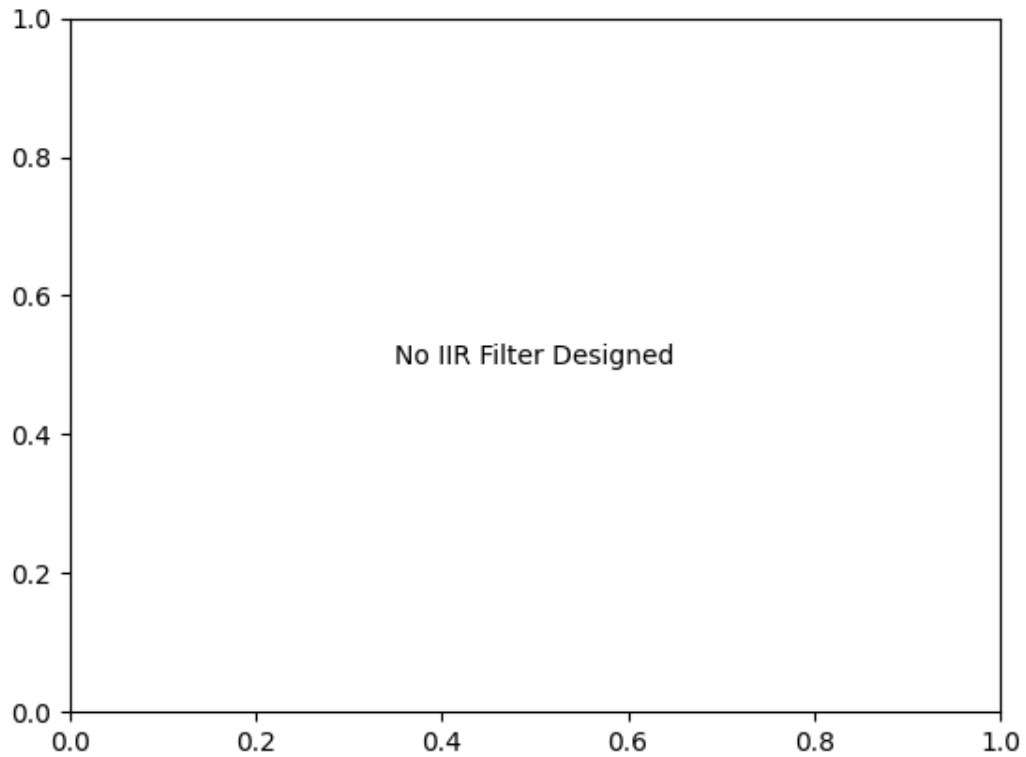
327	15848.4	5.3	stft_voting	Yes
328	15950.7	4.3	stft_voting	No (below 5 dB threshold)
329	15999.2	4.4	stft_voting	No (below 5 dB threshold)
330	16047.6	6.4	stft_voting	Yes
331	16101.5	5.2	stft_voting	Yes
332	16149.9	3.5	stft_voting	No (below 5 dB threshold)
333	16198.4	5.4	stft_voting	Yes
334	16252.2	6.2	stft_voting	Yes
335	16300.6	4.2	stft_voting	No (below 5 dB threshold)
336	16349.1	4.5	stft_voting	No (below 5 dB threshold)
337	16499.8	4.0	stft_voting	No (below 5 dB threshold)
338	16548.3	5.6	stft_voting	Yes
339	16602.1	5.9	stft_voting	Yes
340	16650.5	4.0	stft_voting	No (below 5 dB threshold)
341	16699.0	4.6	stft_voting	No (below 5 dB threshold)
342	16747.4	6.7	stft_voting	Yes
343	16801.3	4.9	stft_voting	No (below 5 dB threshold)
344	16849.7	3.7	stft_voting	No (below 5 dB threshold)
345	16898.2	5.6	stft_voting	Yes
346	16952.0	5.9	stft_voting	Yes
347	17000.5	4.1	stft_voting	No (below 5 dB threshold)
348	17048.9	4.7	stft_voting	No (below 5 dB threshold)
349	17151.2	4.8	stft_voting	No (below 5 dB threshold)
350	17199.6	4.0	stft_voting	No (below 5 dB threshold)
351	17248.1	5.8	stft_voting	Yes
352	17301.9	5.6	stft_voting	Yes
353	17350.4	3.8	stft_voting	No (below 5 dB threshold)
354	17398.8	4.8	stft_voting	No (below 5 dB threshold)
355	17447.3	6.8	stft_voting	Yes
356	17452.7	6.8	stft_voting	Yes
357	17501.1	4.7	stft_voting	No (below 5 dB threshold)
358	17549.6	3.9	stft_voting	No (below 5 dB threshold)
359	17598.0	5.8	stft_voting	Yes
360	17651.8	5.7	stft_voting	Yes
361	17700.3	4.0	stft_voting	No (below 5 dB threshold)

362	17748.7	5.0	stft_voting	No (below 5 dB threshold)
363	17899.5	4.1	stft_voting	No (below 5 dB threshold)
364	17947.9	6.0	stft_voting	Yes
365	18001.8	5.5	stft_voting	Yes
366	18050.2	3.6	stft_voting	No (below 5 dB threshold)
367	18098.7	5.0	stft_voting	Yes
368	18152.5	6.6	stft_voting	Yes
369	18200.9	4.6	stft_voting	No (below 5 dB threshold)
370	18249.4	4.1	stft_voting	No (below 5 dB threshold)
371	18351.7	5.5	stft_voting	Yes
372	18400.1	4.0	stft_voting	No (below 5 dB threshold)
373	18448.6	5.2	stft_voting	Yes
374	18550.9	4.4	stft_voting	No (below 5 dB threshold)
375	18599.3	4.2	stft_voting	No (below 5 dB threshold)
376	18647.8	6.3	stft_voting	Yes
377	18701.6	5.3	stft_voting	Yes
378	18750.0	3.5	stft_voting	No (below 5 dB threshold)
379	18798.5	5.2	stft_voting	Yes
380	18852.3	6.3	stft_voting	Yes
381	18900.8	4.3	stft_voting	No (below 5 dB threshold)
382	18949.2	4.6	stft_voting	No (below 5 dB threshold)
383	19051.5	4.8	stft_voting	No (below 5 dB threshold)
384	19100.0	4.0	stft_voting	No (below 5 dB threshold)
385	19148.4	5.2	stft_voting	Yes
386	19202.2	5.9	stft_voting	Yes
387	19250.7	4.2	stft_voting	No (below 5 dB threshold)
388	19299.1	4.4	stft_voting	No (below 5 dB threshold)
389	19347.6	6.5	stft_voting	Yes
390	19401.4	5.1	stft_voting	Yes
391	19449.9	3.5	stft_voting	No (below 5 dB threshold)
392	19498.3	5.5	stft_voting	Yes
393	19552.1	6.1	stft_voting	Yes
394	19600.6	4.1	stft_voting	No (below 5 dB threshold)
395	19751.3	5.0	stft_voting	Yes
396	19799.8	4.0	stft_voting	No (below 5 dB threshold)

397	19848.2	5.6	stft_voting	Yes
398	19902.1	5.9	stft_voting	Yes
399	19999.0	4.7	stft_voting	No (below 5 dB threshold)
400	20047.4	6.7	stft_voting	Yes
401	20101.2	4.9	stft_voting	No (below 5 dB threshold)
402	20149.7	3.7	stft_voting	No (below 5 dB threshold)
403	20198.1	5.6	stft_voting	Yes
404	20252.0	5.9	stft_voting	Yes
405	20300.4	4.0	stft_voting	No (below 5 dB threshold)
406	20348.9	4.8	stft_voting	No (below 5 dB threshold)
407	20451.2	4.8	stft_voting	No (below 5 dB threshold)
408	20499.6	4.0	stft_voting	No (below 5 dB threshold)
409	20548.1	5.9	stft_voting	Yes
410	20601.9	5.7	stft_voting	Yes
411	20650.3	3.8	stft_voting	No (below 5 dB threshold)
412	20698.8	4.8	stft_voting	No (below 5 dB threshold)
413	20752.6	6.8	stft_voting	Yes
414	20801.1	4.6	stft_voting	No (below 5 dB threshold)
415	20849.5	3.9	stft_voting	No (below 5 dB threshold)
416	20898.0	5.9	stft_voting	Yes
417	20951.8	5.7	stft_voting	Yes
418	21000.3	4.0	stft_voting	No (below 5 dB threshold)
419	21048.7	5.0	stft_voting	No (below 5 dB threshold)
420	21151.0	4.6	stft_voting	No (below 5 dB threshold)
421	21199.4	4.2	stft_voting	No (below 5 dB threshold)
422	21247.9	6.1	stft_voting	Yes
423	21301.7	5.5	stft_voting	Yes
424	21350.2	3.6	stft_voting	No (below 5 dB threshold)
425	21398.6	5.0	stft_voting	Yes
426	21452.5	6.5	stft_voting	Yes
427	21500.9	4.4	stft_voting	No (below 5 dB threshold)
428	21549.4	4.2	stft_voting	No (below 5 dB threshold)
429	21651.6	5.4	stft_voting	Yes
430	21700.1	3.9	stft_voting	No (below 5 dB threshold)
431	21748.5	5.2	stft_voting	Yes

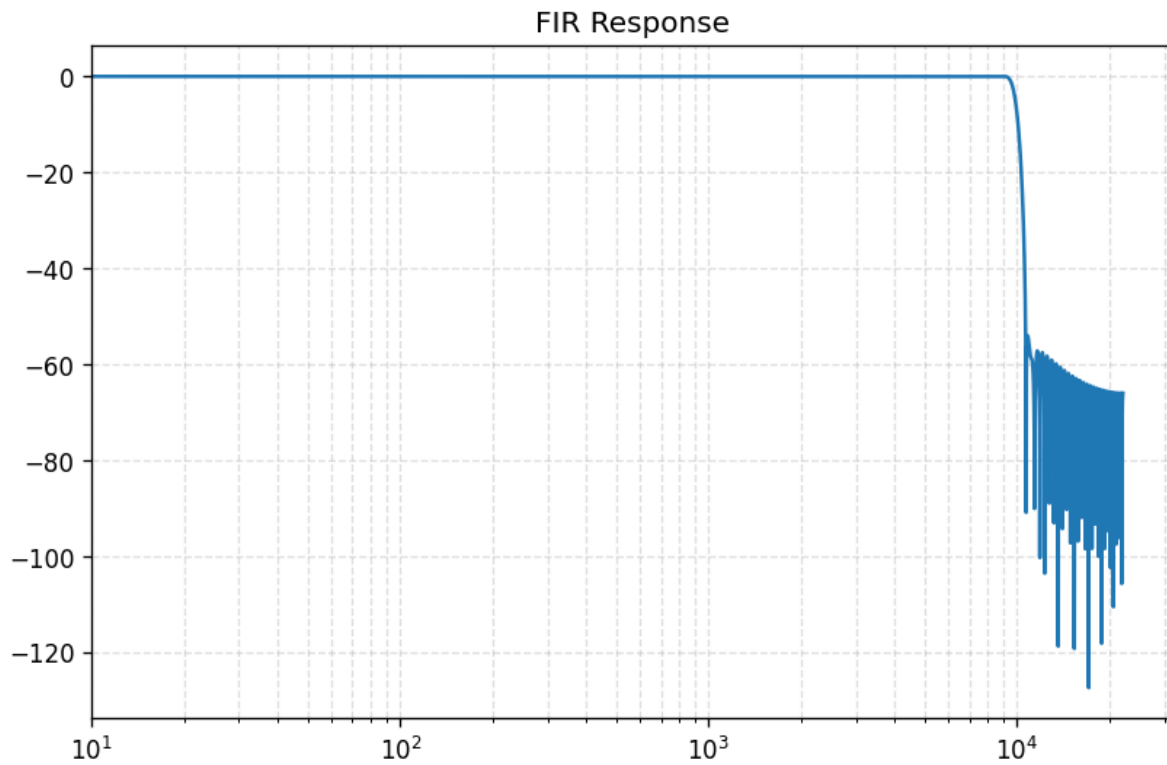
432	21802.4	6.0	stft_voting	Yes
433	21850.8	4.4	stft_voting	No (below 5 dB threshold)
434	21899.3	3.8	stft_voting	No (below 5 dB threshold)
435	21947.7	6.3	stft_voting	Yes
436	22001.6	4.0	stft_voting	No (below 5 dB threshold)

IIR Notch Cascade Response



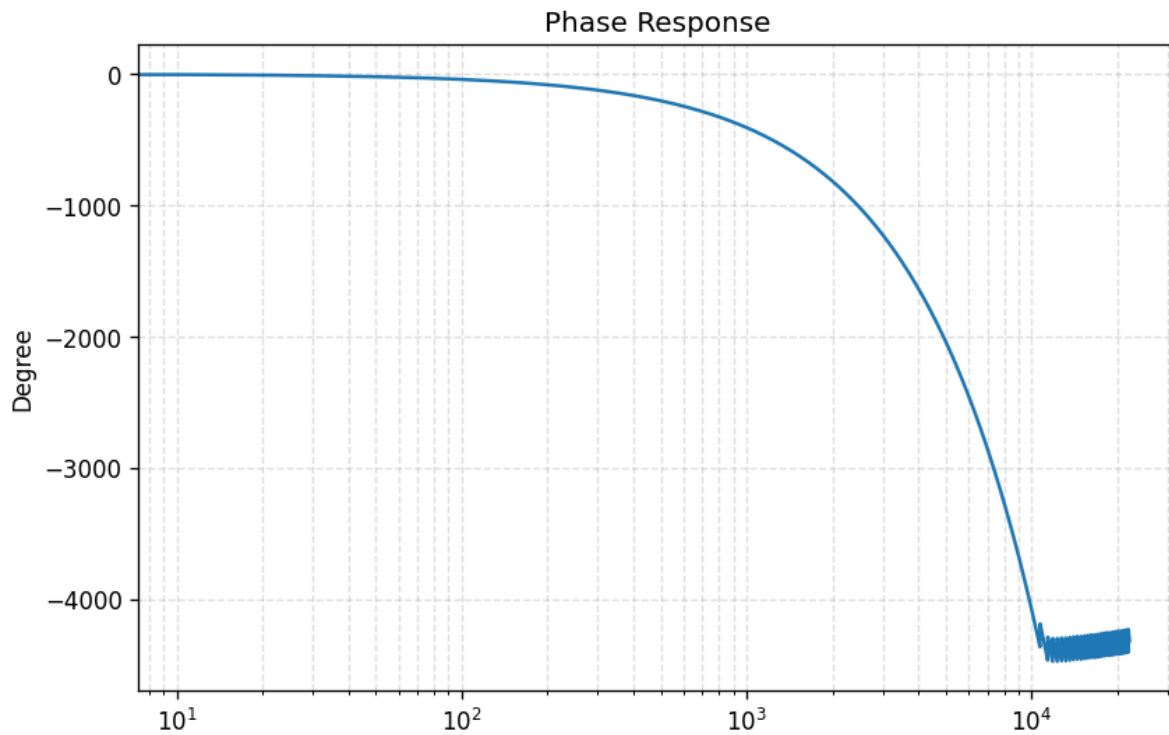
Each notch suppresses a narrow-band interference frequency.

FIR Low-pass Response



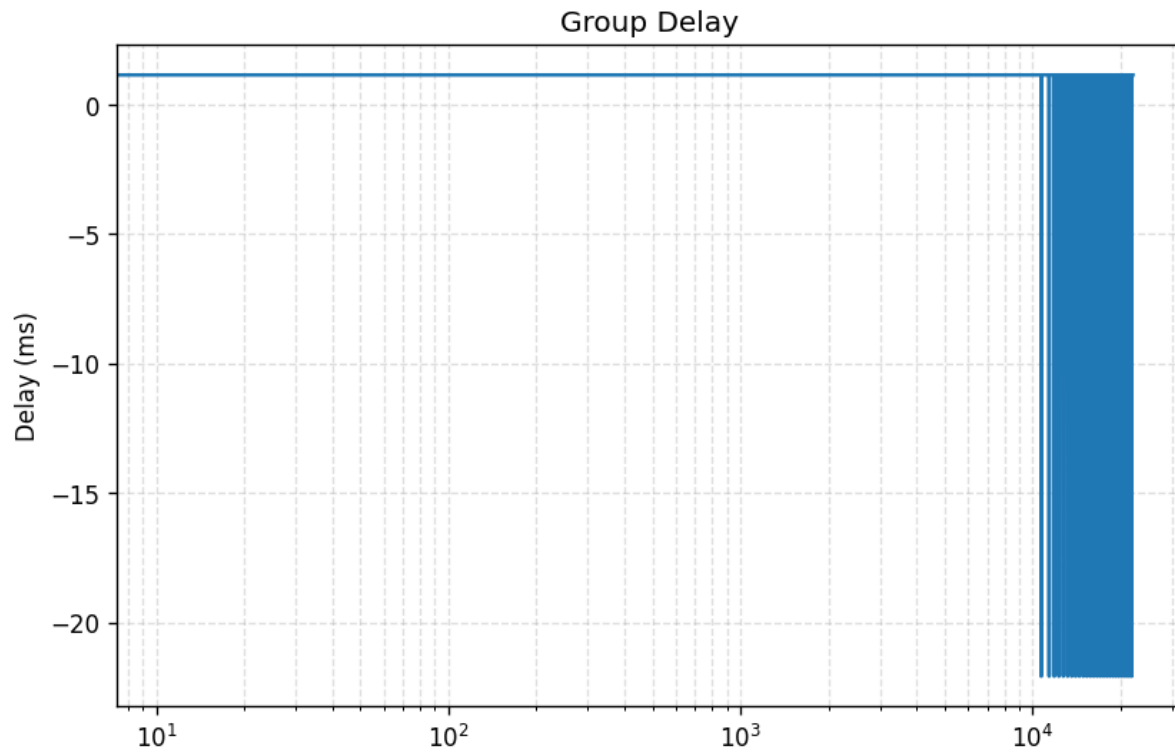
The FIR stage removes high-frequency noise beyond the cutoff.

Phase Response (Pipeline)



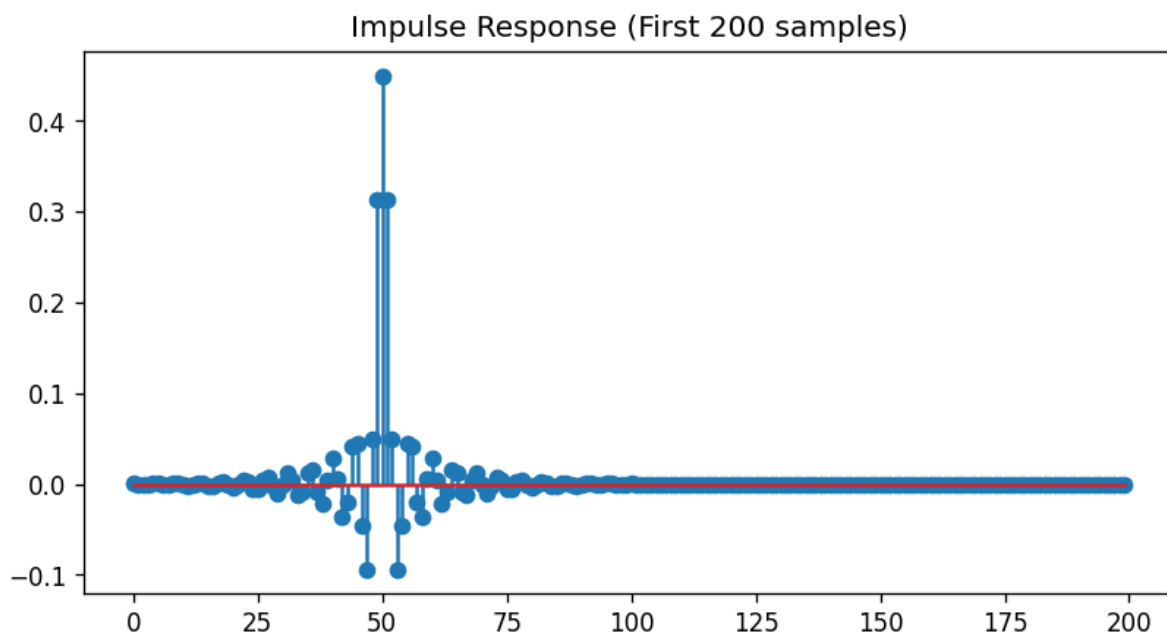
Phase remains approximately linear across most of the passband.

Group Delay (Pipeline)



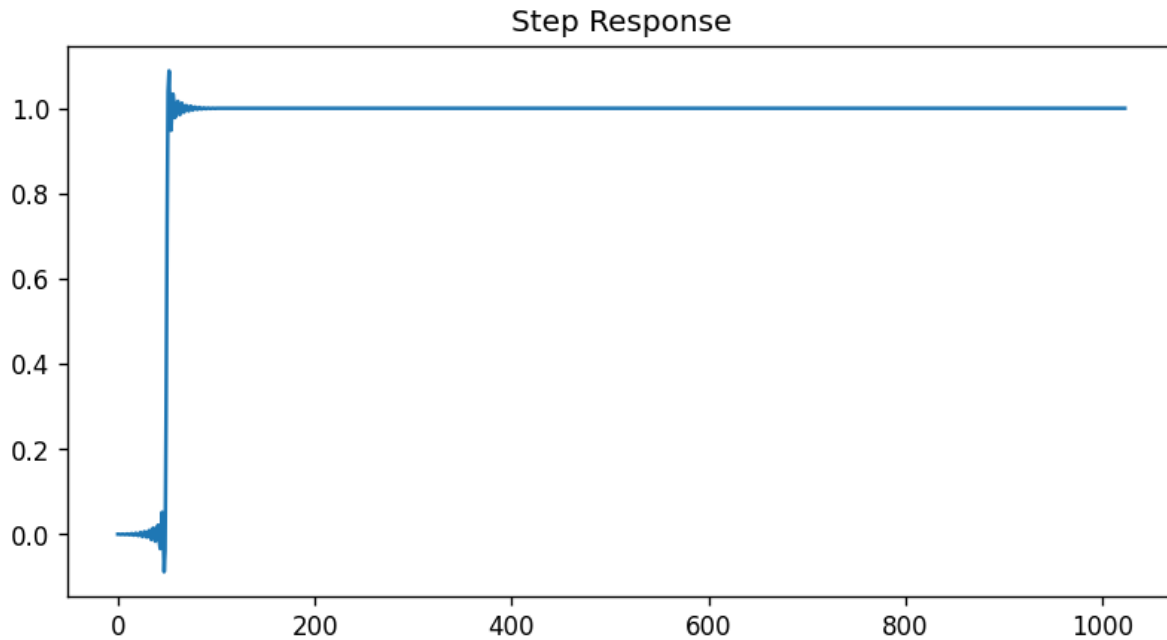
Group delay spikes indicate the frequency of notch filters.

Impulse Response (Pipeline)



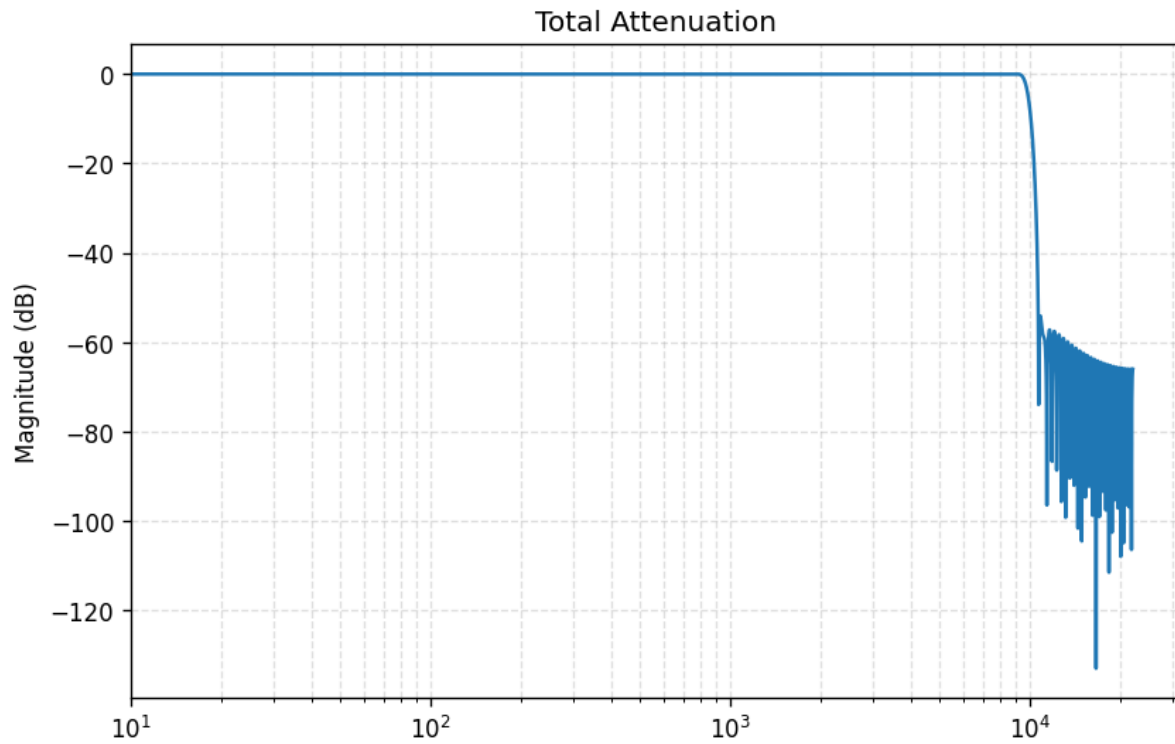
Impulse response reveals filter stability and temporal spread.

Step Response (Pipeline)



Step response highlights settling behavior and overshoot control.

Cumulative Attenuation Mask

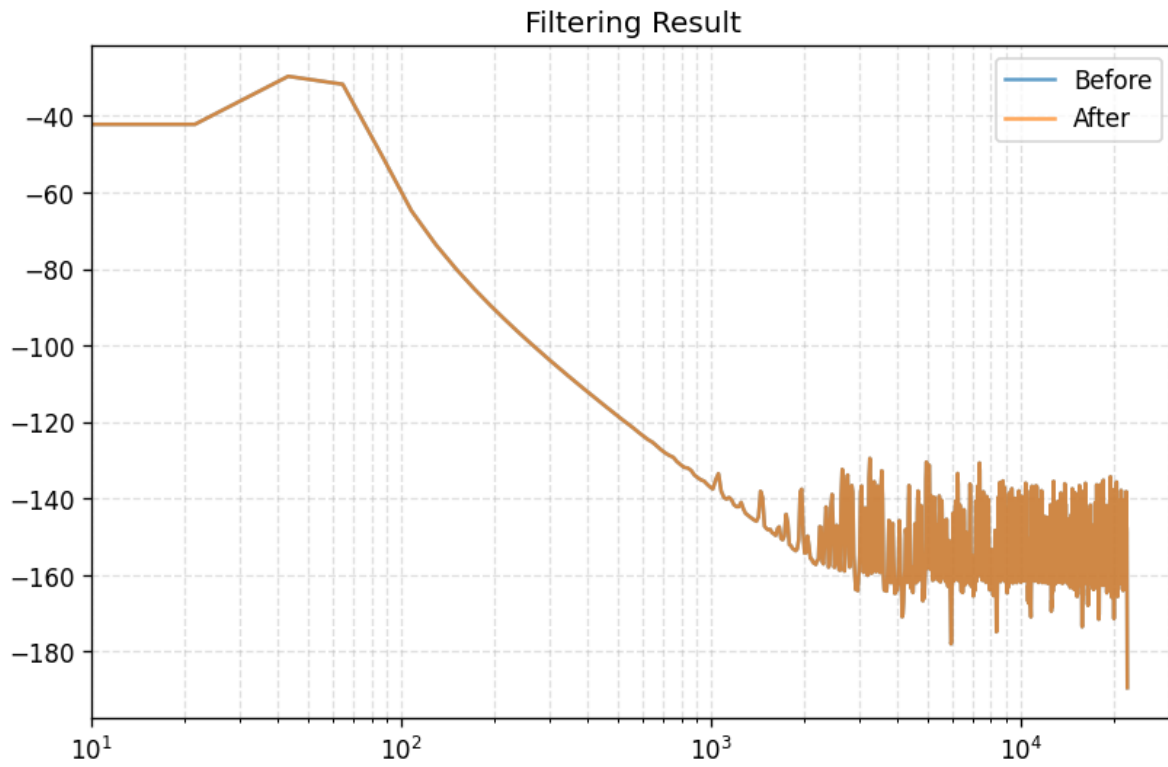


Shows total attenuation of the complete filter pipeline.

Pole-Zero Plot (Overall Pipeline)

Poles and zeros indicate stability and notch sharpness.

PSD Before / After Filtering



Illustrates the spectral changes before and after applying the designed filter pipeline.

Filter Design Summary

Parameter	Value
Source File	low_freq_50hz_hum.wav
Sampling Rate (Hz)	44100.0
FIR Cutoff (Hz)	9922.50
FIR Tap Count	101
IIR Notches	None

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

No IIR notch filters were used in this design. The pipeline relies on the FIR stage and overall spectral shaping.

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 **2.290 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.