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SDR Implementation of Analog FM Broadcast Multipath Filter

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Summary

- FM broadcast and multipath interference
- Overview of our SDR receiver *airspy-fmradion*
- FM multipath filter in detail
- Evaluation and results
- Conclusion and future works

Errata on the report

- Page 21, Table 4: NLMS coefficient update rate
  - ~~48kHz (once in 8 samples)~~ -> **96kHz (once in 4 samples)**
- Corresponding report text in Page 21:
  - [...] empirically set to ~~48kHz~~ **96kHz** to [...]

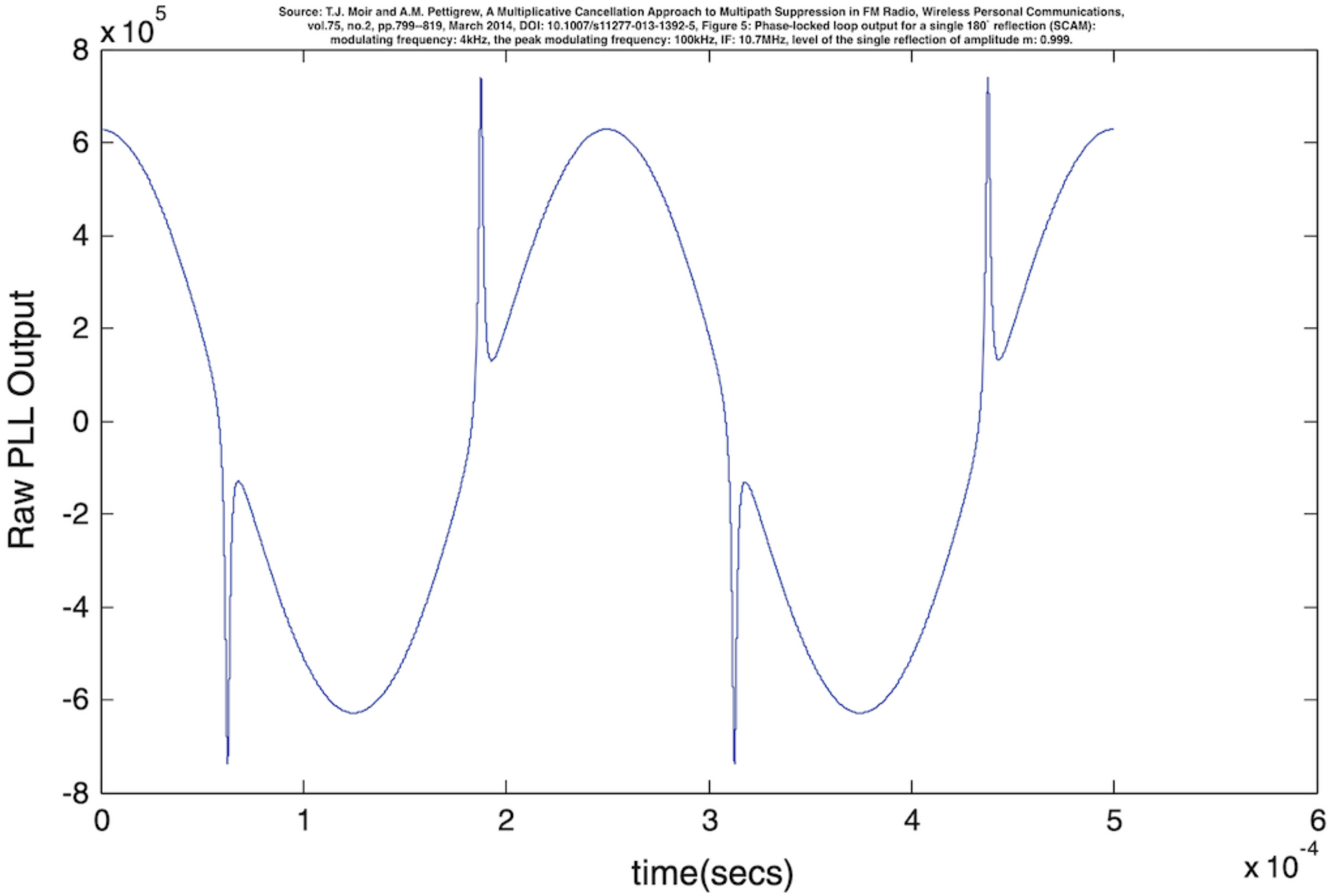
FM broadcast and multipath interference

The amplitude level of FM signals is theoretically *fixed*

Multipath interference causes change of amplitude level and phase

Amplitude level change may cause destructive results on demodulation, e.g., large-level spikes

Question: how can this amplitude and phase distortion be removed?



Source: T.J. Moir and A.M. Pettigrew, A Multiplicative Cancellation Approach to Multipath Suppression in FM Radio, Wireless Personal Communications, vol.75, no.2, pp.799--819, March 2014, DOI: 10.1007/s11277-013-1392-5, Figure 5: Phase-locked loop output for a single 180˚ reflection (SCAM): modulating frequency: 4kHz, the peak modulating frequency: 100kHz, IF: 10.7MHz, level of the single reflection of amplitude m: 0.999.

Removing FM multipath distortion

Directional beam antenna: antenna might be too large, inapplicable for mobile or portable receiver installations

Diversity reception: system might become too complex

Audio noise reduction: not directly addressing the root cause

A possible solution: making a model compensating the amplitude and phase changes in the propagation path -> **adaptive FIR filter**

The overview of our SDR receiver

airspy-fmradion

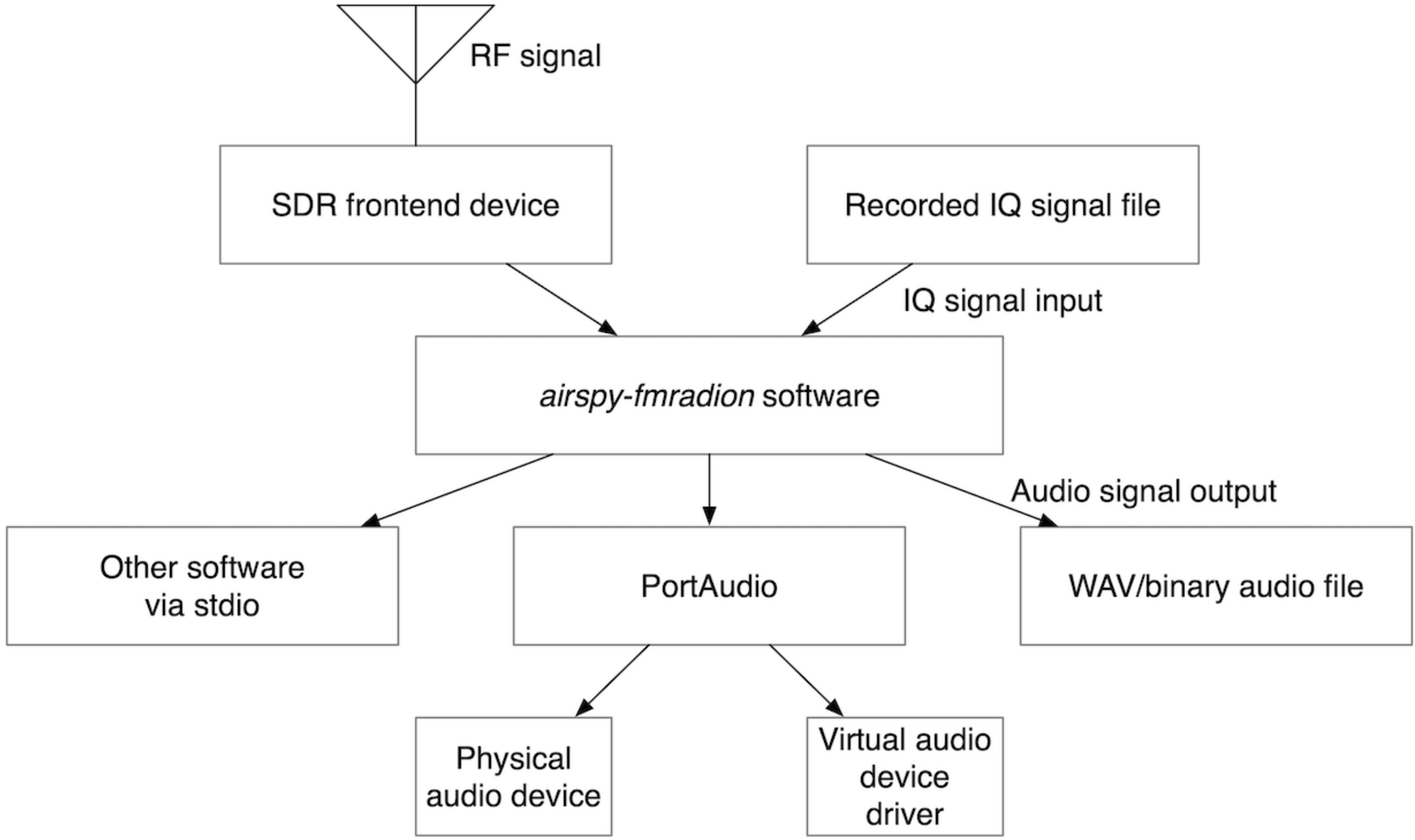
airspy-fmradion functions

Supported SDR frontends: **Airspy HF+**, Airspy R2/mini, RTL-SDR, and pre-recorded IQ signal files

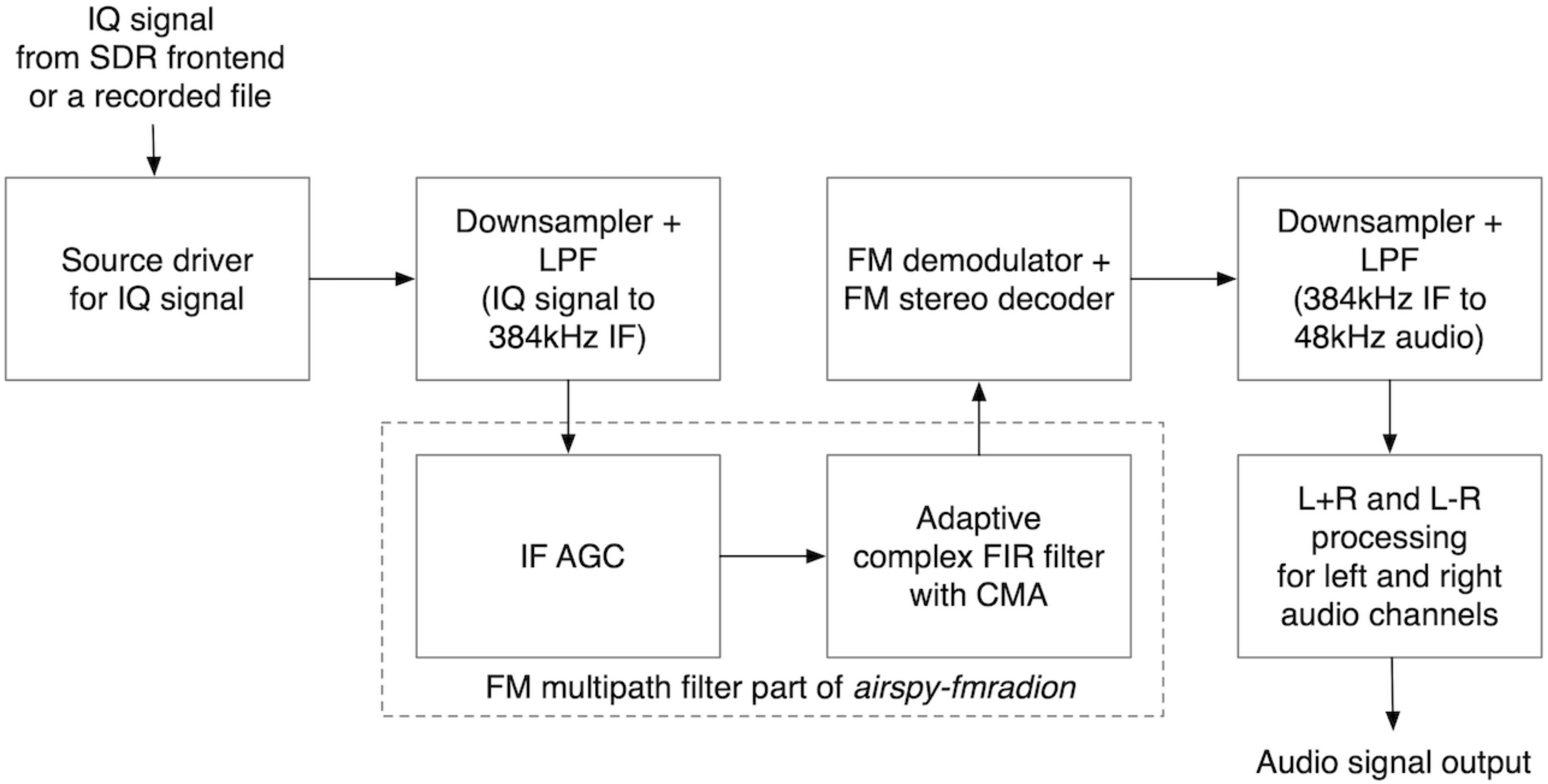
For macOS, Ubuntu, and Raspberry Pi OS

Output: 48kHz 16-bit integer / 32-bit float PCM output (WAV/RF64, raw PCM)

Open-sourced: source code available at https://github.com/jj1bdx/airspy-fmradion



airspy-fmradion FM broadcast receiver



FM multipath filter in detail

Advantage of our filter design

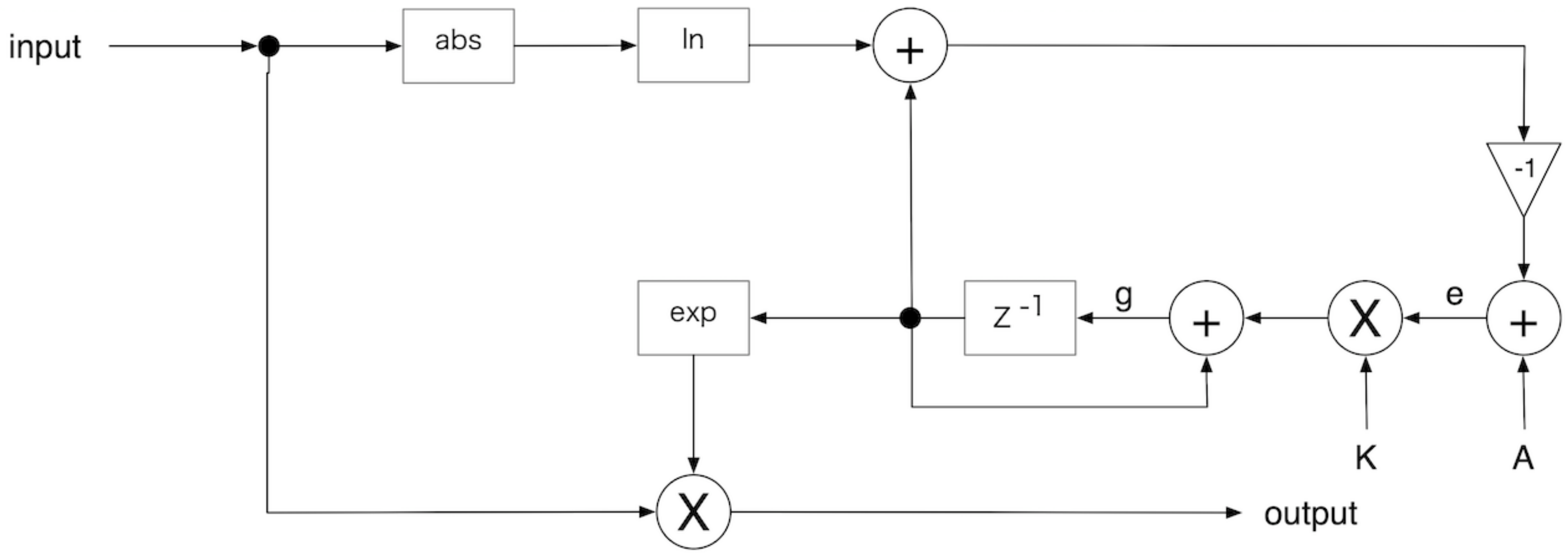
Allocating IF AGC *before* the FIR filter for more stability

Full 32-bit float computation for mathematical stability

Using VOLK to fully utilize SIMD instructions

Weighted FIR filter stage allocation for optimizing computational resource usage

IF AGC before the multipath filter



abs: absolute value (for IQ signal: sqrt(I^2+Q^2)
ln: natural logarithm ($\log_e x$)

exp: exponential (e^x)
Z^{-1}: step time delay

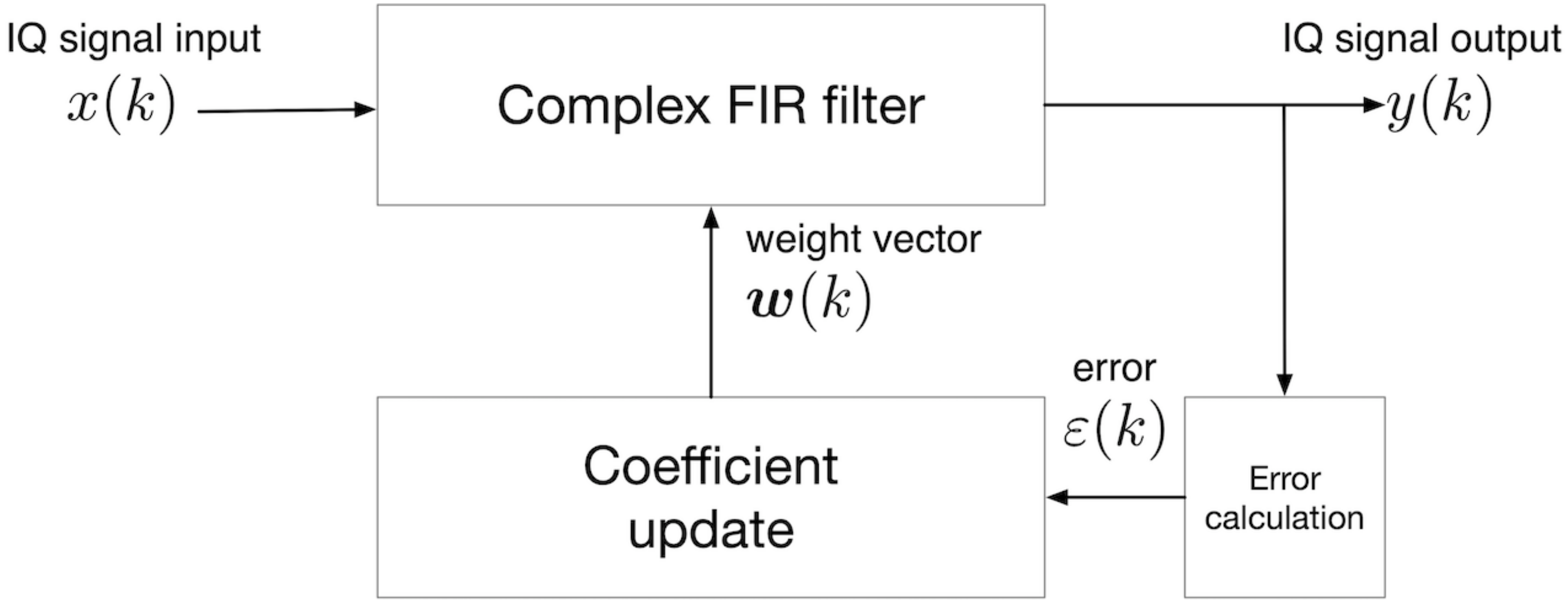
A: reference level
e: error signal
K: step size
g: loop gain
(loop gain does not exceed
the pre-defined maximum value)

Adaptive filter design by Constant Modulus Algorithm (CMA)

Objective: recover the original *fixed* amplitude (*not* like the traditional hard-limiting)

Adaptive filter coefficient algorithm (LMS/NLMS) target: keep the complex amplitude to the reference value (unity)

Allocates more FIR filter stages for reflecting past data than future data from the reference point



Evaluation and results

Evaluation: filter configuration

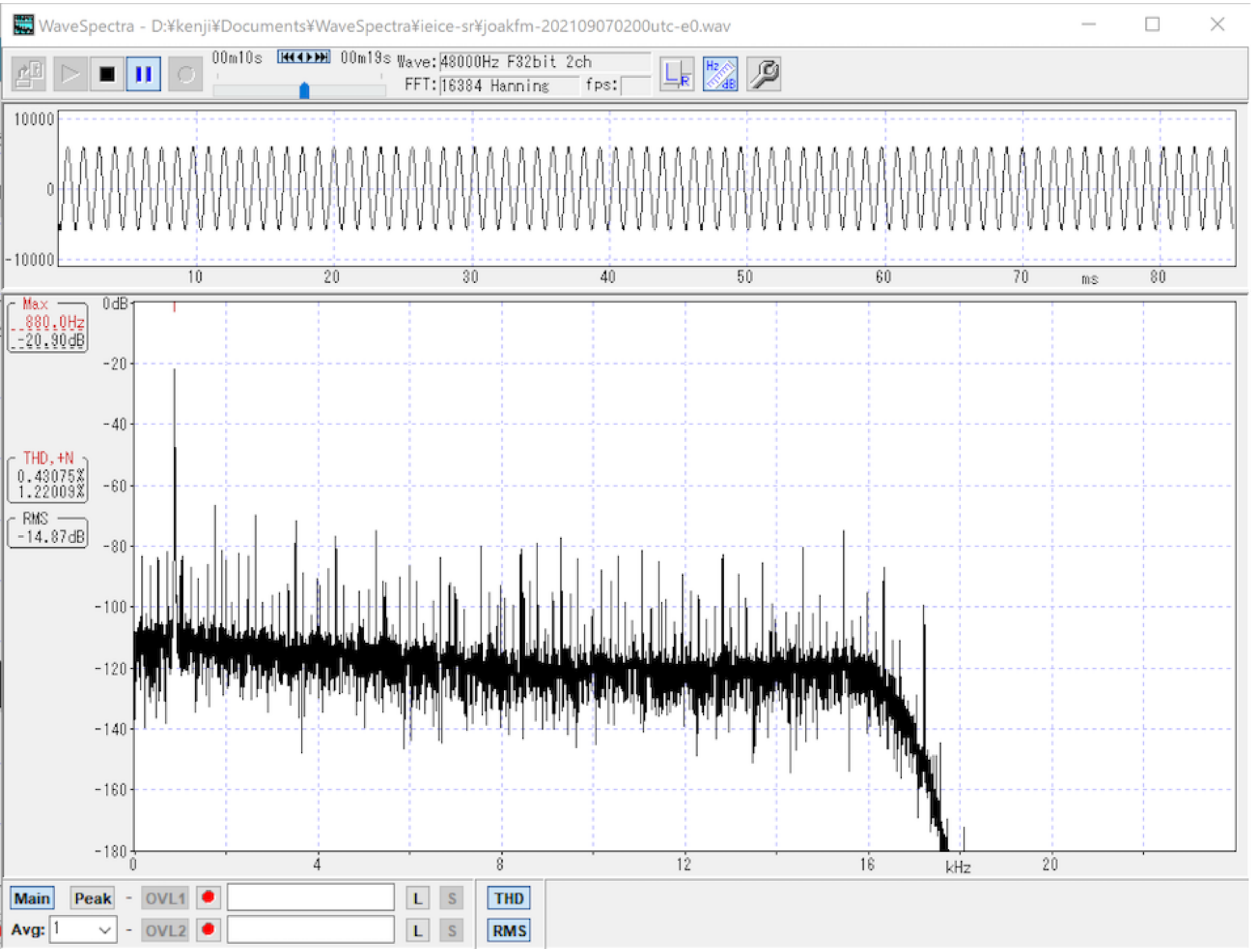
- Filter sampling rate: 384kHz (2.6μs/sample)
- IF AGC: step size K = 0.001, reference level A = 1
- NLMS: adaptation gain α = 0.1, update rate = 96kHz
- Changing filter stage S from 0 ... 10, 15, 20, 30, 40, 50
  - FIR filter stages for S = 15: 61 samples total, past samples: 46, future samples: 14

Evaluation: FM stations received

- Received in Setagaya City, Tokyo, Japan
- Simple whip antenna at the balcony
- NHK-FM Tokyo (JOAK-FM, 82.5MHz)
    - Tokyo Skytree, 17km east, ERP: 57kW
- InterFM Tokyo (JODW-FM, 89.7MHz)
    - Tokyo Tower, 11km east, ERP: 13kW

Evaluation indices

- THD+N for 880Hz time tone of NHK-FM
- Quadratic Multipath Monitor (QMM)
  - π/2-shifted DSB demodulation of L-R signal with 38kHz
  - Ideally: no output → reality: distortion output
  - Suitable for high-modulation music contents


WaveSpectra - D:¥kenji¥Documents¥WaveSpectra¥ieice-sr¥joakfm-202109070200utc-e0.wav

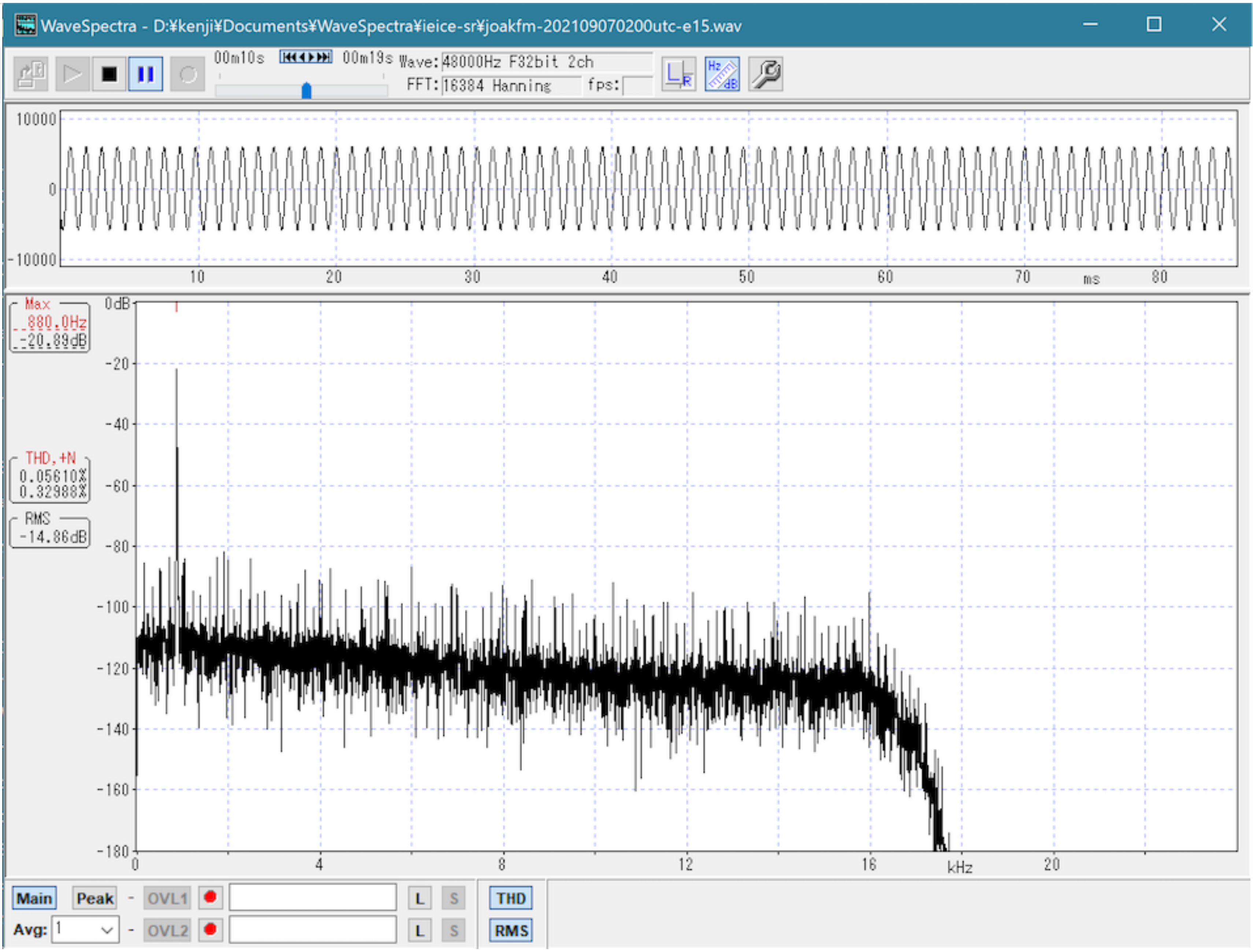
00m10s 00m19s Wave: 48000Hz F32bit 2ch

FFT: 16384 Hanning fps:

Max
880.0Hz
-20.90dB

THD, +N
0.43075%
1.22009%

RMS
-14.87dB


WaveSpectra - D:¥kenji¥Documents¥WaveSpectra¥ieice-sr¥joakfm-202109070200utc-e15.wav

00m10s 00m19s Wave: 48000Hz F32bit 2ch

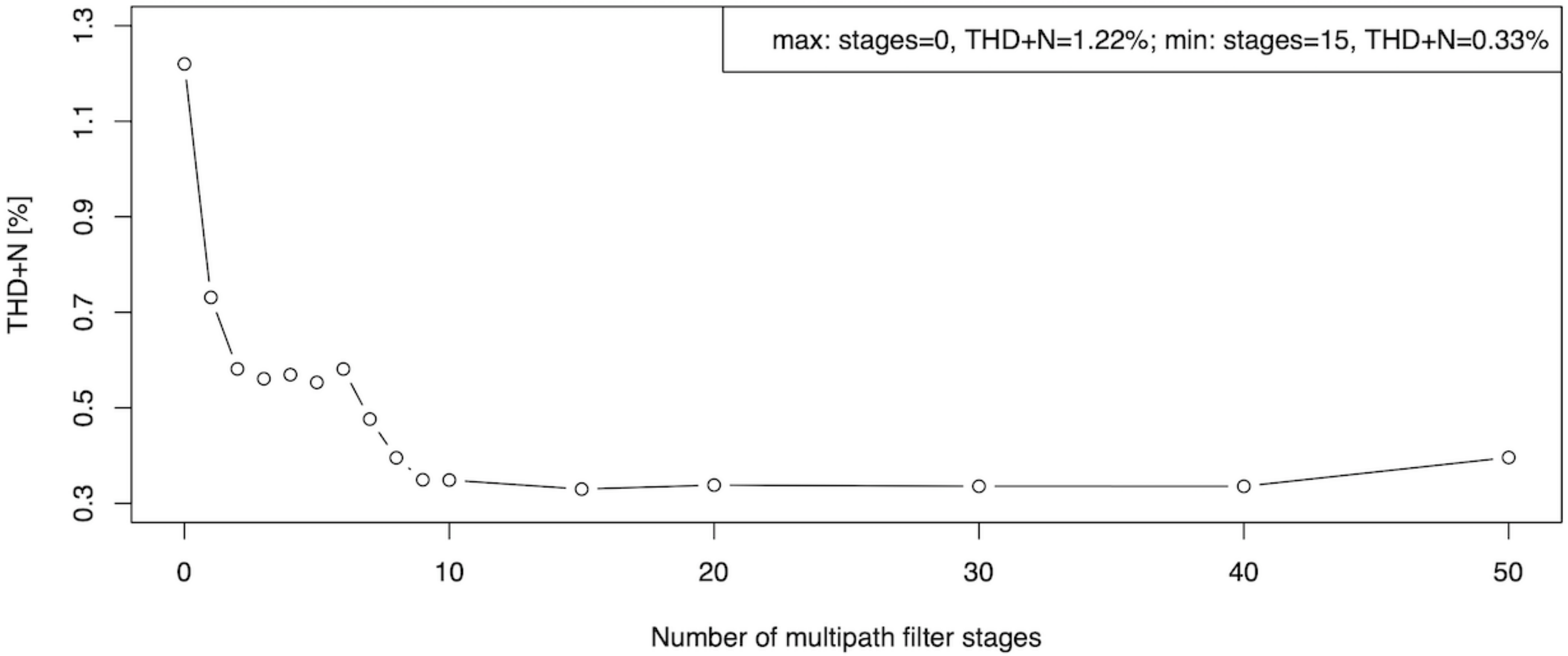
FFT: 16384 Hanning fps:

Max
880.0Hz
-20.89dB

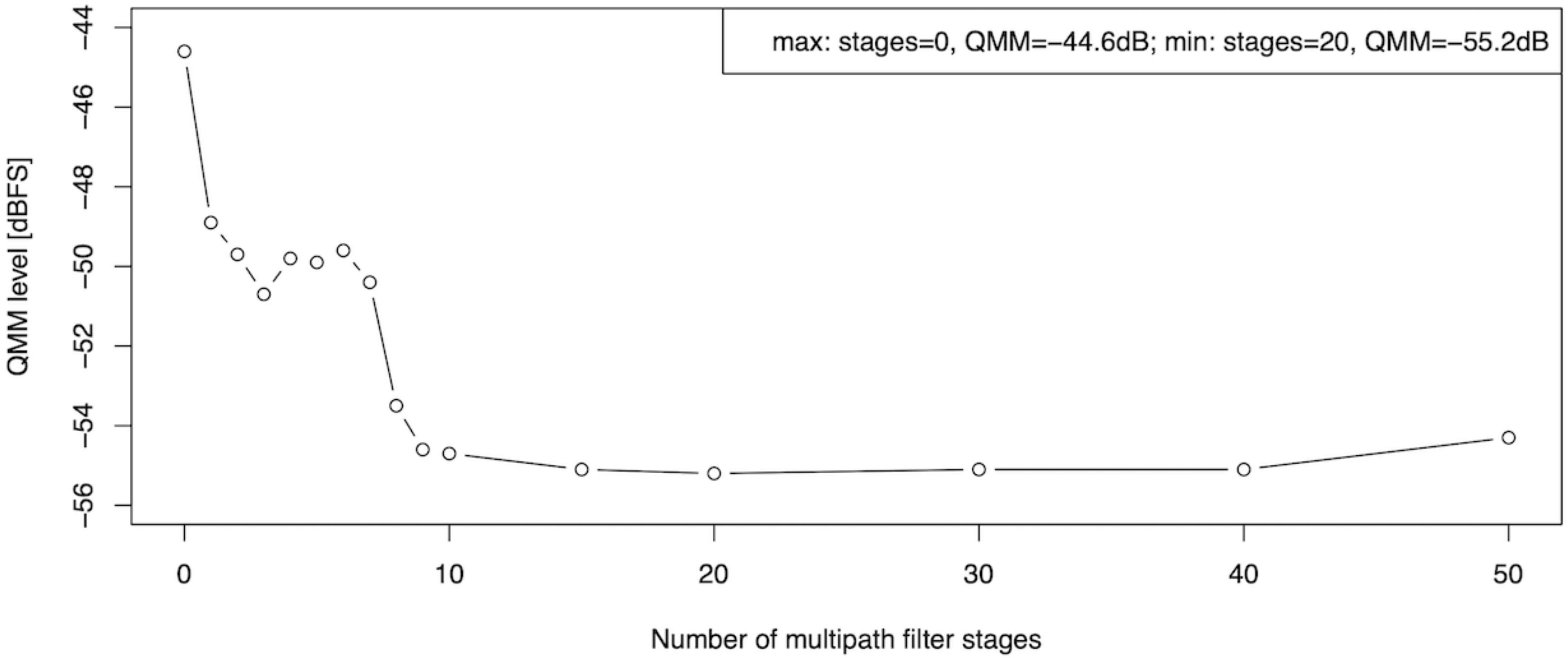
THD, +N
0.05610%
0.32988%

RMS
-14.86dB

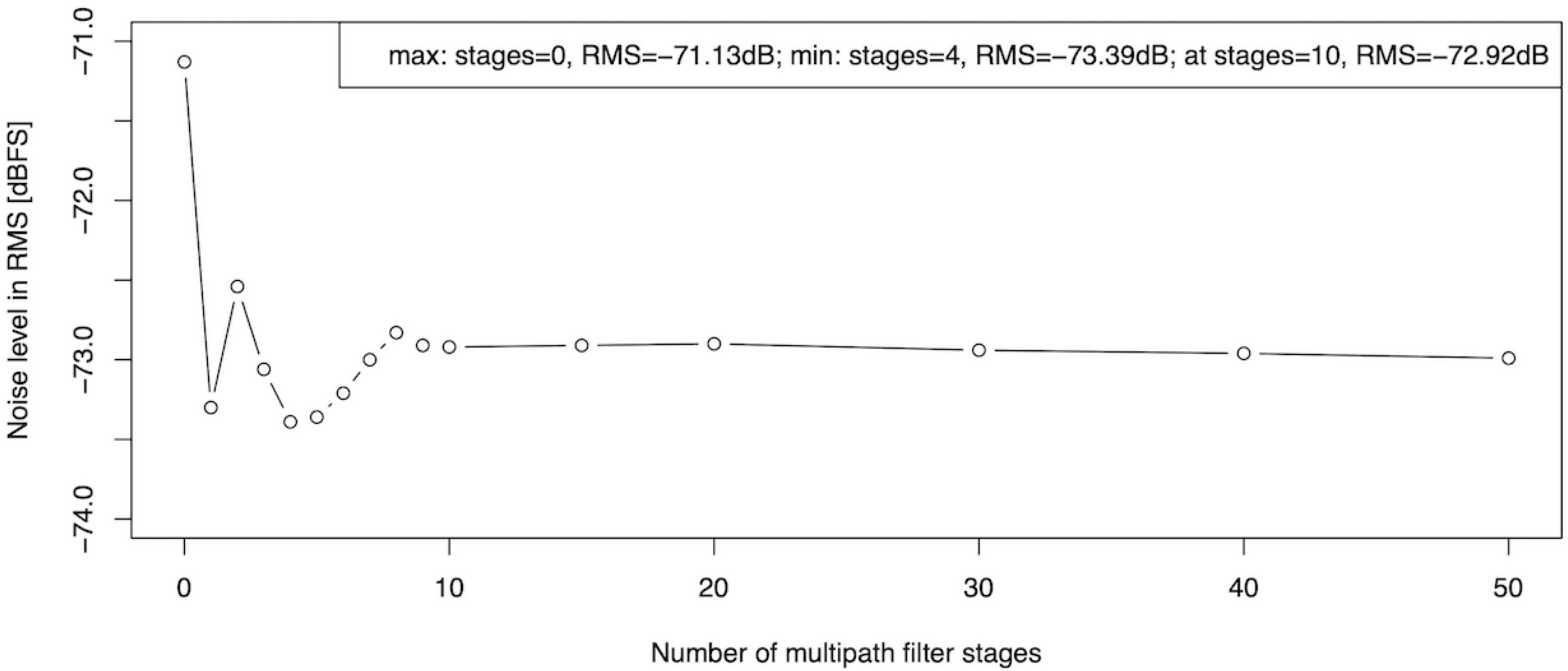
THD+N of NHK-FM Tokyo time tone



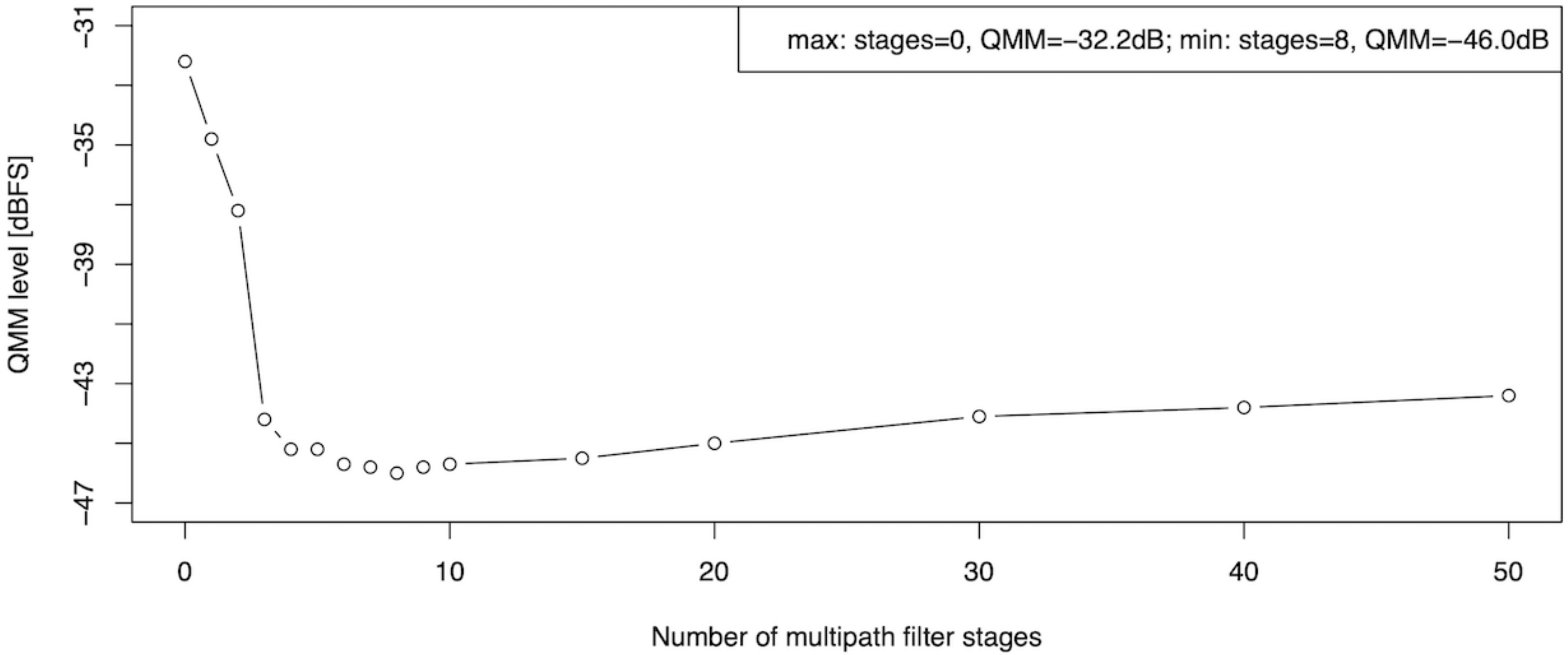
QMM output of NHK-FM Tokyo time tone



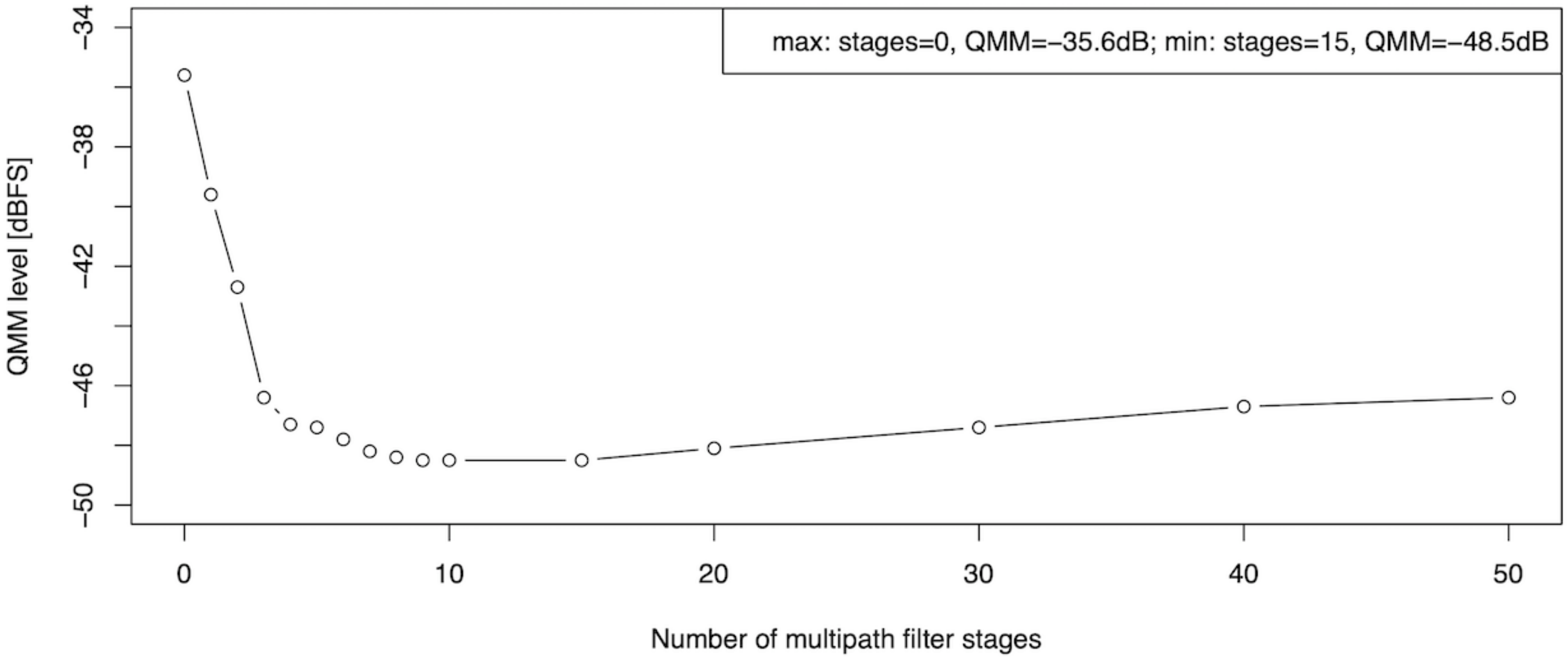
RMS level of NHK-FM Tokyo no-sound output



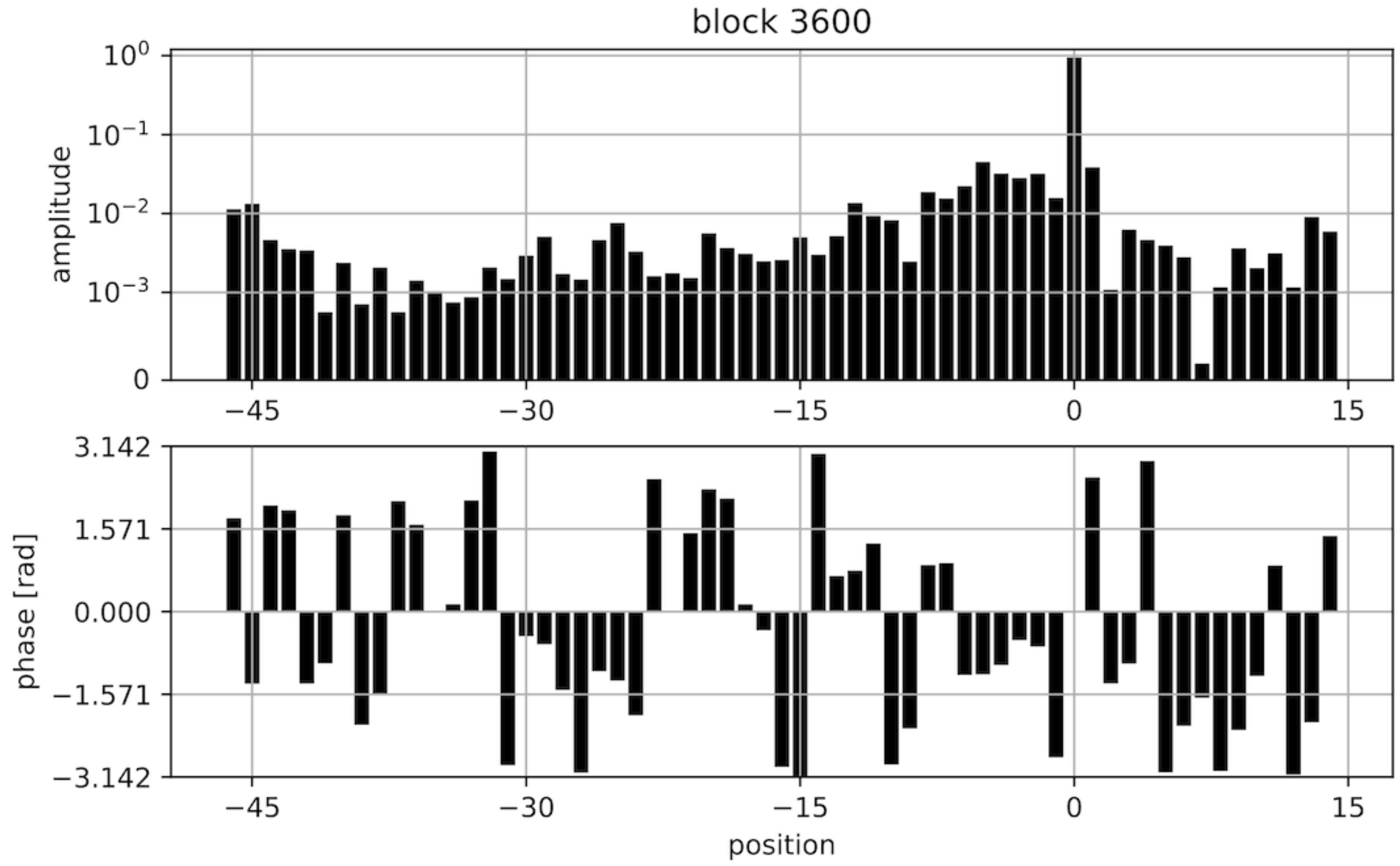
QMM output of InterFM Tokyo by Airspy HF+ Discovery



QMM output of InterFM Tokyo by RTL-SDR



FIR filter coefficients for NHK-FM Tokyo reception



Other observations

- For S=100, CPU usage: with VOLK, 19%; without VOLK, 43%
- IF AGC worked well on long-distance stations in Yokohama
- CMA does not work well with hard-limited Cable TV signal
- Alternative measurement index is required for non-music contents, such as 19kHz pilot tone distortion

Conclusion and future works

Conclusion and future works

Our filter design effectively reduced NHK-FM time tone THD+N from 1.22% to 0.33%, with **audibly noticeable improvement**

Our filter design can be practically implemented on modern computers including Raspberry Pi 4B and Intel NUC

CMA is not effective on hard-limited signal environment such as Cable TV; alternative algorithm required