Delayless Polyphase Implementation of Filters in Active Noise Control Systems

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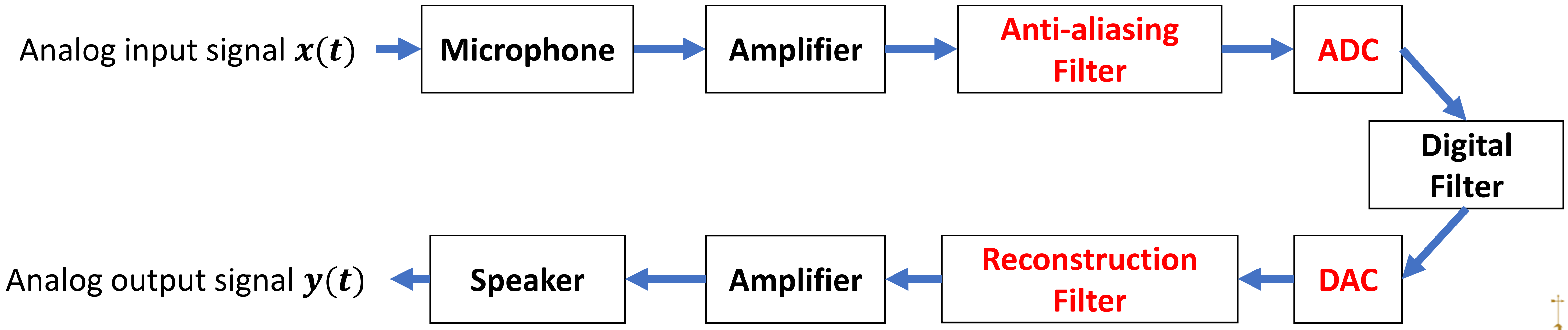
Content

- Motivation
- Theory
  - Review of conventional polyphase structure
  - Proposed delayless polyphase method
- Results
- Summary

Motivation

- In ANC applications, delay introduced in electronic devices will significantly impact noise control performance.
- High sampling rate can be used to reduce delay in:
  Anti-aliasing/reconstruction filters (higher cut-off frequency)
  ADC and DAC (fixed number of delay samples)



Motivation

- To **reduce delay**, we can **increase sampling frequency**
- But it will require **higher real-time computational power**

- Traditional **polyphase method** can **reduce real-time computations**
- But adding low-pass filter as anti-aliasing/reconstruction filter is required, which introduces **additional delay**

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- Can we have **delayless polyphase method** ?

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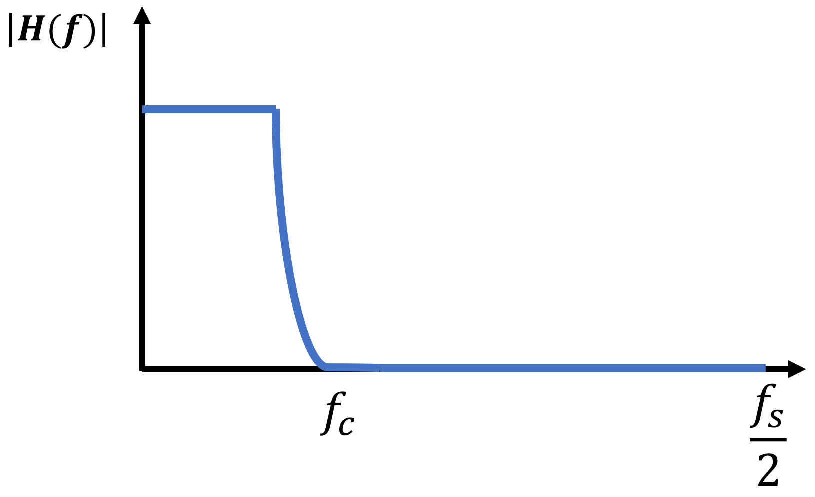
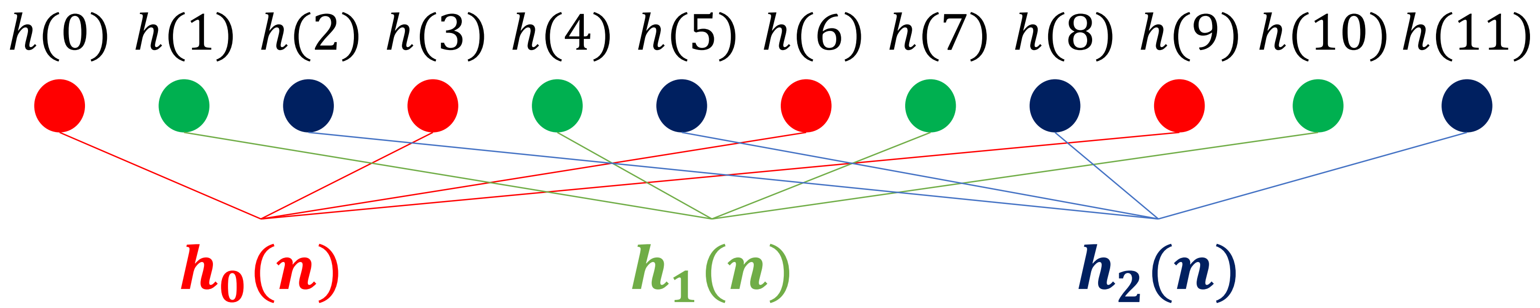
Method – Review of conventional polyphase method

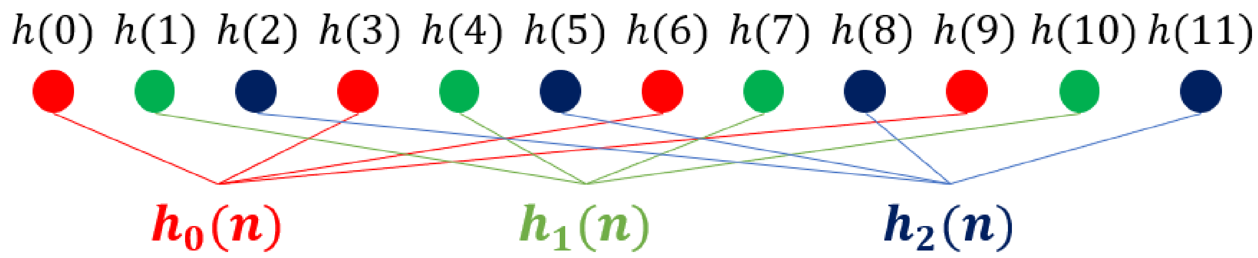
Suppose the filter h(0), h(1), h(2), … , h(n) is a low pass filter:



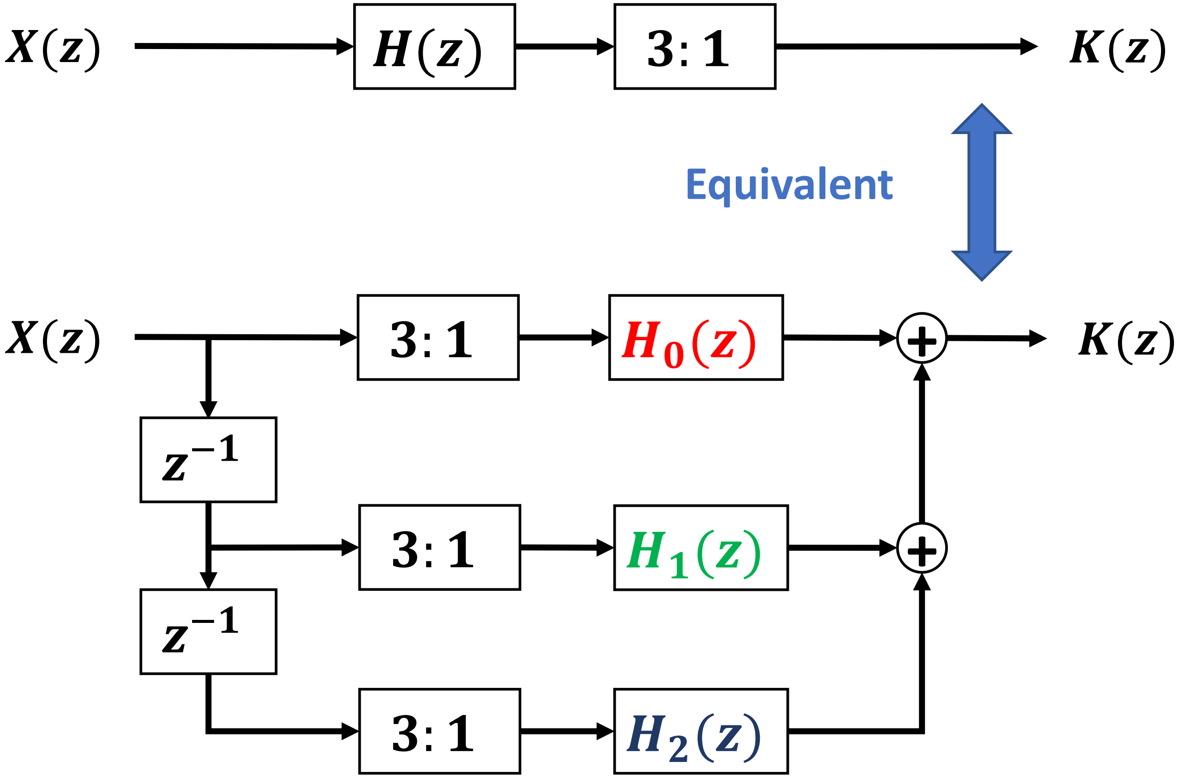
For example, suppose M = $\frac{f_s}{2f_c} = 3$, and n = 12, then we can split h(n) to 3 different filters:



Method – Review of conventional polyphase method



By Noble identity:



Needs n = 12 multiplication
for **each** sampling period of X(z)

Needs n = 12 multiplication
for **M = 3** sampling period of X(z)

Saves a lot of computation effort!

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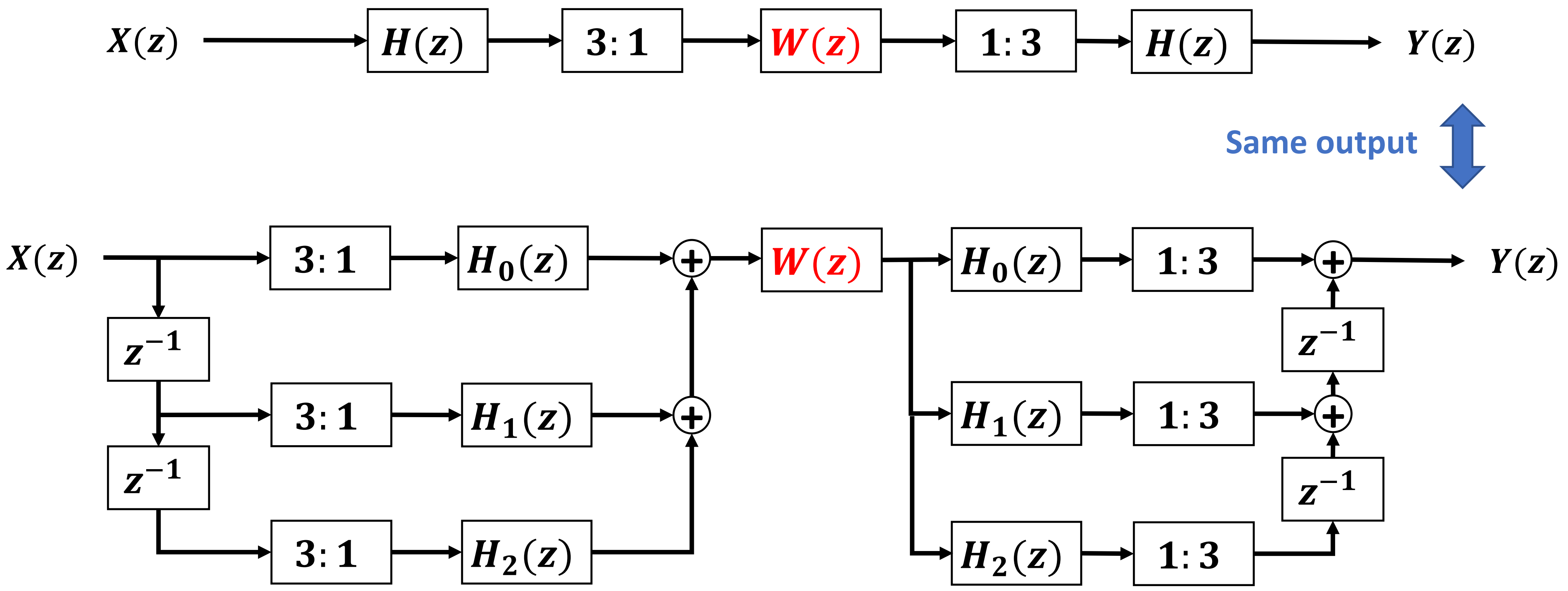
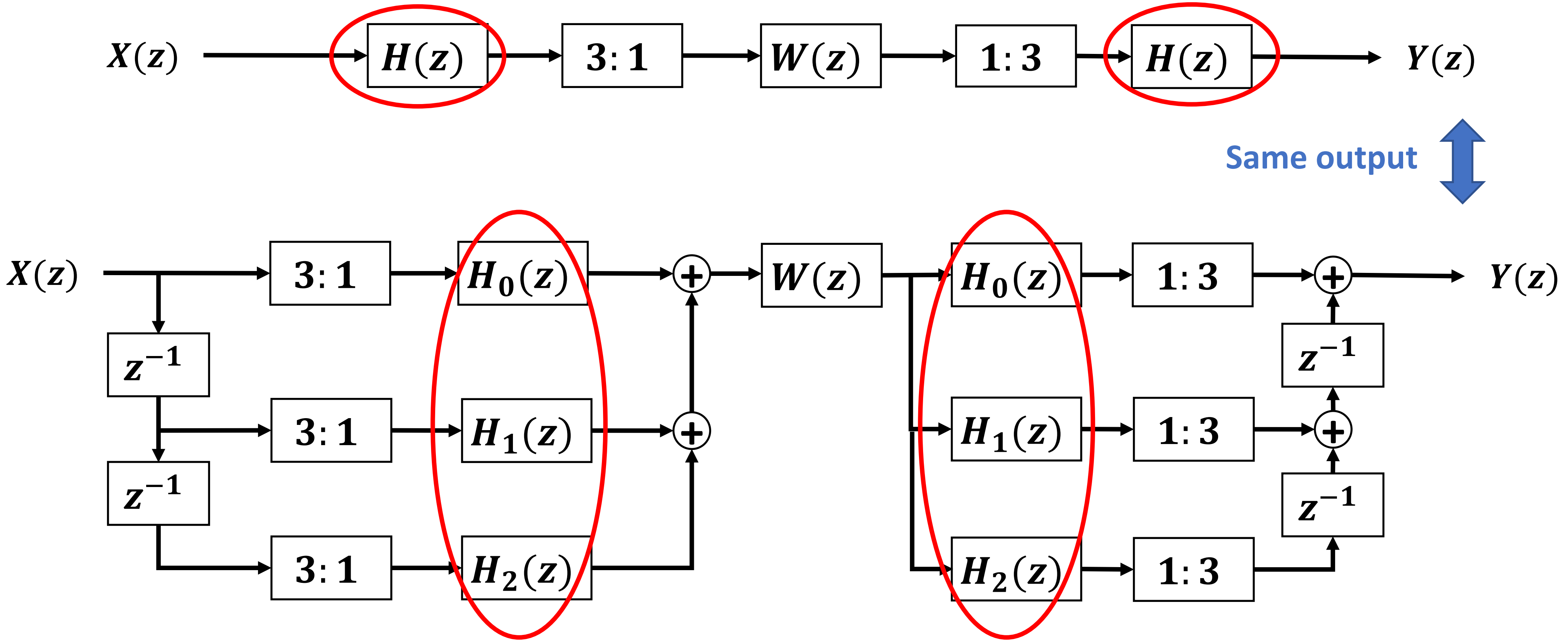
Method – Review of conventional polyphase method

W(z) operates in a lower sampling rate, which saves computation



Method – Review of conventional polyphase method

But the low pass filter H(z) introduce additional delay



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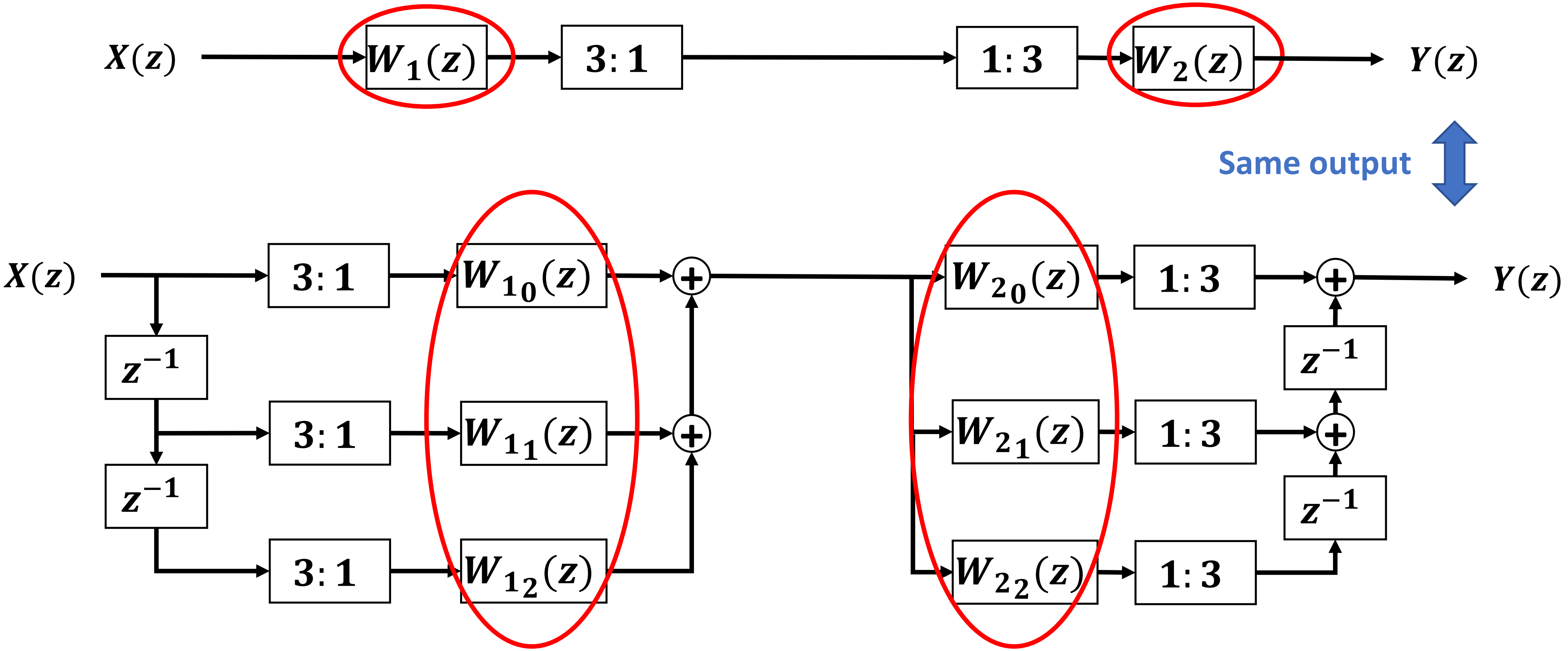
Method – Proposed delayless polyphase method

Suppose if $W(z) = W_1(z)W_2(z)$, and two sub-filters $W_1(z)$ $W_2(z)$ are attenuated above cut-off frequency
Then we can have delayless polyphase structure:



Method – Proposed delayless polyphase method

- Suppose there is a desired control filter W(z) with high sampling rate.
- Cut-off frequency of W(z) is f_c and attenuation is at least 2K dB

⬇

- Design a minimum-phase lowpass filter $W_1(z)$ with cut-off frequency f_c and attenuation approximately K dB

⬇

- Let $W_2(z) \approx \frac{W(z)}{W_{1(z)}}$ such that it also has a cut-off frequency at f_c and attenuation approximately K dB

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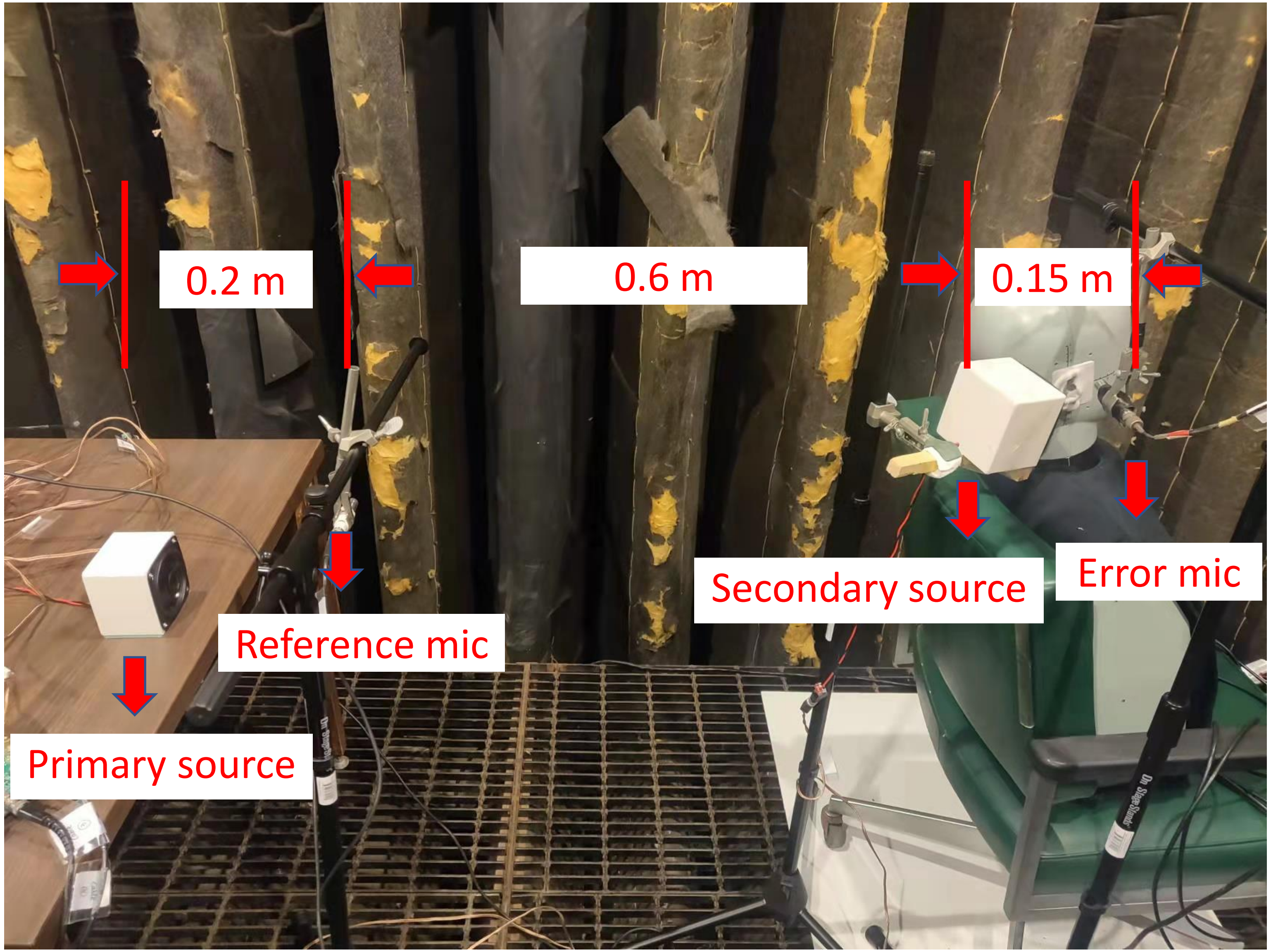
Results – Experimental setup

fs : Sampling rate
T : Number of filter coefficient/fs

Filter order	T = 15 ms	T = 3 ms
fs = 4 kHz (high delay)	60	
fs = 20 kHz (low delay)	300	60

The ANC filter is designed by convex optimization method: [Zhuang and Liu, JASA, 2021]



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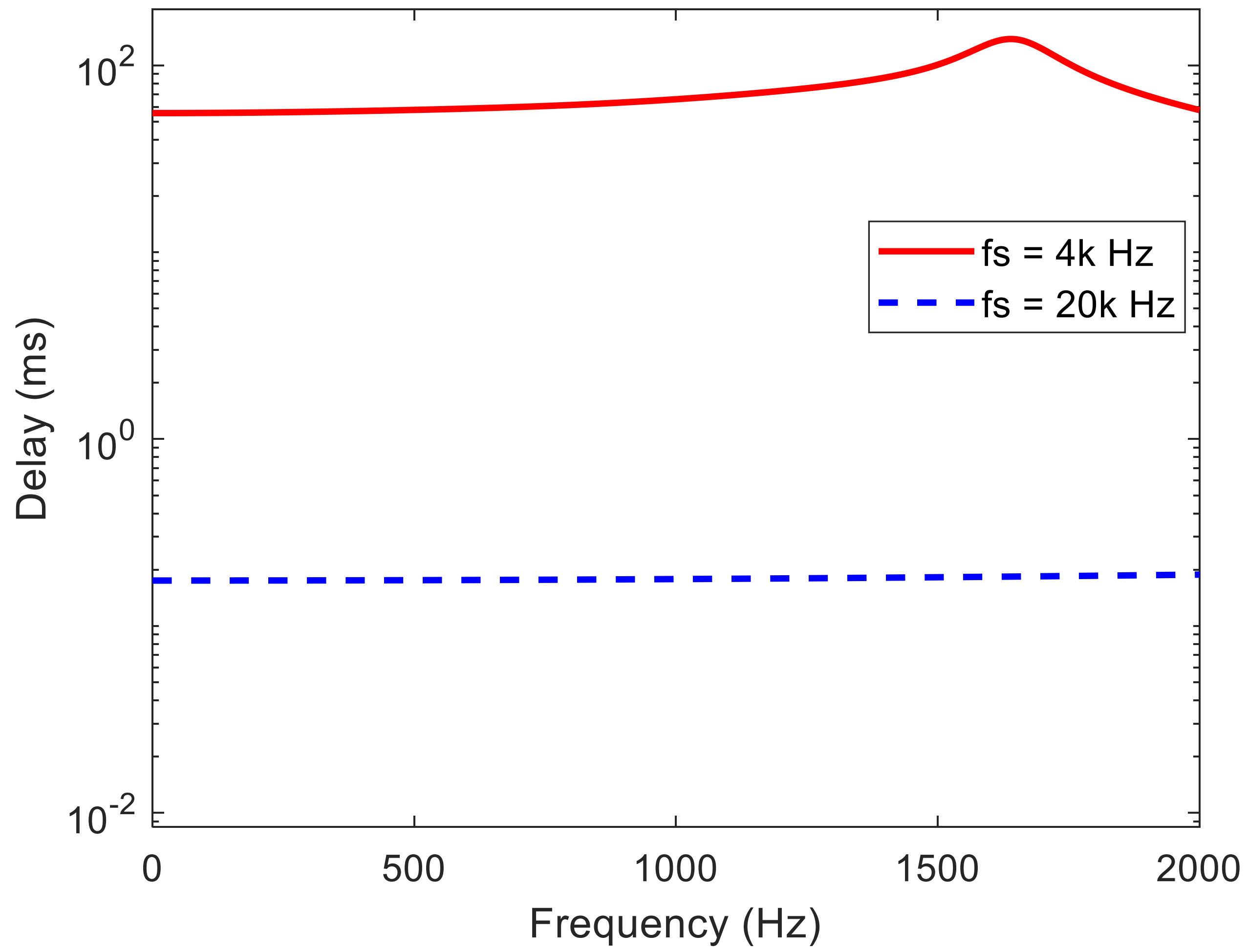
Results – Compare the introduced group delay



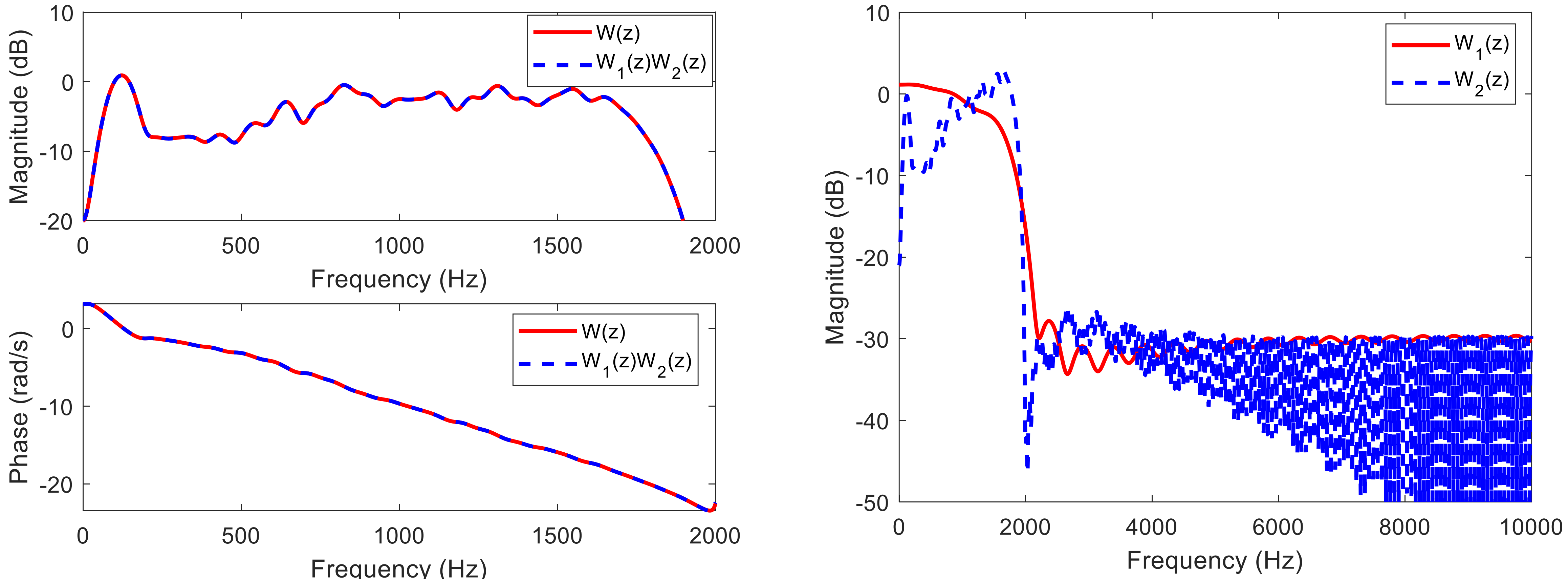
When using minimum order butterworth filter as anti-aliasing/reconstruction filter:

- Passband ends at about 1.5 kHz
- Stopband starts at about 2 kHz
- 1 dB ripple at passband
- 30 dB attenuation at stopband

And another one sample additional delay.

Results – Designed sub-filters for delayless polyphase

Frequency response shows the sub-filters fit the control filter well and each sub-filter has the desired stopband



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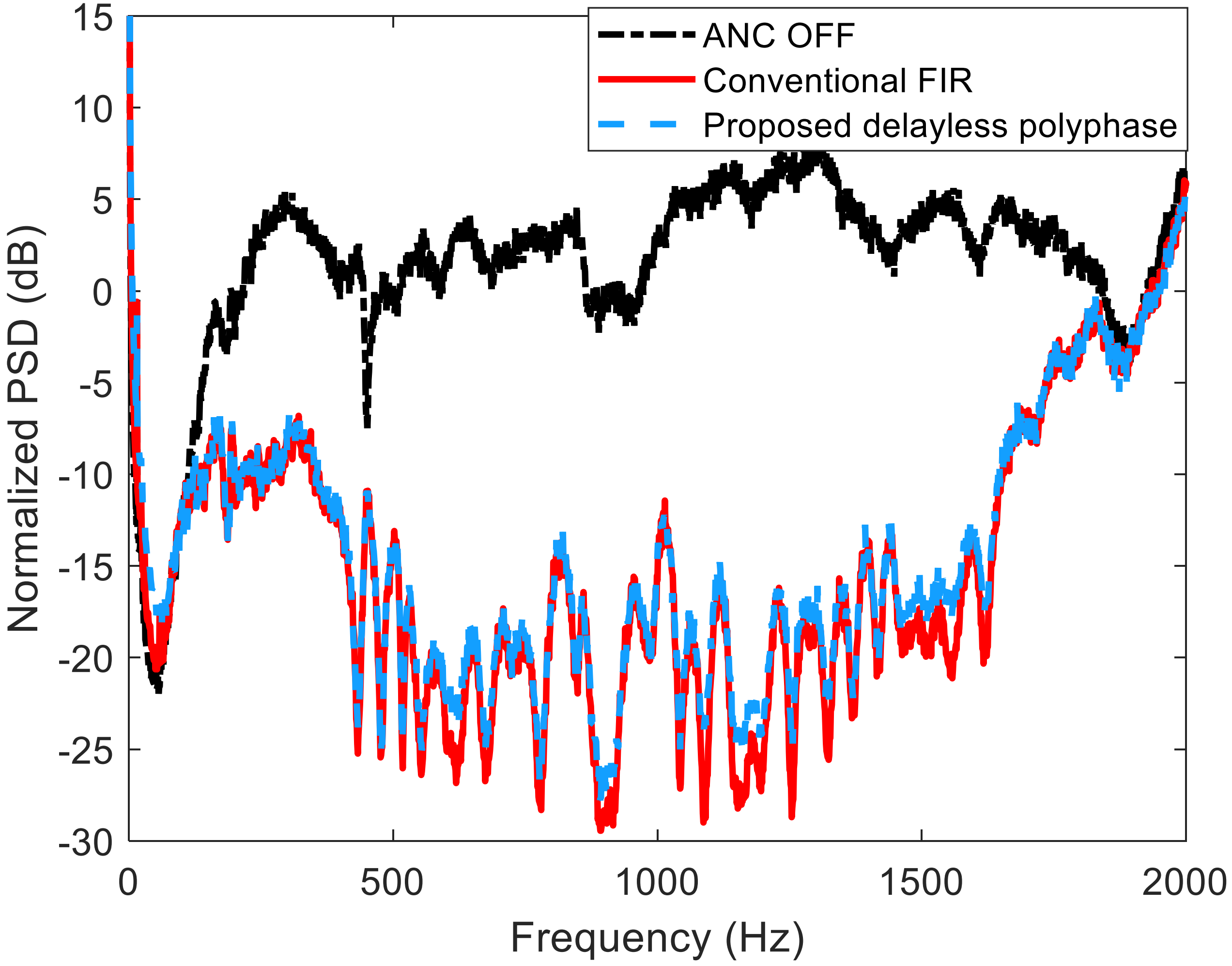
Results – Comparison of noise control performance

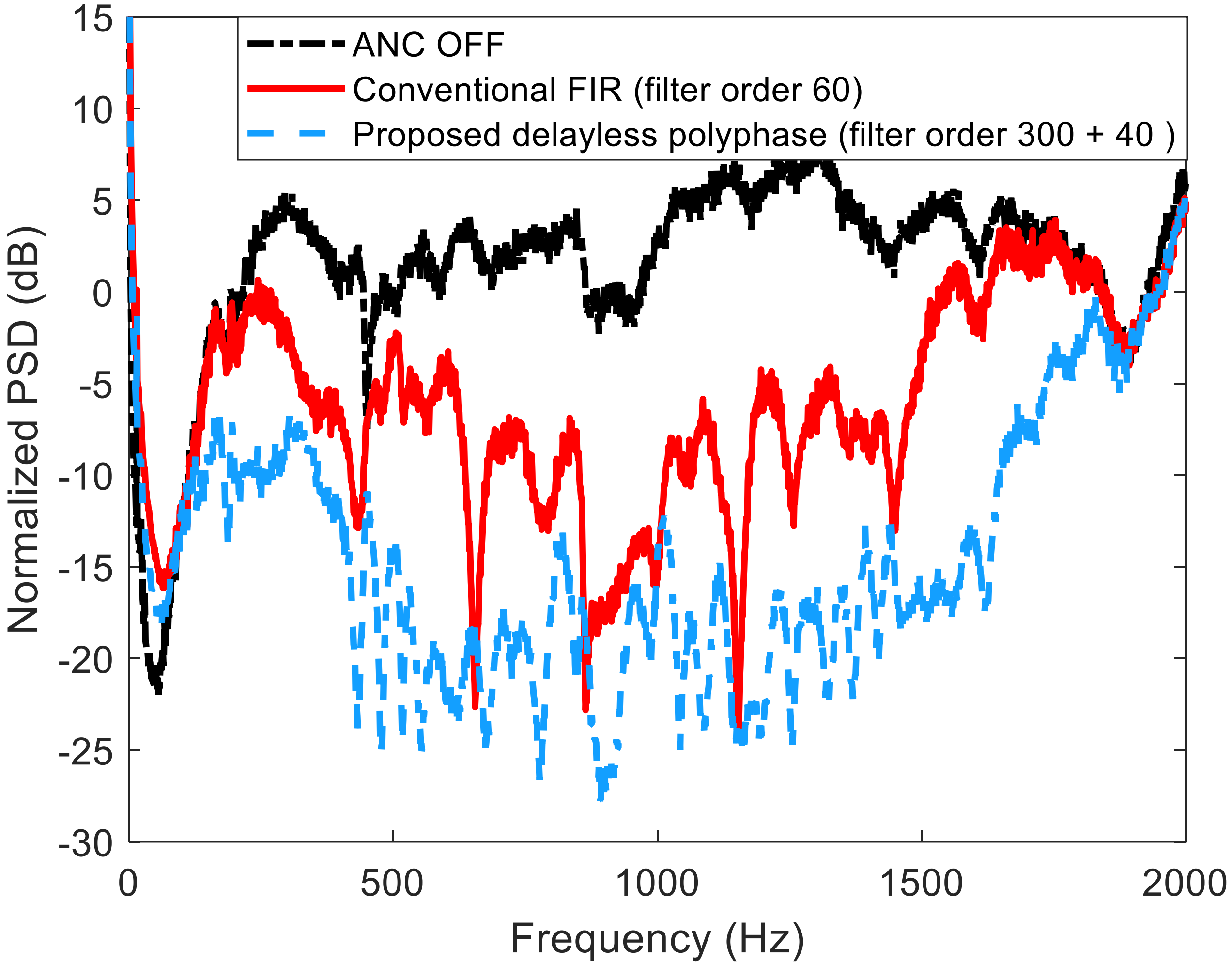


Both methods use 20 kHz sampling rate, and the same filter order.

Compared with conventional FIR implementation, the proposed method:

- reduce about 80% real-time computational load (multiplications reduced from 300 to 68)
- does not sacrifice noise control performance

Results – Comparison of noise control performance

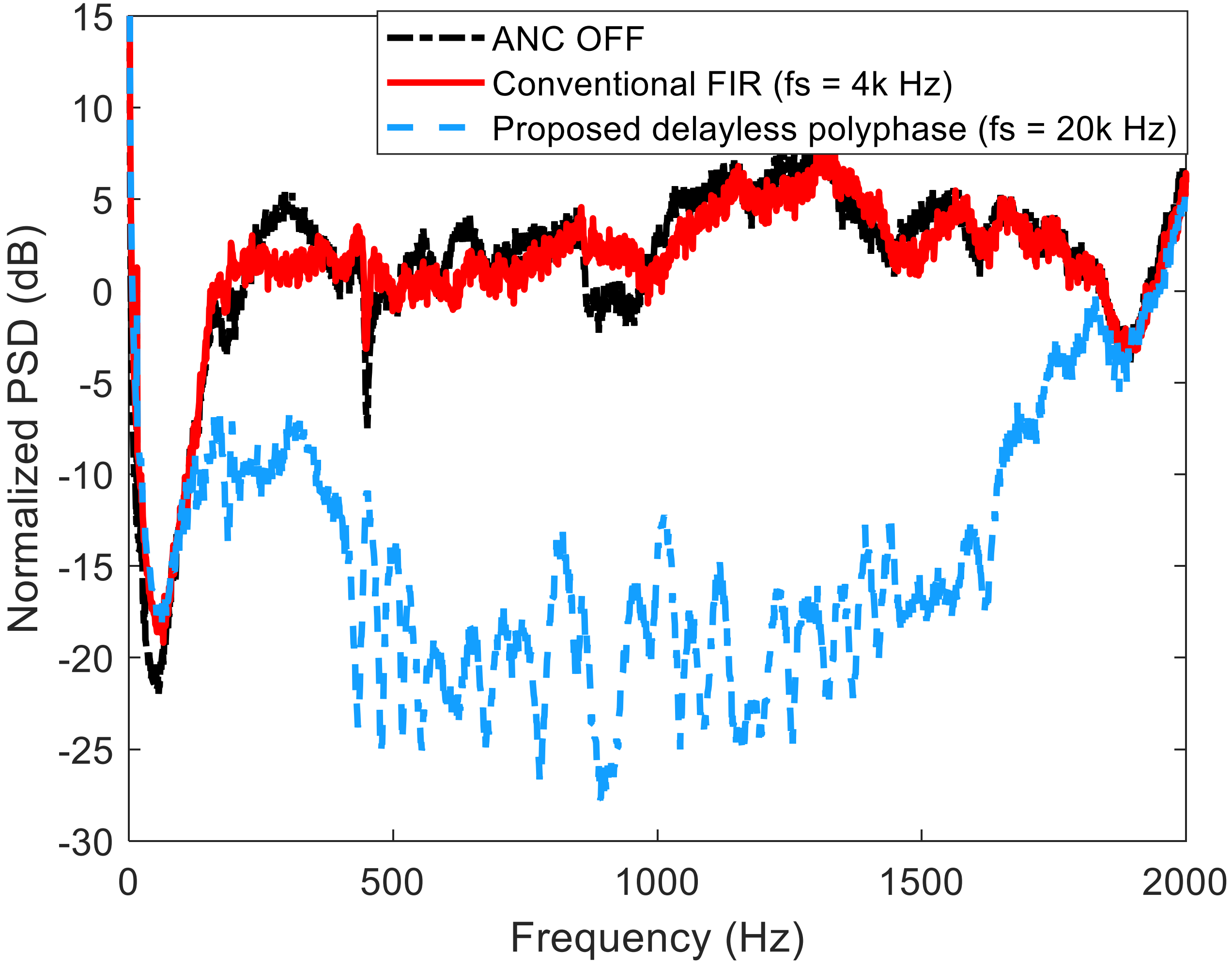


Both methods use 20k Hz sampling rate, and different filter order.

Compared with lower order conventional FIR implementation, the proposed method:

- has similar computational load
- has better noise control performance because longer filter response

Results – Comparison of noise control performance



Both methods use the same filter response length, but use different sampling rate

Compared with lower sampling rate conventional FIR implementation, the proposed method:

- has similar computational load
- has much better noise control performance because lower delay

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- Increasing sampling rate can reduce electronic delay which improves ANC performance. But real-time computational load is increased, too.
- The proposed delayless polyphase method can implement the increased sampling rate ANC control filter without increasing real-time computational load.
- By using the proposed method, either better performance can be achieved, or less real-time computational load is needed.

Thanks for your attention!

Q & A

References

For constrained filter design used in this work:

- Zhuang, Yongjie, and Yangfan Liu. "Constrained optimal filter design for multi-channel active noise control via convex optimization." *The Journal of the Acoustical Society of America* 150.4 (2021): 2888-2899.
- Zhuang, Yongjie, and Yangfan Liu. "Development and application of dual form conic formulation of multichannel active noise control filter design problem in frequency domain." *INTER-NOISE and NOISE-CON Congress and Conference Proceedings*. Vol. 261. No. 6. Institute of Noise Control Engineering, 2020.