

# Sound quality evaluation of high-speed train interior noise by adaptive Moore loudness algorithm

*Key Words: high-speed train, sound quality evaluation, ERB spectrum, AMLA, unusual random noise*

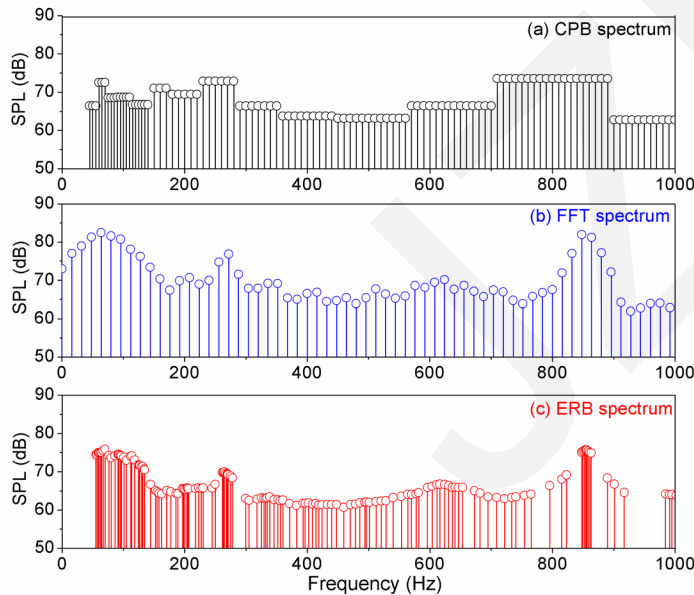
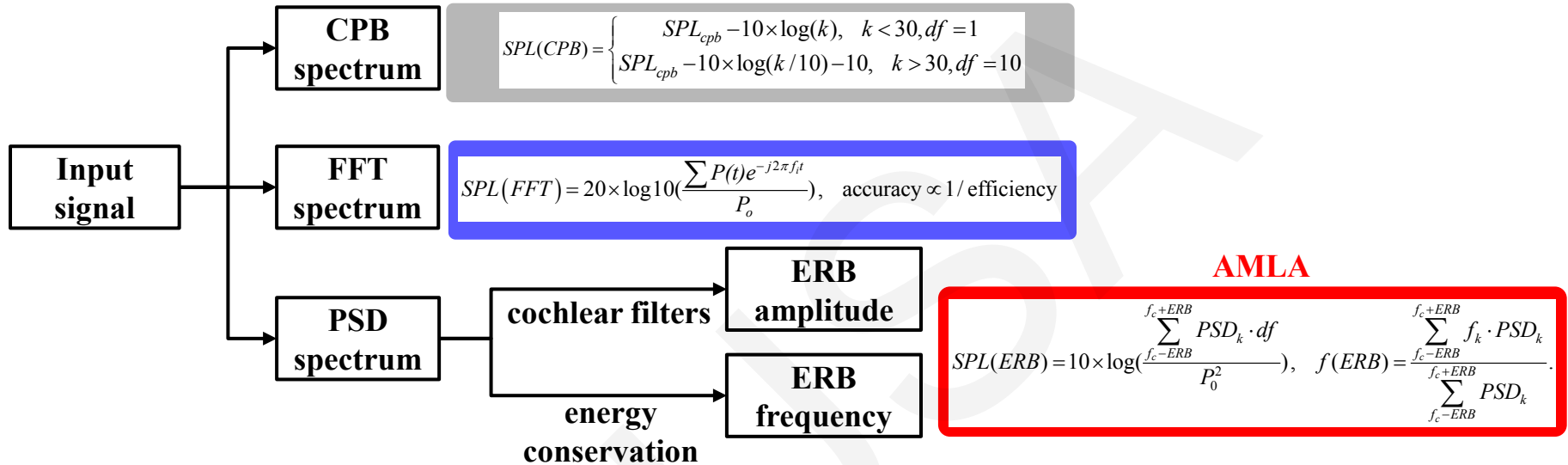
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# Background

- The high-speed train interior noise will greatly influence the riding comfort of the passenger, and has become one of the biggest complaints. Therefore it is important to find a proper way to evaluate the noise in agreement with the subjective feelings of human ears.
- Most research work has been focused on the psychoacoustic parameters of sound quality, and loudness is the most important one to evaluate the intensity of a sound. Among the traditional loudness models, the accuracy, efficiency and application range are varied along with different input signals, which may affect the sound quality evaluation directly.
- In this paper, an adaptive Moore loudness algorithm (AMLA) is proposed and applied to the sound quality evaluation inside the CRH carriage under various steady and transient running conditions.

# Development of AMLA



## ➤ Disadvantages of the existing algorithms

- ✗ **CPB spectrum**: the amplitude peaks of the original signal are blurred or even distorted.
- ✗ **FFT spectrum**: calculation efficiency and accuracy are bounded by Heisenberg's uncertainty principle.

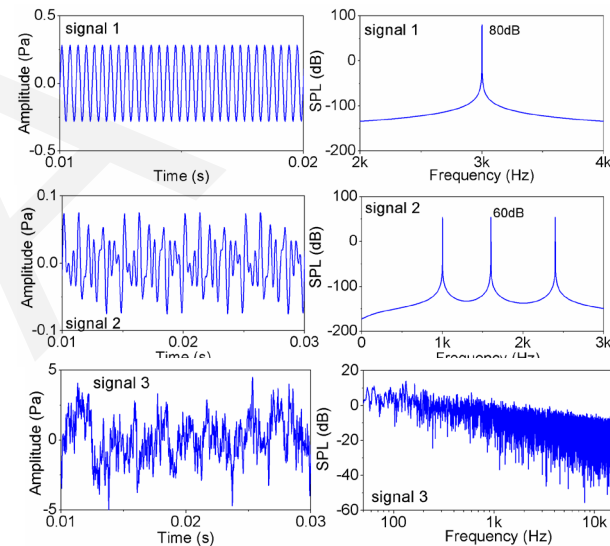
- ✓ **AMLA**: the ERB spectrum is exclusive and signal adaptive.

# Validation of AMLA

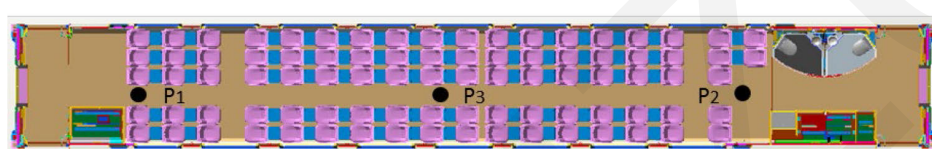
## (a) Accuracy comparison of different simulated noises

Signal	Reference	CPB spectrum	relative error	FFT spectrum	relative error	AMLA	relative error
Pure tone	27.50	28.95	5.27%	27.62	0.44%	27.62	0.44%
Complex tone	12.75	14.43	13.18%	12.90	1.18%	12.77	0.16%
Pink noise	3.83	3.91	2.09%	3.86	0.78%	3.85	0.52%

Table. 1 Overall loudness results of different simulated signals



## (b) Signal distinguishing between on-line experiment and colored noises



P1: rear-end P2: front-end P3: center  
P4: bottom P5: top P6: side P7: bywindow

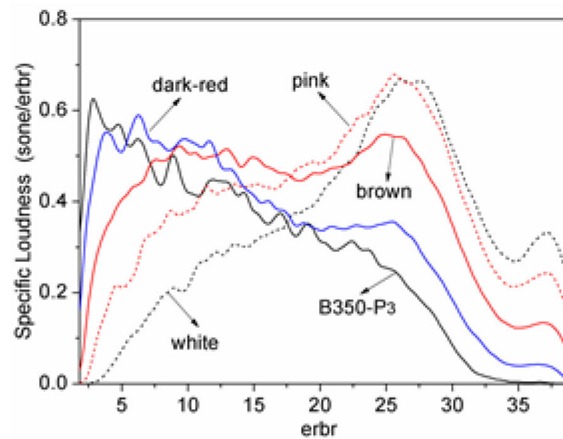
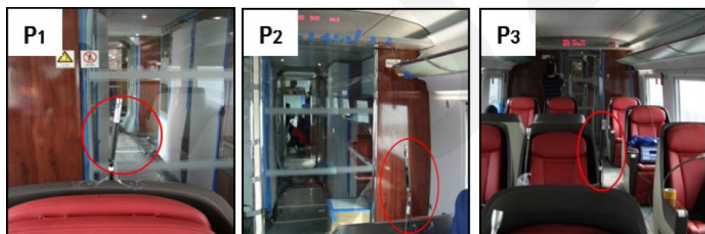
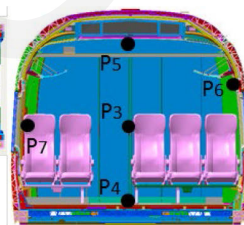


Fig. 1 The specific loudness results of different noises

# Application of AMLA

## Sound quality analysis at different running speeds

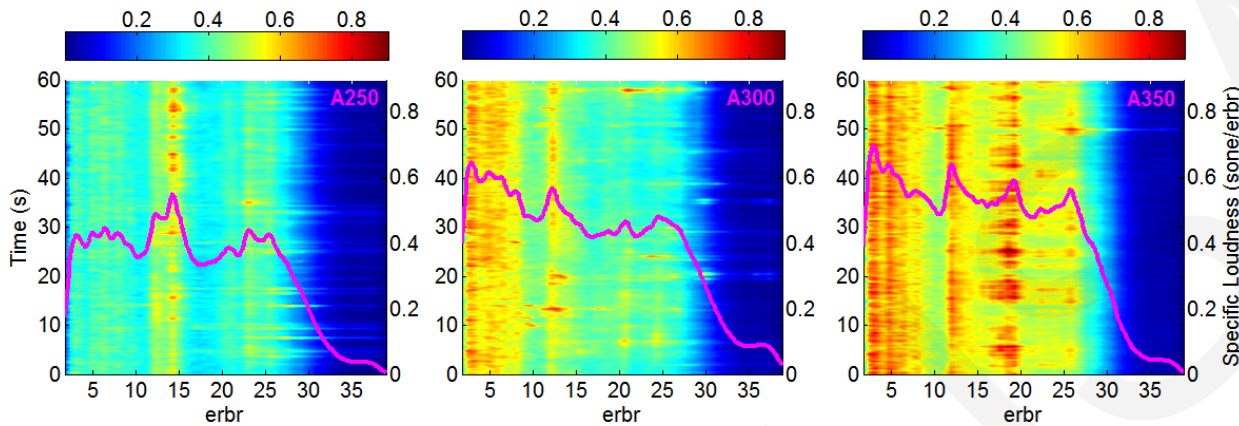


Fig.2(a) Time-erbr color maps of the specific loudness

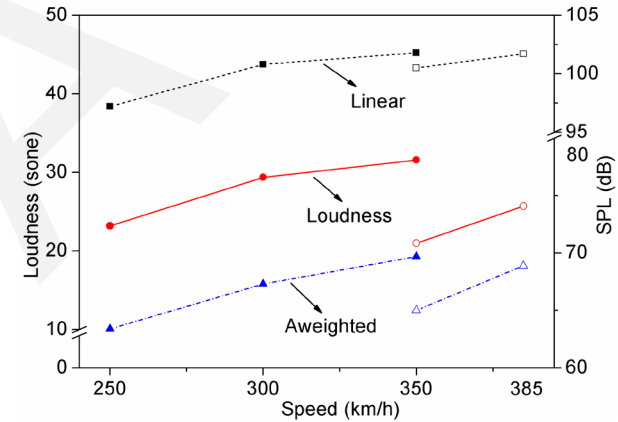


Fig.2(b) The overall results comparison

## Sound quality analysis at different spatial locations

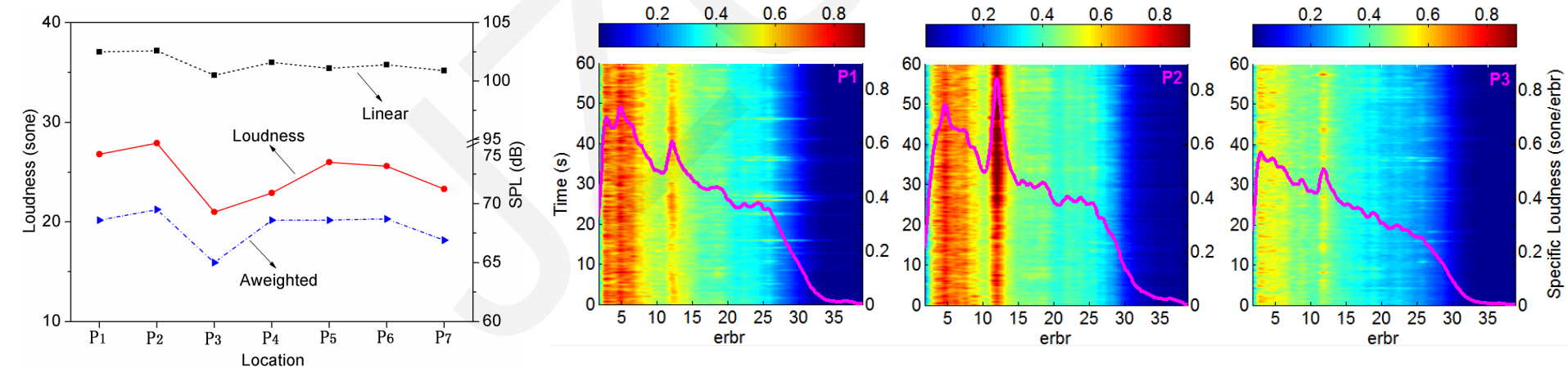


Fig. 3(a) Time-erbr color maps of the specific loudness

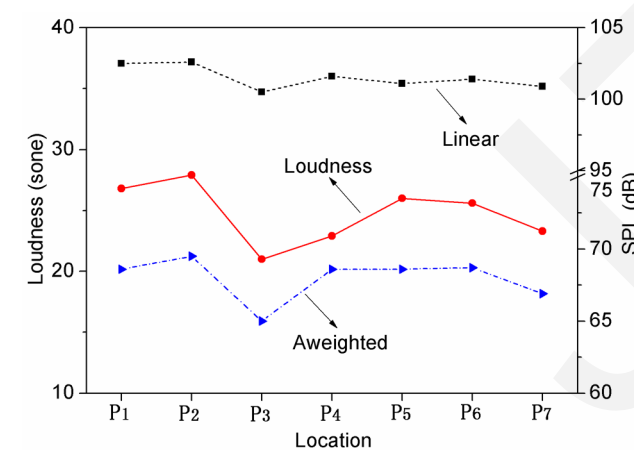


Fig.3(b) The overall results comparison

# Application of AMLA

## ➤ Sound quality variation under transient conditions

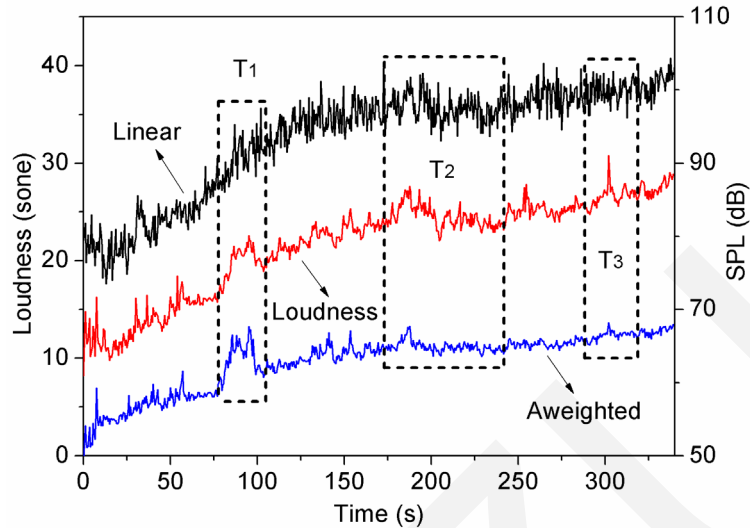


Fig.4(a) The overall value variation as a function of time

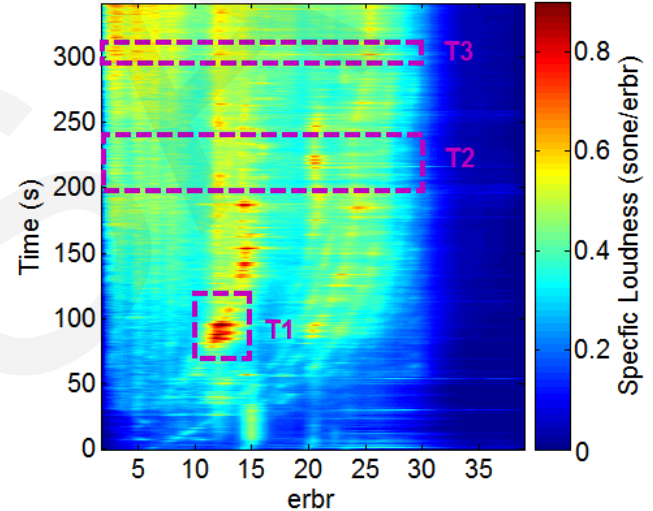


Fig.4(b) Time-erbr color map of the specific loudness

- ✓ The long time series recorded four processes of the train running states: 0-40s as the adjustment process, 40-190s as the rapid acceleration process, 190-240s as the gradual deceleration process, and 240-340s as the gradual acceleration process respectively.
- ✓ The trend of the overall loudness curve is well matched with the different running states, and the appearance of loudness peaks is also in accord with the auditory assessment of the researchers.
- ✓ The specific loudness components among 12-15 erbr are relatively stable, while components among 20-27 erbr are speed-related.

# Conclusions

- (1) The core idea of AMLA is the signal-adaptive ERB spectrum, which retains the nonlinear auditory characteristics of human ears. Compared with the existing algorithms based on CPB or FFT spectrum, AMLA can obtain higher accuracy and efficiency.
- (2) The interior noise of the high-speed train is mainly composed of middle-low frequency components, which has the similar auditory feeling with the dark red noise. AMLA can effectively distinguish the interior noise from the colored noises with the same A-weighted SPL value.
- (3) The interior sound quality under different steady conditions is analyzed in depth comprehensively by AMLA, for the first time in the area of high-speed train research. Results show that the main loudness component of the interior noise is below 27.6 erbr, and the sound quality is relatively stable between 300-350 km/h.
- (4) The specific loudness components among 12-15 erbr remain invariable throughout the acceleration or deceleration process, while components among 20-27 erbr are speed-related. The overall loudness curve and specific loudness color map can effectively identify the unusual random noises under transient conditions. This should be helpful for the next generation high-speed train design to provide low noise and high comfort.