ME5106 CA2 Team Paper

Noise Measurement and Analysis of Singapore Mass Rapid Transit (SMRT) at Buona Vista Station

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1 Introduction

In recent years, the noise caused by trains has drawn more and more citizens attention, due to its possible impact on public health and well- being. Noise levels in metro stations can lead to anxiety for residents in and around the station, disrupt sleep, and even cause adverse health effects. Moreover, exposure to high noise levels for a long time can also cause hearing damage and undermine existing health problems.

In this CA2 report of ME5106, our group measured the noise properties in and around the Buona Vista Station, including the noise generated by trains in a semi-enclosed environment and fully close environment as well as the noise level from pedestrian perspective.

To have a better understanding of the sonic phenomenon around this station, our group managed to build a measurement system with higher precision, including condenser microphone, audio interface, and digital audio workstation Studio One. This system is calibrated by iZotope Ozone. Then, the noise levels and the frequency characteristics were analyzed in iZotope Insights.

Based on them, our group focused on the loud noise generated by Singapore Mass Rapid Transit (SMRT). We analyzed the sound level and frequency near the Buona Vista station.

2 Background

Nowadays, public transportation has become the primary mode of travel for most individuals, driven by environmental and economic considerations. And SMRT has emerged as a vital choice for commuters due to its punctuality and the absence of traffic congestion. The appearance of the SMRT has greatly alleviated the pressure on road traffic, which means more citizens choose to take SMRT instead of driving. However, people who frequently take the SMRT are often bothered by the loud noise, especially during the period when train arrives and departures at the stations. Under such circumstances, the SMRT operating company has implemented some noise reduction measures to mitigate this issue. In this research, we examine two distinct sonic phenomena at the Buona Vista SMRT station to study. They are the noise generated by trains operating in semi-enclosed noise reduction mode and noise generated by trains in fully enclosed noise reduction mode.

2.1 Experiment Location Buona Vista

In order to compare the noise generated by trains when entering and exiting in semi- enclosed and fully enclosed noise reduction environments, our group initiated the experiment by selecting Buona Vista SMRT station as the data collection location. Because this metro station serves a transfer point, with the green line running above ground and the circle line running underground. This unique transport structure makes it more conveniently to detect the characteristic of train noises. As illustrated in **Fig. 2.1.**, our group chose 6 locations to assess train noise characteristics. Trains enter or exit this station in the direction indicated by the green arrow.

Location 1 and location 5 are situated in the upper station, known as the “green line”, which are also depicted in **Fig. 2.2.**, **Fig. 2.3.**, **Fig. 2.4.** and **Fig. 2.5.**.These images reveal the fact that this “green line” station at Buona Vista is emi- enclose, meaning only half of the propagation path is obstructed by sound barriers. Consequently, when trains enter or exit, relatively significant noise is anticipated for people waiting on the platform.

Location 2 and 6 are in the underground station, known as the “circle line”, which are also illustrated in **Fig. 2.8.** and **Fig. 2.9.**. These images indicate the fact that this “circle line” station at Buona Vista is fully enclosed, requiring noises to pass through the sound barrier before reaching passengers’ ears.

Location 3 and 4 are positioned outside the station, which are also illustrated in **Fig. 2.6.** and **Fig. 2.7.**. These images indicate that trains pass over pedestrians’ heads at a considerable height without any sound barriers.

To assess the impact of a semi- enclosed sound barrier, our group collected noise data from both below the sound barrier and above the sound barrier, illustrating in **Fig. 2.2.**, **Fig. 2.3.**, **Fig. 2.4.** and **Fig. 2.5.**. During this process, we also managed to extract some insightful information regarding noise variations across different areas of the station.

Fig. 2.8. and **Fig. 2.9.** illustrate the data collection process in the underground station, from which we could learn the impact of an enclosed sound barrier. Additionally, we also gained insight into the differences between semi- enclosed sound barriers and fully enclosed sound barriers.

Fig. 2.6. and **Fig. 2.7.** depicts the noise level detection process from the perspective of pedestrians. This data enables us to determine whether the noise poses a disturbance to pedestrians near the station.

Fig. 2.1. Locations of the sound test.

Fig. 2.2. Detect below the sound barrier in the upper station at location 1.

Fig. 2.3. Detect above the sound barrier in the upper station at location 1.

Fig. 2.4. Detect below the sound barrier in the upper station at location 5.

Fig. 2.5. Detect above the sound barrier in the upper station at location 5.

Fig. 2.6. Detect in pedestrian street at location 3.

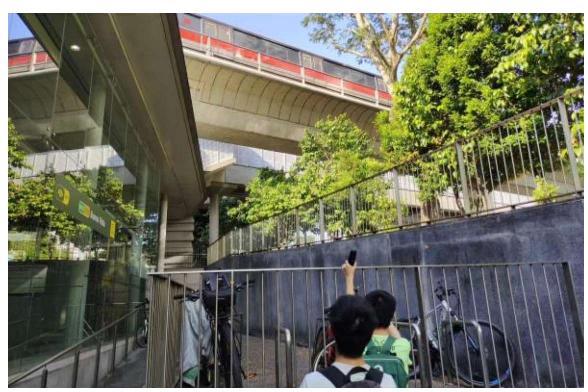

Fig. 2.7. Detect in pedestrian street at location 4.

Fig. 2.8. Detect behind the sound barrier in the underground station at location 6

Fig. 2.9. Detect behind the sound barrier in the underground station at location 2

2.2 Regulations on SMRT Noise

In order to reduce the impact of noise on people's health, various relevant departments have implemented regulations to govern noise levels. According to a report by World Health Organization (WHO), it is strongly recommended to reduce average noise exposure from railway traffic to below 54 dB and nighttime noise exposure to below 44 dB. Exposure above these levels have been linked to adverse health effects.[1] Therefore, it is crucial to examine whether the SMRT complies with these regulations, especially in relation to the well- being of surrounding residents.

Although there are currently no specific regulations about SMRT issued by National Environmental Agency (NEA) of Singapore, this industrial noise control measures can serve as a reference to assess whether the noise generated by the SMRT might disturb nearby residents. The limitation to the decibel of noise is illustrated in **Tab. 2.1.** and **Tab. 2.2.**.

Tab. 2.1. Industrial noise control regulations (over the specified period) [2].

Types of affected premises	Maximum permitted noise level (reckoned as the equivalent noise level over the specified period) in decibels(dBA)		
	Day(7am-7pm)	Evening(7pm-11pm)	Night(11pm-7am)
Noise Sensitive Premises	60	55	50
Residential Premises	65	60	55
Commercial premises	70	65	60

Tab. 2.2 Industrial noise control regulations (over 5 minutes) [2].

Types of affected premises	Maximum permitted noise level (reckoned as the equivalent noise level over 5 minutes) in decibels(dBA)		
	Day(7am-7pm)	Evening(7pm-11pm)	Night(11pm-7am)
Noise Sensitive Premises	65	60	55
Residential Premises	70	65	60
Commercial premises	75	70	65
Factory Premises	75	70	65

2.3 Theory of noise

Insertion loss

Insertion loss is the definition which refers to the effect of acoustic material or equipment used to reduce noise propagation or control sound propagation. Specifically, insertion loss refers to the degree to which sound energy is lost after passing through soundproofing materials or acoustic equipment. Insertion loss is usually expressed in dB, representing the power loss of noise after passing through soundproofing materials or acoustic equipment. It is commonly calculated using the formular below [3].

$$Insertion\ Loss = 10\log_{10}(\frac{P_{in}}{P_{out}}) \quad (2.1)$$

Here, P_{in} represents the input sound power before propagates to soundproofing materials or acoustic equipment; P_{out} is the output sound power of sound passing through soundproofing materials or acoustic equipment.

Sound Barrier

The outdoor noise barrier is one of the most effective and economical method for reducing the transmission of noise from the source to the receiver. This reduction is frequency- dependent, meaning that high-frequency noise is much more effectively blocked than low-frequency noise, due to the phenomena of sound diffraction.

Consequently, the best location for a barrier is close to either the receiver or the sound source. Both locations can minimize the impact of diffraction.

Fresnel Number

Fresnel Number is a dimensionless value used to describe diffraction phenomena. We could use it to calculate the effect of a sound barrier approximately. The Attenuation of noise barrier can be calculated using this formula:[3]

$$N = \frac{2}{\lambda}\ (A + B - d) \quad (2.2)$$

Here, λ is the wavelength of the sound at the frequency of interest. And the other parameters are shown in **Fig. 2.10.**.

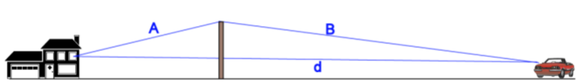

Fig. 2.10. Some parameters of Fresnel Number.

3 Results and Analysis

3.1 Spectrum and waterfall diagram

In our measurement analysis, the resulting data will primarily be used to generate spectrum and waterfall diagrams for specification and comparison. Using the spectrum, we can visually describe and analyse the typical frequency domain distribution characteristics of the noise generated by trains entering or exiting a station. The waterfall diagram adds a time dimension to the spectrum, which better helps to analyze the source of the noise and the change of the frequency distribution over time. By using these two types of diagrams, the measured data can be analyzed more comprehensively and accurately to obtain the required results.

During our noise measurements at the MRT stations, we observed that we mainly focused on the noise of trains entering and exiting the stations. However, in reality, there are several different types of noise that can affect the results. In conjunction with our data enquiry, the sources of station noise consist of two main components: train operating noise and station operating noise. Train operation noise includes wheel-rail noise, traction motor and drive noise, brake whistling, air-conditioning equipment noise, and noise radiating from the platform structure. Station operation noise includes the operation of fixed equipment, broadcasting sound sources, station multimedia, and noise from passenger flow [4]. Due to our limited measurement equipment and data processing capabilities, our primary focus has been on noise from train entry and exit, but we will also briefly discuss and analyze other significant noise sources.

3.2 Semi-enclosed environment (EW21)

Table #.1 gives the peak noise obtained in several cases. During the tests, with only one piece of equipment available, we measured the sound of one train entering and leaving the station one at a time at a single point, and thus the results for each point are based on a different train and a different time period. The data results from each point can be briefly analysed and compared, although various variables limit the accuracy of these comparisons to only provide basic ideas. Combining the tables, it can be seen that, whether at the middle or the front of the platform, the peak noise levels for trains inbound at the

Table 3.1 Max sound level of EW21 during train entry and exit

Max Sound Level /dB	Middle of the Platform		Platform Front-End	
	Lower point	Upper point	Lower point	Upper point
Train Entry	75.3	73.5	71.7	72.9
Train Exit	74.9	69.7	66.1	65.5

low and high points are slightly greater than those for trains outbound. Considering the perception at the time of measurement, the train's brake whistling appears to play a major role. In addition, comparing the results at different heights within the same location, the differences in noise levels between the high and low points is not significant and not clearly characterised, which may be due to the differences in the model and condition of each train, as well as the distribution of the location and number of passengers. Comparing the equipment in the middle of the platform and the front of the platform, it can be found that the peak noise level at the front of the platform is significantly lower than that at the middle of the platform when the train leaves the station, which will be continued to be analysed in a later section.

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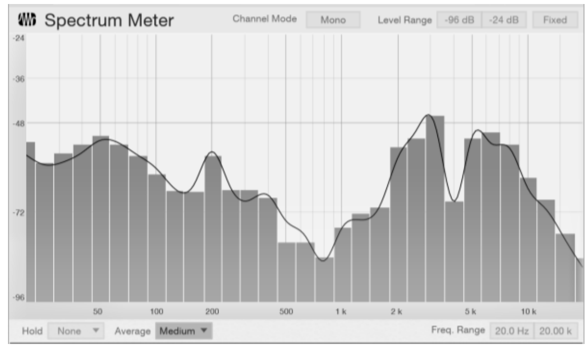

Fig.3.1. Spectrum Analysis of Noise at lower point of mid-platform during train entry.

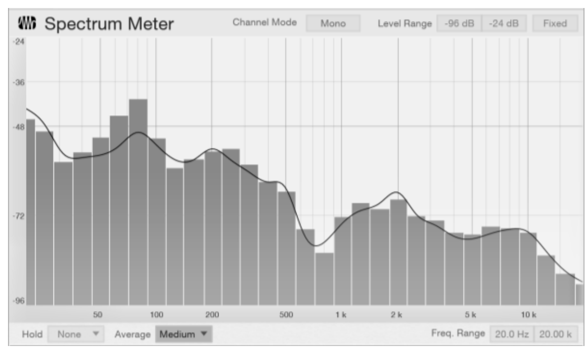

Fig.3.2. Spectrum Analysis of Noise at lower point of mid-platform during train exit.

Fig.3.3. Spectrum Analysis of Noise at upper point of mid-platform during train entry.

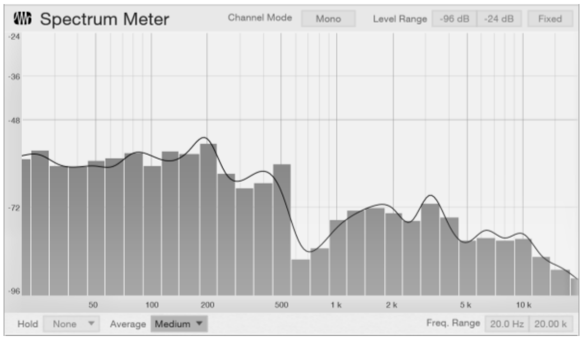

Fig.3.4. Spectrum Analysis of Noise at upper point of mid-platform during train exit.

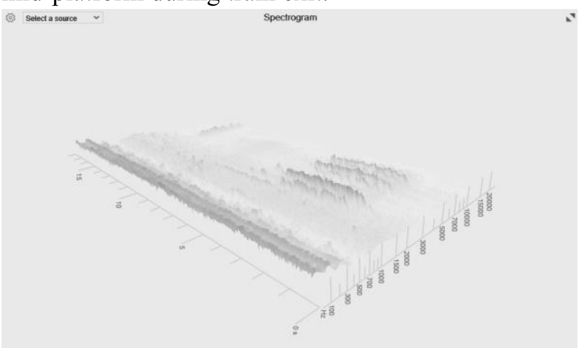

Fig.3.5. Waterfall diagram of Noise at lower point of mid-platform during train entry.

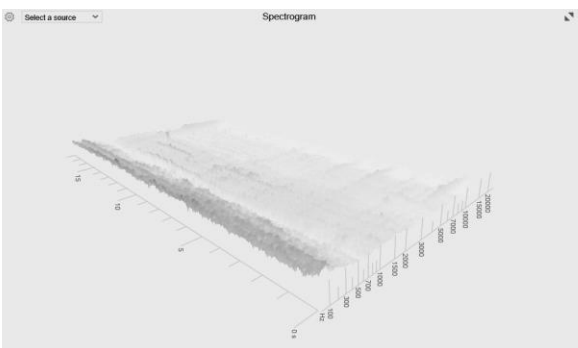

Fig.3.6. Waterfall diagram of Noise at lower point of mid-platform during train exit.

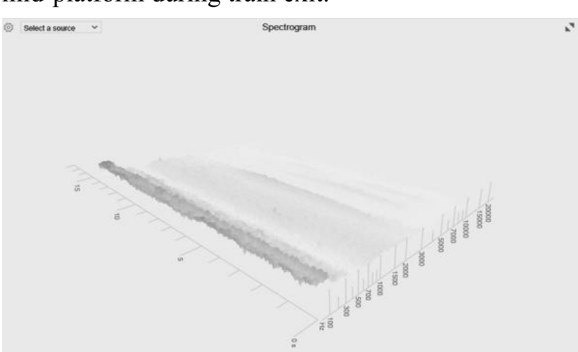

Fig.3.7. Waterfall diagram of Noise at upper point of mid-platform during train entry.

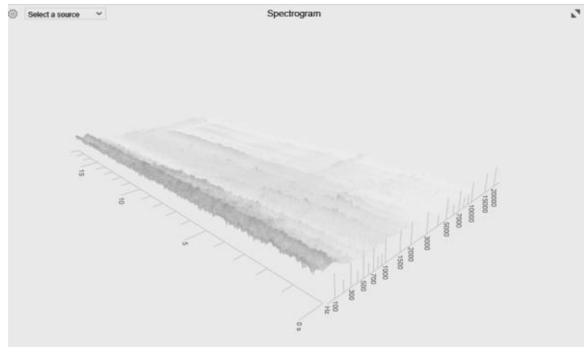

Fig.3.8. Waterfall diagram of Noise at upper point of mid-platform during train exit.

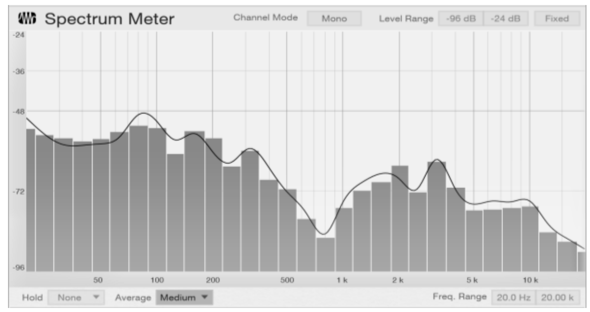

Fig.3.9. Spectrum Analysis of Noise at lower point of platform front during train entry.

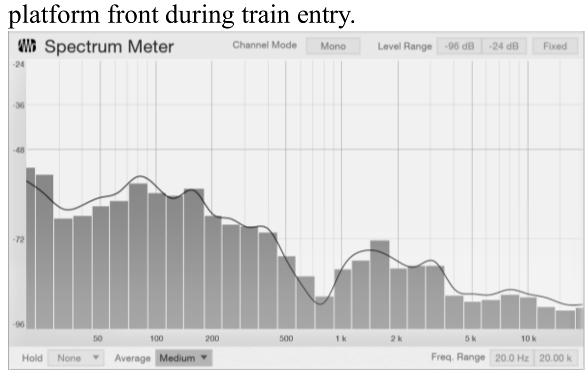

Fig.3.10. Spectrum Analysis of Noise at lower point of platform front during train exit.

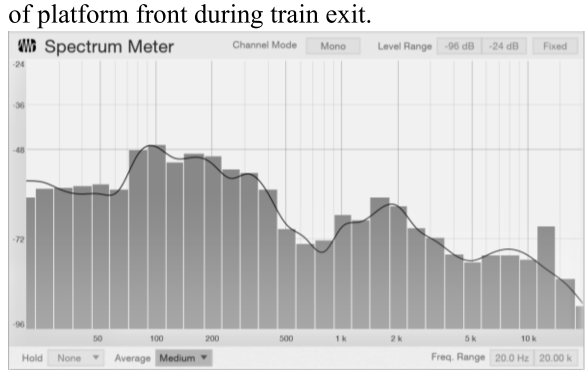

Fig.3.11. Spectrum Analysis of Noise at upper point of platform front during train entry.

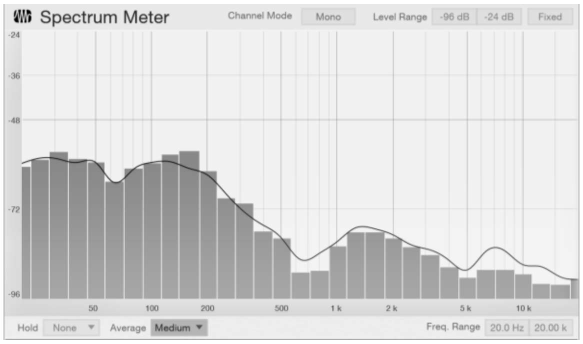

Fig.3.12. Spectrum Analysis of Noise at upper point of platform front during train exit.

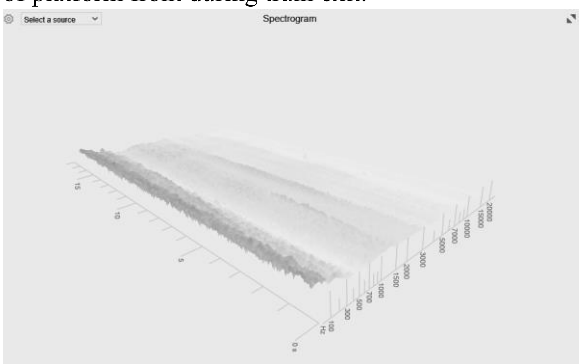

Fig.3.13. Waterfall diagram of Noise at lower point of platform front during train entry.

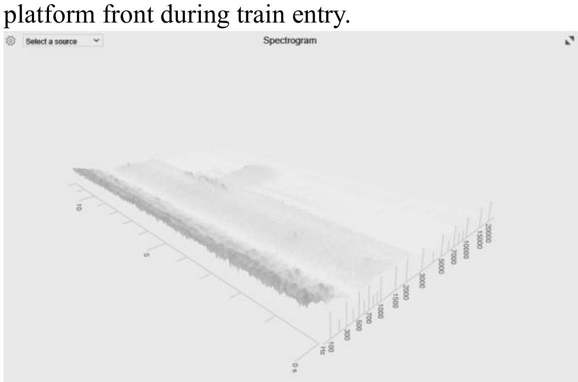

Fig.3.14. Waterfall diagram of Noise at lower point of platform front during train exit.

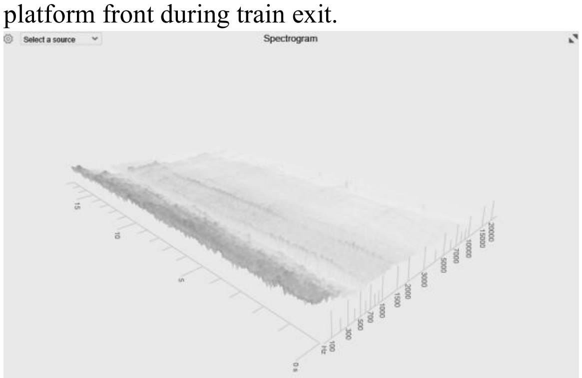

Fig.3.15. Waterfall diagram of Noise at upper point of platform front during train entry.

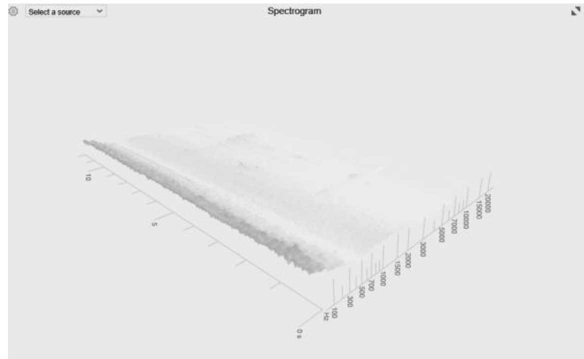

Fig.3.16. Waterfall diagram of Noise at upper point of platform front during train exit.

Train Entry and Exit Noise Analysis

In **Fig.3.1.**, **Fig.3.2.**, **Fig.3.3.**, and **Fig.3.4.**, the spectrum analysis shows the sound frequency range from 20Hz to 20k Hz, and the noise level ranges from -96dB to -24dB. In **Fig.3.1.**, and **Fig.3.2.**, we measured the noise at the lower and upper points of the mid-platform, respectively, during the same train's entry and exit. The **Fig.3.1.** illustrates that higher noise levels concentrate within the sound frequency range of 50 to 200 Hz. This noise produced by the deceleration movement in the MRT station is related to the vibration related to the MRT movement and the wheel-rail contact sound. On the other sides of the spectrum in **Fig.3.1.**, the noise levels peak in the higher frequency ranges from 2kHz to 4kHz. This is potentially attributed to the speed of the metro decelerating to a speed close to 0, causing the squeal from the friction between the brake pads and the wheels or tracks. In short, the peak of the noise in higher frequency range could be further accentuated by sound reflection within the brake squeal of the metro, also referred to brake whistling noise, as mentioned in our overview of applying spectrum and waterfall diagram.

In **Fig.3.2.**, the pattern of the noise level in the lower frequency range is similar to **Fig.3.1.**, but in the higher frequency range in **Fig.3.2.**, the noise level of the metro exit to the station is lower than the noise of the metro entry to the station during the higher frequency region from 2kHz, 4kHz. This potential reason may be due to the fact that high-frequency noise sources, such as the brake whistling noise is louder than the engine noise, resulting in a higher noise level when metro entry to the station.

In **Fig.3.3.** and **Fig.3.4.**, we observed that the noise level in lower frequency range from 20 Hz to 200 Hz in **Fig.3.4.** is generally lower than the noise level in **Fig.3.3.**. When the metro exits, the brake system of the metro will not be utilised as much as when the metro enters the station. This is potentially due to the metro being accelerated by motor drive, while the noise level will be lower when metro departs from the station.

In conclusion, the peak noise level in higher frequency region at the upper point of mid-platform during metro entry in **Fig.3.3.**, is lower than the peak noise level in the same frequency region at the lower point of mid-platform during both metro entry and exit. This indicates that the brake whistling noise is lower at the upper point of the mid-platform during metro entry compared to the other cases in **Fig.3.3.** and **Fig.3.4.**. However, the noise levels in the higher frequency region for the upper point of metro entry or exit the station are relatively similar. Our group believes these variations are due to differing metro models and conditions. Another observation is that the platform screen door does not significantly contribute to insulate the metro's noise in the lower or upper point at mid-platform or platform front. This conclusion is drawn from the observation that the noise level in lower frequency range is lower in **Fig.3.2.** than in **Fig.3.4.**, suggesting that the primary function of the platform screen door is only in use for protecting passengers from falling onto the tracks rather than to provide sound insulation.

A corresponding waterfall diagram is formed by observing the changes in the spectrum over a period of time as the train enters and exits the station. The changes in the spectrum of the train as it enters and exits the station can be visualised from **Fig.3.5.** and **Fig.3.6.**. When the train enters the station, it is a process that the speed decreases from fast to slow and finally reaches 0. According to **Fig.3.5.**, as the trains slowdown from fast to slow, the early stage is dominated by the wheel-rail contact noise, with a relatively stable frequency spectrum. As the speed approaches 0, there is a very obvious braking whistling noise, which generates high frequency noise as mentioned in the spectrum analysis. According to **Fig.3.6.**, during the outbound process, as the speed increases, the spectral distribution remains dominated by wheel-rail noise. High-frequency motor noise has an obvious distribution in the front part of the figure, but the amplitude has a large gap compared to the brake whistling noise. According to **Fig.3.7.** and **Fig.3.8.**, the distribution of brake whistling noise and motor operation noise can still be clearly found respectively, but the amplitude of brake whistling noise is obviously smaller than the previous data, which is analysed to be due to the difference of different train models and vehicle conditions.

Front/Mid Platform Noise Analysis

When comparing the noise levels in the spectrum between the front platform in **Fig.3.9.**, **Fig.3.10.**, **Fig.3.11.** and **Fig.3.12.**, and mid-platform in **Fig.3.1.**, **Fig.3.2.**, **Fig.3.3.** and **Fig.3.4.**, we noticed that the distribution of the noise level in the higher frequency range, from 1 kHz to 20 kHz, at the front platform is lower than that at the mid-platform. This difference may be attributed to the effect of the metro train types.

According to **Fig.3.13.**, **Fig.3.14.**, **Fig.3.15.**, and **Fig.3.16.**, the waterfall plots measured at the front of the station points demonstrate a more consistent spectral variation with the middle of the station points. Both at the lower and upper point locations, the high-frequency whistling at the inbound station and the motor operation at the outbound station are more pronounced, with the main difference being the difference in amplitude.

However, when combined with the data in **Table.3.1.**, the peak train departure noise at the front of the platform is all less than in the middle of the station. In order to explore the cause of this phenomenon more accurately, we looked for some information. Upon enquiry, we found that trains running on the EW Line are dominated by the Kawasaki Heavy Industries C151 and its derivatives.

As shown in **Fig.3.17.**, The configuration of a C151 in revenue service is DT-M1-M2-M2-M1-DT. This means that there is no motor present in the carriages at either end of the train. The carriages corresponding to the measurement points in the middle of the platform have motors, and the noise of the motors running on exit will be more noticeable than at the two ends. This largely explains the reason for this type of feature in the data.

Cars of C151						
Car Type	Driver Cab	Motor	Collector Shoe	Car Length		Wheelchair Space
				mm	ft in	
DT	✓	✗	✓	23,650	77 ft 7.1 in	✗
M1	✗	✓	✓	22,800	74 ft 9.6 in	✗
M2	✗	✓	✓	22,800	74 ft 9.6 in	✓

Fig.3.17. Cars of C151.

3.3 Fully Enclosed Environment (CC22)

Our group collected the noise results in a fully enclosed environment at Circle line 22(CC22) at Buona Vista interchange station. The platforms of CC22 are separated from the tracks by complete screen doors, making the platform area a fully enclosed environment. During our measurements, one feature of this station had a significant impact on the results: the station broadcasts. Circle Line has a high level of train automation. Whenever a train is about to enter or leave the station, various audio reminders are automatically played in the station and last for a long period of time, almost completely covering the train's arrival and departure sounds. According to **Table.3.2.**, it can be observed that the peak inbound and outbound noise levels are similar in the middle of the platform and at the front of the platform. In fact, the differences are more related to the station broadcasts than to the trains themselves. During data processing, we managed to intercept a small section of train inbound audio without broadcast interference and plotted the spectrum for a simple comparison.

Table.3.2. Max sound level of CC22 during train entry and exit

Max Sound Level /dB	Platform Front-End	
	Lower point	Lower point
Train Entry	71.4	68.2
Train Exit	70.5	70.6

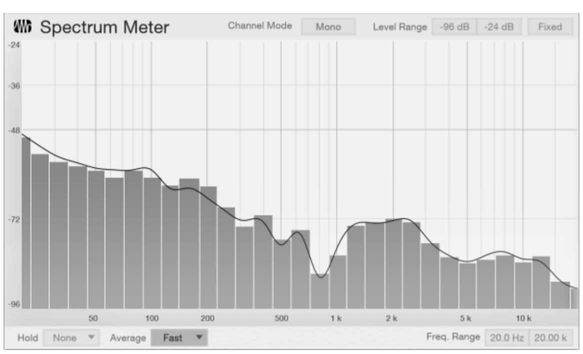

Fig.3.18. Spectrum Analysis of Noise at mid-platform during train entry.

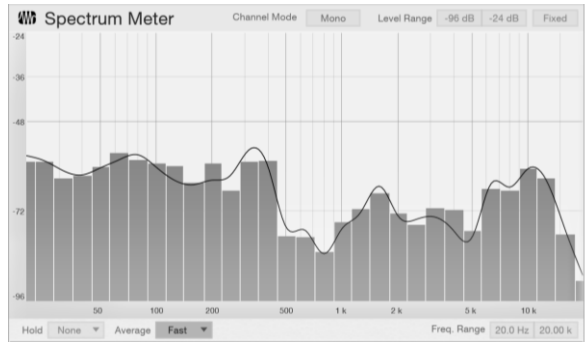

Fig.3.19. Spectrum Analysis of Noise at mid-platform during train entry with broadcast background noise.

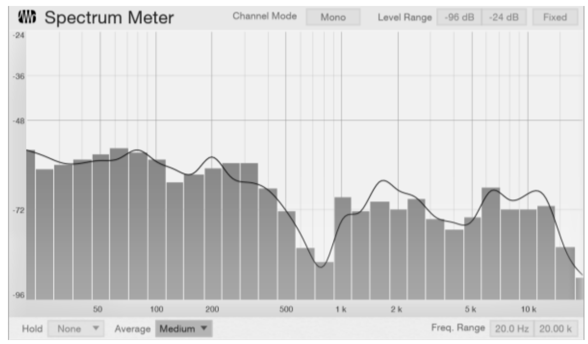

Fig.3.20. Spectrum Analysis of Noise at mid-platform during train exit.

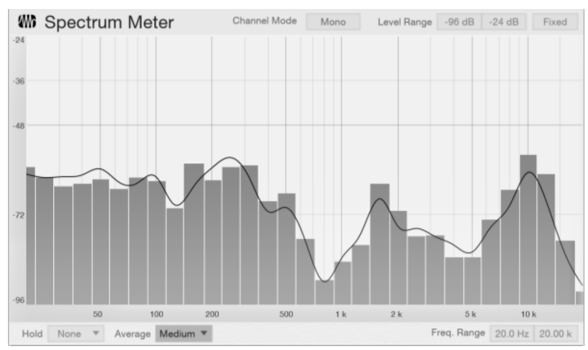

Fig.3.21. Spectrum Analysis of Noise at platform front during train entry.

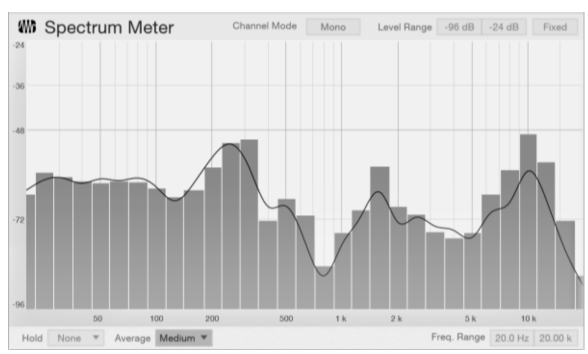

Fig.3.22. Spectrum Analysis of Noise at platform front during train exit.

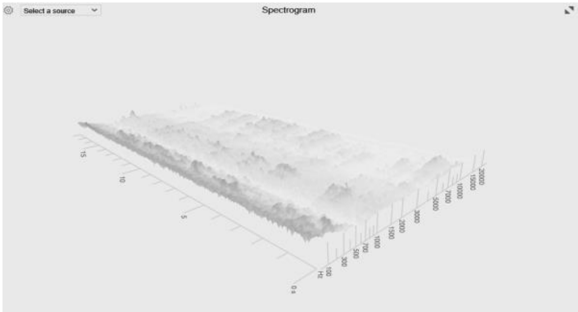

Fig.3.23. Waterfall diagram of Noise at mid-platform during train entry.

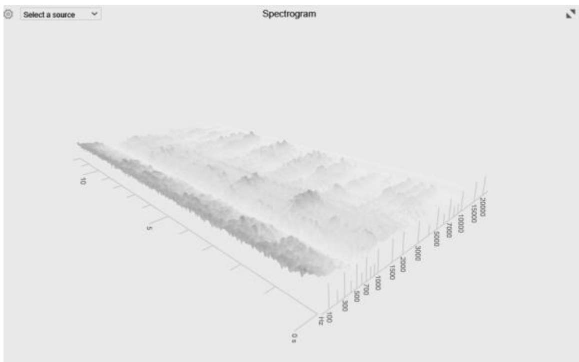

Fig.3.24. Waterfall diagram of Noise at mid-platform during train exit.

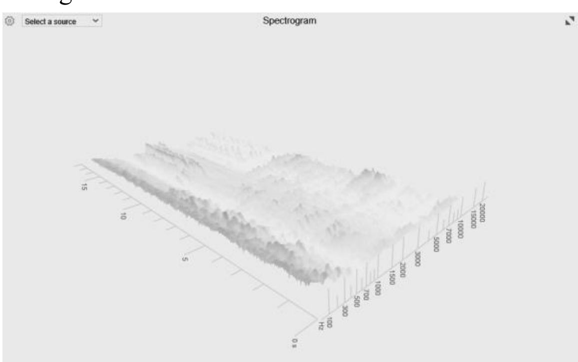

Fig.3.25. Waterfall diagram of Noise at platform front during train entry.

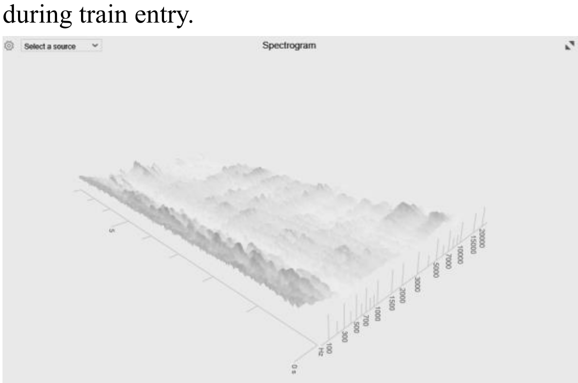

Fig.3.26. Waterfall diagram of Noise at platform front during train exit.

In **Fig.3.18.**, the spectrum of noise at mid-platform during train entry without the broadcast background noise is shown, and **Fig.3.19.**, **Fig.3.20.**, **Fig.3.21.** and **Fig.3.22.** are noise at mid-platform and platform front during train entry or exit with the broadcast background noise. When we compared the **Fig.3.18.** with **Fig.3.19.**, **Fig.3.20.**, **Fig.3.21.** and **Fig.3.22.**, we conclude that there are noise level peaks from the middle to higher frequency range, which largely cover the noise of trains entering and leaving the station. We also observed that the distribution of the noise levels in respect to the frequency range in the spectrums shown in **Fig.3.19.**, **Fig.3.20.**, **Fig.3.21.** and **Fig.3.22.** are almost the same, meaning that these figures are influenced by the broadcast background noise.

As shown in **Fig.3.23.**, **Fig.3.24.**, **Fig.3.25.**, and **Fig.3.26.**, the features of the waterfall diagram further illustrate the effect of station broadcasts on the noise generated by the train as it enters and exits the station.In the data from each point, there are periodic noticeable peaks in the middle and high frequency bands of the spectrum as time passes, which are in fact the broadcasts that accompany the trains as they enter and exit the station. It is the presence of these broadcasts that causes the noise generated by the trains to be virtually covered, presenting relatively homogeneous data than those of EW Line station.

3.4 Noise Near the Train Station

In order to investigate the noise impact on the outside of the station when trains are entering and exiting the station, we exited the station and measured the noise data when trains were entering and exiting the station at points on the ground directly in front of the centre of the EW Line station and at the front of the station platform, respectively. The distance between the measurement points and the corresponding locations in the station was about 20-30 metres. During the measurement process, no measurements were taken because it was not possible to judge the train exit situation at the corresponding point at the front of the station platform. According to **Table.3.3.**, it can be noticed that the peak noise is significantly lower in the data from the point directly in the middle of the platform than in the station. It can be seen that the train entry and exit process has a relatively limited impact on the outside noise. The measured data at the point directly in front of the station platform is even higher, which may be related to the fact that the measurement point is next to an urban road.

Table.3.3. Max sound level of ground near EW21 during train entry and exit

Max Sound Level/dB	Middle of the platform	Platform front-end
Train Entry	63.6	74.5
Train Exit	64.4	Nil

Fig.3.27. Spectrum Analysis of Noise at mid-platform near the station during train entry.

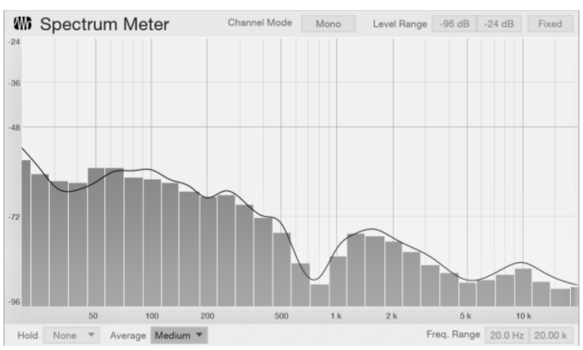

Fig.3.28. Spectrum Analysis of Noise at mid-platform near the station during train exit.

Fig.3.29. Spectrum Analysis of Noise at platform front near the station during train entry.

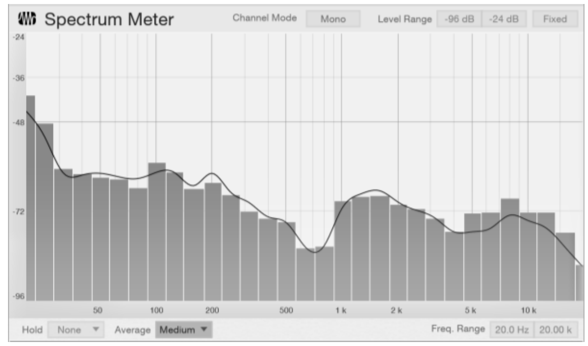

Fig.3.30. Spectrum Analysis of Noise at platform front near the station affected by road traffic.

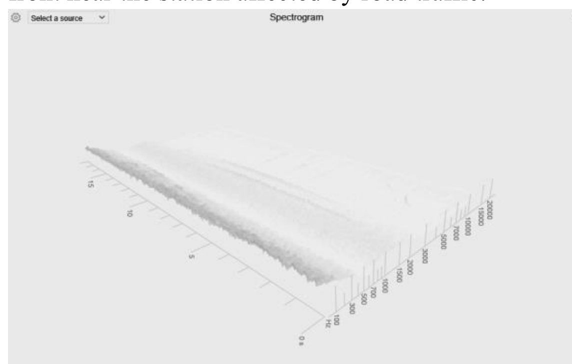

Fig.3.31. Waterfall diagram of Noise at mid-platform near the station during train entry.

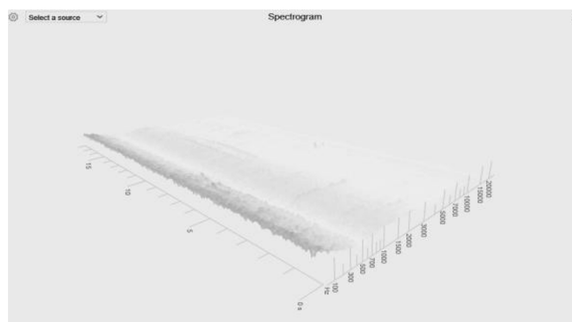

Fig.3.32. Waterfall diagram of Noise at mid-platform near the station during train exit.

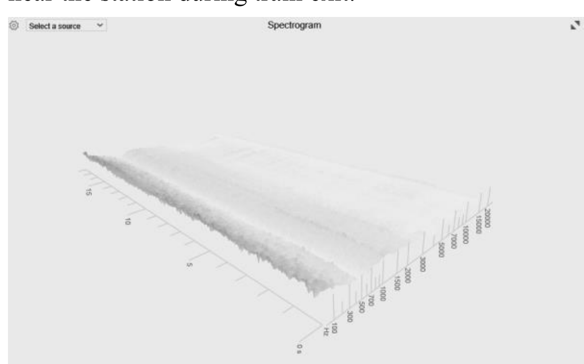

Fig.3.33. Waterfall diagram of Noise at platform front near the station during train entry.

Through the observation outside of the station and the analysis of the spectrogram in **Fig.3.27.** and **Fig.3.28.**, we first noticed that the noise level of the middle platform when train entry and exit is relatively low in each frequency band, which indicates that the noise is attenuated with the increase of distance, especially in the high frequency region.

Since we can't tell when the train is leaving the station, we ignore the noise of the train leaving the station when we measure it near the platform.

When looking at the spectrum of the platform front near the station shown in **Fig.3.29.** and **Fig.3.30.**, we found that the noise level was significantly higher than that of the middle platform near the station when train entry to the station. This phenomenon may be due to the proximity of urban roads and high traffic volume, and road vehicle noise has a significant effect on this. By analysing the spectrum of road vehicles, it is found that the influence is mainly concentrated in the middle and high frequency band which is above 1000 Hz with the high noise level.

As shown in **Fig.3.31.**, **Fig.3.32.**, and **Fig.3.33.**, the characteristics of the waterfall diagram remain similar at the mid-platform points to those in the station, with a section of brake whistling noise and a section of motor operation noise, respectively. The main difference is that the overall amplitude is slightly lower and the high frequency band is reduced more (lighter color in the waterfall plot), presenting the noise generated throughout the train operation as attenuated due to distance. The overall noise level is better controlled. For the points at the front of the platform, the overall amplitude has increased compared to the middle points, and the whistling sound that occurs in the latter part of the train deceleration still occurs, but is not significant enough. The increase in overall amplitude is mainly due to the high volume of traffic on the road next to the point, and the denser road traffic noise makes the measured data significantly higher, and also highlights the impact of changes in ambient noise at a certain distance on the noise of the train operation.

3.5 Time Sequence Analysis

As a SMRT train goes into the station, it has three main phases: deceleration, stopping, and acceleration. There are some common characteristics among all the sound signals among all the measuring points. For the deceleration phase, the sound pressure always firstly increases in a very short time, then decreases in several seconds, and finally increases and decreases again, shown in **Fig 3.34.** In fact, the first lifting process is the electric braking process of the train, mainly completed by cutting off the power supply, and increasing the resistance of the driving unit (also conducting kinetic energy recycling at the same time). The second lifting is achieved through a mechanical braking process, for which the air compressor applies a pressure lifting to the brake drum, causing the brake pads and discs to come into contact, and produce a strong braking effect in a very short period of time.

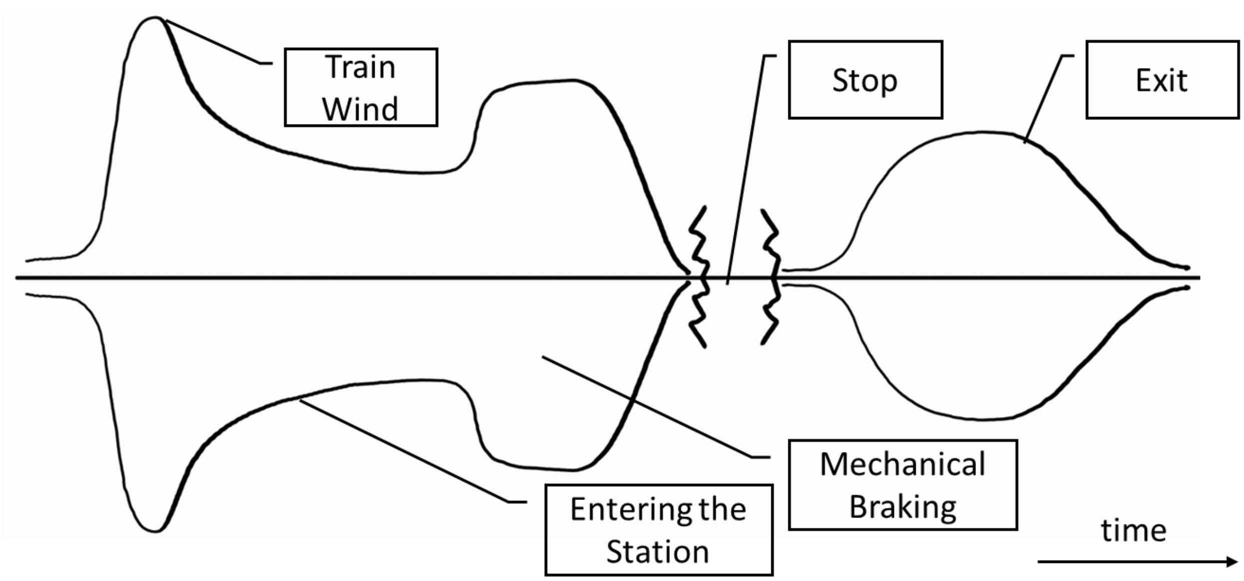

Fig. 3.34. The time-domain signal schematic of recorded noise: the train entering and exiting the station.

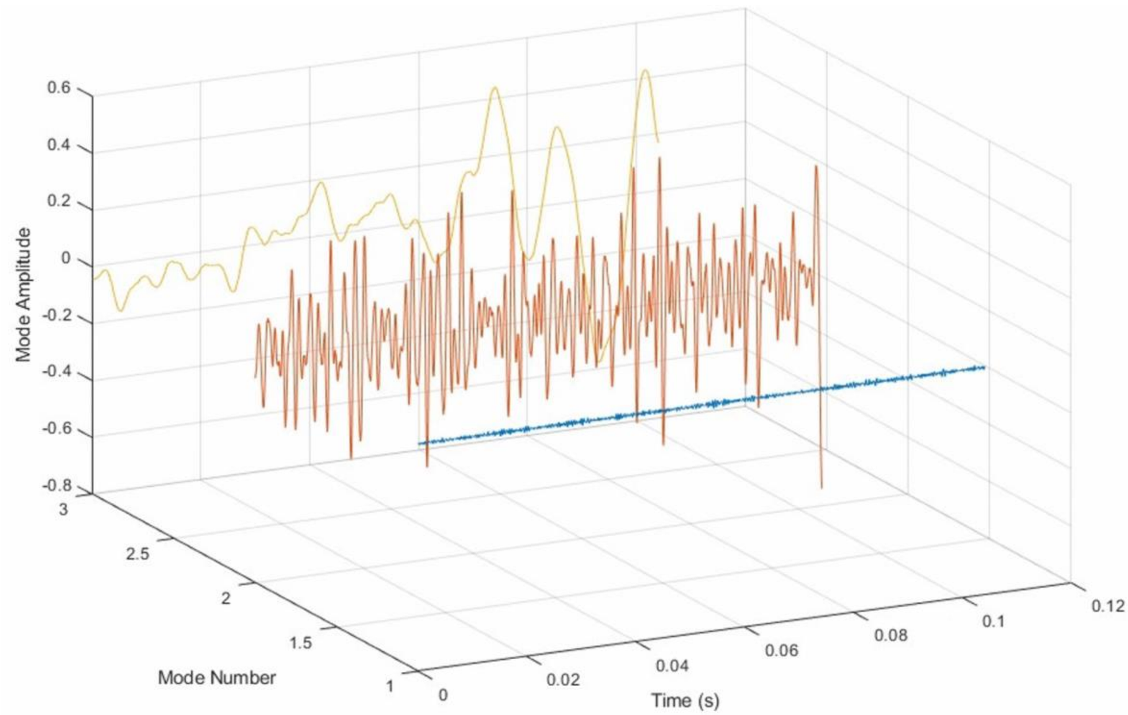

Fig.3.35. The separated AWPF (yellow), TWPF (orange), and other noise (blue).

When going depth into them, the first increasing is caused by train wind. With high dynamic pressure, it also drives the train-head wind noise, following by the train-side wind noise. During this process, another sound source is the interaction between wheels and the rail component. The former one is known as turbulent wall pressure fluctuation (TWPF), and the later one belongs to acoustic wall pressure fluctuation (AWPF). From the theoretical perspectives, the noise caused by the wind shows a lower transmission speed lower than sonic speed, as the later one is just the sonic speed. They are mixed into one signal, but can also be separated by modal composition method. The original sound signal and the separated ones are shown in **Fig 3.35.** For this separation, the Variable Modal Decomposition (VMD) method was used in programming in Matlab. Under the controlling of i=3, three components are obtained, namely the TWPF, AWPF, and the other noise components.

As the speed of train gets a gradual fall, the sound level also decreases as well. During this process, the main mode changed. From the perspective of energy changing over time, the low-frequency and high-frequency components of the noise when the train first enters the station are relatively balanced, and two peaks are obtained (this is explained in more detail in the previous chapter). As time goes on, the train speed decreases, and low-frequency fading occurs. A possible reason from personal point of view is the decrease of TWPF. The turbulent energy of the train wind is proportional to the square of the turbulent energy (considering the boundary layer as a linear development), and the head of the train generates greater wind pressure. On the other hand, when the train enters the station, the measurement of TWPF actually has directionality. Due to the fact that the diaphragm of the condenser microphone is parallel to the direction of train travel, the measured object is actually a variation of the component of pulsation in the vertical direction of the platform. For the details, the variation is the first-order derivative of its spatial gradient in time. Referring to the work from Shen et al., (Research progress on wheel-rail noise prediction model), a sound cavity is created between the track and the wheel, prolonging its decay time. Therefore, the decreasing speed is lower than TWPF.

"Wu↓~Wu↓~": Doppler Effects

In addition, during the deceleration process, the Doppler effect is easily audible. When we replay these signals, we can clearly hear the sound sweeping from high frequency to low frequency. This kind of sweeping occurs more than once, but after sweeping to a very low frequency, another main mode appears in the high-frequency part and sweeps again. From the spectrum, it can be seen that the Doppler effect is most pronounced in the last few seconds of the deceleration phase (before entering mechanical braking). In a logarithmic coordinate system, they are presented as straight lines. In a quasi-logarithmic coordinate system (log-linear mixed coordinate system), they are curves with an increasing negative slope. In **Fig. 3.36.**, they are marked as blue (low frequency area) and red (high frequency area). When the train exits, the spectrum is the similar to this one, but not shown in this report.

"Pong-Pong": Wheel-Rail Collision

Another noteworthy point is that the time cycle of noise from wheel-rail collisions is decreasing. It is obvious that this is caused by the decrease in train speed. This can also be seen from **Fig. 3.36.** The green lines highlight these noises, and the time gap between them is gradually lengthening, and the level is also decreasing (represented by the color of the spectrum). After the last collision at 0:16.3 s, this sound no longer became noticeable from the spectrum, although still can be directly slightly heard.

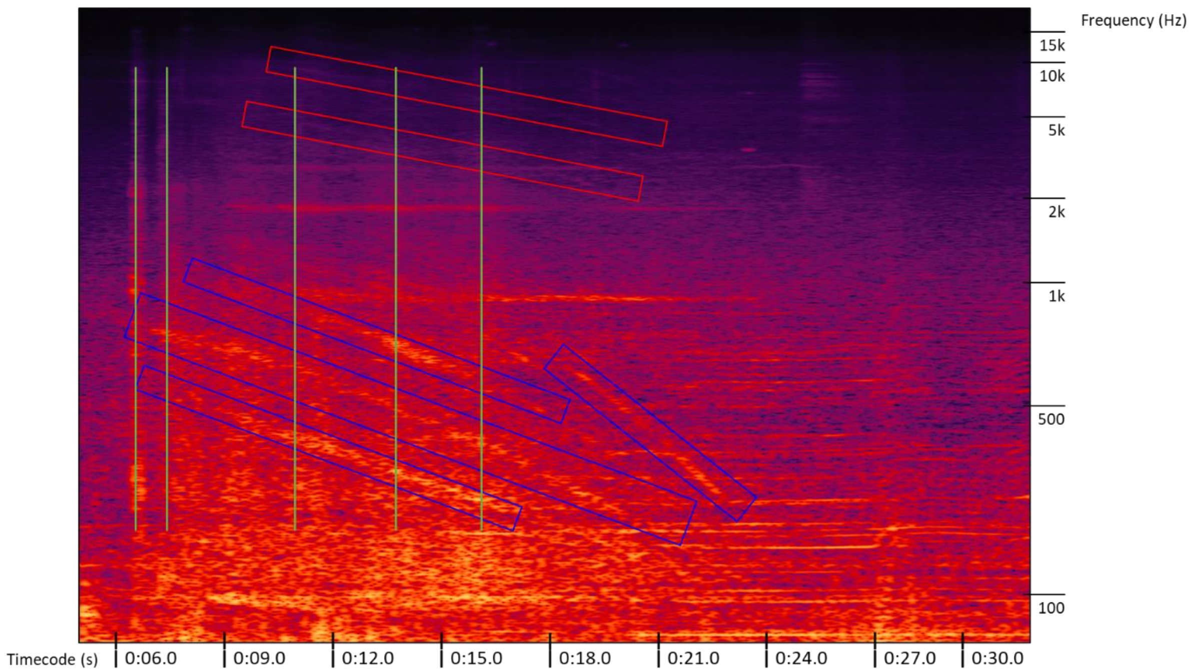

Fig.3.36. The spectrum with the wheel-rail noise and Doppler effects highlighted.

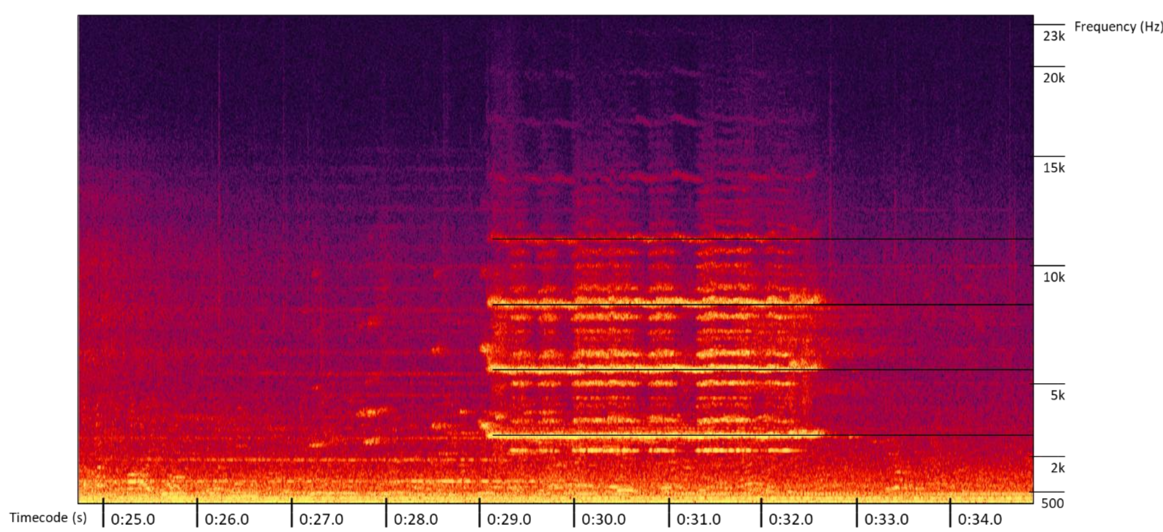

Fig.3.37. The spectrum with the mechanical braking noise highlighted.

"Zhi —" : Mechanical Braking

Following this process, the mechanical braking produces a high-level noise for 2 – 4 seconds. This sound is very sharp, and has a very poor listening experience for people. It can be clearly seen from the spectrum **(Fig. 3.37.)** that the main frequency distribution of noise is concentrated in the mid to high frequencies (marked in black lines). The main peak frequency is in the octave ranges of 2800Hz (2800Hz, 5600Hz, 8400Hz, etc.).

During the SMRT's departure from the station, the speed increases. Therefore, the Doppler effect occurs again. Its trend of change is opposite to that of entering the station (the frequency increases). The duration of departure is basically equivalent to the process of entering the station, while the loudness is slightly lower. For specific time-independent analysis, please refer to the relevant content in the previous text. In order to fairly compare the relationship between the departure and entering, this comparison was obtained through the analysis of the midpoint measurement points on the platform.

Due to the different measuring points, the properties of the time sequence show great differences, which are worthy noting. When measuring at the entrance end, the entire process of the train entering the station will be fully recorded. At this location, the train does not pass through this point when exiting the station (however, some of the sound can be transmitted back to the measuring point at here, especially the low-frequency components). Although, the situation is not totally the same at the exit end. It is probably due to the wind of the train, the peak of the noise entering the station still rises rapidly, with more low frequency components, and the loudness is sufficient, but the decreasing is very fast.

4 Conclusion

In this report, we select Buona Vista station as the measurement location, measuring noise in semi-enclosed and fully enclose environment as the experiment objects. We also choose to measure the noise generated by trains from the perspective of pedestrians to see whether the noise would bother citizens near the station.

At the beginning of the report, we give a detailed introduction of the location and perspective from which we carried out our experiments. After that, some regulations from WHO and NEA is illustrated to help with the analysis. A brief introduction of noise theory is also illustrated in the next part.

we examined in detail the noise generated by trains entering and leaving the station in the fully enclosed, semi-enclosed and near platform metro train station through the comprehensive analysis of spectrum and waterfall diagram. Through the measurement data in the middle of the platform and the front of the platform, we observe from the spectrum diagram and waterfall diagram that the brake whistling noise occurs when the train enters the station and the motor driving noise happens as the train exits the station. We also observed that the platform screen door in the semi-enclosed environment does not provide sound insulation. Additionally, the broadcast in the fully enclosed station and the road noise near the platform front both contributes to the overall noise effect. Despite the limitation of the measuring equipment and the data processing, the research highlights the complexity of the noise in the middle platform and platform front and the need of considering a variety of noise factors in order to fully understand the source of the noise. Future studies can explore more on diversity factors of noise attributes to the metro train stations.

Additionally, we analyzed noise as time sequence. Focusing on the loudness and frequency of each phase, using variable modal decomposition (VMD) method, it could be obtained that the wheel-rail noise and the mechanical braking noise are the main sources. The Doppler effects could also be visualized and analyzed with the help of waterfall spectrum meter.

5 References

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