Cotton Belt Corridor Regional Rail

Noise and Vibration Test Program for the
DCTA Stadler DMU

April 14, 2014
Final Version

Prepared by Harris Miller Miller & Hanson Inc.
## Document Revision Record

<table>
<thead>
<tr>
<th>Project/Report Name: Noise and Vibration Test Program for the DCTA Stadler DMU</th>
<th>URS Project Number: 25338842</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM: Dan Meyers</td>
<td>PIC: Jerry Smiley</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Revision Number:</th>
<th>Date:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draft Version 1</td>
<td>February 5, 2013</td>
</tr>
<tr>
<td>Draft Version 2</td>
<td>February 8, 2013</td>
</tr>
<tr>
<td>Draft Version 3</td>
<td>May 13, 2013</td>
</tr>
<tr>
<td>Final Version</td>
<td>April 14, 2014</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Originator:</th>
<th>Name</th>
<th>Date:</th>
</tr>
</thead>
<tbody>
<tr>
<td>David A. Towers</td>
<td>Harris Miller Miller &amp; Hanson Inc.</td>
<td>February 5, 2013</td>
</tr>
<tr>
<td>Timothy M. Johnson</td>
<td>Harris Miller Miller &amp; Hanson Inc.</td>
<td>February 5, 2013</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Comments by:</th>
<th>Name, Firm</th>
<th>Date:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Megan Inman</td>
<td>URS</td>
<td>February 5, 2013</td>
</tr>
<tr>
<td>Nancy Stavish</td>
<td>URS</td>
<td>February 6, 2013</td>
</tr>
<tr>
<td>John Hoppie</td>
<td>DART</td>
<td>April 23, 2013</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task Manager Approval:</th>
<th>Date:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Verified/Approved by:</th>
<th>Date:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Name</th>
<th>Title</th>
<th>Firm</th>
</tr>
</thead>
</table>
TABLE OF CONTENTS

TABLE OF CONTENTS ........................................................................................................................................... i
LIST OF TABLES .................................................................................................................................................. ii
LIST OF FIGURES ................................................................................................................................................ ii
1.0 INTRODUCTION AND SUMMARY ............................................................................................................. 1
  1.1 Introduction............................................................................................................................................... 1
  1.2 Summary of Results .................................................................................................................................. 2
    1.2.1 Wayside Noise ............................................................................................................................... 2
    1.2.2 Ground-Borne Vibration ................................................................................................................ 2
  1.3 Rail Transit Vehicle Noise and Vibration Level Comparison ................................................................. 3
    1.3.1 Noise Level Comparison ............................................................................................................... 3
    1.3.2 Ground-Borne Vibration Level Comparison .................................................................................. 4
2.0 WAYSIDE NOISE MEASUREMENTS ........................................................................................................... 5
  2.1 Noise Measurement Methodology .......................................................................................................... 5
    2.1.1 Measurement Site and Test Locations ........................................................................................... 5
    2.1.2 Test Instrumentation and Procedures .......................................................................................... 6
  2.2 Noise Measurement Results .................................................................................................................... 7
3.0 GROUND-BORNE VIBRATION TESTS ....................................................................................................... 11
  3.1 Measurement Locations ........................................................................................................................ 11
  3.2 Test Procedures ...................................................................................................................................... 12
    3.2.1 DMU Measurements ...................................................................................................................... 12
    3.2.2 Vibration Propagation Tests ........................................................................................................ 12
  3.3 Instrumentation and Data Analysis ........................................................................................................ 13
  3.4 Vibration Measurement Results ............................................................................................................ 13
    3.4.1 DMU Measurements ...................................................................................................................... 13
    3.4.2 Vibration Propagation Tests ........................................................................................................ 15
4.0 EVALUATION OF TEST RESULTS .............................................................................................................. 16
  4.1 DMU Noise Prediction Model ................................................................................................................ 16
  4.2 DMU Vibration Prediction Method ......................................................................................................... 19
APPENDIX A. VEHICLE DATA ........................................................................................................................ A-1
APPENDIX B. NOISE DATA .......................................................................................................................... B-1
APPENDIX C. VIBRATION DATA .................................................................................................................... C-1
LIST OF TABLES

Table 1-1 Comparison of Vehicle Noise at 50 Feet ................................................................. 3
Table 1-2 Comparison of Vehicle Vibration at 50 Feet............................................................ 4
Table 2-1 Summary of DCTA Stadler DMU Noise Measurement Results................................. 7
Table 3-1 Vibration Test Equipment ......................................................................................... 13

LIST OF FIGURES

Figure 1-1 DCTA Stadler DMU Test Train ................................................................................. 1
Figure 2-1 Noise Measurement Site and Test Locations ............................................................. 5
Figure 2-2 Noise Level Spectra for the DMU Test Train at Constant Speeds ......................... 8
Figure 2-3 Noise Level Spectra for the Accelerating and Decelerating DMU Test Train .......... 9
Figure 2-4 Noise Level Spectra for the Idling DMU Test Train ................................................ 9
Figure 3-1 Ground-Borne Vibration Test Locations .............................................................. 11
Figure 3-2 Average Vibration Level Spectra for the DMU Test Train vs. Speed (at 50 Feet) .... 14
Figure 3-3 Average Vibration Level Spectra for the DMU Test Train vs. Distance (at 45 mph) .... 14
Figure 3-4 Line Source Responses at Vibration Test Site ......................................................... 15
Figure 4-1 Maximum Noise Level vs. Speed for the DCTA DMU Test Train ....................... 17
Figure 4-2 Sound Exposure Level vs. Speed for the DCTA Stadler DMU Vehicle ................. 17
Figure 4-3 Sound Exposure Level Prediction Model for the DCTA Stadler DMU Vehicle ....... 19
Figure 4-4 Maximum Overall Vibration Level vs. Distance for a Vehicle Speed of 45 mph .... 20
Figure 4-5 Maximum Overall Vibration Level vs. Vehicle Speed at 50 Feet from the Track ....... 20
Figure 4-6 Force Density Levels for the DCTA Stadler DMU .................................................. 22
Figure 4-7 Comparison of Force Density Levels for Rail Vehicles at 45 mph ....................... 22
1.0 INTRODUCTION AND SUMMARY

1.1 Introduction

This technical report presents the results of a noise and vibration test program for the Stadler diesel-electric GTW 2/6 articulated diesel multiple unit (DMU) rail vehicles currently operating on the Denton County Transportation Authority (DCTA) A-Train system. The test program was conducted adjacent to the DCTA tracks in Lewisville, TX on December 2, 2012 using a dedicated train consisting of two DMU vehicles (#105 and #111) as shown below in Figure 1-1.

Figure 1-1
DCTA Stadler DMU Test Train

Dallas Area Rapid Transit (DART) is planning to operate commuter trains with similar DMU vehicles on the Cotton Belt Regional Rail Corridor, and the objective of the test program was to determine the wayside noise and ground-borne vibration characteristics of the DCTA vehicles for use in projecting future noise and vibration levels from the DART Cotton Belt trains. The test program was carried out for DART by Harris Miller Miller & Hanson Inc. (HMMH) under subcontract to URS Corporation.

A summary of the test program results is provided below in Section 1.2, and an overall comparison with other rail transit vehicles operating in the North Texas area is provided in Section 1.3. The test methodology and results are described in Section 2 for noise and in Section 3 for vibration, and an evaluation of the results is provided in Section 4. Lastly, supporting vehicle, noise and vibration data are provided in Appendix A, Appendix B and Appendix C, respectively.
1.2  Summary of Results

1.2.1  Wayside Noise

The results of the wayside noise measurements indicate that noise emissions from the DCTA Stadler DMU vehicles are relatively low compared to existing standards. In terms of maximum A-weighted noise levels, the measured values were found to be well below the applicable limits of the U.S. Federal Railroad Administration (FRA) noise emission standards for moving and idling locomotives and rail cars, contained in 40 CFR Part 201. However, the frequency spectra were found to exhibit pronounced peaks in one-third octave frequency bands ranging from 40 Hertz (Hz) to 100 Hz, depending on operating condition. Although noise at these frequencies does not significantly affect the A-weighted sound level, it has the potential to cause noise-induced vibration and annoyance inside residential buildings if the DMU vehicles are left idling for extended periods of time in proximity to such buildings.

Compared to the U.S. Federal Transit Administration (FTA) noise model, the measurement results indicate that the A-weighted noise levels from operation of the DCTA Stadler DMU at constant speed generally fall in between the levels predicted using the FTA DMU and rail car noise models. Up to speeds of at least 60 miles per hour (mph), the noise levels from operation of the Stadler DMU are less than would be predicted using the FTA DMU model and, at speeds below 45 mph, the noise levels for the Stadler DMU are greater than would be predicted using the FTA rail car noise model. At a reference speed of 50 mph, the noise level of the DCTA Stadler DMU is about the same as would be predicted using the FTA noise model for rail cars.

Finally, the test results for the DCTA Stadler DMU accelerating under full throttle and decelerating to a typical station stop indicated higher A-weighted noise levels than for constant speed operation at lower speeds. These results, along with the results for the constant speed tests, were used to develop a noise prediction model for the DCTA Stadler DMU.

1.2.2  Ground-Borne Vibration

The results of the ground-borne vibration measurements indicate that the DCTA Stadler DMU overall vibration levels decreased more rapidly with distance than for the FTA General Vibration Assessment prediction model, with levels 10 decibels or more below the FTA generalized curve for rail cars at distances of 50 feet or more. However, the results indicate a speed dependence similar to the FTA model, with overall vibration levels roughly proportional to 20 log(speed).

The vibration measurement data for the DCTA Stadler DMU were used along with the results of vibration propagation tests to calculate the Force Density Level (FDL), used in the FTA Detailed Vibration Analysis method to predict maximum ground vibration levels. The FDL values for the Stadler DMU were found to lie in between the average values given by FTA for commuter and light rail vehicles within the 10 Hz to 80 Hz frequency range, and to exceed the average values for commuter rail vehicles at frequencies below and above this range. In addition, the FDL values over the measured speed range were proportional to about 12.5*log(speed), on average.
1.3 Rail Transit Vehicle Noise and Vibration Level Comparison

This section summarizes a comparison of the overall noise and vibration levels from the Stadler DMU with the levels generated by other types of rail transit vehicles currently operating in the North Texas area. The comparison is provided for the following types of rail transit vehicles:

- Denton County Transportation Authority (DCTA) A-Train – Stadler DMU vehicle
- DART Low-Floor LRV – DART’s LRT vehicle with a low floor section in the center and an additional truck
- Trinity Railway Express Commuter Rail (TRE) – Commuter rail diesel locomotive vehicle

The data presented here for the DART low-floor vehicle and the TRE locomotive are from measurements conducted by HMMH and summarized in a technical memorandum submitted to DART titled “Vehicle Noise and Vibration Level Comparison” dated January 27, 2006.

1.3.1 Noise Level Comparison

The noise level comparison is presented in Table 1-1 below. Data are given for all three vehicle types at two operating speeds: 20 mph and 50 mph. The noise levels are presented in terms of both sound exposure level (SEL) and maximum noise level (Lmax). Both are expressed as A-weighted sound levels (dBA). The data in Table 1-1 are for single vehicles only. The data have been normalized to a distance of 50 feet from the track centerline and to speeds of 20 mph and 50 mph for comparison purposes based on the noise measurement results for each vehicle type.

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>SEL at 50 feet (dBA)</th>
<th>Lmax at 50 feet (dBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20 mph</td>
<td>50 mph</td>
</tr>
<tr>
<td>DCTA Stadler DMU</td>
<td>78</td>
<td>82</td>
</tr>
<tr>
<td>DART Low-Floor LRV</td>
<td>78</td>
<td>82</td>
</tr>
<tr>
<td>TRE Commuter Rail Locomotive</td>
<td>96</td>
<td>92</td>
</tr>
</tbody>
</table>

Source: Harris Miller Miller & Hanson Inc., 2014

As shown in Table 1-1, the noise levels from the DCTA DMU and the DART LRV are very similar. The SEL and Lmax values for both vehicles increase as the speed of the vehicle increases. The noise from both vehicles is caused primarily by the wheel-rail interaction. However, the noise levels from the TRE locomotive are greater than both the DCTA DMU and DART LRV. Noise from locomotives is dominated by the engine noise and does not typically depend on speed. The SEL is greater at 20 mph than at 50 mph because, as the vehicle travels slower, the exposure time increases and the Lmax remains constant.
### 1.3.2 Ground-Borne Vibration Level Comparison

A ground-borne vibration level comparison for the three vehicle types operating at two different speeds at a distance of 50 feet is presented in **Table 1-2** below. The results are given in terms of the maximum overall vertical ground vibration level, described by the “smoothed” root mean square (rms) vibration velocity level in decibels (VdB). Because ground vibration from rail vehicles is highly dependent on the soil composition at the site where the vibration is measured, the measured vibration levels for each vehicle in **Table 1-2** have been adjusted to reflect the ground composition at two different sites in the Dallas area for comparison purposes. The selected sites were ones where vibration propagation tests were previously carried out along the DART Green Line alignment, one in South Dallas and one in Farmers Branch. The South Dallas site was located along Trunk Avenue and the Farmers Branch site was located at the DART Farmers Branch Park & Ride Lot.

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Maximum Vibration Level at 50 feet (VdB)</th>
<th>20 mph</th>
<th>50 mph</th>
<th>20 mph</th>
<th>50 mph</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCTA Stadler DMU</td>
<td></td>
<td>72</td>
<td>79</td>
<td>62</td>
<td>69</td>
</tr>
<tr>
<td>DART Low-Floor LRV</td>
<td></td>
<td>74</td>
<td>82</td>
<td>60</td>
<td>68</td>
</tr>
<tr>
<td>TRE Commuter Rail Locomotive</td>
<td></td>
<td>77</td>
<td>85</td>
<td>68</td>
<td>76</td>
</tr>
</tbody>
</table>

Source: Harris Miller Miller & Hanson Inc., 2014

The results in **Table 1-2** show that there is a wide variation in the ground vibration levels, depending on the site and the vehicle type. However, it can be noted that the vibration levels from the DCTA DMU and the DART LRV are similar and that the vibration levels from the TRE locomotive are higher.
2.0 WAYSIDE NOISE MEASUREMENTS

2.1 Noise Measurement Methodology

2.1.1 Measurement Site and Test Locations

The noise measurements were made at a site in an open field on the east side of the DCTA tracks near Civil Station 1150 in Lewisville, TX. This site is located between the tracks and S. Railroad Street, north of an existing radio tower and south of the newly constructed grade crossing at E. Corporate Drive. The tracks at this location are straight and level, consisting of continuous welded rail (CWR) supported by concrete ties and stone ballast. The rails, although generally smooth, had been ground fairly recently and brush marks were noticeable on the rail heads. Noise measurements were made at two positions, located at distances of 50 feet and 100 feet from the near (eastern-most) track center line as shown in Figure 2-1.

Figure 2-1
Noise Measurement Site and Test Locations
2.1.2 Test Instrumentation and Procedures

The noise measurements were made using Bruel & Kjaer (B&K) Model 2250 sound level analyzers (serial numbers 2579775 and 2619790) that conform to American National Standards Institute (ANSI) Standard S1.4 for Type 1 (Precision) sound level meters. The analyzers were programmed to continuously monitor noise during the measurement period and to record the maximum A-weighted sound level (Lmax) with both fast and slow response, as well as the A-weighted and one-third octave frequency band equivalent sound levels (Leq) for each one-second interval. Calibrations, traceable to the U.S. National Institute of Standards and Technology (NIST) were carried out in the field using B&K Model 4231 acoustical calibrators (serial numbers 2579293 and 2579291). The measurement microphones were protected by windscreen and supported on tripods at a height of six to seven feet above the ground, corresponding to a height of one to two feet above the top-of-rail elevation.

All measurements were carried out with a fully-equipped Stadler GTW 2/6 DCTA A-Train consisting of two 134-foot long articulated vehicles with an unloaded weight of 161,500 pounds each (AW0); a set of vehicle specifications is included in Appendix A. During the tests, vehicle #105 was positioned at the north end of the train and vehicle #111 was positioned at the south end of the train and the vehicles were unoccupied except for the two-person operating crew. All tests were made with the train on the near (eastern-most) track. The noise measurements included four types of tests as follows:

- **Constant Speed Tests**: Two or three runs in each direction were made with the train passing by the microphone positions at constant speeds of 15, 30, 45 and 60 mph.

- **Acceleration Tests**: Two runs were made in each direction with the train accelerating at full throttle (from 0 mph to 30 mph) while passing by the microphone positions. At the start of these test runs, the front of the leading car was positioned approximately 65 feet ahead of the microphone locations and, at the end of the runs, the rear of the trailing car was located about 65 feet beyond the microphone locations.

- **Deceleration Tests**: Four runs were made in the northbound direction with the train decelerating (from 30 mph to 0 mph) while passing by the microphone positions, simulating a normal station stop. At the end of the runs, the rear of the trailing car was located about 65 feet beyond the microphone locations. To evaluate brake noise, two additional runs were made by stopping the train when the center of the leading car was directly opposite the microphone positions.

- **Stationary Tests**: Tests of the stationary vehicle were made with the center power modules of the vehicles positioned directly opposite the microphone locations. These measurements were made at low idle speed for both vehicles, as well as at high idle speed for vehicle #111.
2.2 Noise Measurement Results

The noise measurement results are summarized in Table 2-1 below in terms of A-weighted sound level (dBA) averages; a complete set of test results is included in Appendix B. For the train pass-by tests, the average maximum sound levels measured at 50 feet and 100 feet are provided for both fast (0.125 second) and slow (1 second) averaging times in terms of Lmax(fast) and Lmax(slow) as well as in terms of maximum one-second Leq. The table also includes the average Sound Exposure Level (SEL) values for the train pass-by tests at the 50-foot reference distance; SEL values for a single DMU vehicle have been calculated by subtracting 3.0 dB from the measured values for the two-car test train. The SEL represents the sound energy at the measurement location during the pass-by and is used for the calculation of cumulative noise exposure in the areas adjacent to a rail corridor. For the stationary vehicle and background noise measurements, the results in Table 2-1 represent the Leq over a 30-60 second averaging period.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Speed (mph)</th>
<th>Sound Level at 100 ft</th>
<th>Sound Level at 50 ft</th>
<th>SEL at 50 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lmax (fast)</td>
<td>Lmax (slow)</td>
<td>Leq$^1$</td>
</tr>
<tr>
<td>Constant Speed Test</td>
<td>15</td>
<td>65.3</td>
<td>64.3</td>
<td>64.5</td>
</tr>
<tr>
<td>Constant Speed Test</td>
<td>30</td>
<td>71.1</td>
<td>70.1</td>
<td>70.4</td>
</tr>
<tr>
<td>Constant Speed Test</td>
<td>45</td>
<td>73.9</td>
<td>72.8</td>
<td>73.3</td>
</tr>
<tr>
<td>Constant Speed Test</td>
<td>60</td>
<td>76.2</td>
<td>75.1</td>
<td>75.6</td>
</tr>
<tr>
<td>Acceleration Test</td>
<td>0-30</td>
<td>74.3</td>
<td>73.3</td>
<td>73.6</td>
</tr>
<tr>
<td>Deceleration Test</td>
<td>30-0</td>
<td>71.9</td>
<td>70.9</td>
<td>71.1</td>
</tr>
<tr>
<td>Braking Test</td>
<td>30-0</td>
<td>70.8</td>
<td>68.9</td>
<td>68.8</td>
</tr>
<tr>
<td>Low Idle (Vehicle #105)</td>
<td>0</td>
<td>--</td>
<td>--</td>
<td>58.4</td>
</tr>
<tr>
<td>Low Idle (Vehicle #111)</td>
<td>0</td>
<td>--</td>
<td>--</td>
<td>59.1</td>
</tr>
<tr>
<td>High Idle (Vehicle #111)</td>
<td>0</td>
<td>--</td>
<td>--</td>
<td>64.2</td>
</tr>
<tr>
<td>Background Noise Test</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>46.6</td>
</tr>
</tbody>
</table>

$^1$ Values correspond to the maximum one-second Leq.
Source: Harris Miller Miller & Hanson Inc., 2014

For the train pass-by event maximum noise levels, the measurement results indicate that the Lmax(fast) and Lmax(slow) data differ by only a small amount, typically by about one decibel, with the one-second Leq data falling somewhere in between the two. The primary significance of the Lmax(fast) data is to compare the results to the FRA noise emission standards for moving locomotives and rail cars, contained in 40 CFR Part 201. In terms of Lmax(fast) at 100 feet, these standards specify limits of 90 dBA for locomotives, 88 dBA for rail cars moving at 45 mph or less and 93 dBA for rail cars moving at speeds greater than 45 mph. Standards are also provided for stationary locomotives in terms of Lmax(slow) at 100 feet, with limits of 70 dBA at idle and 87 dBA at all other throttle settings. The results in Table 2-1 indicate that the measured values are all well below the applicable FRA noise limits.
In terms of sound propagation, the results in Table 2-1 indicate that maximum noise levels from the accelerating and idling vehicles drop off by about six decibels between 50 feet and 100 feet. Given that the primary noise sources under these operating conditions are the diesel engine, exhaust and fans, which are located on the upper portion of the vehicles, this reduction suggests point-source sound propagation with no significant ground absorption effect. For the train pass-by tests, where noise from wheel-rail interaction becomes more significant, the results indicate that maximum noise levels drop off by four to five decibels between 50 feet and 100 feet. This drop off suggests line-source sound propagation with some ground absorption effect for the wheel-rail noise where the sound path between the two microphone positions is located closer to the ground. To minimize the effect of excess sound propagation, as well as the influence of noise from S. Railroad Street traffic at the 100-foot microphone position, the remainder of this report focuses on analysis of the noise measurement results at the 50-foot microphone position.

In addition to the A-weighted sound level data, the noise measurements were also analyzed in terms of one-third octave band frequency spectra. The results of this analysis for the 50-foot microphone position are summarized in Figure 2-2 for the constant speed tests, in Figure 2-3 for the acceleration, deceleration and braking tests and in Figure 2-4 for the idling tests. It should be noted that the spectra for train pass-by events in Figures 2-2 and 2-3 represent averages of the maximum noise levels whereas the idling spectra in Figure 2-3 and the background noise spectrum in all of the figures represent Leq calculated over a 30-60 second sampling period.

Figure 2-2
Noise Level Spectra for the DMU Test Train at Constant Speeds

![Figure 2-2](image-url)

DCTA Stadler DMU: Maximum Noise Level Spectra (2-car train at 50 feet)
Figure 2-3
Noise Level Spectra for the Accelerating and Decelerating DMU Test Train

DCTA Stadler DMU: Maximum Noise Level Spectra (2-car train at 50 feet)

Figure 2-4
Noise Level Spectra for the Idling DMU Test Train

DCTA Stadler DMU: Idling Noise Level Spectra (Leq at 50 feet)
The spectra in Figure 2-2 for the constant speed tests indicate that the noise levels typically increase with increasing speed at frequencies above the 63 Hz one-third octave band that influence the A-weighted sound level. However, the spectra at the lower speeds include a pronounced peak in the 50 Hz one-third octave band that is likely generated by the diesel engines on the DMU vehicles.

The spectra in Figure 2-3 indicate higher noise levels for acceleration than for deceleration, with a peak in the 100 Hz one-third octave band. Although the noise levels for braking are generally lower than for acceleration and deceleration, the spectrum for braking exhibits a peak in the 1,600 Hz one-third octave band due to brake squeal that occurred as the train came to a stop. This spectrum also includes a pronounced peak at 50 Hz, similar to the spectra for the constant speed tests depicted in Figure 2-2.

Unlike the spectra for moving trains, the spectra in Figure 2-4 for the low idle condition exhibit a pronounced peak in the 40 Hz one-third octave band rather than in the 50 Hz one-third octave band. This figure also shows that this peak shifts to the 63 Hz one-third octave band for the high idle condition, with increased levels at higher frequencies. It should be noted that, although the low-frequency noise does not significantly affect the A-weighted sound level, it has the potential to cause noise-induced vibration and annoyance inside residential buildings if the DMU vehicles are left idling for extended periods of time in proximity to such buildings.
3.0 GROUND-BORNE VIBRATION TESTS

The ground-borne vibration tests for the DCTA Stadler DMU included (1) measurements of ground vibration from DMU train operation at various speeds and (2) vibration propagation tests using an impact source to characterize the soil properties at the test site. The results of these tests were then combined to develop a site-independent source vibration level that could be used to predict ground-borne vibration from the DMU at other sites. The vibration test locations, procedures, instrumentation and results are described in the sub-sections below.

3.1 Measurement Locations

The vibration measurements were made at the same site as the noise measurements, in an open field on the east side of the DCTA tracks near Civil Station 1150 in Lewisville, TX. The specific test positions at this site are shown in plan view in Figure 3-1, including the ground vibration measurement locations as well as the locations of the impacts for the vibration propagation tests. The test procedures for the DMU measurements and vibration propagation tests are described below in Section 3.2.

Figure 3-1
Ground-Borne Vibration Test Locations

![Ground-Borne Vibration Test Locations](image)
3.2 Test Procedures

3.2.1 DMU Measurements

Ground-borne vibration from DMU operations was measured at six positions at the test site using high-sensitivity accelerometers mounted in a vertical orientation on top of steel stakes driven into soil. As indicated in Figure 3-1, these positions were located at distances of 15, 25, 50, 75, 100 and 125 feet from the near (eastern-most) track centerline.

Similar to the noise tests, vibration measurements were conducted using an unloaded (AW0), fully-equipped Stadler GTW 2/6 DCTA A-Train consisting of two 134-foot long articulated vehicles (#105 and #111) weighing 161,500 pounds each. Two or three runs in each direction were made with the train passing by the test location at constant speeds of 15, 30, 45 and 60 mph. All tests were made with the train on the near (eastern-most) track.

3.2.2 Vibration Propagation Tests

The vibration propagation test procedure consisted of dropping a 60 pound weight from a height of three to four feet to produce an impulsive force on the ground, and simultaneously measuring the force and the vibration response at various distances from the impact location. The relationship between the impact force and the ground surface vibration, called the transfer mobility, characterizes the vibration propagation at the test site. The force was measured using a load cell and the vibration responses from the impacts were measured using accelerometers, similar to the DMU measurements.

The impact force was generated at 11 points spaced 15 feet apart along a line parallel to and 15 feet east of the near track as indicated in Figure 3-1. The vibration response was measured at a series of positions located on the ground along a line perpendicular to the track, at distances of 10, 35, 60, 85 and 110 feet from the impact line, as shown in Figure 3-1. The resulting transfer mobility from this test characterizes the soil at the test site and can be compared to similar tests at locations where vibration from DMU operations is to be predicted.

3.3 Instrumentation and Data Analysis

The vibration signals from the accelerometers and load cell were amplified as needed and recorded in the field using digital recording equipment. Table 3-1 lists the models and serial numbers for the measurement instrumentation used in the tests. All equipment was calibrated in the field and by a laboratory traceable to the U.S. National Institute of Standards and Technology (NIST).

Vibration acceleration levels were measured and then converted to vibration velocity levels using digital signal processing software. After the data were recorded on digital audio tape, they were processed into one-third-octave band form using a digital signal processing software program. For the DMU tests, the vibration levels for each event were determined by computing the energy-average vibration levels (Leq) over the duration between the “3-dB down points” with respect to the maximum vibration levels in each one-third -octave band. For the vibration propagation tests, the data were processed into point source transfer mobilities, and these point source transfer mobilities were then integrated into a line source transfer mobility (LSTM) or line source response (LSR).
Table 3-1
Vibration Test Equipment

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Serial Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEAC Model RD-130TE Digital Audio Tape Recorder</td>
<td>512546</td>
</tr>
<tr>
<td>Honeywell Sensotec Load Cell</td>
<td>958559</td>
</tr>
<tr>
<td>PCB 393A Accelerometers</td>
<td>4739, 5394, 5397, 5730</td>
</tr>
<tr>
<td>PCB 393C Accelerometers</td>
<td>10001, 10002</td>
</tr>
<tr>
<td>PCB 480E09 Power Supplies</td>
<td>18974</td>
</tr>
<tr>
<td>PCB 480C02 Power Supplies</td>
<td>6959, 8255, 8257, 8258, 6958</td>
</tr>
<tr>
<td>EPAC Model 60/10 LN Amplifiers</td>
<td>115, 114, 260, 261, 256, 251</td>
</tr>
<tr>
<td>PCB 492B Transducer Simulator</td>
<td>316</td>
</tr>
</tbody>
</table>

Source: Harris Miller Miller & Hanson Inc., 2014

3.4 Vibration Measurement Results

3.4.1 DMU Measurements

The results of the DMU vibration measurements were found to be fairly consistent at any given distance and speed, except for a few events which were discarded. Otherwise, the results were averaged to obtain the DMU vibration levels for each of the four constant speed tests (15, 30, 45 and 60 mph) at each of the six measurement distances (15, 25, 50, 75, 100 and 125 feet). The average results are summarized in terms of vibration level versus frequency in the spectral graphs included in Appendix C.

Representative examples of the DMU vibration measurement results are provided in Figure 3-2 and Figure 3-3. Figure 3-2 compares the average ground vibration level spectra for different train speeds at a measurement distance of 50 feet from the track center line; the figure also includes the average background vibration spectrum at that measurement position in terms of the L90 (level exceeded 90% of the time over a 20-60 second period during which the train passed by). Figure 3-3 compares the average ground vibration level spectra for different measurement distances at a train speed of 45 mph. The results indicate that the vibration levels typically increase with increasing train speed and decrease with increasing distance, with peak levels in the frequency range of 20 Hz to 100 Hz. However, it should be noted that the measured DMU vibration levels are specific to the ground-borne vibration propagation characteristics of the measurement site which are determined based on the tests described below in Section 3.4.2.
Figure 3-2
Average Vibration Level Spectra for the DMU Test Train vs. Speed (at 50 Feet)

Figure 3-3
Average Vibration Level Spectra for the DMU Test Train vs. Distance (at 45 mph)
3.4.2 Vibration Propagation Tests

The results of the vibration propagation tests at the measurement site were summarized in terms of the LSTM at each of the six measurement distances (15, 25, 50, 75, 100 and 125 feet). These results, which characterize the relationship between the input force and the ground vibration response, are described by the spectra in Figure 3-4. It should be noted that, due to abnormal propagation results at some higher frequencies and limited signal-to-noise ratio at some lower frequencies, certain data were excluded from the transfer mobility computations.

Figure 3-4
Line Source Responses at Vibration Test Site

The results in Figure 3-4 indicate that the peaks in the vibration response at the test site occur in the frequency range of 20 Hz to 40 Hz, depending on distance. However, to be able to predict vibration from DMU operation at other sites with different ground characteristics, it is necessary to combine the vibration propagation data with the DMU vibration level data as described below in Section 4.2.
4.0 EVALUATION OF TEST RESULTS

4.1 DMU Noise Prediction Model

A method for predicting noise from DMU operations is included in the FTA “Transit Noise and Vibration Impact Assessment” guidance manual (FTA-VA-90-1003-06, May 2006). However, the FTA model is based on older DMU technology that may not be applicable to the newer Stadler vehicles used by DCTA and proposed for use on the DART Cotton Belt Rail Corridor. Thus, a primary objective of the DMU test program was to develop a model for predicting noise from the DCTA vehicles that can be used to assess potential noise impact for the DART Cotton Belt Project. The development of this model is based on the noise measurement data presented in Section 2 and is described below.

Figure 4-1 provides a graph of the average Lmax data at 50 feet as a function of speed from the constant speed tests of the DCTA Stadler DMU test train. For modeling purposes, the maximum one-second Leq data are used to represent Lmax, and it is assumed that the Lmax for a single DMU vehicle would not be significantly different than for the measured two-car train at a distance of 50 feet. Based on the data points from the measurements, Figure 4-1 includes a best-fit regression curve, indicating that Lmax for the DCTA vehicles varies roughly in proportion to 20*log(speed). The figure also shows the FTA prediction models for DMU vehicles and rail cars, which assume that Lmax varies in proportion to 10*log(speed) for DMU vehicles and in proportion to 30*log(speed) for rail cars. These results indicate that, up to at least 60 mph, the Lmax for the DCTA DMU is less than would be predicted using the FTA DMU model. The results also indicate that, at speeds below 45 mph, the Lmax for the DCTA DMU is greater than would be predicted using the FTA rail car model.

Figure 4-2 provides a graph of the average SEL data for a single DCTA Stadler DMU vehicle at 50 feet as a function of speed, where the measured values for the two-car test train have been reduced by 3.0 decibels to determine the SEL for a single vehicle. Based on the data points from the measurements, Figure 4-2 includes a best-fit regression curve, indicating that SEL for the DCTA vehicles varies roughly in proportion to 10*log(speed). The figure also shows the FTA prediction models for DMU vehicles and rail cars, which assume that SEL is independent of speed for DMU vehicles and varies in proportion to 20*log(speed) for rail cars. These results indicate that, up to at least 60 mph, the SEL for the DCTA DMU is less than would be predicted using the FTA DMU model. The results also indicate that, at speeds below 45 mph, the SEL for the DCTA DMU is greater than would be predicted using the FTA rail car model.

Because the FTA noise exposure prediction methodology is based on vehicle source levels in terms of SEL for a single vehicle at a distance of 50 feet, it is proposed that the SEL for the DCTA Stadler DMU be determined as follows:

\[ SEL(50\text{-ft}) = 10.63 \times \log_{10}(\text{mph}) + 63.74 \text{ (in dBA)} \]  

[1]

At the FTA reference speed of 50 mph, the above equation predicts a SEL of 81.8 dBA which is about the same as the FTA reference SEL for rail cars (82 dBA) and less than the FTA reference level for DMU vehicles (85 dBA).
Figure 4-1
Maximum Noise Level vs. Speed for the DCTA DMU Test Train

Figure 4-2
Sound Exposure Level vs. Speed for the DCTA Stadler DMU Vehicle
It should be noted that, unlike the FTA model for locomotives and DMU vehicles that applies a two decibel adjustment to the SEL for each throttle notch setting above five, the DMU noise model for SEL as a function of speed in Equation 1 above does not take the DMU throttle settings into account. Because the throttle on the DCTA Stadler DMU does not have distinct notch settings, the throttle conditions during the constant speed tests are not precisely known. However, given that the train was not accelerating and was operating on level track, it is likely that the throttle was set at no more than 50 percent of the full throttle position and that the noise prediction model reflects conditions comparable to the FTA DMU model with no throttle correction.

The effect of throttle setting on noise from the DCTA Stadler DMU was estimated based on the acceleration tests performed at full throttle. The measurement results presented in Section 2 indicate an average SEL value of 83.5 dBA for a single accelerating vehicle at a distance of 50 feet from the track center line. Assuming that this value represents excess noise from the power modules under full throttle at an average speed of about 20 mph, the SEL from this source at other speeds was estimated using a correction factor of \(-10\times\log{(mph/20)}\); this relationship accounts for the reduction in noise exposure from a fixed noise level source as speed increases. The full-throttle SEL was then combined with the low-throttle, constant-speed SEL in Figure 4-2 to determine the overall SEL at full throttle as a function of speed. Because the latter SEL values increase by a factor of about \(10\times\log{\text{speed}}\), the combined SEL was found to be roughly independent of speed, with a value of approximately 84 dBA.

Based on the above evaluation, it is proposed that the reference SEL for the DCTA Stadler DMU at a distance of 50 feet from the track center line be calculated using Equation 1 for operation at up to 50 percent of full throttle and be taken to be 84 dBA for operation at full throttle. Because throttle setting data are often unavailable, a conservative approach is to assume full throttle operation at all locations where the DMU vehicles are accelerating. In the event that throttle setting data are available, the SEL can be estimated by interpolating between the 0-50 percent and full throttle noise levels. The resulting DCTA Stadler DMU SEL noise model is summarized by the prediction curves in Figure 4-3.

Finally, the noise measurement data presented in Section 2 indicate that additional noise is also generated by regenerative braking as the DMU vehicles decelerate. The results indicate an average SEL of 80.6 dBA for a single vehicle at a distance of 50 feet from the track centerline. Based on the best-fit curve in Figure 4-2, this corresponds to the SEL for operation at a constant speed of about 35 mph. Therefore, as a conservative approach, it is recommended that speeds no lower than 35 mph be used to predict noise for DMU vehicles that are decelerating to a stop at a station.
4.2 DMU Vibration Prediction Method

Similar to noise, general and detailed methods for predicting ground-borne vibration from transit vehicle operations are included in the FTA guidance manual. However, the FTA manual does not include specific source information for DMU vehicles such as the Stadler vehicles. Thus, a primary objective of the DMU test program was to develop information to predict ground-borne vibration from the DCTA vehicles that can be used to assess potential vibration impact for the DART Cotton Belt Project. The development of this model is based on the vibration measurement data presented in Section 3 and is described below.

A comparison of the DMU vibration measurement data with the FTA General Vibration Assessment prediction model for rail cars is given in Figure 4-4 in terms of the average maximum overall vibration velocity level, expressed in decibels (VdB) referenced to one micro-inch/second, versus distance for a vehicle speed of 45 mph. These results indicate that the DMU vibration level measured at a distance of 15 feet is similar to the level shown by the generalized FTA curve for rail cars. However, the DMU vibration levels are seen to decrease more rapidly with distance than indicated by the FTA model, with levels 10 decibels or more below the FTA curve at distances of 50 feet or more. Figure 4-5, which compares the measured DMU vibration levels to the FTA model as a function of speed at a distance of 50 feet from the track, indicates a similar speed dependence, with overall vibration levels roughly proportional to 20 log(speed).
Figure 4-4
Maximum Overall Vibration Level vs. Distance for a Vehicle Speed of 45 mph

Figure 4-5
Maximum Overall Vibration Level vs. Vehicle Speed at 50 Feet from the Track
The FTA Detailed Vibration Analysis prediction method is based on the FDL for the rail vehicle at a given speed. The FDL describes the force that excites the ground; it includes the effects of both the vehicle and track structure at a given location but excludes the effects of the vibration propagation characteristics of the soil. The FDL is calculated on a one-third octave band frequency basis from the measured DMU ground vibration level (Lv) and the measured LSTM at each site using the following equation:

\[ \text{FDL} = \text{Lv} - \text{LSTM} \]

In general, FDL spectra were calculated for specific DMU speeds based on averages of the data at all frequencies and measurement distances. However, due to abnormal propagation results at greater distances for the impact response tests, as well as limited signal-to-noise ratio for the propagation data and for the DMU ground vibration data in some cases, certain data at lower and higher frequencies were excluded from the calculated averages.

It should also be noted that the FDL spectra were calculated based on DMU vibration levels in terms of Leq obtained by root mean square (rms) averaging over the period when the one-third octave band vibration levels were within three decibels of the maximum level (Lmax). The Lmax was not used directly to calculate FDL because Leq tends to be a more consistent measure of train vibration than Lmax. However, the FTA impact criteria for ground-borne vibration are based on Lmax (measured using a one-second time constant). Therefore, based on the average difference between the Lmax and Leq values for all of the one-third octave band vibration data at each speed, the FDL curves have been adjusted up for use in predicting DMU vibration levels in terms of Lmax. The adjustments applied amounted to 2.1 decibels at 15 mph, 1.4 decibels at 30 mph, 0.9 decibels at 45 mph and 0.8 decibels at 60 mph.

The average FDL spectra for DMU speeds of 15, 30, 45 and 60 mph are provided in Figure 4-6 and the spectra used to compute these averages are included in Appendix C. Figure 4-6 indicates that the FDL values typically increase with speed, as would be expected. While the relationship between FDL and speed varied widely depending on frequency, the FDL values over the measured speed range were roughly proportional to 12.5*\log(speed), on average.

For reference, Figure 4-7 compares the FDL for the DCTA Stadler DMU at 45 mph to the average values for commuter rail and light rail vehicles from the FTA guidance manual. For purposes of comparison, the FTA curves at 40 mph have been adjusted to 45 mph by adding one decibel to the FDL values. As shown in the figure, the FDL values for the Stadler DMU are in between the FTA average values for commuter and light rail vehicles within the 10 Hz to 80 Hz frequency range and are above the average values for commuter rail vehicles at frequencies below and above this range.

For predicting ground-borne vibration from the DCTA Stadler DMU using the FTA Detailed Analysis methodology it is recommended that the FDL spectra in Figure 4-6 be used for DMU speeds of 15, 30, 45 and 60 mph, interpolating as needed to obtain the spectra for intermediate speeds. As a conservative approach for estimating the FDL at speeds above 60 mph, it is suggested that the FDL spectrum at 60 mph be increased by a factor of \(20\log\text{(speed)}/60\), which represents the speed dependence for the overall DMU ground-borne vibration level.
Figure 4-6
Force Density Levels for the DCTA Stadler DMU

![Graph showing force density levels for the DCTA Stadler DMU across different one-third octave band center frequencies.](Image)

Figure 4-7
Comparison of Force Density Levels for Rail Vehicles at 45 mph

![Graph comparing force density levels for rail vehicles at 45 mph across different one-third octave band center frequencies.](Image)
**APPENDIX A. VEHICLE DATA**

**GTW DMU 2/6 low-floor**

*for Denton County Transportation Authority (DCTA), Texas, USA*

The Denton County Transportation Authority (DCTA) ordered 11 diesel-electric GTW 2/6 articulated rail vehicles from Stadler Rail. DCTA is constructing a passenger rail line known as the A-train to serve Denton County residents and visitors. The route follows along the east side of I-35E and is 21 miles long from Denton to Carrollton. Five stations will be located in Denton County and a transfer station will be built at Trinity Mills Road in Carrollton to allow travel to Dallas and other points in the North Texas region via Dallas Area Rapid Transit’s (DART) light rail and bus systems. The vehicles will be compliant with the Americans with Disabilities Act (ADA), and will incorporate enhanced air conditioning, passenger information system, video surveillance and a significant part of the Federal Railroad Administration (FRA) compliant elements. The generous interior has room for wheelchairs, strollers and bicycles. There are 104 seats and standing room for 96 persons in every vehicle, with bright compartments, large windows and plush seating.
Technical features

- Bright, friendly interior with large windows and plush seating
- Fully ADA compliant with wide access doors
- EPA compliant
- Nophe 130 compliant
- Passenger compartment with 75% low level section providing level boarding at all passenger doors
- Enhanced air conditioning systems (fully redundant) for passenger compartments and driver's cab. Systems designed for ambient temperatures up to 40°C (104°F)
- Unique and very efficient crash absorption system for the protection of driver and passengers (fulfills European crashworthiness standards)
- Air-suspended motor and trailer trucks
- Ergonomically designed driver's cab
- Traction equipment housed in a separate power car, efficiently insulating the passenger compartments from noise
- Redundant traction power system consisting of two units, each with a diesel engine, asynchronous generator, IGBT power converter and asynchronous drive motor
- Car body of end cars incorporates an extended aluminum superstructure
- Car body of power car incorporates a steel superstructure
- Latest generation of vehicle control systems including detailed diagnostic features
- Multiple-unit control for up to three vehicles
- CCTV equipped
- Event recorder monitoring of on-board systems
- Fire detection and suppression systems
- Interior seating arranged to allow passengers unobstructed access to emergency exit windows
- Enhanced fuel tank protection
- Emergency roof access system
- Emergency Intercoms in passenger sections
- Luminous emergency decal installed within interior to aid with emergency egress

Vehicle data

- Customer: Denton County Transportation Authority (DCTA), Texas, USA
- Line operated: A-train from Denton to Carrollton
- Gauge: 1435 mm (4’-8.5’’)
- Axle arrangement: 2’’B’’C’’2’’
- Number of vehicles: 11
- Service start-up: 2012
- Seating capacity: 104 (including flip-up seats)
- Flip-up seats: 16
- Stand capacity: 9% (at 4 persons/m²)
- Floor height:
  - Low floor: 600 mm (23.6’’)
  - High floor: 1000 mm (39.4’’)
- Door width: 1500 mm (51.2’’)
- Longitudinal strength: 1500 kN
- Overall length: 48890 mm (159.1’’)
- Vehicle width: 2950 mm (9’-8’’)
- Tare weight: 72200 kg
- Truck ( bogie) wheelbase: 2100 mm (82.7’’)
- Motor truck, new: 860 mm (33.9’’)
- Trailer truck, new: 750 mm (29.5’’)
- Maximum power at wheel: 470 kW
- Starting tractive power: 80 kN
- Max acceleration empty/full: 1.0/0.8 m/s²
- Max braking service/emerg max: 1.3/2.1/2.4 m/s²
- Maximum speed: 120 kph (75 mph)
# APPENDIX B. NOISE DATA

## DCTA A-TRAIN NOISE MEASUREMENT RESULTS

<table>
<thead>
<tr>
<th>EVENT</th>
<th>TIME</th>
<th>SPEED (mph)</th>
<th>DIRECTION</th>
<th>SOUND LEVEL AT 100 FT (dBA)</th>
<th>SOUND LEVEL AT 50 FT (dBA)</th>
<th>PASSBY SEL @ 50 FT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LAfmax</td>
<td>LASmax</td>
<td>Laeq (1s)</td>
</tr>
<tr>
<td>PASSBY</td>
<td>12:31:44</td>
<td>15 SB</td>
<td></td>
<td>65.2</td>
<td>64.2</td>
<td>64.4</td>
</tr>
<tr>
<td></td>
<td>12:41:29</td>
<td>15 NB</td>
<td></td>
<td>65.3</td>
<td>64.8</td>
<td>64.9</td>
</tr>
<tr>
<td></td>
<td>12:51:18</td>
<td>15 SB</td>
<td></td>
<td>64.8</td>
<td>63.9</td>
<td>64.0</td>
</tr>
<tr>
<td></td>
<td>13:05:56</td>
<td>15 SB</td>
<td></td>
<td>65.7</td>
<td>64.4</td>
<td>64.6</td>
</tr>
<tr>
<td>AVERAGE</td>
<td></td>
<td>15</td>
<td></td>
<td>65.3</td>
<td>64.3</td>
<td>64.5</td>
</tr>
<tr>
<td>PASSBY</td>
<td>13:13:42</td>
<td>30 NB</td>
<td></td>
<td>70.3</td>
<td>69.7</td>
<td>69.9</td>
</tr>
<tr>
<td></td>
<td>13:19:30</td>
<td>30 SB</td>
<td></td>
<td>71.4</td>
<td>70.2</td>
<td>70.6</td>
</tr>
<tr>
<td></td>
<td>13:26:55</td>
<td>30 NB</td>
<td></td>
<td>71.4</td>
<td>70.5</td>
<td>70.8</td>
</tr>
<tr>
<td></td>
<td>13:32:26</td>
<td>30 SB</td>
<td></td>
<td>71.3</td>
<td>70.1</td>
<td>70.5</td>
</tr>
<tr>
<td>AVERAGE</td>
<td></td>
<td>30</td>
<td></td>
<td>71.1</td>
<td>70.1</td>
<td>70.4</td>
</tr>
<tr>
<td>PASSBY</td>
<td>13:39:50</td>
<td>45 NB</td>
<td></td>
<td>74.3</td>
<td>73.1</td>
<td>73.7</td>
</tr>
<tr>
<td></td>
<td>13:45:00</td>
<td>45 SB</td>
<td></td>
<td>74.6</td>
<td>73.2</td>
<td>73.8</td>
</tr>
<tr>
<td></td>
<td>13:52:01</td>
<td>45 NB</td>
<td></td>
<td>73.6</td>
<td>72.7</td>
<td>73.0</td>
</tr>
<tr>
<td></td>
<td>13:57:17</td>
<td>45 SB</td>
<td></td>
<td>73.4</td>
<td>72.5</td>
<td>72.9</td>
</tr>
<tr>
<td></td>
<td>14:04:25</td>
<td>45 NB</td>
<td></td>
<td>73.4</td>
<td>72.4</td>
<td>72.9</td>
</tr>
<tr>
<td>AVERAGE</td>
<td></td>
<td>45</td>
<td></td>
<td>73.9</td>
<td>72.8</td>
<td>73.3</td>
</tr>
<tr>
<td>PASSBY</td>
<td>14:10:24</td>
<td>60 SB</td>
<td></td>
<td>76.9</td>
<td>75.7</td>
<td>76.3</td>
</tr>
<tr>
<td></td>
<td>14:16:57</td>
<td>60 NB</td>
<td></td>
<td>75.7</td>
<td>75.0</td>
<td>75.2</td>
</tr>
<tr>
<td></td>
<td>14:22:38</td>
<td>60 SB</td>
<td></td>
<td>76.6</td>
<td>75.2</td>
<td>75.7</td>
</tr>
<tr>
<td></td>
<td>14:29:34</td>
<td>60 NB</td>
<td></td>
<td>75.6</td>
<td>74.3</td>
<td>75.1</td>
</tr>
<tr>
<td></td>
<td>14:35:33</td>
<td>60 SB</td>
<td></td>
<td>76.3</td>
<td>75.1</td>
<td>75.6</td>
</tr>
<tr>
<td>AVERAGE</td>
<td></td>
<td>60</td>
<td></td>
<td>76.2</td>
<td>75.1</td>
<td>75.6</td>
</tr>
<tr>
<td>ACCEL</td>
<td>14:44:01</td>
<td>30 NB</td>
<td></td>
<td>74.9</td>
<td>74.0</td>
<td>74.4</td>
</tr>
<tr>
<td></td>
<td>14:45:33</td>
<td>30 SB</td>
<td></td>
<td>74.1</td>
<td>72.9</td>
<td>73.5</td>
</tr>
<tr>
<td></td>
<td>14:47:00</td>
<td>30 NB</td>
<td></td>
<td>74.5</td>
<td>73.7</td>
<td>73.7</td>
</tr>
<tr>
<td></td>
<td>14:49:08</td>
<td>30 SB</td>
<td></td>
<td>73.6</td>
<td>72.6</td>
<td>72.9</td>
</tr>
<tr>
<td>AVERAGE</td>
<td></td>
<td>30</td>
<td></td>
<td>74.3</td>
<td>73.3</td>
<td>73.6</td>
</tr>
<tr>
<td>DECEL</td>
<td>14:53:23</td>
<td>30 NB</td>
<td></td>
<td>72.3</td>
<td>71.4</td>
<td>71.3</td>
</tr>
<tr>
<td></td>
<td>14:56:09</td>
<td>30 NB</td>
<td></td>
<td>71.5</td>
<td>70.9</td>
<td>71.1</td>
</tr>
<tr>
<td></td>
<td>14:58:01</td>
<td>30 NB</td>
<td></td>
<td>71.9</td>
<td>70.7</td>
<td>70.9</td>
</tr>
<tr>
<td></td>
<td>14:59:45</td>
<td>30 NB</td>
<td></td>
<td>71.8</td>
<td>70.5</td>
<td>71.2</td>
</tr>
<tr>
<td>AVERAGE</td>
<td></td>
<td>30</td>
<td></td>
<td>71.9</td>
<td>70.9</td>
<td>71.1</td>
</tr>
<tr>
<td>BRAKE</td>
<td>15:02:43</td>
<td>30 NB</td>
<td></td>
<td>72.3</td>
<td>70.8</td>
<td>71.3</td>
</tr>
<tr>
<td></td>
<td>15:04:25</td>
<td>30 NB</td>
<td></td>
<td>69.4</td>
<td>67.0</td>
<td>66.3</td>
</tr>
<tr>
<td>AVERAGE</td>
<td></td>
<td>30</td>
<td></td>
<td>70.8</td>
<td>68.9</td>
<td>68.8</td>
</tr>
</tbody>
</table>
### DCTA A-Train Noise Measurement Results

**Noise and Vibration Test Program for the DCTA Stadler DMU**

<table>
<thead>
<tr>
<th>EVENT</th>
<th>SPEED (mph)</th>
<th>DIRECTION</th>
<th>ONE-THIRD OCTAVE BAND</th>
<th>MAXIMUM SOUND PRESSURE</th>
<th>IDLE</th>
<th>AVERAGE</th>
<th>BRAKE</th>
</tr>
</thead>
</table>

**DCTA A-TRAIN NOISE MEASUREMENT RESULTS:**

**EVENTS:**

- **13:57:17:**
  - **Speed (mph):** 13.8
  - **DIRECTION:** 12.5, 14.7, 14.9, 14.6, 14.3, 14.2, 14.1, 14.0, 13.9, 13.8, 13.7, 13.6, 13.5, 13.4, 13.3, 13.2, 13.1, 13.0, 12.9, 12.8, 12.7, 12.6, 12.5

- **14:29:34:**
  - **Speed (mph):** 14.6

---

Cotton Belt Corridor Regional Rail Project

Noise and Vibration Test Program for the DCTA Stadler DMU

B-2
APPENDIX C. VIBRATION DATA
Cotton Belt Corridor Regional Rail Project

Noise and Vibration Test Program for the DCTA Stadler DMU

Average DMU Vibration Levels vs Speed at 15 Feet

Average DMU Vibration Levels vs Speed at 25 Feet
Average DMU Vibration Levels vs Speed at 50 Feet

Average DMU Vibration Levels vs Speed at 75 Feet
Average DMU Vibration Levels vs Speed at 100 Feet

Average DMU Vibration Levels vs Speed at 125 Feet
Average DMU Force Density Levels at 15 mph

Average DMU Force Density Levels at 30 mph
Average DMU Force Density Levels at 45 mph

Average DMU Force Density Levels at 60 mph