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NOISE TEST-CORRUGATED RAILS WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY

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Letter Report

Prepared for

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PREFACE

Appreciation is expressed to personnel and officials of the Washington Metropolitan Area Transit Authority (UMATA) for their help in performing this study and for information they supplied. Thanks are also extended to Mr. Anthony Bruno of Fairmont Railway Motors Inc. for information he supplied.

A. DiTomaso and J. Hickey, of the Noise Measurement and Assessment Laboratory of the Transportation Systems Center, contributed to the preparation of this report.

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SUMMARY

Noise and ground-borne vibration level measurements were made on a section of the Huntington subway route of the Washington Area Metropolitan Transit Authority (WMATA). Measurements were made before, in between, and after a WMATA sponsored rail grinding operation to eliminate corrugations from a section of rails between Foggy Bottom and Rosslyn subway stations.

In-car acoustic measurements showed a 12-19 dB noise reduction as a result of the rail grinding operations. This large amount of noise reduction was achieved partly because the rail test section between Foggy Bottom and Rosslyn subway stations had particularly rough rail corrugations before grinding resulting in high in-car noise levels compared to other parts of the WMATA system. The large reductions in levels probably would not be realized in other parts of the system where the rails were not as badly corrugated. The largest noise reduction took place when the field side of the rails were ground. No significant reduction was noted in the ground-borne vibration levels measured at the surface on NW I Street as a result of rail grinding operations.

1. INTRODUCTION

This report documents the results of an in-car noise and ground-borne vibration measurement program conducted on June 19-21, 1981 on a section of the Huntington subway route of the Washington Metropolitan Area Transit Authority (WMATA). The test, in conjunction with a WMATA sponsored rail grinding operation, was conducted by the U.S. Department of Transportation-Transportation Systems Center (DOT/TSC) for the U.S. DOT-Urban Mass Transportation Administration.

The lead car of a six-car train was instrumented with two noise measuring and recording systems. Microphones were placed at the ear level to a seated passenger, (without a passenger present), one in a passenger seating area over the front wheel trucks and the other in a passenger seating area over the rear wheel trucks. Measurements were made during runs of the test-train between the Foggy Bottom and Rosslyn stations and back again on the same track. Observers located in the drivers compartment annotated train speed from the operators console onto the third track of the tape recorder in synchronism with the noise recording.

Ground-borne vibration level measurements were made in a residential area above the tunnel at 2426 NW I Street. A vibration tranducer monitoring vertical acceleration levels was secured to the concrete curb-stone. The test track at this point was 40 feet below the street surface.

The objective of the test was to assess the effectiveness of the rail grinding operation in reducing in-car noise levels and ground-borne surface vibration levels.

2. EXPERIMENTAL APPROACH

2.1 GENERAL

Wheel/rail noise is generated by the interaction of steel wheels on steel rails and falls into three broad categories, each produced by a different mechanism: roar, squeal and impact. Rail grinding, among others, is a method of controlling wheel/rail noise.

As part of its track maintenance program, WMATA contracted with Fairmont Railway Motors Inc. of Syracuse, NY, to grind various sections of track in the WMATA system in order to remove built up rail irregularities (corrugations). The TSC Noise Measurement and Assessment Laboratory was requested to conduct a measurement program to evaluate the effectiveness of the rail grinding process in reducing in-car noise.

2.2 TEST TRACK

Track 2, outbound from Foggy Bottom to the Rosslyn subway station, was chosen as the test section of track since it contained badly corrugated rails on both tangent and curved sections of track. Two single track tunnels under the Potomac River connect the two stations which are approximately 6300 feet apart. Trains outbound from Foggy Bottom station proceed into the track 2 tunnel and down a - 3.9 percent grade for 3500 feet, then up a + 4.0 percent grade for 2800 feet to the Rosslyn station. The last 1800 feet of the + 4.0 percent upgrade is a 90 degree curve to the left (approximate curve radius 1300 feet) into Rosslyn station.

2.3 TEST TRAIN

The lead car of a six-car train made up of car no's 1000, 1001, 1029, 1028, 1284, 1285 was instrumented with two noise measuring systems. Microphones were placed at ear level (four feet above the floor) to a seated passenger; one in a passenger seating area over the front wheel trucks and the other in a passenger seating area over the rear wheel trucks (see Figure 1). The instrumented car (No. 1000) was the lead car of the train when run from Foggy Bottom to Rosslyn. On the return trip the instrumented car was the last car of the six-car train. The air conditioning system was shut off during all test runs. All six-cars were unladen.

2.4 SURFACE TEST SITE

Ground-borne vibration level measurements were made in a residential area above the tunnel at NW I and 25th streets at a point 550 feet west of the Foggy Bottom station platform. An accelerometer oriented to monitor vibrations in the vertical axis was attached with epoxy to the concrete curb-stone in front of 2426 NW I Street at a point offset 40 feet south of the test track centerline (track 2, outbound). The test track at this point is 40 feet below the street surface (slant range distance to the measurement point is 56 feet). Outbound trains from Foggy Bottom station accelerate to a speed of approximately 40 mph when passing through this area. Track 1, inbound, was 40 feet directly below the measurement point.

2.5 TEST PROCEDURE

Prior to testing, rail irregularities were measured by WMATA along a 1700 foot section of track 2 between Foggy Bottom and Rosslyn. A Southern Railroad prototype Rail Corrugation Measuring Device, which measures irregularities over a one inch wide section at the center of the rail, was used. In addition, WMATA maintenance personnel torqued all rail fasteners on the Foggy Bottom to Rosslyn test track prior to the acoustic test. Corrugation measurements showed typical ripples (corrugations) which are approximately 2-8 thousandths of an inch deep which repeat every 2 inches. Corrugations of this repetition rate correspond to a frequency of 300-600 Hz for a train speed of 40-60 mph. A few larger corrugations occur which are 12-20 thousandths deep separated by 22-26 inches. These seem to correspond to some of the large intrusive features seen in the noise histories discussed in latter sections.

In car noise measurements were made before, in between and after rail grinding operations to remove rail irregularities (corrugations). Measurments were made during three round trips each to increase the statistical confidence in the noise data. The test train was run at normal revenue speeds on track 2 between the Foggy Bottom and Rosslyn stations and back again on the same track. This constituted one round trip. The instrumented car was the lead car in the six-car train outbound (Foggy Bottom to Rosslyn); however, on the return trip (Rosslyn to Foggy Bottom) the instrumented car was the last car in the six-car train.

The test sequence over the 2-day period during non-revenue service hours was as follows:

June 20	Acoustic Test Runs	No. 1-3
	Grinding Run	No. 1 (gauge side)
	Acoustic Test Runs	No. 4-6
	Grinding Runs	No. 2-3 (gauge side)
June 21	Acoustic Test Runs	No. 7-9
	Grinding Runs	No. 4-5 (field-side)
	Acoustic Test Run	No. 10-12
	Grinding Runs	No. 6-7 (field side)
	Acoustic Test Run	No. 13-15

Noise data from the two microphone systems were recorded on magnetic tape. Observers located in the operators compartment annotated train speed from the operators console onto the third track of the tape recorder in synchronism with the noise data. The train was set in the automatic mode of operation for these tests; however during the latter stages of the test, system problems prevented automatic operation. Under manual control, the operator tried as closely as possible to simulate automatic operation.

Vibration level recordings on the surface at the NW I Street location were made in synchronism with the in-car noise level recordings. The surface site was alerted by radio when the test train left the station on each acoustic data run.

In addition to the above, a continuous noise level recording was made in the lead car of the six-car test train during one of the trips from the maintenance yard at New Carrolton to the test area in order to obtain a measure of the in-car noise levels over various sections of track both in tunnel and at grade. Speed and location data were annotated on tape in synchronism with the noise data. Vibration data was also measured at 1600 hours June 19, 1981 at the NW I Street site to obtain a measure of the vibration levels generated prior to grinding during normal revenue service.

Details of the noise measurement system are illustrated in the Appendix (Figures A1-A4).

2.6 RAIL GRINDING

Fairmont Railway Motors Inc., under contract to WMATA and using the Fairmont Railway Motors Inc. Model RG24C Grinding Machine, ground the rails on track 2 between Foggy Bottom and Rosslyn according to the schedule shown in section 2.5. Telephone conservations with Mr. Anthony Bruno of Fairmont are the basis for the following comments: For grinding runs 1-3, the grinding machine was set for the standard AAR (American Association of Railroads) grinding pattern for tapered wheels; i.e., set to grind the gauge side of the rails.

For grinding runs 4-7, the grinders were set to grind the field side of the rails; i.e., the portion of the rail where cylyndrical wheels have their greatest contact with the rails. Cylyndrical wheels are presently used exclusively on the WMATA system. It was estimated by Mr. Bruno that each grinding run removed 2 to 8 thousandths of material from the rails.

3. MEASUREMENT DATA

3.1 SUMMARY DATA

Summary tabulations of the noise level data measured at two in-car locations and of the ground-borne vibration level data measured at the surface in a residential area are presented.

Tables 1 and 2 contain the maximum noise level measured for each acoustic test run in two passenger seating areas of the test train (over the front wheel trucks and over the rear wheel trucks respectively). The speed of the test train at the time of the measured maxima is included.

An inspection of the average levels of Tables 1 and 2 show the following in car noise reductions were achieved as a result of the rail grinding process:

Noise Reduction (dB)

	Over Front Wheel Trucks		Over Rear Wheel Trucks	
	FB-Ross*	Ross-FB	FB-Ross	Ross-FB
After 1 rail grinding operation - gauge side				
	3.6	2.5	3.7	7.9
After 2 additional rail grinding operations - gauge side				
	1.6	3.0	3.0	2.6
After 2 rail grinding operations - field side				
	6.8	6.1	7.2	7.3
After 2 additional rail grinding operations - field side				
	0.9	0.4	1.1	1.1
Total	12.9	12.0	15.0	18.9

*FB-Ross Foggy Bottom to Rosslyn
Ross-FB Rosslyn to Foggy Bottom

It can be seen that the largest noise reduction is achieved by rail grinding on the field side of the rails. This is probably due to the fact that cylindrical type wheels, as used by WMATA subway trains, maintain greater contact area with the rails on the field side than on the gauge side. Also, the first one to two rail grinding operations (on either side) are more effective than subsequent rail grinding operations. Table 3 contains a summary of the average ground-borne vibration levels (acceleration) measured, over the period of the event (8 seconds), in the vertical axis during the pass-by of the test train for each acoustic run. An overall reduction in the ground vibration levels of 0.5-2 dB is noted.

3.2 NOISE LEVEL TIME HISTORIES

Representative graphic level time history recordings of in-car noise levels are presented in Figures 2 thru 8. Figure 2 contains noise data measured in the passenger seating area over the front wheel trucks during the Foggy Bottom to Rosslyn run (Figure 2A) and during the Rosslyn to Foggy Bottom run (Figure 2B). The data shown in Figure 2 was measured during acoustic run no. 1 before any grinding of the rails. Superimposed on the charts is the speed information obtained from the operators console. Three points are identified in Figures 2A and 2B and are lettered a through f. Each point represents the start of a 4-second analysis period over which the average 1/3-octave frequency spectrum was obtained for the in-car noise level data (see section 3.3). The physical location of the test train at each of these points is estimated to be as follows:

Points a and f - approximately 1000 feet west of the Foggy Bottom station on a -3.9 percent downgrade.

Points b and e - approximately 2200 feet west of the Foggy Bottom station on a -3.9 percent downgrade, approximately 500 feet before the transition from downgrade to a +4.0 percent upgrade.

Points c and d - approximately 5300 feet west of the Foggy Bottom station at the mid-point of the 90 degree curve on a +4.0 percent upgrade (see Section 2.2).

As described earlier in Section 2.5, measurements of rail irregularities in the center of the rail over a 1700 foot section or track in the vicinity of points b and e indicate specific areas where there are significant peaks in rail corrugations. These corrugations are approximately 20-20 thousandths of an inch deep separated by 22-26 inches. They seem to correspond to areas where noise impulse peaks can be seen in the noise time history recordings before grinding operations (Figures 2 and 7).

Figures 3-6 contain in-car noise level time history data measured (over the front wheel trucks) after subsequent grinding operations; Figure 3-after one grinding operation - gauge side; Figure 4- after two additional grinding operations - gauge side; Figure 5- after two grinding operations - field side; Figure 6- after two additional grinding operations - field side. Note in comparing Figures 2-6 the decrease in the noise levels as a result of the grinding process as well as the elimination of the sharp intrusive character of the noise to that of one with gradual predictable changes based on speed of the train.

For comparative purpose Figures 7 and 8 are included and contain in-car noise level time histories of data measured in the passenger seating area over the rear wheel trucks during acoustic run 1 (before grinding) and during acoustic run 13 (after 3 gauge side and 4 field side grinding operations). Comparing the pre-grinding data at the two in-car locations (Figure 2 and 7) shows the levels in the area over the rear wheel trucks of the test car to be greater than those over the front wheel trucks (2.7 dB Foggy Bottom to Rosslyn; 8.0 dB Rosslyn to Foggy Bottom). (Note: during the Rosslyn to Foggy Bottom run, the test car is at the rear of the six-car train therefore the "front" wheel trucks are now at the the rear of the train). The levels over the rear wheel trucks are not only higher but the peaks are sharper in character. The higher noise levels in the area over the rear wheel trucks are probably due to the following: (1) As the train moves from Rosslyn to Foggy Bottom on the outbound track, it encounters rail corrugations from a different direction than during normal revenue service. The increased jaggedness of the corrugations in this direction produces greater noise levels than when the train was traveling from Foggy Bottom to Rosslyn; (2) Compared to the microphone position over the front wheel truck, the microphone position over the rear wheel truck is much closer to the adjacent truck on the next car where additional noise is generated.

Comparison of the post-grinding data in the two areas of the test train (Figure 6 and 8) shows the levels measured in the area of the rear wheel trucks to be only slightly higher than those measured over the front wheel trucks (0.6 dB Foggy Bottom to Rosslyn; 1.1 dB Rosslyn to Foggy Bottom). In addition the character of the noise signatures are less impulsive and very similar at both locations regardless of the direction of the train.

3.3 NOISE LEVEL FREQUENCY SPECTRA

One-third-octave frequency spectra of selected 4-second periods of in-car noise data are presented in Figures 9-15. The start of the 4-second period chosen for spectral analysis has been indicated on the noise level time history charts of Figures 2-8. In addition the physical area along the test section of track has been identified in Section 3.2. The band number conversion tables and explanation of the information on the spectral photograph is shown in Appendix A.

A comparison of the pre-grinding spectral noise data as measured in the passenger seating area over the front wheel trucks (Figure 9) with that of the post-grinding data (Figure 13) shows the dramatic reduction of a band of noise approximately centered at 500 Hz. This is the frequency range of noise calculated to be from the rail corrugations as described earlier (see Section 2.5). The gradual reduction in this band of frequencies as a result of the intermediate grinding steps can be seen in Figures 9-11.

A similiar result (although a greater reduction) can be seen by comparing Figures 14 and 15 for the data measured in the passenger seating area over the rear wheel trucks. A greater noise reduction over the rear wheel trucks results because noise levels were greater there before rail grinding operations as compared to noise levels over the front wheel trucks. This is particularly true during the Rosslyn to Foggy Bottom run (see explanation in Section 3.2 and Figure 7).

3.4 VIBRATION DATA

Graphic level time listings recordings and one-third octave frequency spectra of ground-born vibration data measured in the vertical axis on NW I Street are presented.

Figure 16 contains acceleration data measured during the passby of the test train on track 2 during acoustic run 1 (before grinding) both to and from the Rosslyn station. Included are the 1/3- octave frequency spectra measured of an 8-second period centered around each event. The spectrum in both cases is very similar and is seen to be centered around band 14 (25 Hz).

Figure 17 contains acceleration data measured during acoustic run 13 (after 3 gauge side and 4 field side grinding operations). A comparison of the data of Figure 16 and 17 (pre-grinding vs post-grinding) shows a reduction in the acceleration level of 0.5 and 2 dB. No significant difference is noted in the frequency spectrum.

Vibration measurements were also made at NW I Street during revenue service prior to grinding. Thirteen events were measured during a twenty-five minute period at 1600 hours on June 19, 1981. An average level of 57.7 dB re 1 micro-g was measured for six trains outbound from Foggy Bottom on track 2 while an average level of 59.8 dB re 1 micro-g was measured for six trains inbound to Foggy Bottom on track 1. The average outbound level is in agreement with the pregrinding measurement of the test train on track 2. The higher levels for inbound trains on track 1 are expected because track 1 inbound is closer to the measurement point than the test track, track 2 (see Section 2.4).

A representative 4-minute period of the above 25 minutes of recording is shown in the graphic level time history of Figure 18A. Shown are the acceleration levels resulting from the passby of three events during revenue service (8-car trains); the first event shown was outbound from Foggy Bottom on track 2; events 2 and 3 were inbound on track 1. One third-octave frequency spectra of a period of non-activity (local ambient) and for the first two events is shown in Figure 18B. Note that the spectrum of Figure 18B2 (outbound train, track 2) is the same as that shown for the test train on track 2 (Figure 16 and 17). The spectrum for the inbound train on track 1, Figure 18B3 however, is higher in level and includes additional low level high frequency data. This is expected since track 1 is closer to the measurement point.

3.5 IN-CAR NOISE-LANDOVER TO FARRAGUT WEST

A graphic level time history is presented in Figure 19 of the noise levels measured at the two in-car locations during a simulated revenue run between the Landover and Farragut West stations. The train traveled mostly at grade from Landover until just before Stadium Armory where the train entered the tunnel for the remainder of the run. The train stopped for a portion of the trip between Stadium Armory and Potomac Avenue to change from automatic to manual operation. The air conditioner was also turned off at this point.

It can be seen that the in-car noise levels in the tunnel are approximately 5 dB greater than the in-car levels at grade. Also, the ambient noise with the train stopped and the air conditioner on is approximately 5 dB greater than the ambient with the air conditioner off. It can also be seen that in-car noise levels over the rear truck are 1-3 dB greater than over the front truck.

4. CONCLUSIONS

1. In-car noise measurements showed a reduction of 12-19 dB as a result of complete rail grinding operations (3 operations gauge side, 4 operations field side) on the test section of track between Foggy Bottom and Rosslyn subway stations. It should be recognized that the section of test track was judged to have had particularly rough rail corrugations resulting in high in-car noise levels compared to other parts of the WMATA system. Therefore, these large reductions in levels probably would not be realized in other parts of the system where the rails are not as badly corrugated.

2. Complete rail grinding operations result in a very small reduction in ground-borne vibration levels(0.5-2 dB).

3. Rail grinding on the field side of the rails was more effective in reducing in-car noise levels than rail grinding on the gauge side of the rails. This is due to the fact that the WMATA system uses cylindrical wheels on their cars which maintain more contact area with the field side of the rails then the gauge side of the rails.

4. The first one to two rail grinding operations were generally more effective than additional rail grinding operations on any one side (field or gauge) of the rails.

5. Rail grinding reduces transients and non-uniformities in noise character. The noise level time histories show that changes noise level history after grinding are smoother and correlate more closely with changes in train speed.

6. Rail grinding results in considerable noise reduction from approximately 125 Hz to over 4000 Hz. The noise reduction is generally greatest around 500 Hz (between 250 Hz and 1000 Hz). This frequency range corresponds to the frequency of rail corrugations along the test track section for typical WMATA train operating speeds.

7. In-car noise levels over the rear wheel trucks are greater than those over the front wheel trucks (approximately 3 dB before grinding and 1 dB after grinding).

Table No. 1

Summary In-Car Noise Level Data

(Passenger Area Over Front Wheel Trucks)

June 20-21, 1981

Acoustic Run		Foggy Botom to Rosslyn		Rosslyn to Foggy Bottom	
		Max Noise Level†	Speed	Max Noise Level†	Speed
No.		dBA	mph	dBA	mph
		before rail grinding operations			
1		97.2	60	95.0	50
2		97.2	62	89.5*(1)	42
3		97.2	62	90.0*(1)	50
	Average	97.2	61	95.0	50
		1 rail grinding operation - gauge side			
4		93.7	60	93.0*	55
5		93.5	60	91.7*	55
6		93.5	60	92.7*	55
	Average	93.6	60	92.5	55
		2 additional rail grinding operations - gauge side			
7		88.7*(2)	50	89.5*(2)	38
8		88.0*(2)	42	-	-
9		92.0*	58	89.5*	52
	Average	92.0	58	89.5	52
		2 rail grinding operations - field side			
10		85.5*	55	83.2*	45
11		85.0*	57	83.2*	58
12		85.0*	50	84.0*	55
	Average	85.2	54	83.4	53
		2 additional rail grinding operations - field side			
13		84.2*	62	83.0*	58
14		84.5*	62	83.0*	60
15		84.2*	62	83.0*	58
	Average	84.3	62	83.0	59

*Test train under manual operator control.
†dBA re 20 micro-Pascal
(1) Train stopped approximately mid-tunnel - not included in average.
(2) Speed contour not representative of automatic operation - not included in average.

Table No. 2

Summary In-Car Noise Level Data

(Passenger Area Over Rear Wheel Trucks)

June 20-21, 1981

Acoustic Run		Foggy Bottom to Rosslyn Max Noise Level†	Foggy Bottom to Rosslyn Speed	Rosslyn to Foggy Bottom Max Noise Level†	Rosslyn to Foggy Bottom Speed
No.		dBA	mph	dBA	mph
		before rail grinding operations			
1		99.7	60	103.0	50
2		99.7	62	92.0*(1)	42
3		100.0	62	92.2*(1)	50
	Average	99.9	61	103.0	50
		1 rail grinding operation - gauge side			
4		96.7	60	95.0*	55
5		96.2	60	95.5*	55
6		95.7	60	94.7*	55
	Average	96.2	60	95.1	55
		2 additional rail grinding operations - gauge side			
7		90.2*(2)	50	88.2*(2)	38
8		90.2*(2)	42	-	-
9		93.2*	58	92.5*	52
	Average	93.2	58	92.5	52
		2 grinding operations - field side			
10		86.2*	60	84.2*	60
11		85.5*	60	85.7*	58
12		86.2*	55	85.7*	58
	Average	86.0	58	85.2	59
		2 additional rail grinding operations - field side			
13		84.7*	62	84.2*	60
14		85.0*	62	84.2*	58
15		85.0*	62	84.0*	58
	Average	84.9	62	84.1	59

*Test train under manual operator control.
†dBA re 20 micro-Pascal.
(1) Train stopped approximately mid-tunnel - not included in average.
(2) Speed contour not representative of automatic operation - not included in average.

Table No. 3

Ground-borne Vibration

Average Acceleration Levels - Vertical Axis

Street Level - NW I Street -- June 20-21, 1981

Acoustic Run No.		Acceleration Level† dB	Speed mph	Acceleration Level† dB	Speed mph
		before rail grinding operations			
1		57.5	40	56.0	45
2		57.0	40	56.5	40
3		57.5	40	59.0	40
	Average	57.3	40	57.2	42
		1 rail grinding operation - gauge side			
4		57.5	40	56.5	40
5		58.0	45	58.0	40
6		58.0	40	54.5	35
	Average	57.8	42	56.3	38
		2 additional rail grinding operations - gauge side			
7		55.2	40	53.5	35
8		57.2	45	59.8	40
9		54.0	40	54.0	40
	Average	55.5	42	55.8	38
		2 rail grinding operations - field side			
10		57.0	40	56.2	40
11		56.5	40	53.2	40
12		56.4	40	56.5	35
	Average	56.6	40	55.3	38

†8 second average - dB re 1 micro-g (RMS)
Note: Accelerometer mounted on concrete curbstone.

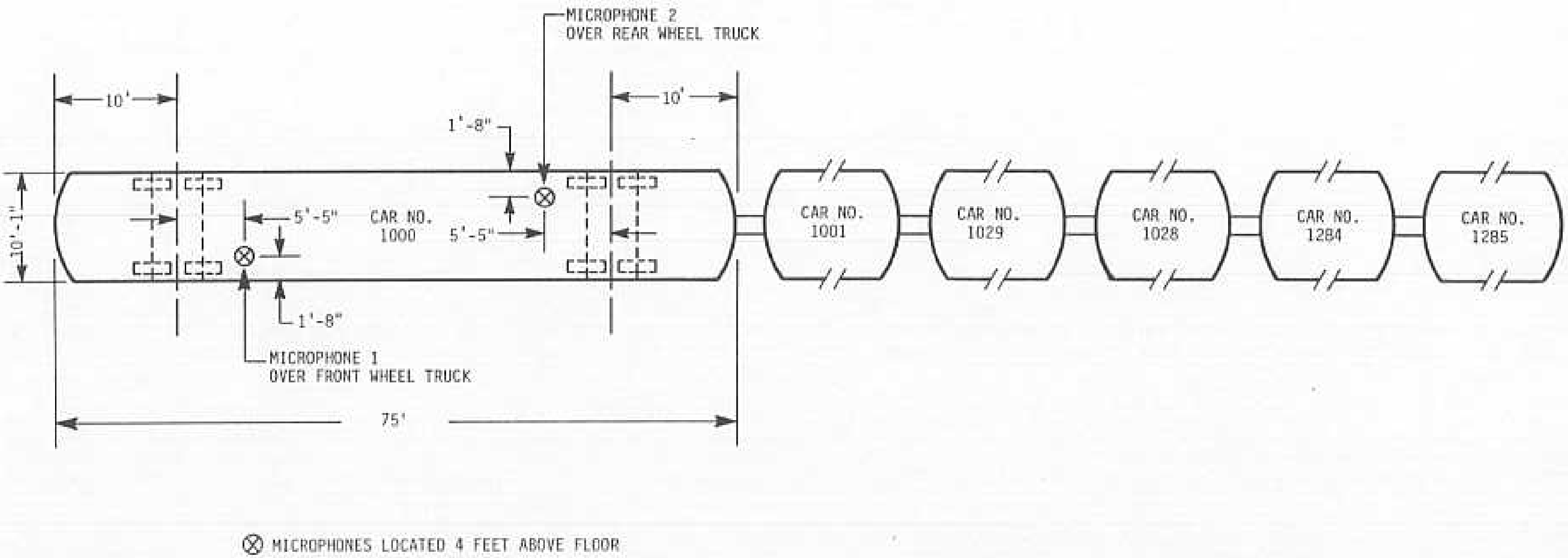
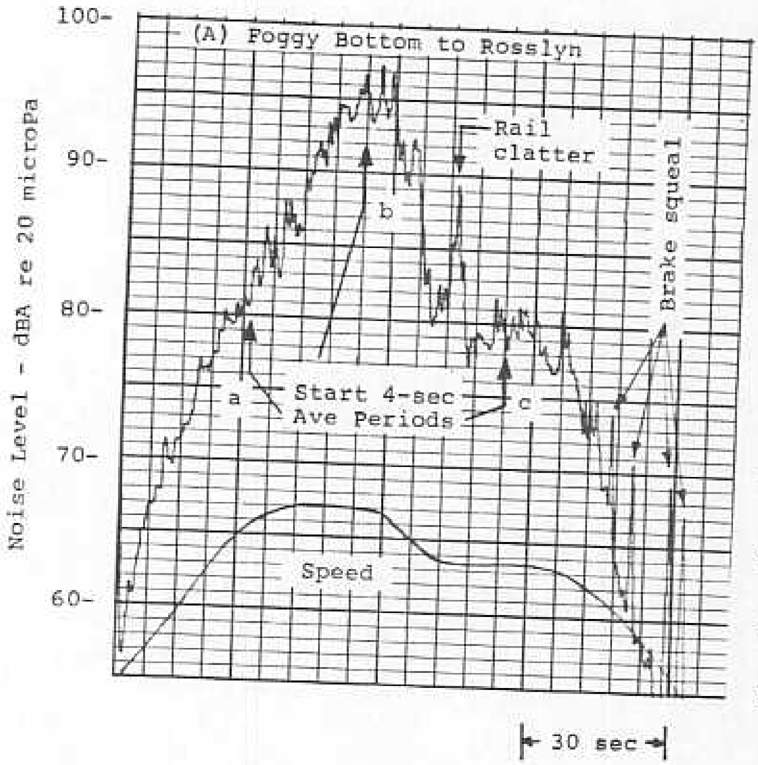
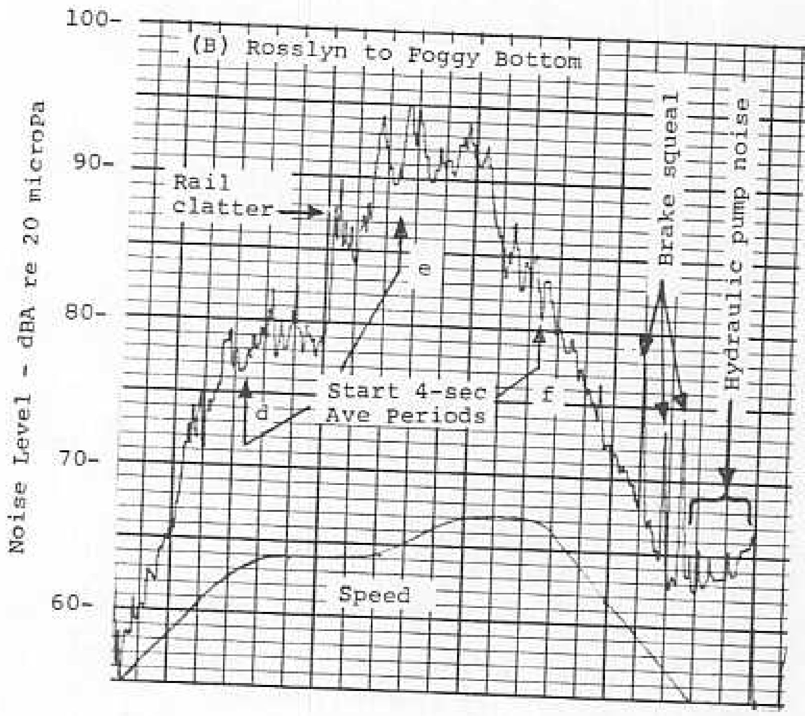


FIGURE 1. MICROPHONE LOCATION 6-CAR TRAIN - WMATA - JUNE 20-21, 1981



For 1/3 octave frequency spectrum see

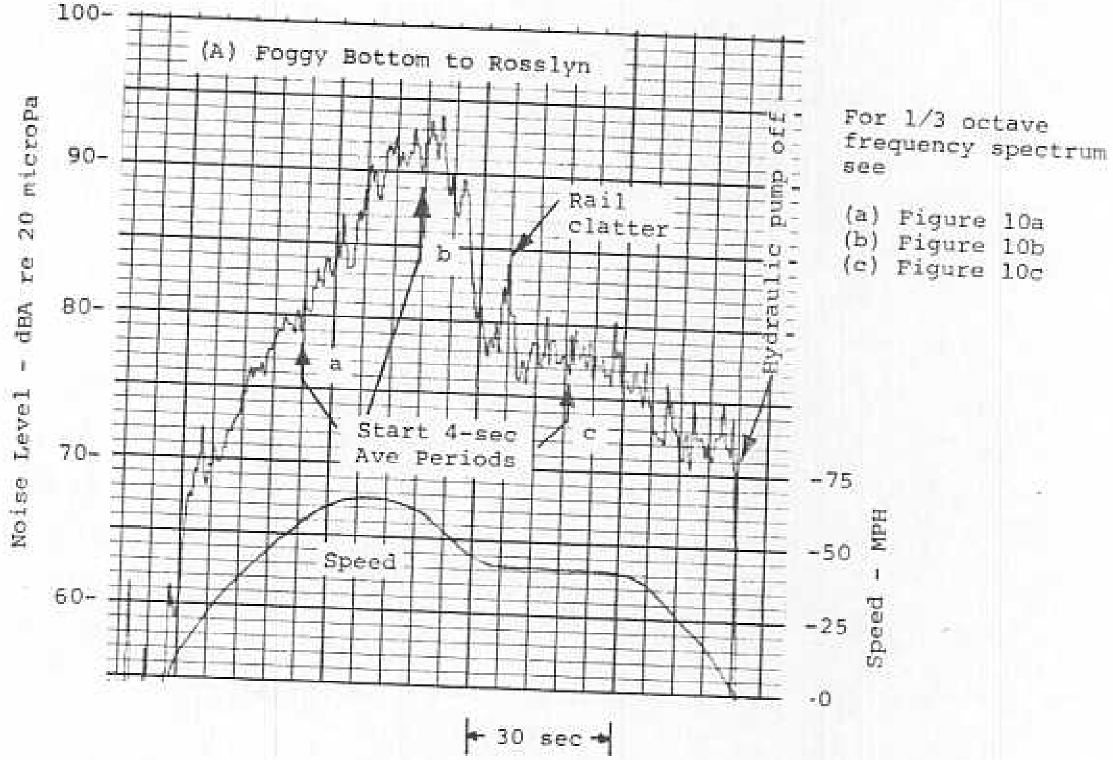
(a) Figure 9a
(b) Figure 9b
(c) Figure 9c



For 1-3 octave frequency spectrum see

(d) Figure 9d
(e) Figure 9e
(f) Figure 9f

Figure 2. In-Car Noise Level Time History
Passenger Seating Area Over Front Wheel Trucks
WMATA - Huntington Route - June 20-21,1981
Acoustic Run 1 - Before Rail Grinding Operations



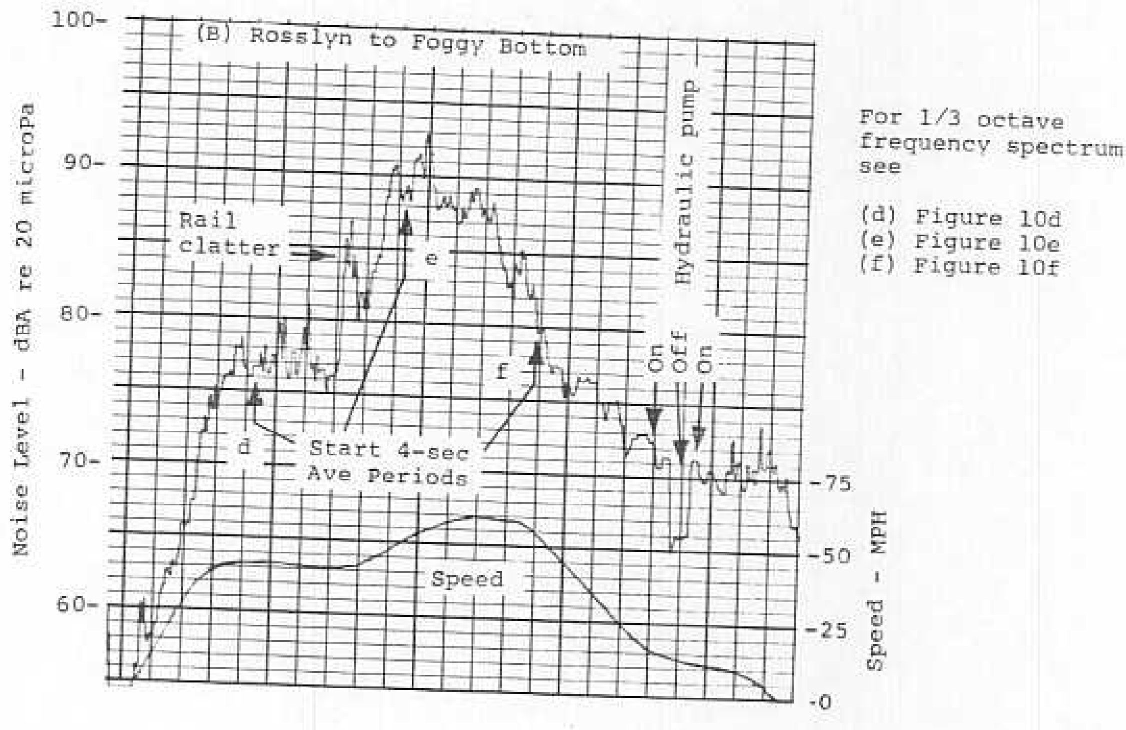


Figure 3. In-Car Noise Level Time History
Passenger Seating Area Over Front Wheel Trucks
WMATA - Huntington Route - June 20-21, 1981

Acoustic Run 6 - After 1 Gauge Side
Rail Grinding Operation

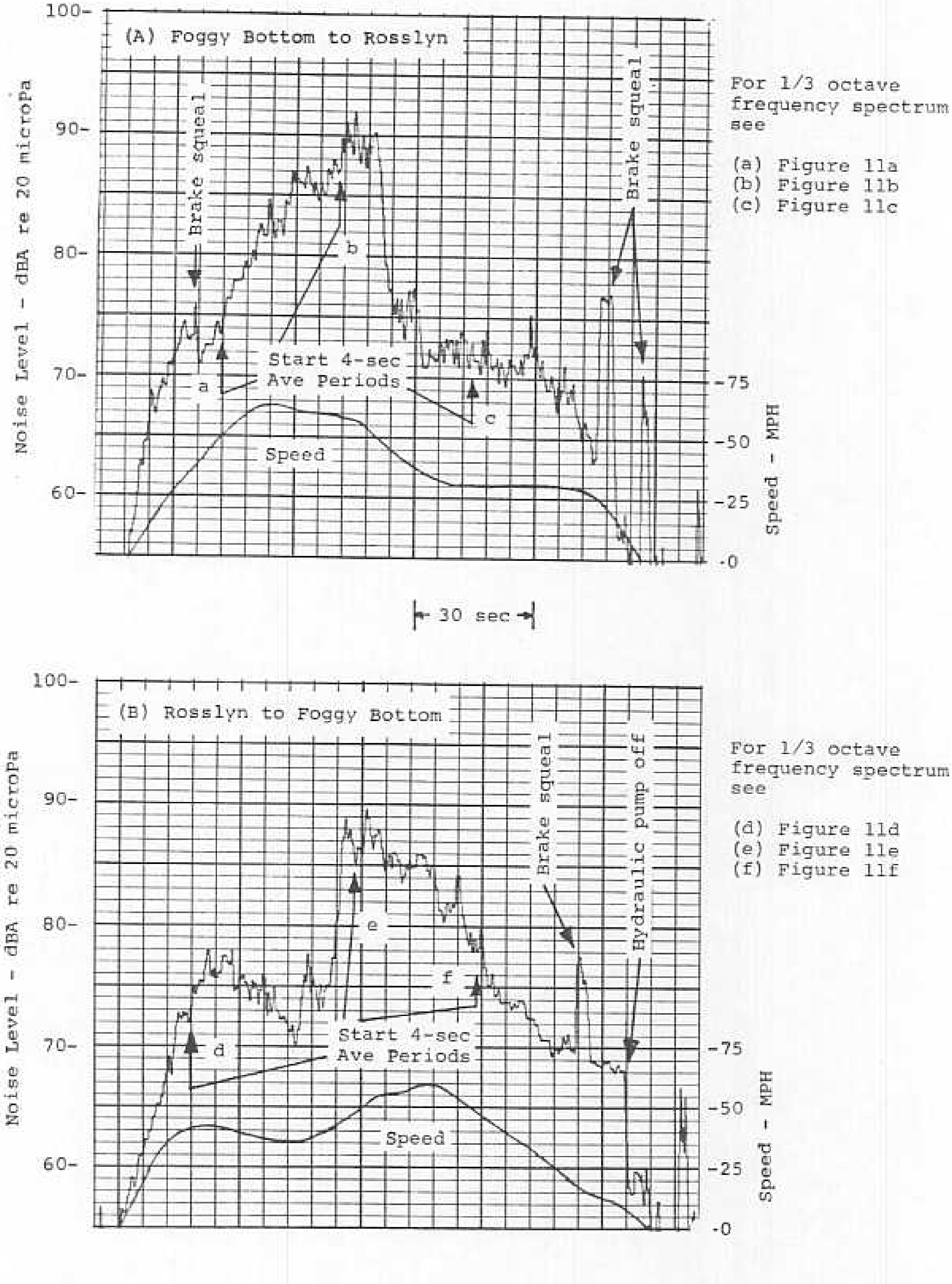
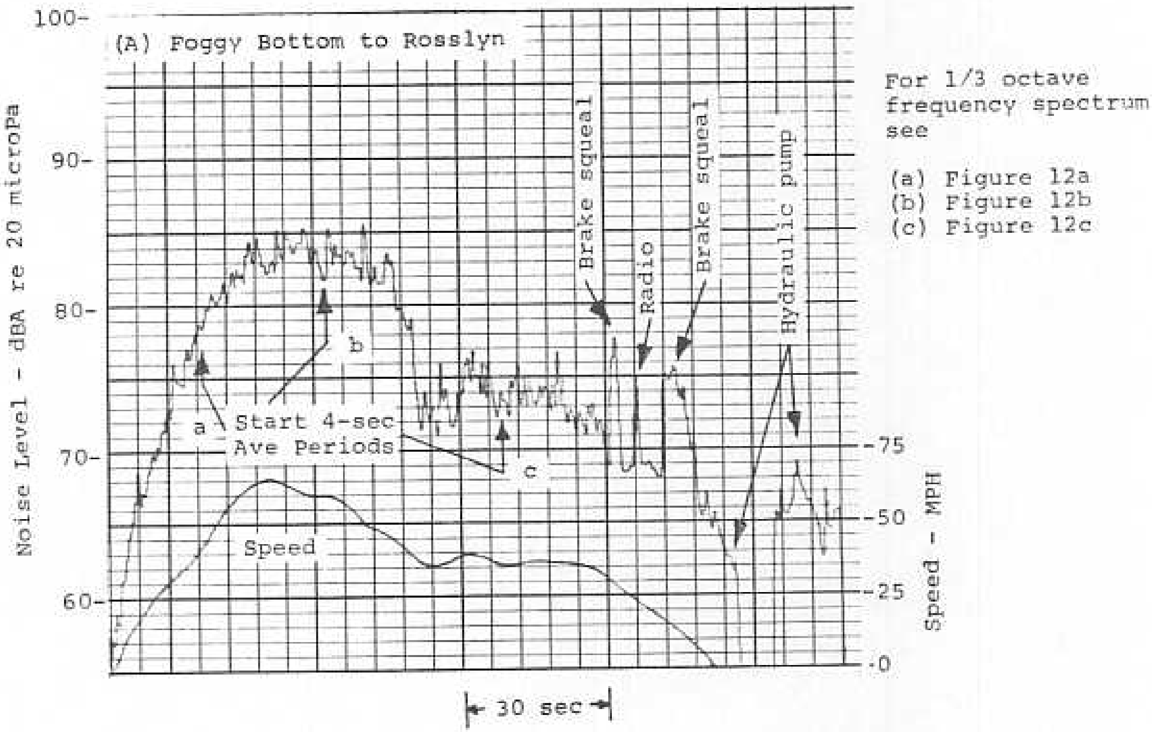


Figure 4 In-Car Noise Level Time History
Passenger Seating Area Over Front Wheel Trucks
WMATA - Huntington Route - June 20-21, 1981

Acoustic Run 9 - After 3 Gauge Side
Rail Grinding Operations



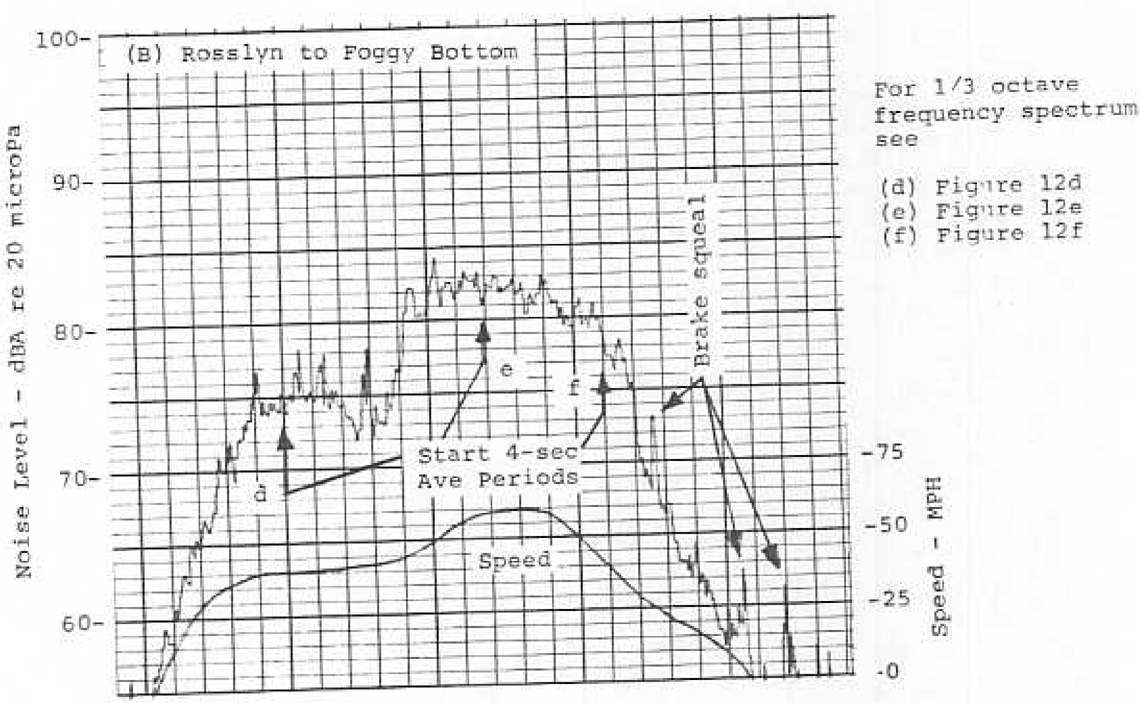
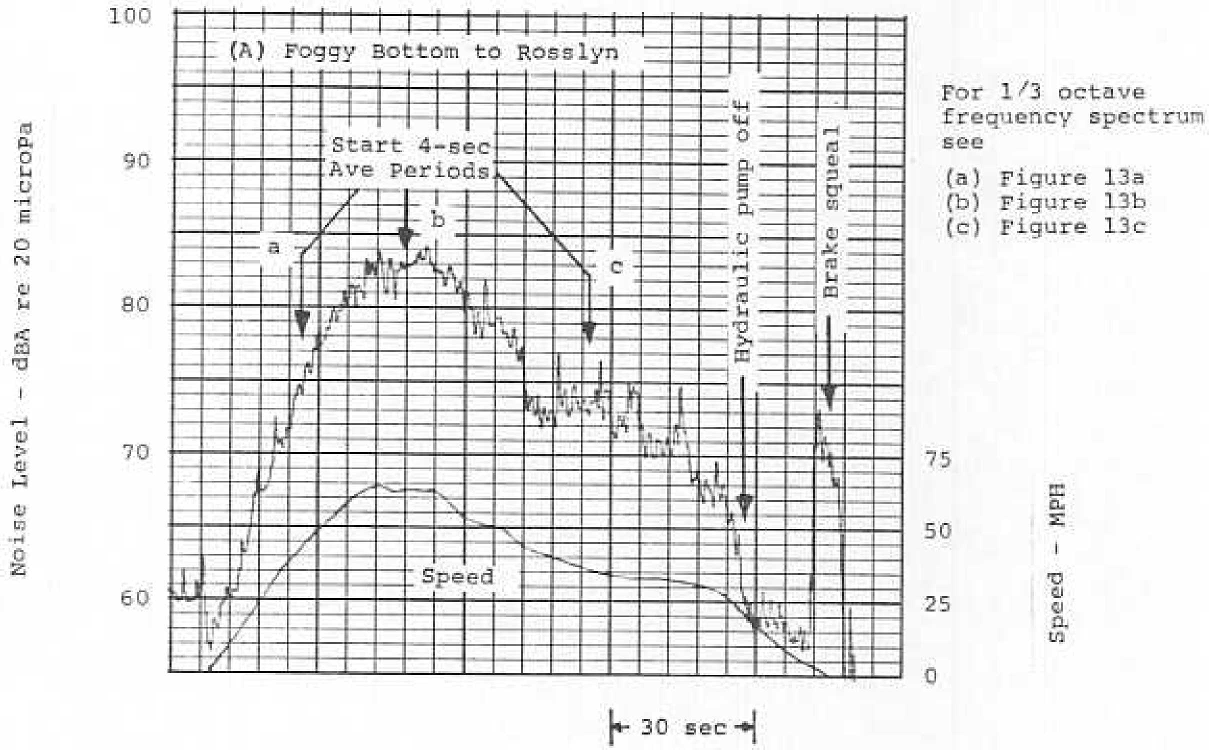


Figure 5 In-Car Noise Level Time History
Passenger Seating Area Over Front Wheel Trucks
WMATA - Huntington Route - June 20-21, 1981

Acoustic Run 12 - After 3 Gauge Side And 2 Field Side Rail Grinding Operations



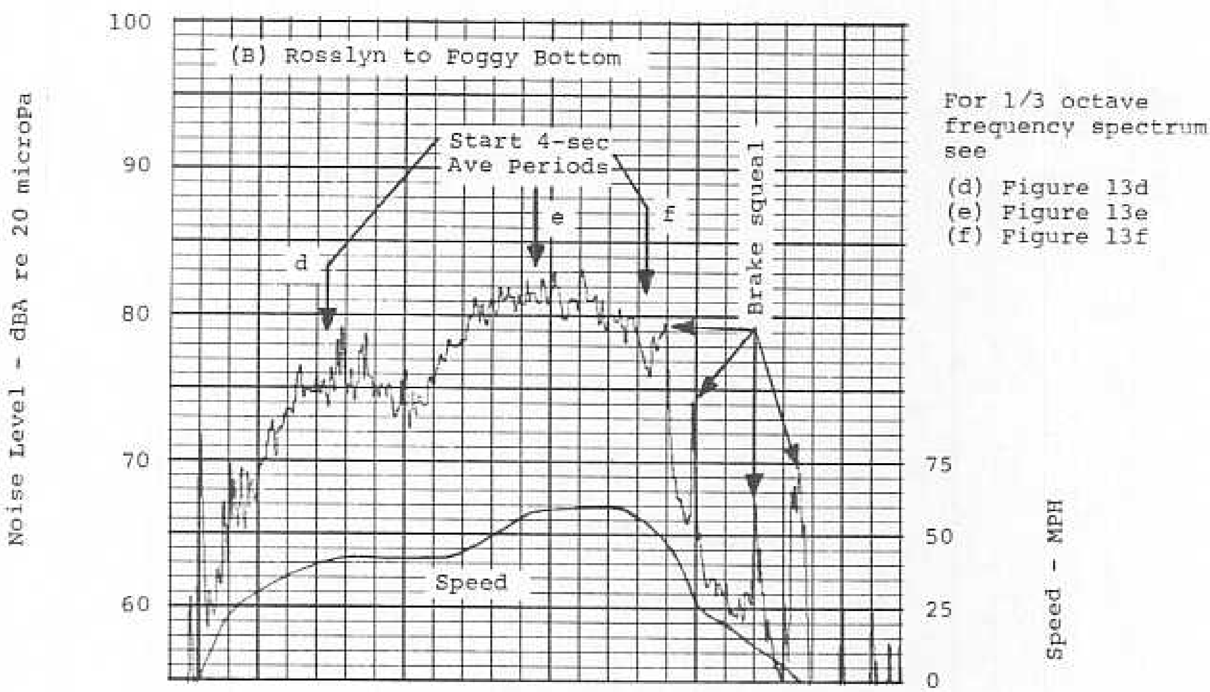
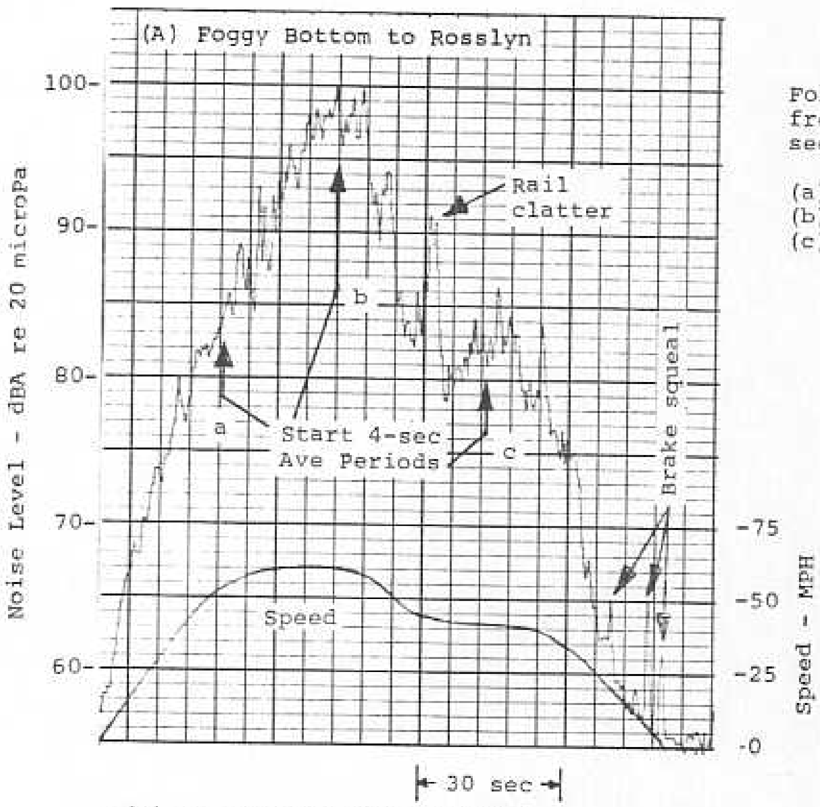


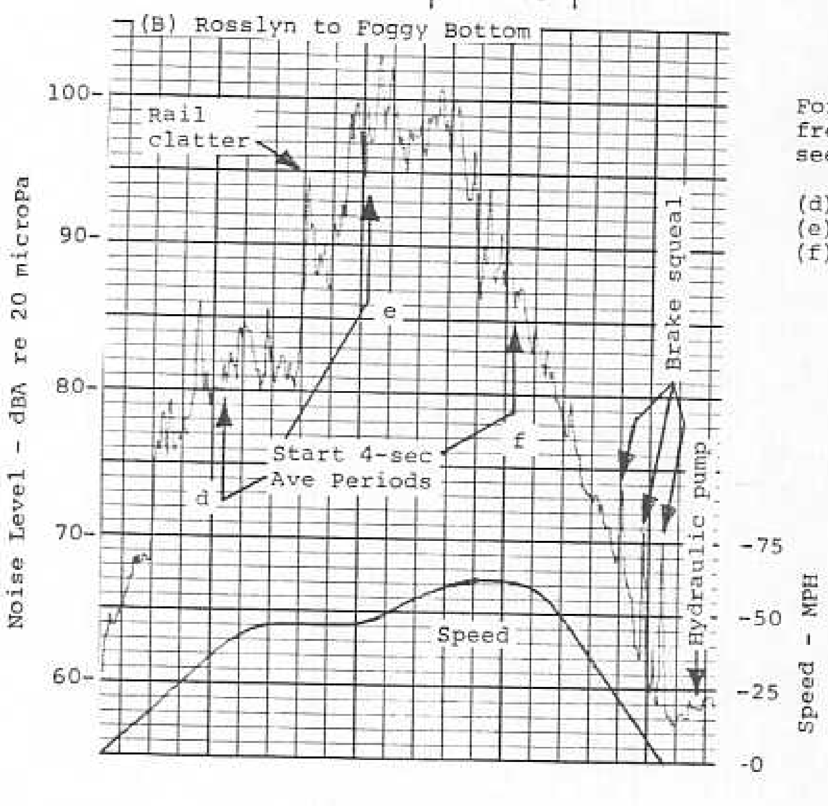
Figure 6 In-Car Noise Level Time History
Passenger Seating Area over Front Wheel Trucks
WMATA - Huntington Route - June 20-21,1981

Acoustic Run 13 - After 3 Gauge Side and 4 Field Side Rail Grinding Operations on Track 2



For 1/3 octave frequency spectrum see

(a) Figure 14a
(b) Figure 14b
(c) Figure 14c

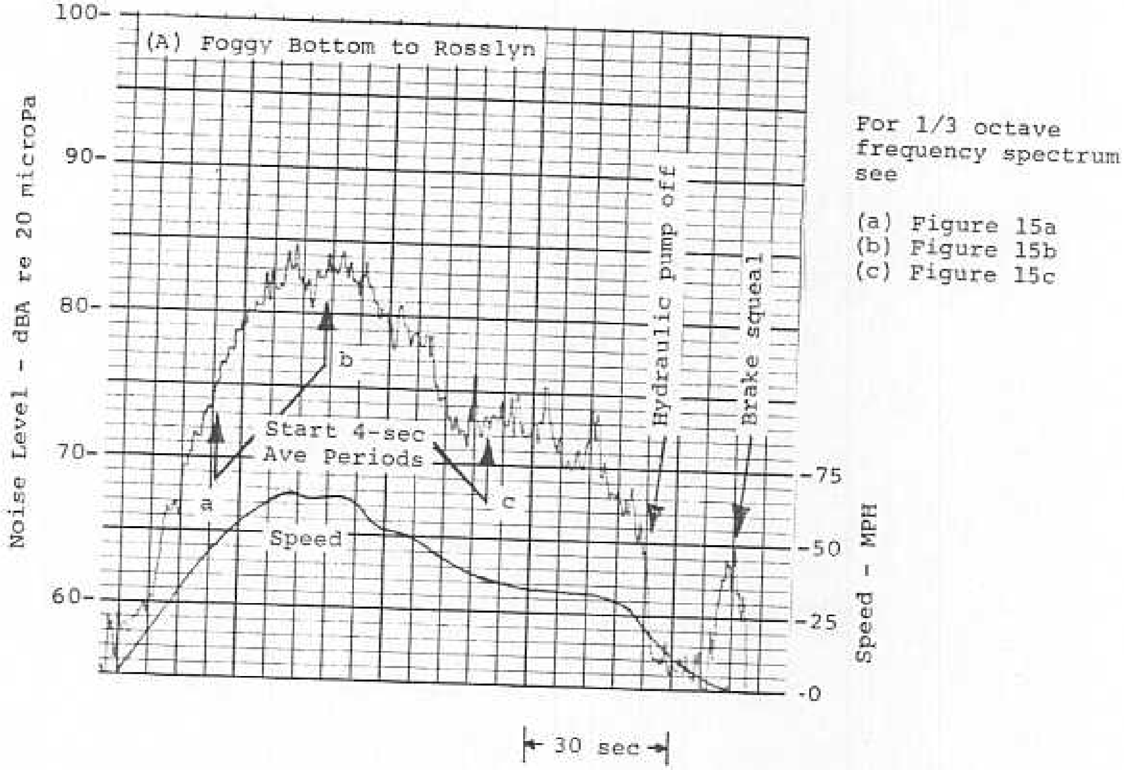


For 1/3 octave frequency spectrum see

(d) Figure 14d
(e) Figure 14e
(f) Figure 14f

Figure 7 In-Car Noise Level Time History
Passenger Seating Area Over Rear Wheel Trucks
WMATA - Huntington Route - June 20-21, 1981

Acoustic Run 1 - Before Rail Grinding Operations



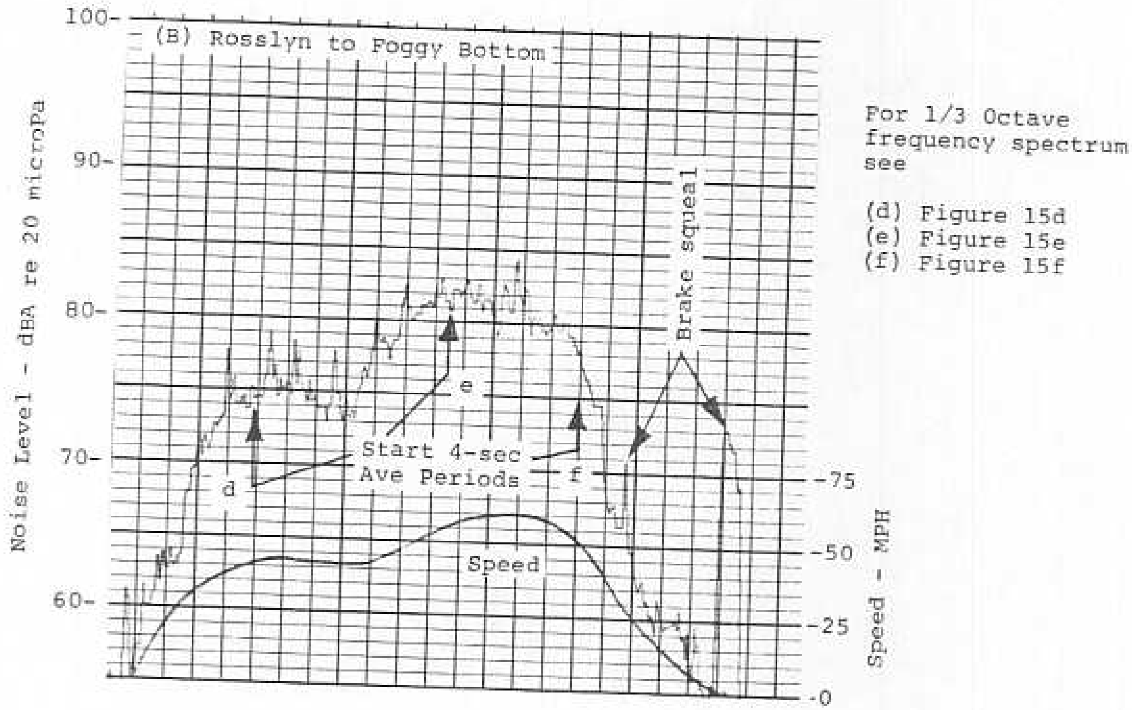
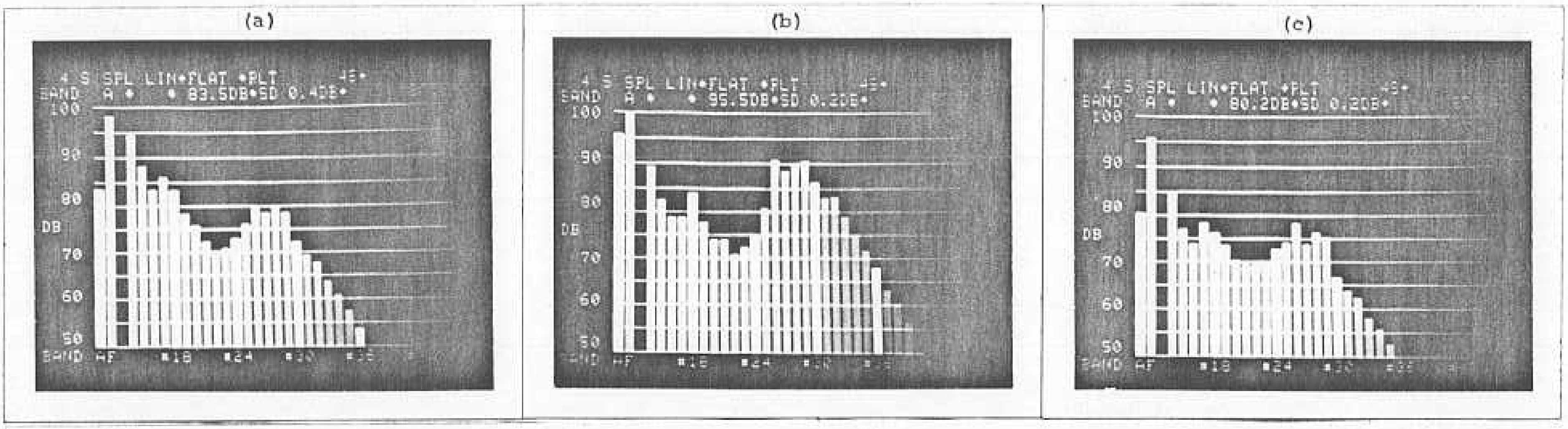


Figure 8 In-Car Noise Level Time History
Passenger Seating Area Over Rear Wheel Trucks
WMATA - Huntington Route - June 20-21, 1981
Acoustic Run 13 - After 3 Gauge Side And 4 Field Side Rail Grinding Operations

Foggy Bottom to Rosslyn →



Integration Period - 4 Seconds
See Figure 2 for Noise Level Time History
See Appendix A for Band Number conversion

← Rosslyn to Foggy Bottom

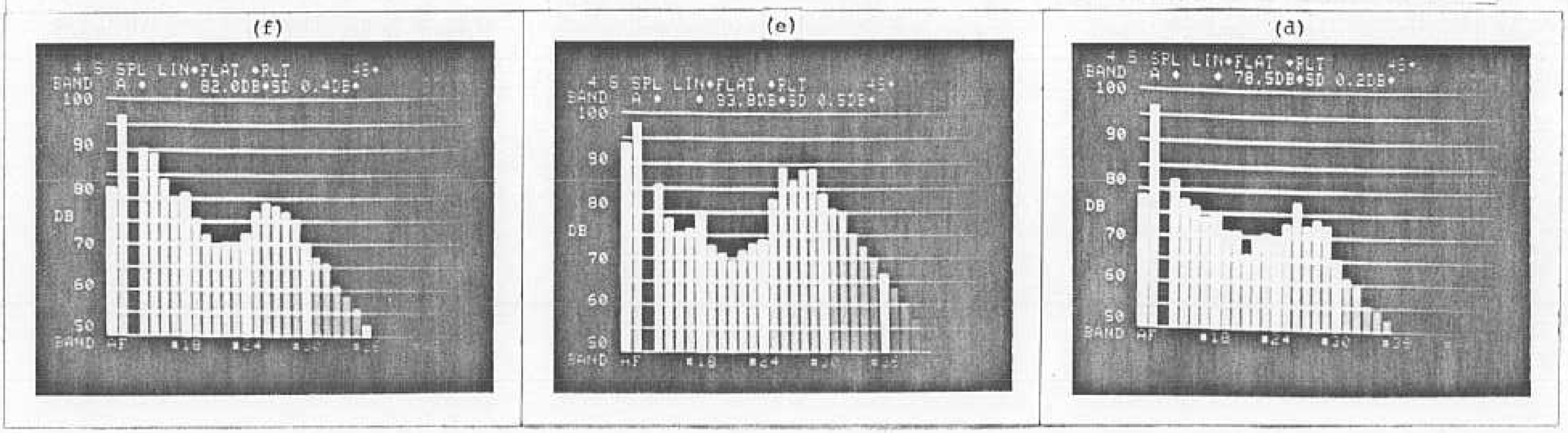
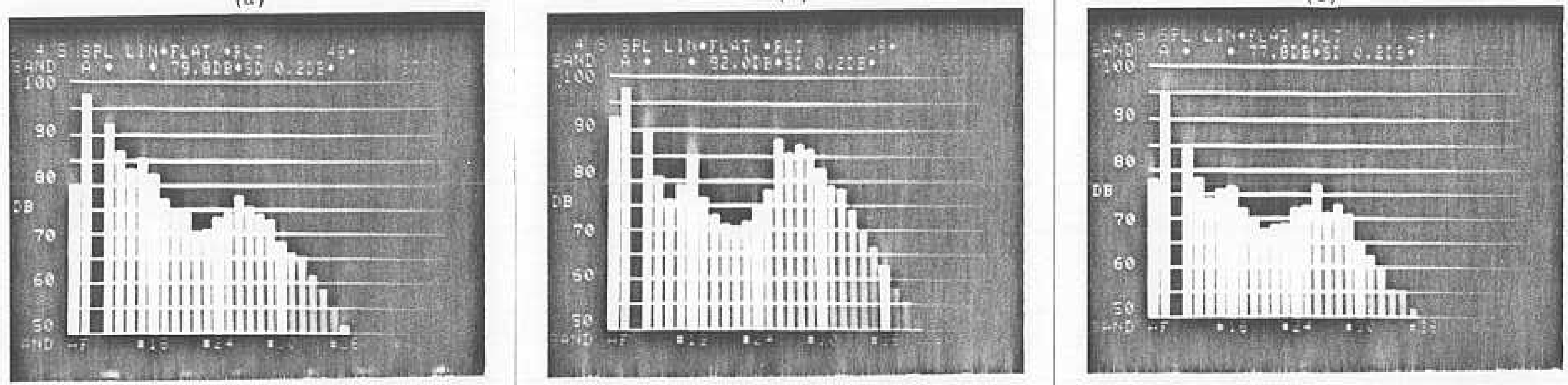


Figure 9. One-Third Octave Frequency Spectra
In-Car Noise Level Data - Over Front Wheel Trucks
WMATA - Huntington Route - June 20-21,1981

Acoustic Run 1 - Before Rail Grinding Operations

Foggy Bottom To Rosslyn →

(a) (b) (c)



Integration Period - 4 Seconds
See Figure 3 for Noise Level Time History
See Appendix A for Band Number conversion

← Rosslyn to Foggy Bottom

(f) (e) (d)

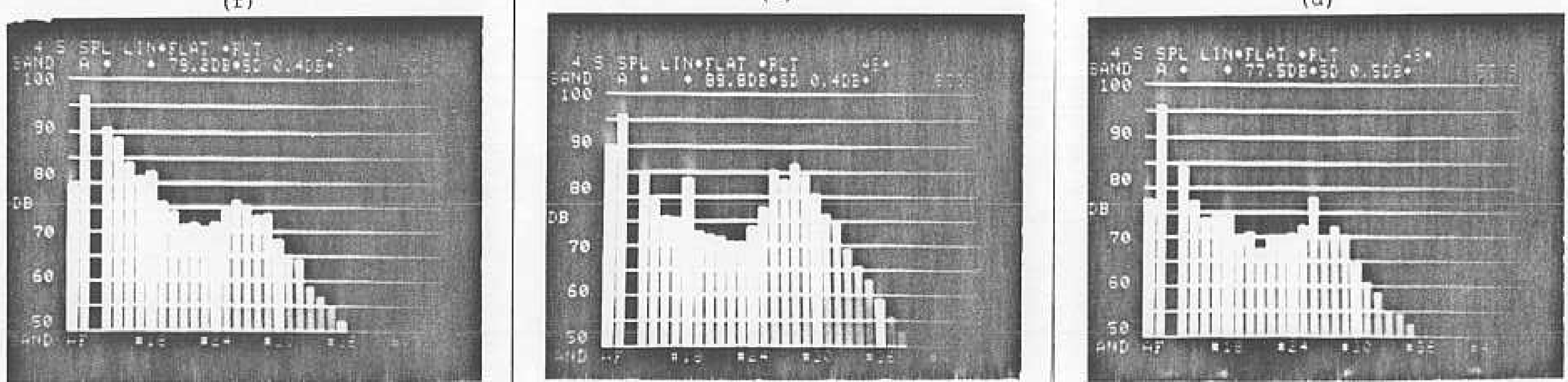
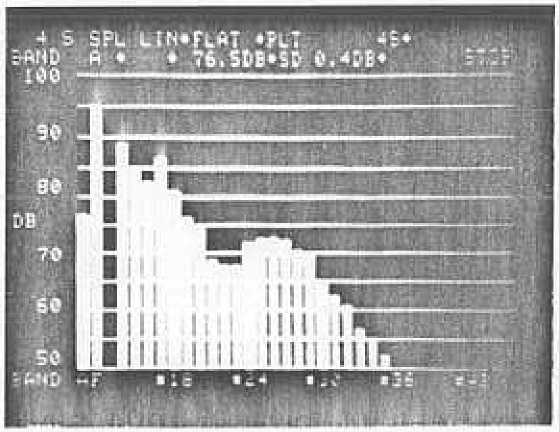


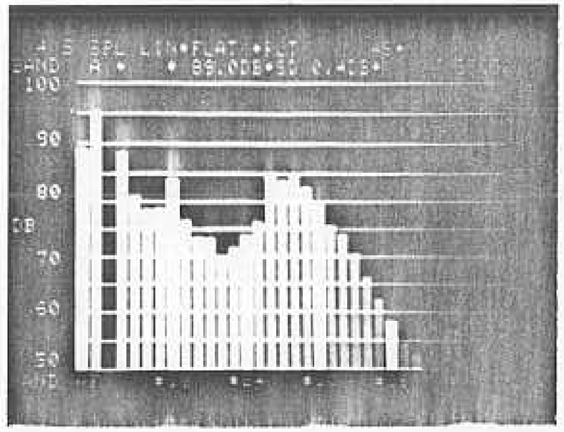
Figure 10. One-Third Octave Frequency Spectra
In-Car Noise Level Data - Over Front Wheel Trucks
WMATA - Huntington Route - June 20-21, 1981
Acoustic Run 6 - After 1 Gauge Side
Rail Grinding Operation

Foggy Bottom To Rosslyn →

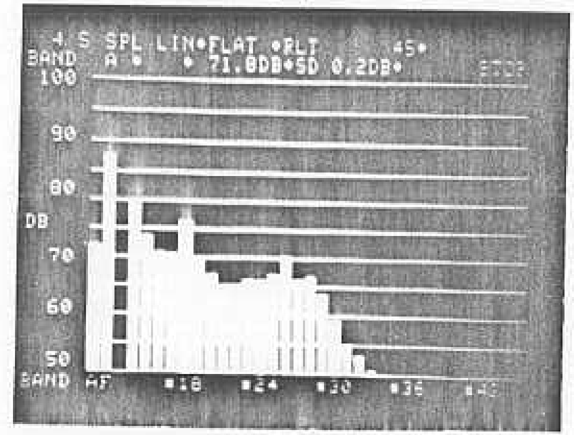
(a)



(b)



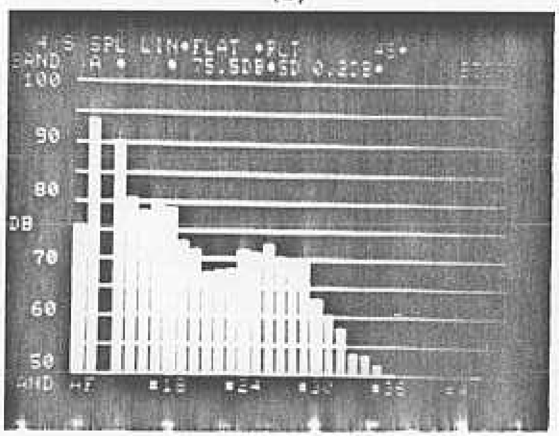
(c)



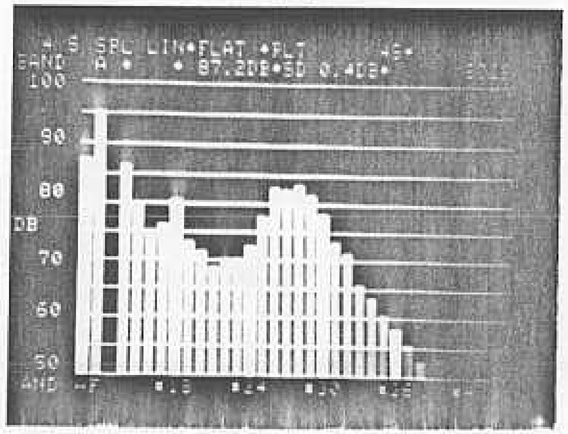
Integration Period - 4 Seconds
See Figure 4 for Noise Level Time History
See Appendix A for Band Number conversion

← Rosslyn To Foggy Bottom

(f)



(e)



(d)

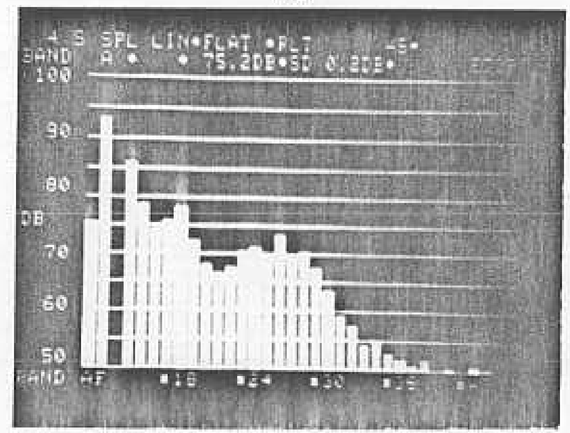
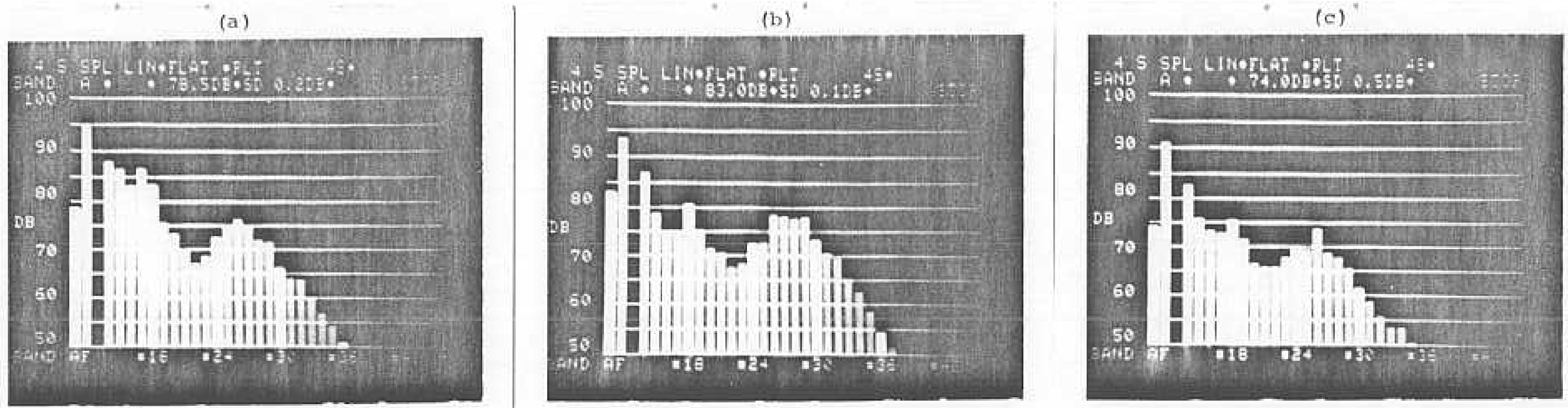


Figure 11. One-Third Octave Frequency Spectra
In-Car Noise Level Data - Over Front Wheel Trucks
WMATA - Huntington Route - June 20-21, 1981

Acoustic Run 9 - After 3 Gauge Side
Rail Grinding Operations

Foggy Bottom To Rosslyn →



Integration Period - 4 Seconds
See Figure 5 for Noise Level Time History
See Appendix A for Band Number conversion

← Rosslyn To Foggy Bottom

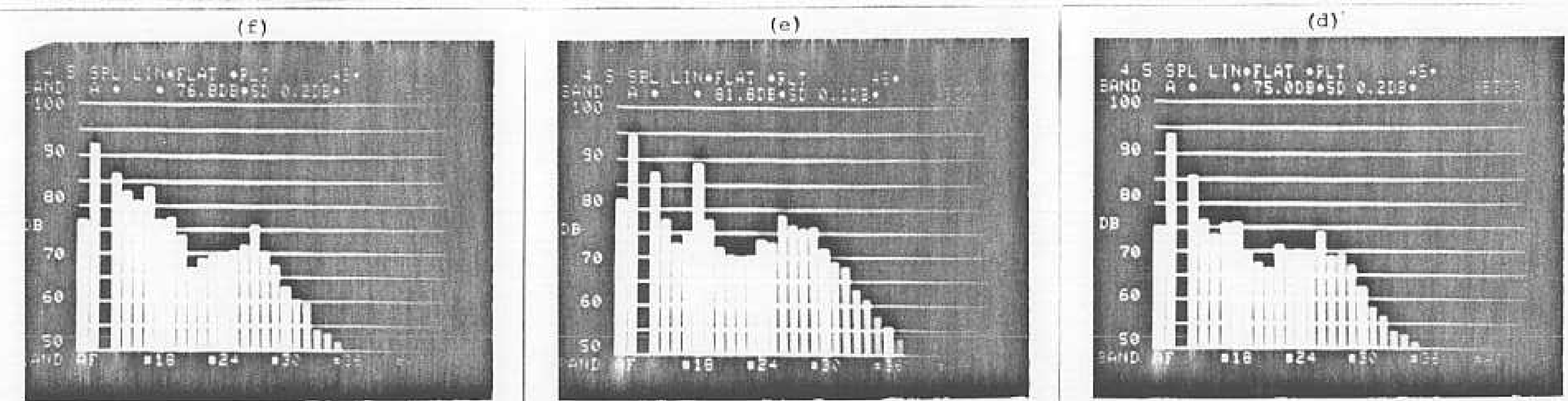
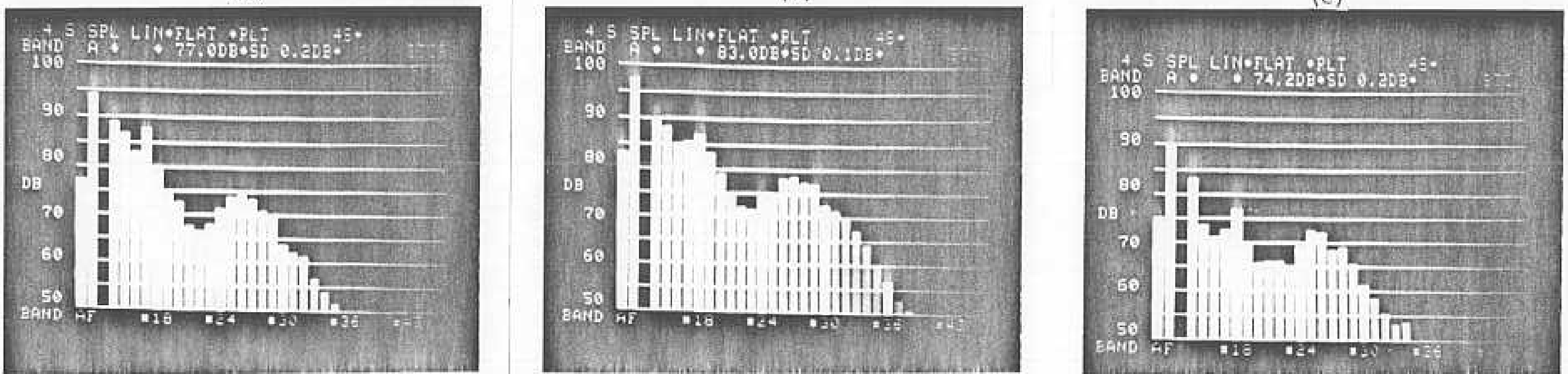


Figure 12. One-Third Octave Frequency Spectra
In-Car Noise Level Data - Over Front Wheel Trucks
WMATA - Huntington Route - June 20-21,1981

Acoustic Run 12 - After 3 Gauge Side And 2 Field Side Rail Grinding Operations

Foggy Bottom to Rosslyn ⟶

(a) (b) (c)



Integration Period - 4 Seconds
See Figure 6 for Noise Level Time History
See Appendix A for Band Number conversion

⟵ Rosslyn to Foggy Bottom

(f) (e) (d)

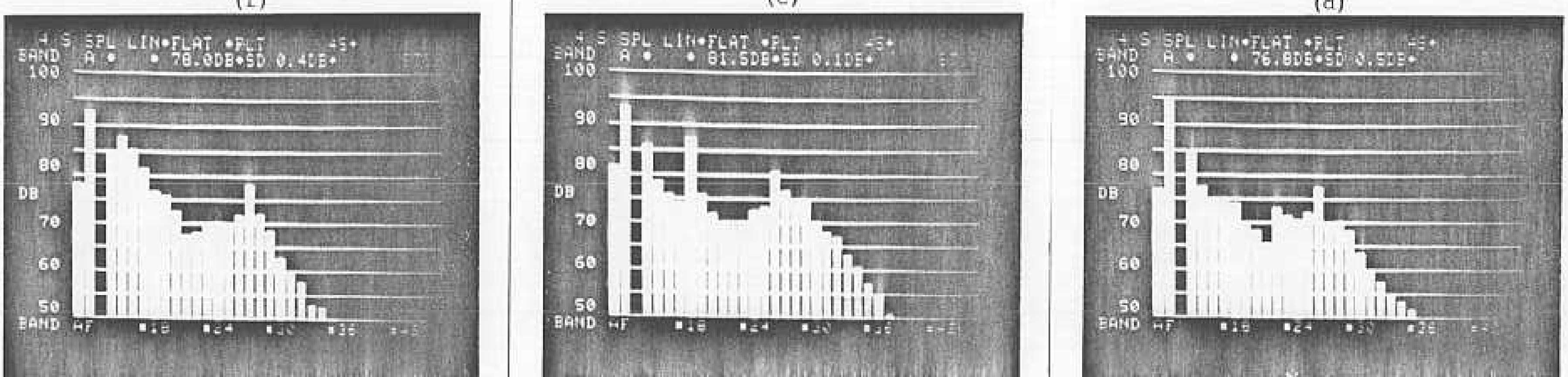
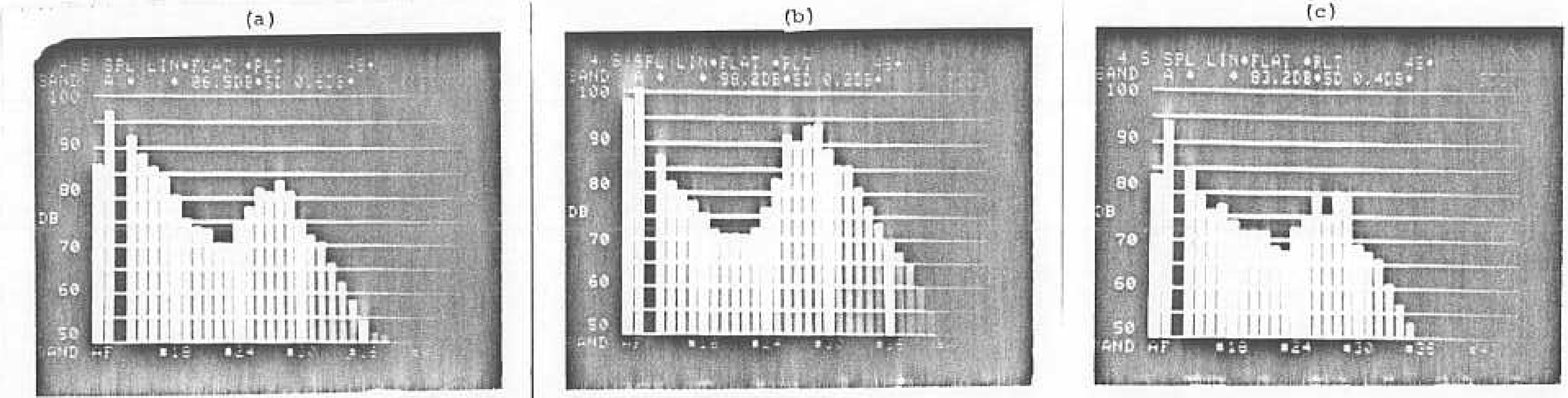


Figure 13. One-Third Octave Frequency Spectra
In-Car Noise Level Data - Over Front Wheel Trucks
WMATA - Huntington Route - June 20-21,1981

Acoustic Run 13 - After 3 Gauge Side And 4 Field Side
Rail Grinding Operations

Foggy Bottom To Rosslyn →



Integration Period - 4 Seconds
See Figure 7 for Noise Level Time History
See Appendix A for Band Number conversion

← Rosslyn To Foggy Bottom

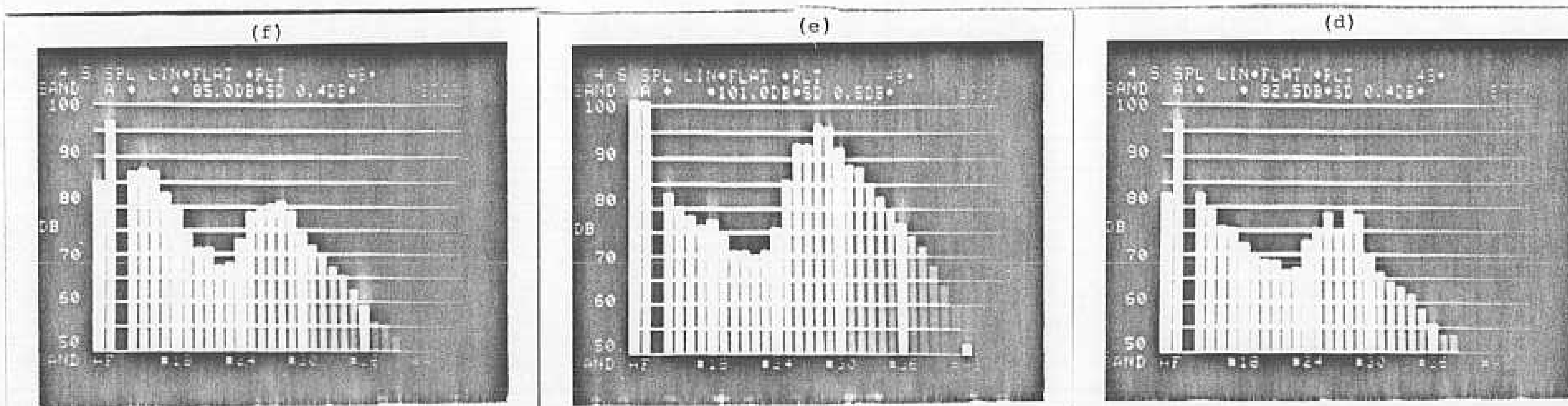
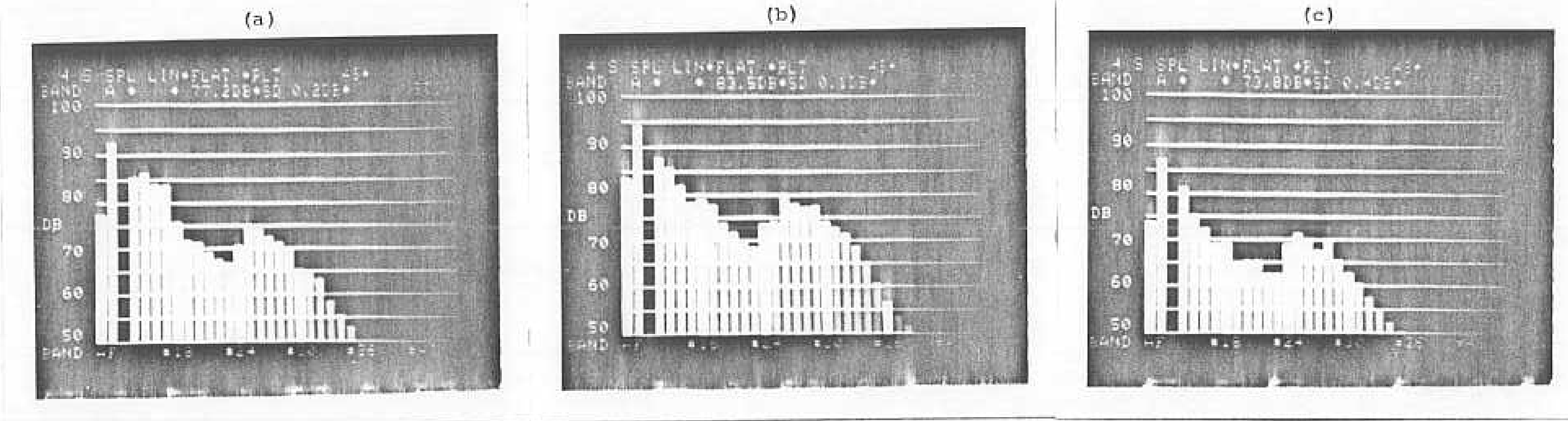


Figure 14. One-Third Octave Frequency Spectra
In-Car Noise Level Data - Over Rear Wheel Trucks
WMATA - Huntington Route - June 20-21, 1981

Acoustic Run 1 - Before Rail Grinding Operations

Foggy Bottom To Rosslyn →



Integration Period - 4 Seconds
See Figure 8 for Noise Level Time History
See Appendix A for Band Number conversion

← Rosslyn to Foggy Bottom

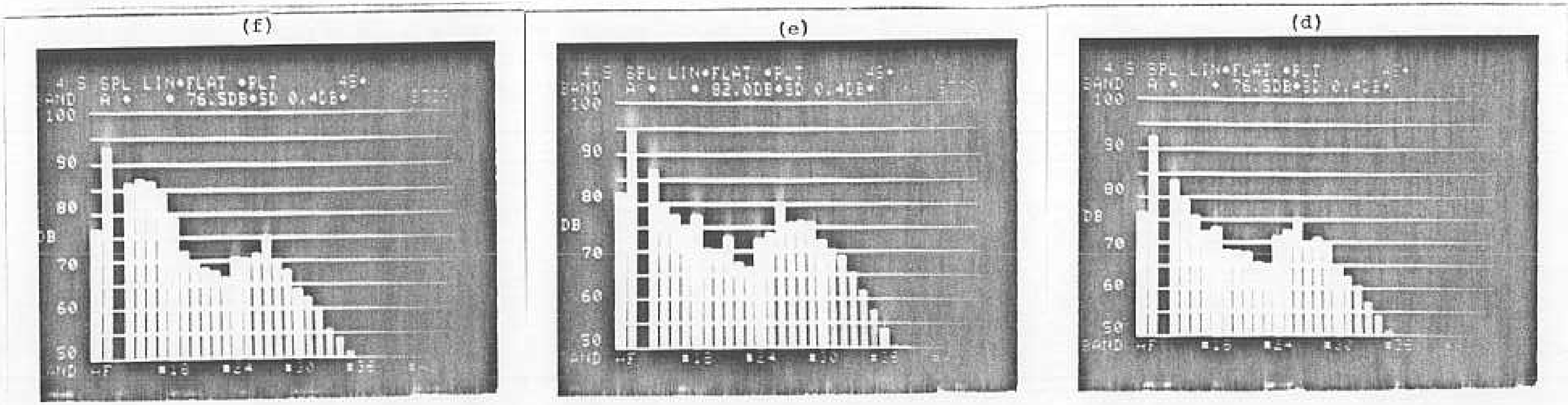


Figure 15. One-Third Octave Frequency Spectra
In-Car Noise Level Data - Over Rear Wheel Trucks
WMATA - Huntington Route - June 20-21, 1981

Acoustic Run 13 - After 3 Gauge Side And 4 Field Side Rail Grinding Operations

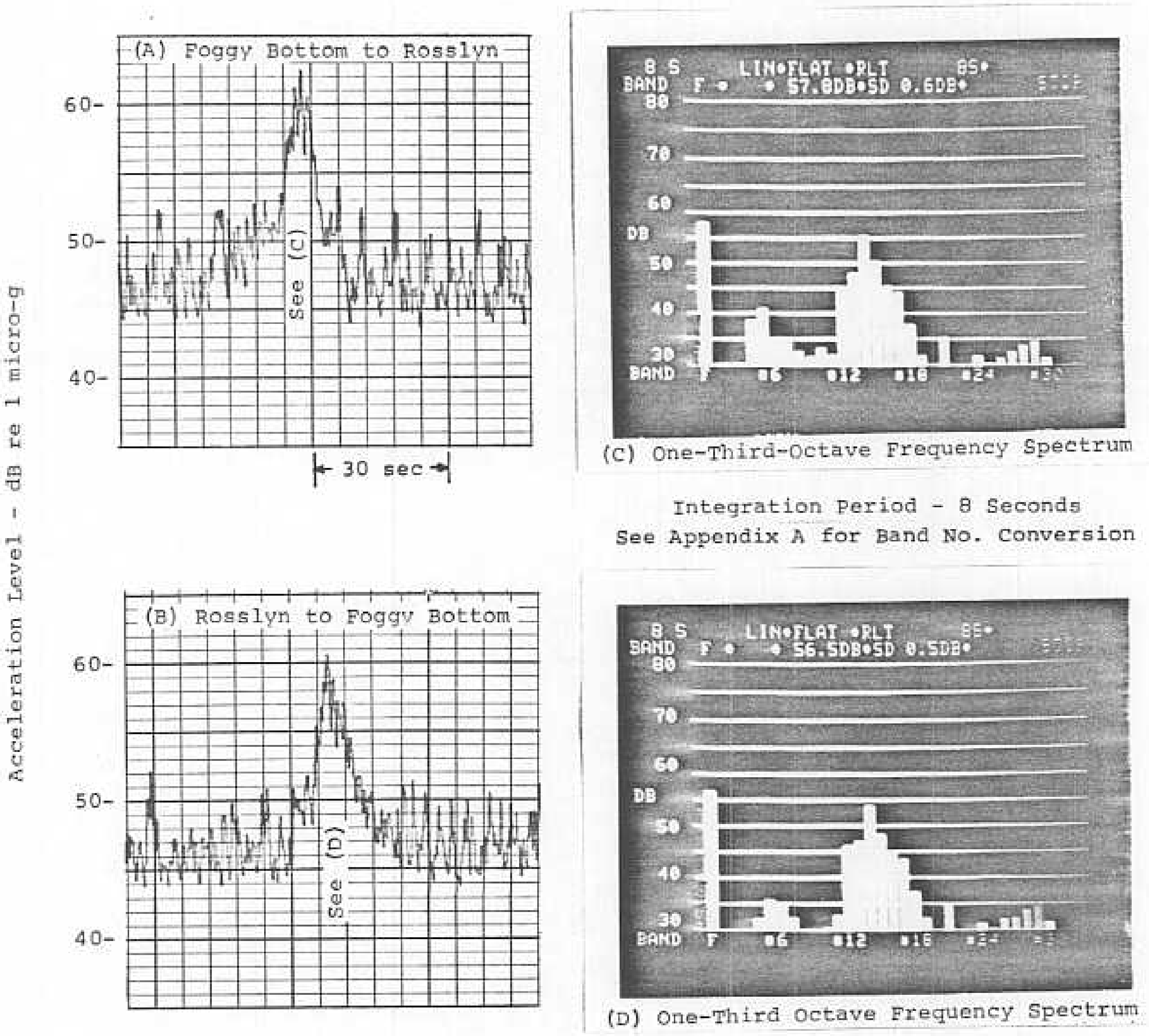


Figure 16 Ground-borne Vibration Data
Residential Area - 2426 NW I Street
WMATA - Huntington Route - June 20-21,1981
Acoustic Run 1 - Before Rail Grinding Operations

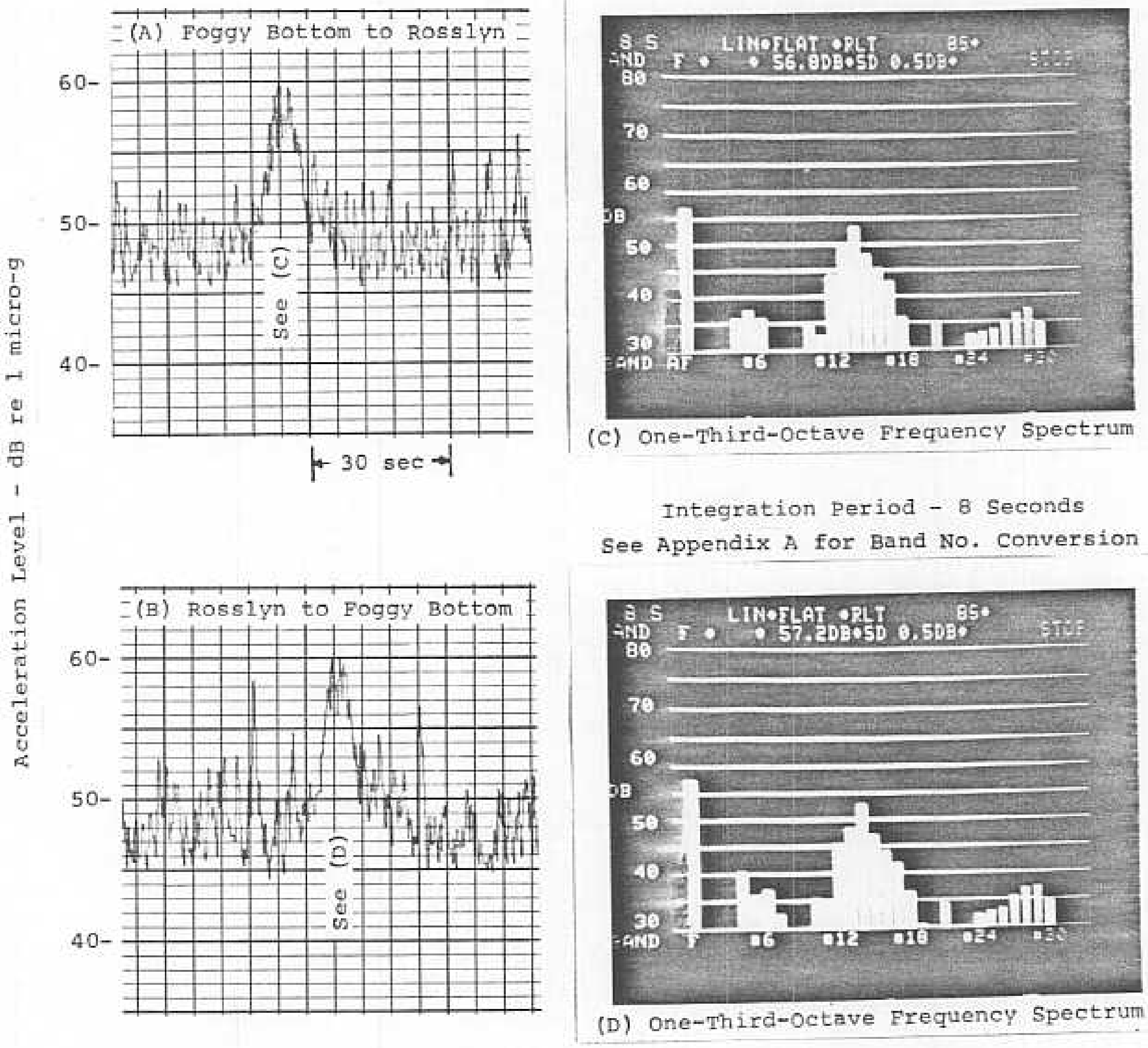
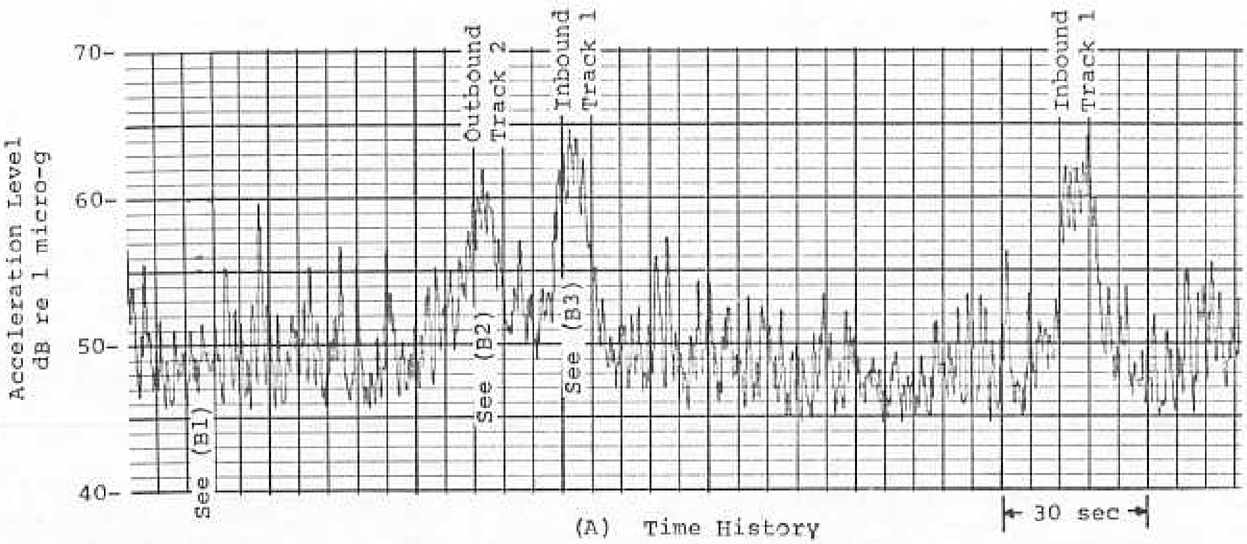
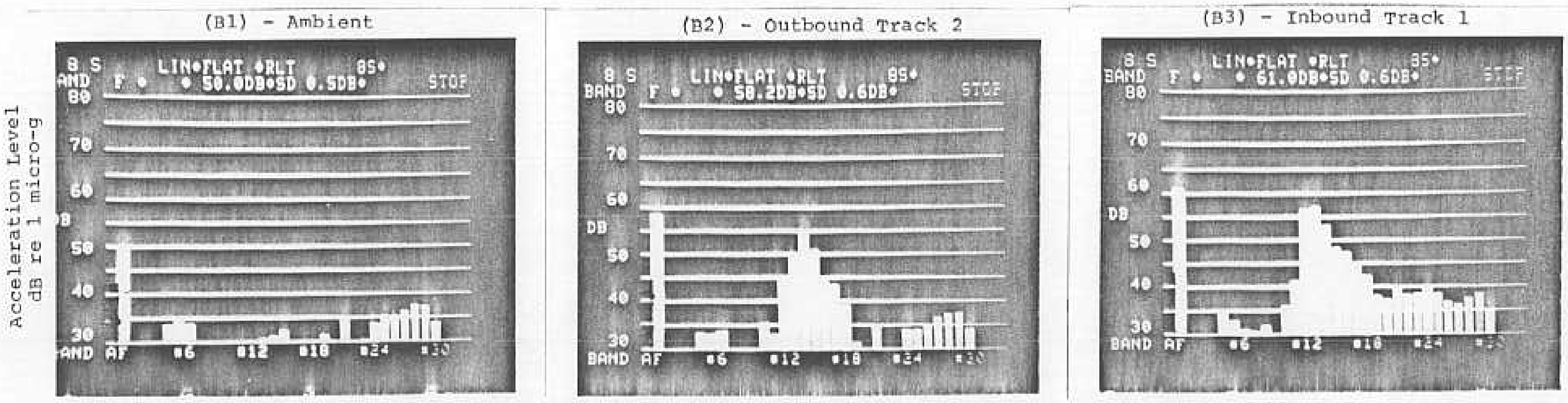


Figure 17 Ground-borne Vibration Data
Residential Area - 2426 NW I Street
WMATA - Huntington Route - June 20-21, 1981

Acoustic Run 13 - After 3 Gauge Side And 4 Field Side Rail Grinding Operations



(A) Time History



(B) One-Third-Octave Frequency Spectra - Integration Period-8 Seconds

See Appendix A for Band No. Conversion

Figure 18 Ground-borne Vibration Data
Residential Area - 2426 NW I Street
WMATA - Huntington Route - June 19,1981
Revenue Trains - Before Rail Grinding Operations

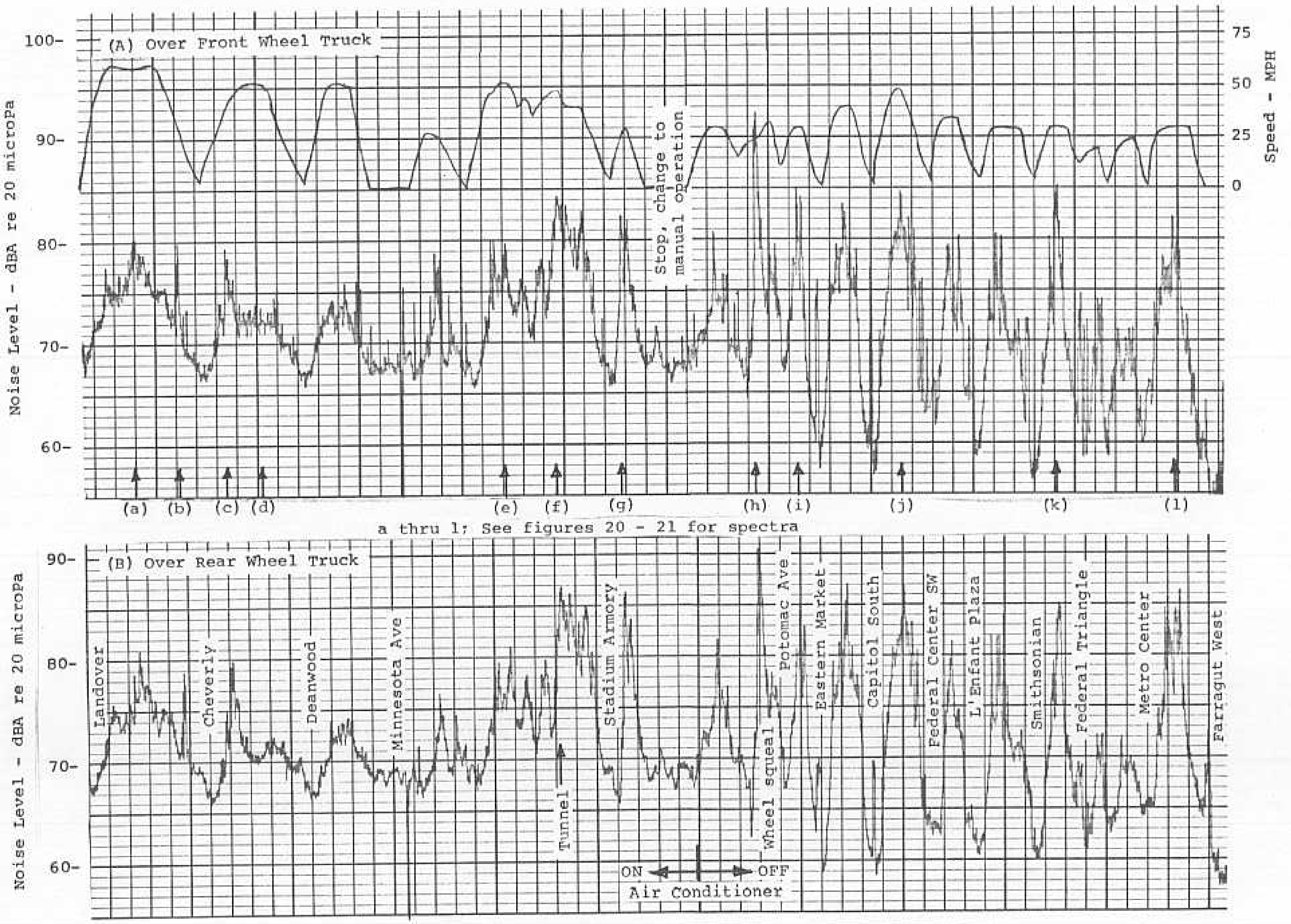
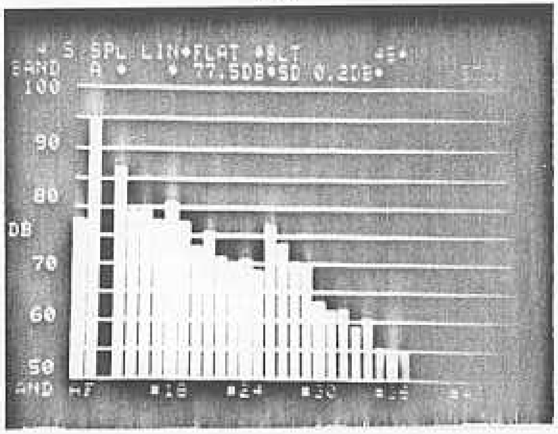
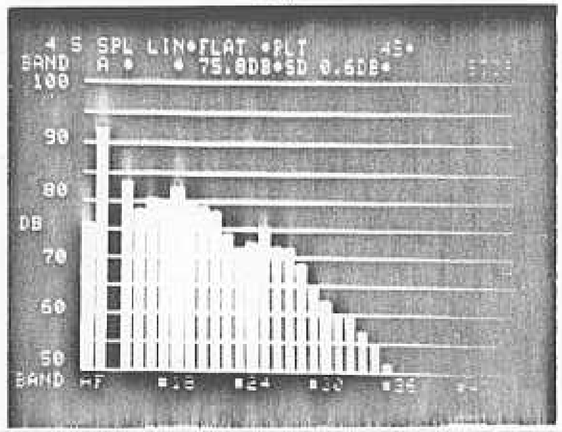


Figure 19 In-Car Noise Level Time History
Simulated Revenue Run - Landover to Farragut West
WMATA - Huntington Route - June 21, 1981

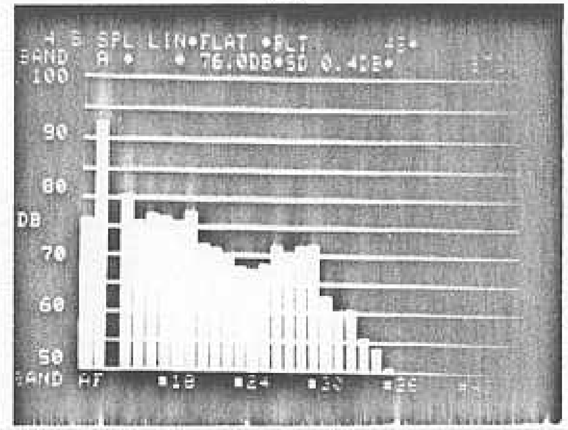
(a)



(b)

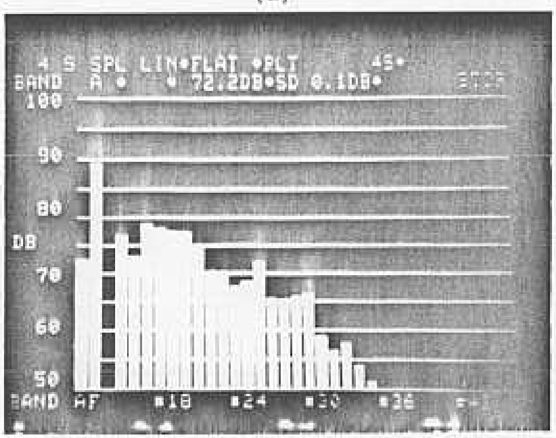


(c)

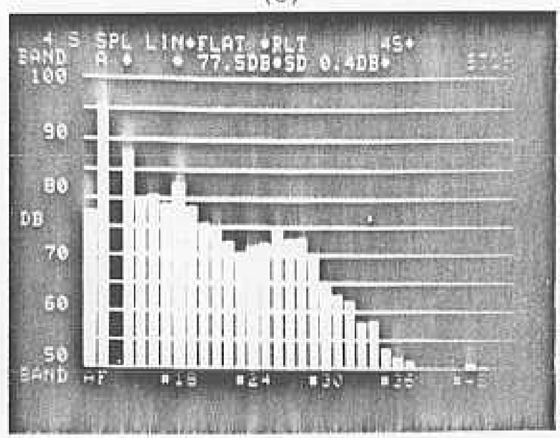


See Appendix A for Band No. Conversion

(d)



(e)



(f)

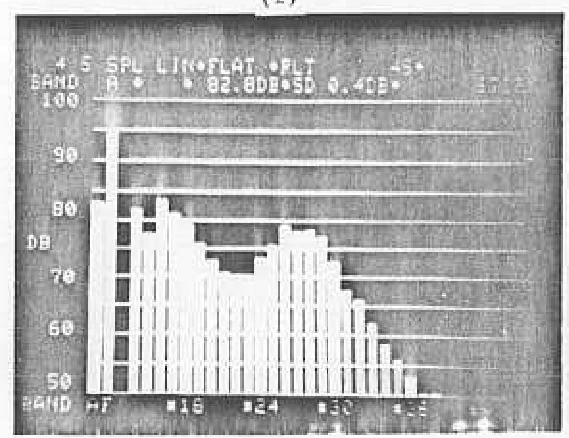
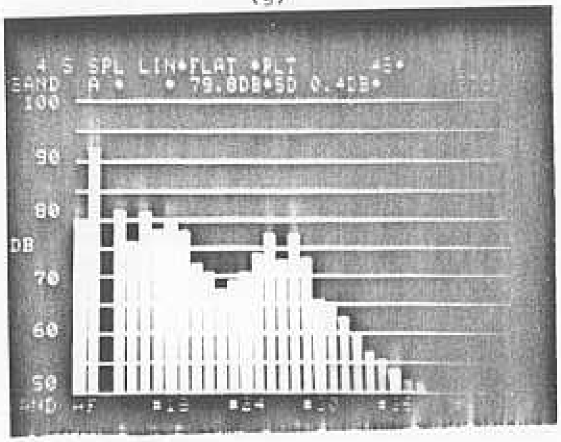


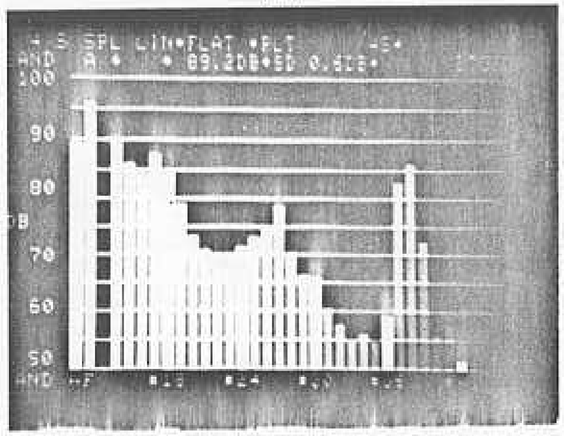
Figure 20 One-Third Octave Frequency Spectra
In-Car Noise Level Data - Over Front Wheel Trucks
WMATA - Huntington Route - June 21,1981
Simulated Revenue Run

(a - f) See Figure 19 for Track Location

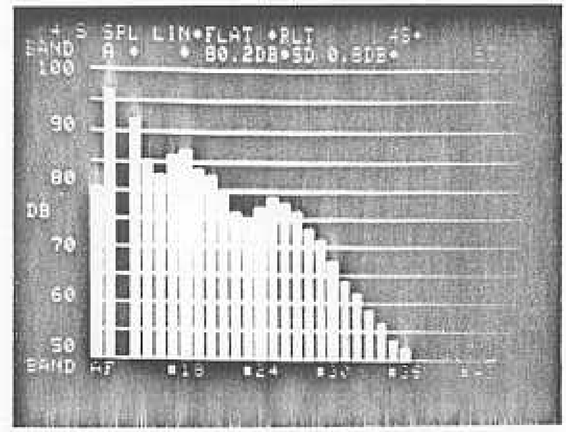
(g)



(h)

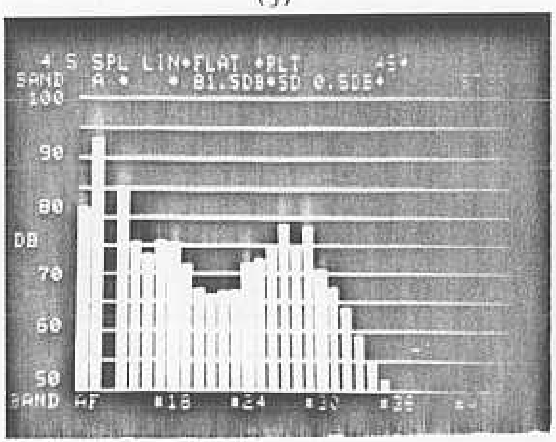


(i)

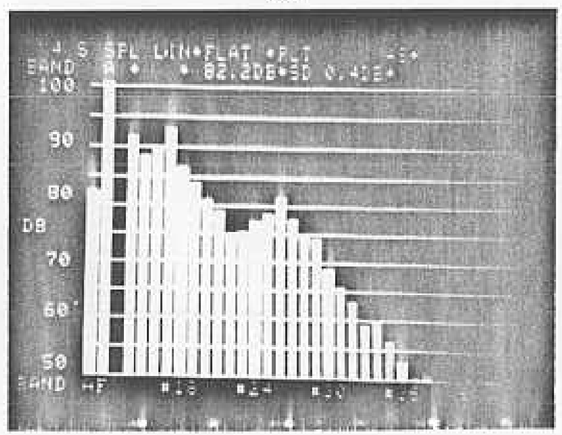


See Appendix A for Band No. Conversion

(j)



(k)



(l)

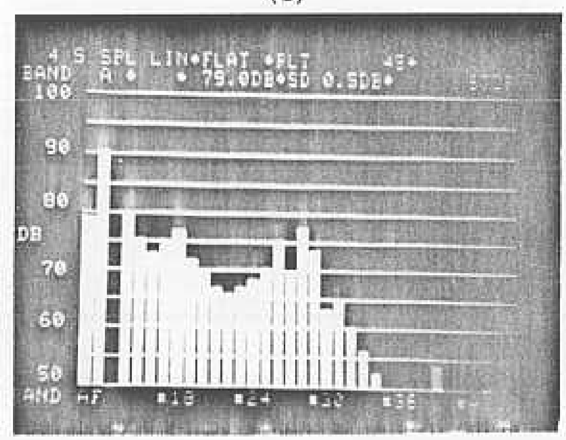


Figure 21 One-Third Octave Frequency Spectra
In-Car Noise Level Data - Over Front Wheel Trucks
WMATA - Huntington Route - June 21,1981
Simulated Revenue Run

(g - l) See Figure 19 for Track Location

APPENDIX A

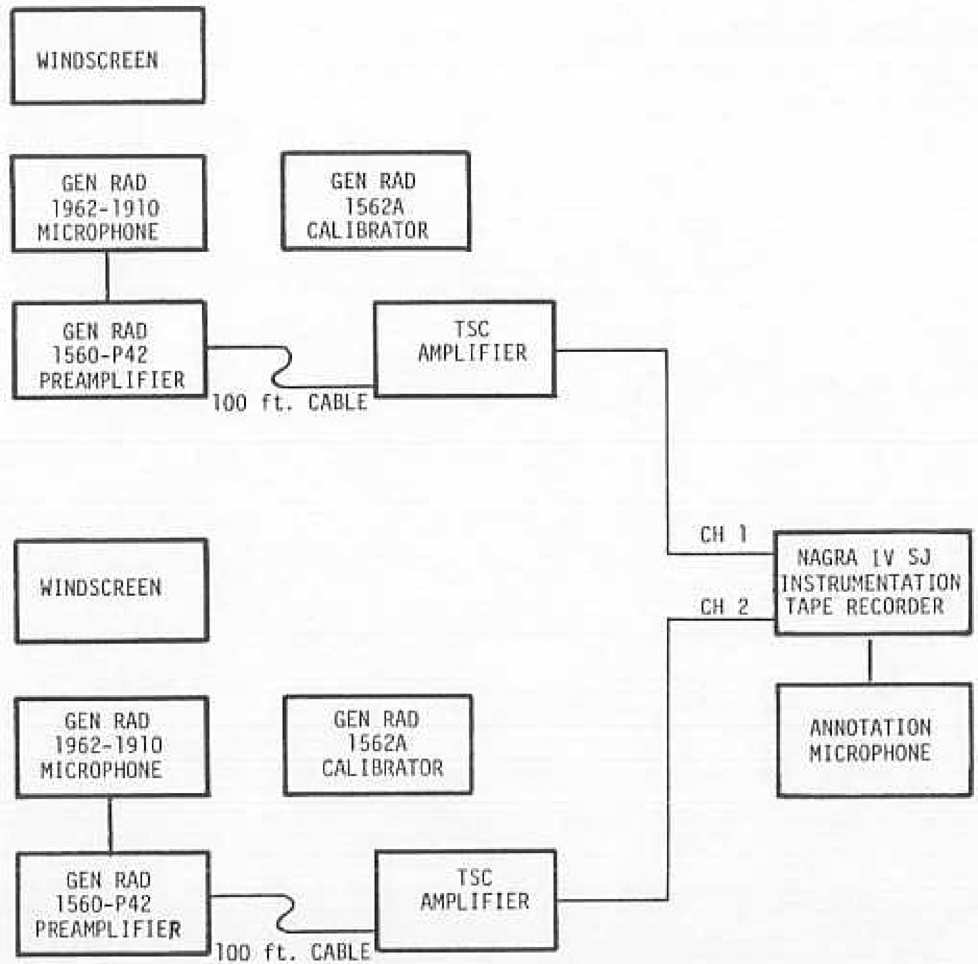


FIGURE A1. 2-CHANNEL ACOUSTIC MEASUREMENT SYSTEM

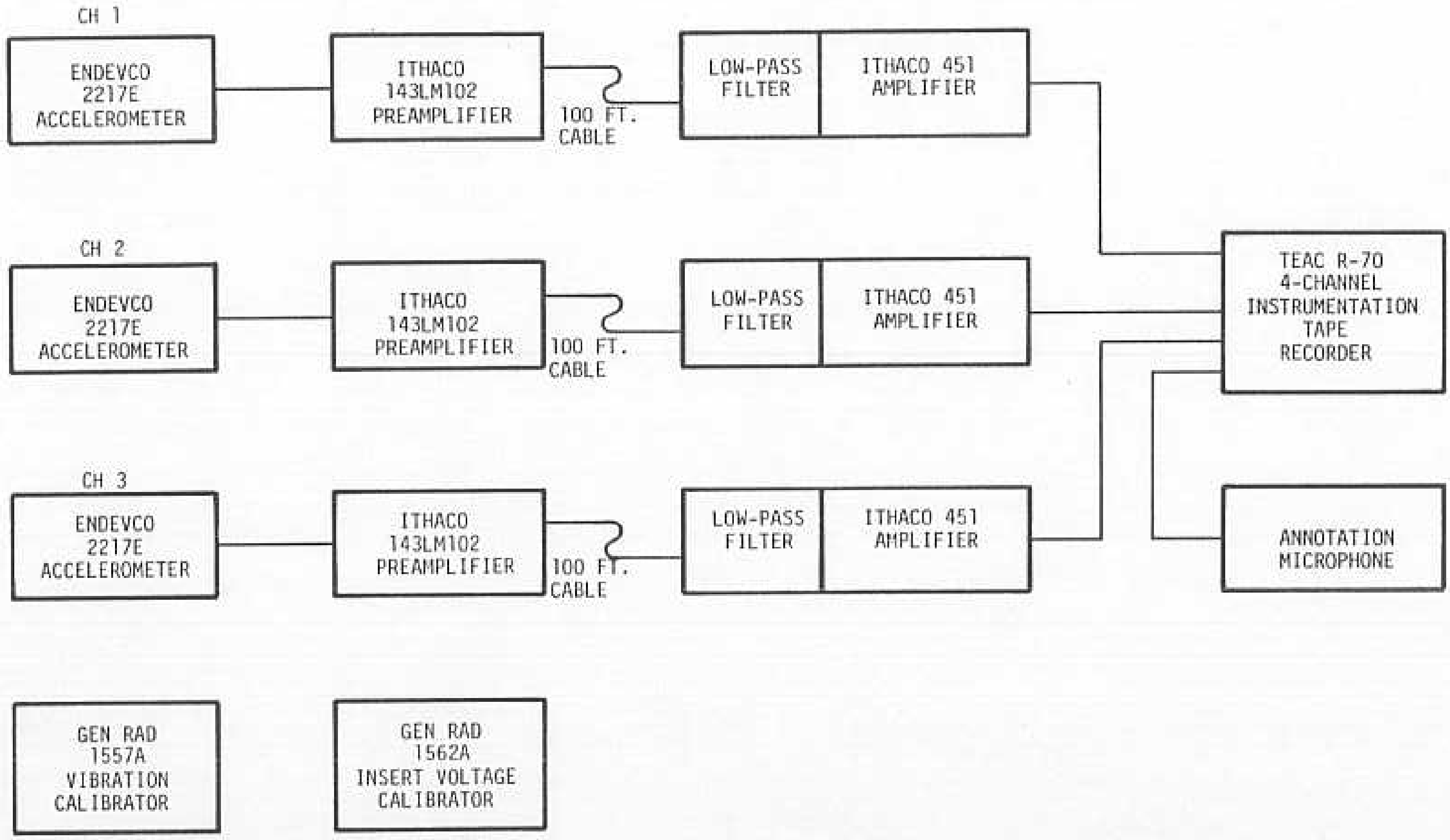


FIGURE A2. 3-CHANNEL VIBRATION MEASUREMENT SYSTEM

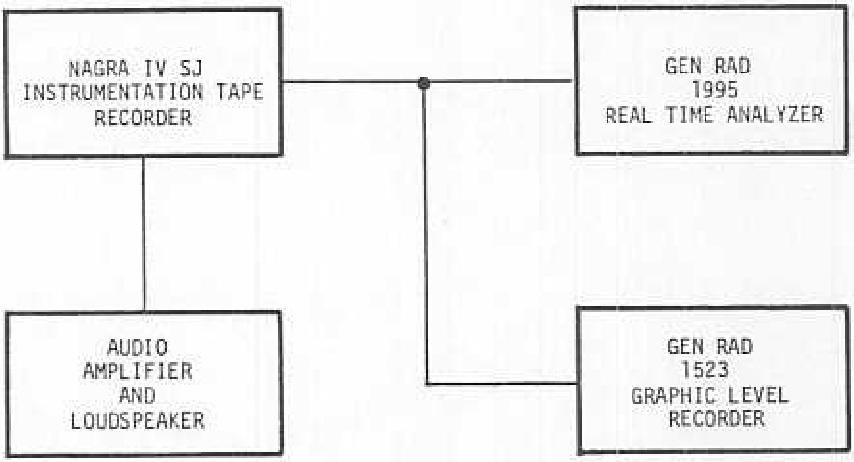


FIGURE A3. ACOUSTIC ANALYSIS SYSTEM

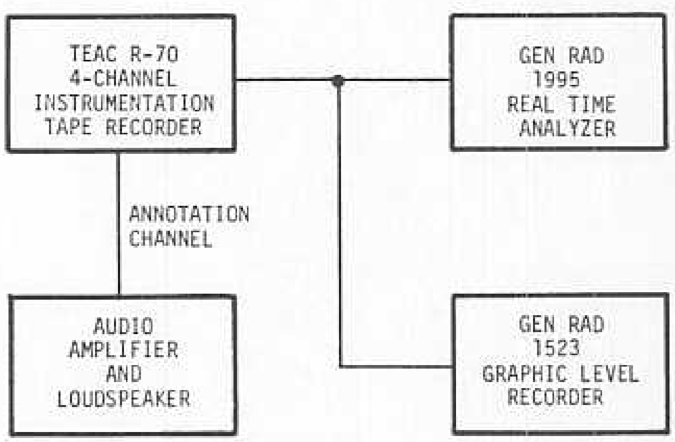


FIGURE A4. VIBRATION ANALYSIS SYSTEM

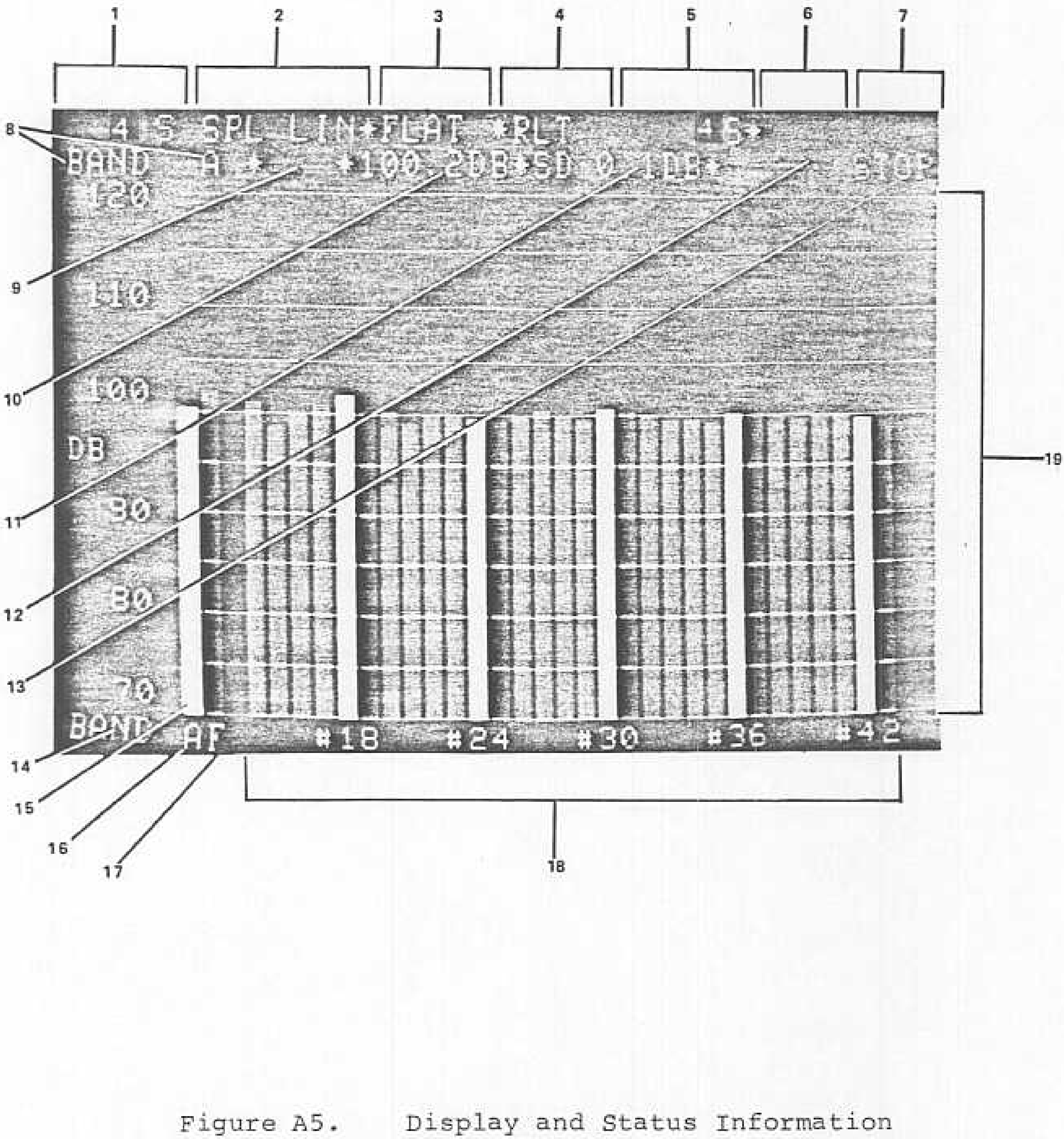


Figure A5. Display and Status Information
See Table A1

Table A1

DISPLAY AND STATUS INFORMATION

Fig. A5 Ref.	Description	Specific Fig. A5 Reading
1	Integration time	4S
2	Integration mode	SPL LIN
3	Frequency response	FLAT
4	Spectrum status	RLT
5	Elapsed time	4S
6	OVLD (overload indication)	–
7	BATT (low-battery indication)	–
8	Band selected by cursor when in level/freq mode	BAND A
9	Period selected by cursor when in level/time mode	–
10	Level of band occupied by cursor	100.2DB
11	Standard deviation of band occupied by cursor	SD 0.1DB
12	NOTE 1 through NOTE 8 (special notes flagged)	–
13	Operating status	STOP
14	"BAND" in level/freq mode or "PERIOD" in level/time mode	BAND
15	Intensified bar indicating cursor position	BAND A
16	Bar graph representing A-preweighted results when in level/freq mode	A
17	Bar graph representing flat-response results when in level/freq mode	F
18	Band identities of bar graphs when in level/freq mode, or period identities of bar graphs when in level/time mode	BANDS 14 through 43
19	Displayed 50-dB range, determined by preselected FULL SCALE-dB pushbutton	70 to 120 dB

BAND NUMBER VERSUS 1/3-OCTAVE CENTER FREQUENCIES

(Low-Frequency Option)

Band Number	Center Frequency (Hz)	Band Number	Center Frequency (Hz)	Band Number	Center Frequency (Hz)	Band Number	Center Frequency (kHz)
4	2.5	14	25	*24	250	34	2.5
5	3.15	*15	31.5	25	315	35	3.15
*6	4	16	40	26	400	*36	4
7	5	17	50	*27	500	37	5
8	6.3	*18	63	28	630	38	6.3
*9	8	19	80	29	800	*39	8
10	10	20	100	*30	1000	40	10
11	12.5	*21	125	31	1250	41	12.5
*12	16	22	160	32	1600	*42	16
13	20	23	200	*33	2000	43	20

* Denotes full-octave band and center frequency.