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WAYSIDE NOISE AND VIBRATION SIGNATURES OF HIGH-SPEED TRAINS IN THE NORTHEAST CORRIDOR

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16. Abstract

Measurements were made of the wayside noise and ground vibration levels generated during the passby of high-speed Metroliner and Turbotrains operating on the tracks of the Penn Central Railroad. The Metroliner in operation on the New York-to-Washington line was measured in Plainsboro, New Jersey. The Turbotrain in operation on the Boston-to-New York line was measured in West Mansfield, MA. In addition, freight trains and conventional passenger trains were measured and recorded.

This report contains tabulations of the passby noise and vibration levels measured, time history level recordings and 1/3-octave frequency analyses of representative passby data. Pertinent comments on information obtained are included.

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PREFACE

This report documents the results of wayside noise and vibration level measurements made on the high-speed "Metroliner", built by the Budd Company, and on the high-speed "Turbotrain," built by United Aircraft.

The Metroliner which is in daily revenue service between New York and Washington DC was measured along the tracks of the Penn Central Railroad (PCRR) in Plainsboro, New Jersey.

The Turbotrain in daily revenue service between Boston and New York was measured along the tracks of the Penn Central Railroad in West Mansfield, Massachusetts.

Other than the primary authors, Messrs. S.C. Skeiber and F.M. Sears of the Noise Assessment Group, Transportation Systems Center, contributed to the preparation of this report.

CONTENTS

CONTENTS (CONT.)

ILLUSTRATIONS

ILLUSTRATIONS (CONT.)

ILLUSTRATIONS (CONT.)

ILLUSTRATIONS (CONT.)

ILLUSTRATIONS (CONT.)

ILLUSTRATIONS (CONT.)

TABLES

1. INTRODUCTION

The U. S. Department of Transportation, Transportation Systems Center (TSC), Cambridge, MA, measured the wayside noise and vibration levels generated by the high-speed Metroliner and Turbotrains operating on the tracks of the Penn Central Railroad (PCRR) between New York and Washington, DC and between Boston and New-York, respectively.

Four and six-car self-propelled Metroliner trains traveling at speeds up to 110 miles per hour were measured on May 23, 1972 at a location in Plainsboro NJ 2600 feet north of mile post No. 46. The PCRR line in this location is part of a 21-mile section of track which was specifically upgraded for high-speed operation and includes welded rail construction. The trains obtained power through a pantograph from the overhead catenary system.

Turbotrain No. I consisting of two power dome cars (engines) and one coach was measured on November 4, 1971. Turbotrain No. II consisting of two power dome cars and three coaches was measured on September 20 and 26, 1972. The measurements were made at a site in West Mansfield, MA, 1310 feet east of mile post No. 201, where the Turbotrain operates at high speed. The PCRR line in this location consists of two tracks with standard non-welded jointed rails. The Turbotrain, powered by gas turbine engines, traveled at speeds up to 106 miles per hour in this area.

In addition freight trains and conventional passenger trains which passed during the test periods were also measured and recorded.

Time history chart recordings were prepared for each microphone output (Noise Level-dBA re 20 $\mu N/m^2$ vs time) and for the three vibration axes (RMS AccelerationLevel-dB re 10^{-6} g vs time). Specific representative events were selected for 1/3-octave spectral analysis. The frequency analysis performed is on a time coincident period during the passby of the selected event for the noise data measured at all three microphone locations and for each axis of the triaxial vibration data. Synchronization of noise and vibration data was possible through the use of a time code signal which was recorded on the fourth channel of each recorder. This time code was used to automatically start the analysis equipment at the proper instant.

Appendixes A, B, C, and D contain the time histories and 1/3-octave frequency spectra of selected events for each microphone and accelerometer output. The periods selected for frequency analysis are marked on the time history.

Appendixes E, F, G, H and I contain: (E) photographs of the measurement sites and relative locations of the microphone and vibration transducers; (F) procedure used in obtaining and reducing data; (G) descriptions and photographs of the Metroliner and Turbotrains; (H) environmental data for each measurement day; and (I) definition of terms.

2. DISCUSSION

2.1 MEASUREMENTS ON METROLINER AND CONVENTIONAL PASSENGER AND FREIGHT TRAINS-PCRR, NEW YORK-TO-WASHINGTON LINE, PLAINSBORO, NEW JERSEY. MAY 23, 1972

Wayside noise and ground vibration measurements were made next to the tracks of the PCRR, New York-to-Washington Line in Plainsboro, New Jersey, 2600 feet north of mile post No. 46, on May 23, 1972. Trains traveled at high speed in this area on welded rails.

Microphones were set up at offset distances of 25, 50, and 100 feet from the centerline of southbound track No. 2 (measurement stations 1, 2, and 3, respectively) and were placed 5.5 feet above grade level and 3.3 feet above the level of the rails of track No. 2 (see diagram figure E-1 and photograph figures E-2 through E-7). The PCRR line at this location consists of four tracks numbered 1 through 4, west to east. The centerline of track No. 3 (northbound) was 38, 63, and 113 feet; and of track No. 4 was 50, 75, and 125 feet, respectively, from the three microphone stations. The noise data were recorded on a four-channel instrumentation tape recorder operated in the direct mode. A time code signal was recorded on the fourth channel. See Table H-1 for environmental data.

Appendix A contains passby time histories and 1/3-octave frequency spectra of the wayside noise levels of selected representative events, which were measured at the three microphone stations.

Wayside ground vibration measurements were made utilizing an insulated triaxial arrangement of vibration transducers mounted on two brass rods (2 feet long and 7/8 inches in diameter). The rods were driven into the ground at a point offset 25 and 50 feet from the centerline of track 2 (measurement stations 1 and 2). The three-axis acceleration data (z-axis vertical motion, x-axis longitudinal motion, y-axis lateral motion) from station 1 were recorded on three of the available four channels of the FM instrumentation tape recorder. The data outputs from station 2 were time-shared on the fourth channel with a time code signal, one axis at a time for several passby events. The time code signal was used for synchronizing the vibration data and the noise data which were simultaneously measured and recorded on a separate four-channel tape recorder.

The vibration rods used were left in the ground at the conclusion of the test for any future measurements.

Appendix B contains time histories and 1/3-octave frequency spectra of the ground vibration levels measured of selected representative events. The same events selected and analyzed for their noise level characteristics in Appendix A are presented in Appendix B.

2.1.1 Metroliner Trains

Measurements were made on four- and six-car Metroliner trains which traveled southbound on track No. 2 and northbound on Track Nos. 3 and 4. Power for the electric traction motors was obtained from the overhead catenary system through a pantograph.

Figure A-1 contains wayside noise level time histories of the passby of a 4-car Metroliner traveling southbound at a speed of 106 mph, on track 2. An examination of figure A-1a, noise data from measurement station 1, shows five individual noise peaks superimposed on the familiar flat-topped bell-shaped history one would expect to obtain from a moving uniform line source of uncorrelated noise. At measurement stations 2 and 3, figures A-1b and A-1c, these distinctive peaks are less obvious and the flat top of the bell shape is more pronounced. At station 1 the noise level history measured seems to be a composite of the noise contribution from each individual noise source in the train (more or less a uniform line source) and the "wheel roar" resulting from wheel-rail interactions. Because the relative level of noise when the sets of wheel trucks are in close proximity to the microphone is greater than the composite noise from the overall train, individual point source noise peaks are generated during their passby. The first and last peaks of figure A-1a were generated during the passby of the front wheel trucks of the first car and the rear wheel trucks of the last car, respectively. The middle three peaks were caused by a combination of the noise from the rear wheel trucks of the first car and the front wheel trucks of the next consecutive car in the train and so forth. The close proximity of these wheel to one another at the junction of two cars produces a single, broader noise peak. This noise is reduced from station 1 to station 2 to station 3 by attenuation due to spreading and is a function of both point source and line source reductions (point source reduction 6 dB, line source reduction 3 dB, both per doubling of the distance from source).

In figures A-1b and A-1c, the noise peaks noted at station 1 are obscured by and have become a part of the overall train noise as measured at station 2. In this first doubling of the distance away from the noise source (25 to 50 feet) the noise peaks from wheel-rail interaction (point sources) are attenuated at twice the rate of the noise from the train proper (line source). Thus the transition from "in-close" conditions (simultaneous presence of line source conditions and non-uniform high level point sources) at 25 feet is essentially complete at 50 feet where we basically have line source conditions. Note the bell-shaped noise level history at 100 ft, where for this length train (340 feet) line source conditions still exist. It is conceivable that the transition to line source conditions could require two or more doublings of distance away from the source depending on the relative levels of the noise peaks at the 25-foot measurement point.

Figures A-2 and A-3 contain the 1/3-octave frequency spectra of a 2-second and a 1/2-second period respectively during the passby of the above 4-car Metroliner. The periods analyzed are as marked on the time history. The 2-second period is centered around the complete passby while the 1/2-second period is centered around the second noise peak. Note the similarity of the spectra between these two measurement periods, showing that the dominant noise during the passby of a Metroliner is associated with wheel-rail interactions.

Comparison of the noise spectra between measurement stations shows that in a narrow frequency band centered at 400 Hz the measured data are attenuated by 0 and 8 dB between measuring stations 1 and 2 and stations 2 and 3, respectively. This is caused by the interference between the direct sound and the ground reflections that reach the microphones. According to Beranek,[1] the amplitude and phase of the reflected sounds are determined by the acoustic impedance of the ground, which varies with frequency, and the conditions for interference are met only in a narrow frequency band in the range of 300 to 500 Hz.

Figure B-1 contains the coincident wayside ground vibration level time histories, in three axes, of the passby of the above 4-car Metroliner (southbound on track 2 at 106 mph). These data were measured at station 1, 25 feet from the centerline of track 2.

Note the similarity in the shape of the y-axis acceleration level time history (figure B-1a) with the noise level history measured at station 1 (figure A-1a). As in the noise data shown in figure A-1a, the peaks in the y-axis acceleration data of figure B-1c were generated during the passby of the sets of wheel trucks in close proximity to the measuring station (point sources). These peaks are not as predominent in the z- and x-axis acceleration histories shown in figures B-1a and B-1b.

The vibration frequency spectra in each axis for a 2-second time coincident period shown in figure B-2. Note that the slight peak in the spectra at 800 Hz is a result of the acoustic sensitivity of the accelerometers used and should be disregarded.

The noise level time history of a 6-car Metroliner also traveling southbound on track 2 at a speed of 110 mph is shown in figure A-4. Note that the level history, including the noise peaks, is approximately equal in level but lasts for a longer period of time when compared with the level history of the passby of a 4-car Metroliner (figure A-1). The bell shape of the line source is even more pronounced.

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(1) Beranek, L.L., Noise and Vibration Control, McGraw-Hill, New York, 1971, 185 - 6.

Figures B-3 and B-4 contain the ground vibration level time histories and frequency spectra for the southbound 6-car Metroliner.

Figures A-5 through A-8 are selected representative time histories of the noise levels measured during the passby of other 4- and 6-car Metroliner trains while traveling northbound on tracks 3 and 4. Tracks 3 and 4 are 38, 63, and 113 feet and 50, 75, and 125 feet from measurement stations 1, 2 and 3, respectively. Note the shape of the top of the level history (figures A-1c, A-5c, A-7c). The flat bell-shaped top becomes rounded with increasing offset and indicates a transition from line source back to point source conditions.

Rath(2) has shown that propagation of sound radiated from a vehicle (finite line source) of length L is proportional to the inverse of the distance ($1/d$) at distances less than L/π, and is proportional to the inverse of the square of the distance ($1/d^2$) at distance greater than L/π. That is to say when d is less than L/π line source conditions prevail, and when d is greater than L/π point source conditions prevail. This results in a reduction of the noise level of 3 or 6 dB, respectively, for each doubling of distance from the source within the above limits.

In the case of the 4-car Metroliner train which is 340 feet long, line source conditions hold to 108 feet which agrees with the rounding of the time history suggesting the transition from line source to point source conditions. Line source conditions will hold for a 6-car Metroliner (510 feet long) to 162 feet. Examination of the shape in figures A-4c, A-6c and A-8c verifies that line source conditions do in fact exist.

Time histories of the wayside ground vibration levels in three axes for the above 4- and 6-car Metroliner trains are shown in figures B-5 through B-8.

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(2) Rath, E.J., Note on two common problems of sound propagation, Journal of Sound and Vibrations, volume 10, page 472. 1969

Table 2.1 is a tabulation of the wayside noise and ground vibration levels for all Metroliner trains measured on May 23, 1972. The peak RMS noise levels (dBA re 20 $\mu N/m^2$) at three measurement stations, and the coincident peak RMS acceleration levels in three axes (dB re $10^{-6}g$) at two measurement stations are tabulated for Metroliners traveling southbound on track 2 and northbound on tracks 3 and 4. Metroliners on tracks 2 and 3 traveled in excess of 100 miles per hour while those on track 4 traveled at approximately 80 miles per hour.

2.1.2 Conventional Passenger and Freight Trains

Table 2.2 is a tabulation of the wayside noise and ground vibration level data obtained during the passby of conventional passenger and freight trains at the Plainsboro NJ measuring site. The trains operating on this line were driven by electric locomotives which obtained power through a pantograph from the overhead catenary system.

In general, the peak RMS noise levels (dBA re 20 $\mu N/m^2$) tabulated occurred during the passby of the locomotives, exceptions are noted in the tabulation. The peak RMS acceleration levels tabulated (dB re $10^{-6}g$) are in time coincidence with the noise data tabulated except where noted.

Figures A-9 and B-9 contain time histories of the wayside noise and ground vibration levels, respectively, of the passby of a conventional six-car passenger train. The train driven by an electric locomotive traveled south on track 2 at a speed of 84 miles per hour.

Note in figure A-9a, the first broad peak is the noise generated during the passby of the locomotive. The individual peaks associated with the passby of the wheel trucks of the passenger cars are visible but are not as prominent as those observed during the passby of a Metroliner (figure A-1a). The broad peaks approximately in the middle and end of the time history (middle and end of train) are associated with extremely noisy cars (note

TABLE 2.1
COINCIDENT WAYSIDE NOISE AND GROUND VIBRATION LEVELS
4- AND 6-CAR METROLINER TRAINS
PENN CENTRAL RAILROAD, PLAINSBORO NJ
5/23/72

No. of Cars	Track No.	Direction	Time of Day	Speed mph	Peak RMS Noise Levels dBA re 20 $\mu N/m^2$ At Measurement Station (A)			Peak RMS Acceleration Levels dB re $10^{-6}g$ At Measurement Station					
								1			2		
					1	2	3	z-axis	x-axis	y-axis	z-axis	x-axis	y-axis
4	2	S	1007	110	99	93	89	80.5	81.5	85.5			
4	2	S	1105	106	98.5	92.5	88.5	81	81.5	85.5			
6	2	S	1208	110	98	92	88.5	82	82	87			
6	2	S	1314	106	98.5	92	89	81.5	80.5	85.5			
4	2	S	1406	106	98	91	88.5	80.5	79.5	85			
4	2	S	1503	103	98	91.5	88.5	81	80.5	83.5			78.5
6	2	S	1602	103	97	91	88.5	80.5	80	84.5	78		
6	2	S	1708	110	96.5	91.5	89.0	80	81	83.5		76.5	
4	3	N	1332	103	91.5	88	82	79.5	77	79			
6	3	N	1425	110	92	89	83	80.5	81	81.5			
6	3	N	1536	110	92	89	84	80	76.5	78			76
4	3	N	1630	106	92.5	88.5	83.5	80.5	77	80	74.5		
6	4	N	1030	84	86	80.5	77.5	82.5	76.5	80.5			
4	4	N	1128	84	83	78.5	75	81	76	80.5			
4	4	N	1232	80	82.5	79	75.5	81.5	74	80.5			

(A) Measurement Stations 1, 2 and 3 located 25, 50 and 100 ft from centerline of Track 2 (southbound); 38, 63 and 113 ft from centerline of Track 3 (northbound); and 50, 75 and 125 ft from centerline of Track 4 (northbound), respectively.

TABLE 2.2
COINCIDENT WAYSIDE NOISE AND GROUND VIBRATION LEVELS
CONVENTIONAL PASSENGER AND FREIGHT TRAINS
PENN CENTRAL RAILROAD, PLAINSBORO NJ
5/23/72

No. of Engine + Cars	Track No.	Direction	Time of Day	Speed mph	Peak RMS Noise Level(B) dBA re 20 μN/m² At Measurement Station(A)			Peak RMS Acceleration Levels(B) dB re 10^{-6}g At 25 ft			At 50 ft			See Note
					1	2	3	z-axis	x-axis	y-axis	z-axis	x-axis	y-axis	
Passenger Trains														
1 + 4	2	S	1121	73	100	94	90	87	83	87.5				
1 + 6	2	S	1323	84	99	96	90.5	88	86	88				
1 + 10	2	S	1515	82	103.5	98	91	85	86	87.5			84.5	
1 + 8	2	S	1632	86	103	97.5	91.5	88.5	90	92	86			
1 + 12	2	S	1643	40	103	98	94	84.5	86	87		78.5		D
1 + 8	4	N	1034	78	97.5	92	87.5				88.5	81	89.5	
1 + 5	4	N	1104	78	93	88.5	83				87.5	80.5	89	
1 + 11	4	N	1205	80	95	89	83.5				87	79.5	85	
1 + 2	4	N	1337	70	83	79.5	73.5				75.5	72.5	74	
1 + 4	4	N	1354	70	84.5	88.5	84				84.5	79.5	82	
1 + 5	4	N	1404	78	96	90.5	83.5				86	79	86.5	
1 + 17	4	N	1550	80	94	89.5	85				86	79.5	85	
1 + 2	4	N	1612	57	87	81.5	78.5				79.5	74	77	
1 + 15	4	N	1635	80	98	93.5	90				81	76	83	C,D
1 + 4	4	N	1709	46	93	89	83				79	77	88	
Freight Trains														
2 + 33	2	S	1136	34	92	87	82	80	87.5	87.5				E
2 + 48	2	S	1144	32	93.5	88	83	79.5	81.5	83				D
2 + 58	2	S	1223	66	103	96	92	85	85	87				E
2 + 95	2	S	1228	50	98	91.5	88.5	86	82	88				
2 + 63	2	S	1306	50	101.5	96.5	91	83	86	88				C,D
2 + 35	4	N	1040	84	98	93	88				87	80	86.5	
3 + 99	4	N	1154	48	92	88	85				84.5	82.5	85.5	
2 + 41	4	N	1309	35	90.5	86.5	82				80.5	80.5	85	C
3 + 71	4	N	1420	40	87.5	83	80				73	75	76	D

A) Measurement Stations 1, 2 and 3 located 25, 50 and 100 ft from centerline of Track 2; and 50, 75 and 125 ft from centerline of Track 4, respectively.

B) Peak Levels occurred during passby of Engine except where noted.

C) Peak level occurred during passby of Passenger or Freight cars.

D) Vibration level tabulated is in time coincidence with peak noise level tabulated but is not the peak level generated during passby.

also the y-axis vibration time history for this train, Figure B-9c). The vibration peaks associated with the passby of the wheel trucks are as prominent as was noted with the Metroliner data. The first broad peak is a result of the closely spaced wheels on the locomotive and the front wheel trucks of the first passenger car. The uniformity of the remaining vibration peaks suggests all wheels were of equal quality (wheel flats, etc.). The excess noise associated with the third, fourth, fifth, and sixth cars is not due to poor wheels in these cars but more likely from the cars themselves.

Note in figure A-9a at 25 feet that the noise level history for the passby of this train is more complex than that measured during a Metroliner passby. The noise level history is made up of broad noise peaks from individual line sources of noise and noise peaks from non uniform point sources, all superimposed on the familiar bell-shaped noise history.

Observe further in figure A-9C that two doublings at distances to 100 feet were required to obtain the flat bell-shaped noise level time history associated with a finite moving uniform line source of incoherent noise.

The noise level frequency spectra, at the three measurement stations, of three time periods during the passby are presented. Figure A-10 contains the noise spectra of the engine passby; figure A-11 contains the noise spectra of the first three cars in the train which were relatively quiet; and figure A-12 contains the noise spectra of the last three relatively noisy cars.

Figure B-10 is the 3-axis vibration spectra generated in a 2-second period during the passby of the above six-car passenger train.

The noise and vibration data measured during the passby of a 63-car freight train driven by two electric locomotives traveling south on track No. 2 at 49 mph are found in figures A-13 and B-11. Note the noise level peaks in figure A-13a associated with the passby of the locomotives and 2/3 down the length of the train the noise peaks associated with one or more noisy freight cars. Examination of the y-axis vibration time history (figure B-11c) shows that at least three cars during this same period produced excess vibration levels, thus indicating that the excess noise produced by this section of the train appears to be associated with either bad wheels or heavily loaded cars or both.

Note, as for the conventional passenger train above, that the noise level time history at 25 feet (figure A-13a) for this freight train is made up of point and individual line sources of various excess levels in addition to the overall train noise. The relative levels are such that even at 100 feet overall line source conditions have not been met. It is estimated from the shape of the history at 100 feet that overall line source conditions, flat-top bell-shaped history, will be achieved at an offset distance of 1600 feet at a level of 69 dBA considering only the attenuation due to geometric spreading.

Figures A-14, A-15, and A-16 contain the frequency spectra of the noise level data in 1/2-second periods during: the passby of the engines; during a relatively quiet period midtrain; and during a relatively noisy period 2/3 down the length of the train.

The three axis vibration spectra of a two-second interval during the freight train passby are shown in figure B-12.

2.2 MEASUREMENT ON TURBOTRAIN AND CONVENTIONAL PASSENGER AND FREIGHT TRAINS - PCRR BOSTON-TO-NEW YORK LINE, WEST MANSFIELD, MA. NOVEMBER 4, 1971 AND SEPTEMBER 20 AND 26, 1972

Wayside noise and ground vibration level measurements were made next to the tracks of the PCRR, Boston to New York Line, in West Mansfield MA 1310 feet east of mile post 201 on November 4, 1971 and repeated again on September 20 and 26, 1972.

Microphones were set up at offset distances of 25, 50, and 100 feet from the centerline of the eastbound track (measurement stations 1, 2, and 3, respectively). The PCRR line at this location consists of two tracks (non-welded jointed rails) with the centerline of the westbound track effectively 12, 37, and 87 feet from the three measurement stations (see diagram figure E-8 and photographs E-9 through E-14). The microphones were placed 5.5 feet above the grade level and 3.5 feet above the level of the rails. The noise data were recorded on a four-channel instrumentation tape recorder operated in the direct mode. A time code signal was recorded on the fourth channel. See table H-1 for environmental data.

Appendix C contains passby time histories and 1/3-octave frequency spectra of the wayside noise levels of selected representative events measured at the three microphone stations.

Wayside ground vibration measurements were made utilizing an insulated triaxial arrangement of vibration transducers mounted on a brass rod (2 feet long and 7/8 inch in diameter). The rod was driven into the ground and located at a point offset 25 feet from the centerline of the eastbound track (measurement station 1). The three-axis acceleration data (z-axis vertical motion; x-axis longitudinal motion; y-axis lateral motion) were recorded on a 4-channel FM instrumentation tape recorder along with a time code signal. The time code signal was used for synchronizing the vibration data to the noise data which were simultaneously measured and recorded on a separate four-channel tape recorder.

The vibration rod was left in the ground at the conclusion of the tests for any future measurements.

Appendix D contains time histories and 1/3-octave frequency spectra of the measured ground vibration levels of selected representative events. The same events selected and analyzed for their noise level characteristics in Appendix C are presented in Appendix D.

2.2.1 Turbotrains

Measurements were made on November 4, 1971 on Turbotrain No. I which was made up of two power dome cars and one coach (3-car train). Turbotrain No. II, made up to two power dome cars and three coaches (5-car train), was measured on September 20 and 26, 1972. The Turbotrains were measured during revenue service traveling eastbound to Boston. The same trains were again measured as "deadhead trains" (operating without passengers) on the west-bound track.

Note in the illustrations, figure G-1, that a two-axle power truck is located at the front and rear of the Turbotrain with single-axle trucks located between adjacent cars. Three gas turbine engines in the front power dome car and two engines in the rear power dome car provide traction power to the two 2-axle power trucks by a direct mechanical drive system from the gas turbine engines. The third turbine engine in the rear power dome car usually drives an alternator and supplies auxiliary power for the train.

Figure C-1 contains wayside noise level time histories of the passby of a 5-car Turbotrain, eastbound at a speed of 97 miles per hour, as measured at the three measurement stations (25, 50, and 100 feet). An examination of figure C-1a (data from station 1 at 25 feet) shows noise peaks of varying amplitude and broadness superimposed on the bell-shaped history expected from a uniform line source. At measurement stations 2 and 3 these peaks are less obvious (figures C-1b and C-1c). Since engines are in operation in both front and rear power dome cars, it appears at first glance that the first and last noise histories are associated with these gas turbine engines.

However, a like examination of the y-axis ground vibration level time history for this 5-car Turbotrain (figure D-1c) shows prominent vibration peaks occurring during the passby of the two-axle power trucks of the front and rear power dome car, respectively. The vibration peaks associated with three out of four of the single-axle wheel truck (located between adjacent cars) are approximately 3 dB less in amplitude than the vibration levels produced during the passby of the two-axle power trucks. The second large vibration peak shown (2nd from the left) was generated during the passby of the first single-axle truck in the train. The larger level generated, during the passby of this truck, relative to level generation from the other single-axle trucks in the train may be a result of an irregularity in the wheels of this truck.

It was noted from Metroliner passby data in section 2.1.2 that a close similarity exists between the shape of the noise level time history, and the shape of the y-axis acceleration level time histories as measured at 25 feet. Wheel truck noise was seen to be the prominent noise source during the Metroliner passby. In the case of the Turbotrain, a distinctive similarity does not exist suggesting noise sources other than that from the wheel trucks predominate.

Using the similarity noted between the Metroliner noise and y-axis acceleration data as a guide, the y-axis time history measured during the passby of the Turbotrain suggests that the noise level history at station 1 should be made up of two distinctive point source peaks of similar amplitude during the passby of the first two axle power truck and the first single axle truck between cars. These should be followed by three additional point source noise peaks each of equal amplitude but lower than the first two noise peaks. The rear two-axle power truck should produce a noise peak of approximately the same amplitude as the first two noise peaks in the passby history.

The actual noise level history measured for this train (figure C-1a) is however, made up of a broad noise peak (marked a) followed by three lower amplitude peaks (marked b, c, d). The peak indicated by (d) is partially obscured by the last higher amplitude noise peak (e).

The broad noise peak measured (a) is made up of the point source noise from the passby of the first two-axle power truck, and the normal noise from the first single-axle truck between the power dome car and the first coach, and noise from a third source of approximately equal amplitude, "engine noise."

The last peak shown (e) is a composite of the engine noise from the passby of the last power dome car and the passby noise from the rear two-axle power truck. The middle three lower amplitude peaks (b, c, d) are as expected from the passby of the single-axle wheel trucks located between adjacent cars.

Figures C-2, C-3, and C-4 contain 1/3-octave frequency spectra of the noise generated during three periods of time during the passby of the above 5-car Turbotrain. The periods analyzed are as marked on the time history figure C-1.

Figure C-2 is the frequency spectra in a two-second period covering essentially the complete passby.

Figures C-3 and C-4 contain the spectra in two one-half-second periods covering essentially the periods during the first broad noise peak and the quieter period during the passby of the second single-axle wheel truck, respectively.

Figures C-5 and C-6 contain time histories and noise spectra of the passby data of the above eastbound 5-car Turbotrain during a "deadhead" run (operating without passengers) on the westbound track. Note that the distances the measuring stations were offset from the westbound track are 12, 37, and 87 feet (See figure E-8). The shape of the noise level history (Figure C-5a) can be seen to be the mirror image of the data in Figure C-1a. Figure C-6 is the noise level frequency spectra of a two-second period covering essentially the complete westbound passby.

Figures D-1, D-2, D-3, and D-4 contain ground vibration time histories and composite passby vibration spectra for the above 5-car Turbotrain during the eastbound and westbound passbys, respectively.

The above Turbotrain and a second 5-car Turbotrain were also measured six days before on September 20, 1972 (only two 5-car Turbotrains were in operation on this line at this time). Because of measuring system problems, no vibration data were obtained and only noise data at stations 1 and 2 were recorded. These passby time histories are shown in figures C-7 through C-9 for the eastbound revenue runs and the westbound "deadhead" runs for both trains.

The shape of these time histories at station 1 show, when compared with the noise level time history measured on September 26, 1972 at station 1 (figure C-1a), that the Turbotrain which generated the levels shown in figure C-1a and C-7a were one and the same. Note that in each case the first single-axle truck generated excess noise in comparison with the other single axle trucks in the train.

By the dissimilarity of the noise history shown in figure C-9a, we note that it was generated by the second 5-car Turbotrain in operation on this line. We note from figure C-9a that the first and fourth single-axle truck in this train generate excess level as compared with the remaining single-axle trucks in the train. The westbound trip for this second Turbotrain (deadhead train) passed the measurement site at 40 mph as compared with the other passby speeds in excess of 90 mph. Note the details of the noise peaks generated in figure C-10a. It can be shown that these noise peaks were generated when the individual wheels of the train came in contact with the joints in the rails. From the photograph, figure E-10, we see that a rail joint on the far rail (from the microphones) of the westbound track was directly opposite the microphone. The joints on the near rail on this track (not shown) were spaced symmetrically on either side of the microphone. Since standard rail sections are 39 feet in length we have rail joints, one directly opposite the microphone and then on alternate rail every 19.5 feet symmetrically on either side of the microphones. Thus, at least one wheel of the train approaching at 39 miles per hour (57.2 feet per second) would pass over a joint every 0.293 second. Note from figure C-10a that the peaks in question occur approximately every 0.3 second.

Because the distance between wheels (59.2 and 56.8 feet, figure G-1) are approximately whole number multiples of 19.5 (3 x 19.5 = 58.5 feet) multiple wheels will strike joints on the track at approximately the same time thus reinforcing some of the noise peaks shown. Note the double hump on the peak marked (a) at the end of the time history (figure C-10a). These are a result of the two closely spaced wheels on the 2-axle power truck individually passing over a joint in the rail.

On November 4, 1971, the original 3-car Turbotrains put in service on this line were measured. Figures C-11 and C-12 contain the noise level histories at the three measurement stations of the eastbound revenue passby and the westbound "deadhead" passby, respectively. Note from Figure C-11a that no irregularities are noted in the levels generated by either of the two single-axle wheel trucks in this train. The large noise peak noted in Figure C-11 at the three stations is the train whistle.

Figures D-5 and D-6 contain the 3-axis ground vibration time histories for the two east- and westbound passby of the above 3-car Turbotrain.

Table 2.3 is a tabulation of the wayside noise and ground vibration levels for the Turbotrains measured on the three days at West Mansfield, MA. The peak RMS noise levels (dBA re 20 $\mu N/m^2$) at the three measurement stations, and the coincident peak RMS accelerations levels in three axes (dB re 10^{-6}g) are tabulated.

2.2.2 Conventional Passenger and Freight Trains

Table 2.4 is a tabulation of the wayside noise and ground vibration level data obtained during the passby of conventional passenger and freight trains at the West Mansfield MA measuring site. The conventional trains operating on this line were driven by diesel locomotives.

In general the peak RMS noise levels (dBA re 20 $\mu N/m^2$) tabulated occurred during the passby of the locomotive, except where noted. The peak RMS acceleration levels tabulated (dB re 10^{-6}g) are in time coincidence with the noise data tabulated except where noted.

TABLE 2.3
COINCIDENT WAYSIDE NOISE AND GROUND VIBRATION LEVELS
3- AND 5-CAR TURBOTRAINS
PENN CENTRAL RAILROAD, WEST MANSFIELD MA
11/4/71, 9/20/72, 9/26/72

Turbo Train Type	Track No.	Direction	Date Time of Day	Speed mph	Peak RMS Noise Levels dBA re 20 μN/m² At Measurement Station (A)			Peak RMS Acceleration Levels dB re 10^{-6}g						See Note
								At 25 ft			At 12 ft			
					1	2	3	z-axis	x-axis	y-axis	z-axis	x-axis	y-axis	
Turbo I	2	E	11/4/71 1935	106 (B)	96	90.5	84	80	85	89.5				C
Turbo II	2	E	9/20/72 1815	90	96.5	89.5	-	-	-	-				
Turbo II	2	E	9/20/72 1937	100	96.5	89	-	-	-	-				C
Turbo II	2	E	9/26/72 2010	97	96	89.5	84	84	86	88.5				
Turbo I	1	W	11/4/71 2050	104 (B)	102	96	89.5				85	96	95	C
Turbo II	1	W	9/20/72 1930	40	90.5	86	-				-	-	-	
Turbo II	1	W	9/20/72 2043	97	100	93.5	-				-	-	-	
Turbo II	1	W	9/20/71 2132	91	99	87	-				89	91	91	C

Turbo I - 2 power dome cars and one couch
Turbo II - 2 power dome cars and three coaches

- Indicates No Data

A) Measurement Station 1, 2 and 3 located 25, 50 and 100 ft from centerline Track 2 (eastbound); 12, 37 and 87 ft from centerline of Track 1 (westbound), respectively.

B) Speed obtained with stopwatch. Doppler radar system in use for remaining events listed.

C) Vibration levels tabulated are in time coincidence with peak noise level but is not the peak level generated during passby.

TABLE 2.4
COINCIDENT WAYSIDE NOISE AND GROUND VIBRATION LEVELS
CONVENTIONAL PASSENGER AND FREIGHT TRAINS
PENN CENTRAL RAILROAD, WEST MANSFIELD MA
9/26/72

No. of Engines & Cars	Track No.	Direction	Time of Day	Speed mph	Peak RMS Noise Level (B) dBA re 20 $\mu N/m^2$			Peak RMS Acceleration Level (B) dB re $10^{-6}g$						See Note
					At Measurement Station (A)			At 25 ft.			At 12 ft.			
					1	2	3	z-axis	x-axis	y-axis	z-axis	x-axis	y-axis	
Passenger Trains														
Single Budd Car	2	E	1740	65	91	86	79.5	82.5	86.5	86				
1 + 15	2	E	2048	71	103	97	93.5	87	89.5	91				C,D
1 + 5	1	W	1625	89	108	102	95				93.5	96.5	98.5	
2-Budd Cars	1	W	1643	63	99.5	92	85				88	92	95	
1 + 6	1	W	1726	66	104.5	98	93				90	94.5	96.5	
2 + 6	1	W	1731	79	107	101	95				95	99	100.5	
1 + 6	1	W	1752	57	103	99.5	93				88.5	94	97	
1 + 3	1	W	1820	76	106	100	94				92	97	98	
1 + 5	1	W	1910	74	105	98	91				90.5	97	97.5	D
1 + 2	1	W	1923	79	107.5	-	94.5				91	95.5	97.5	
Freight Train														
5 + 70	1	W	1719	50	107.5	104	98				90	98.5	98	D
2 + 47	1	W	1929	49	105	-	94				89	94	97	D
1 + 18	1	W	1933	38	98	-	87				84	96	94	D

A) Measurement Station 1, 2 and 3 located 25, 50 and 100 ft from centerline of Track 2; and 12, 37 and 87 ft from centerline of Track 1, respectively.

B) Peak levels occurred during passby of Engines except where noted.

C) Peak levels occurred during passby of Passenger on Freight cars.

D) Vibration level tabulated is in time coincidence with peak noise levels tabulated but is not peak level generated during passby.

Figures C-13 and D-7 contain time histories of the wayside noise and ground vibration levels measured during the passby of a conventional fifteen-car passenger train. The train was driven by one-diesel locomotive eastbound at a speed of 71 miles per hour. The y-axis ground vibration time history (figure D-7c) shows the passby of the locomotive with its closely spaced wheels and the adjacent front wheel truck of the first car (possibly a baggage car) in the first broad vibration peak. The vibration levels generated during the passby of the wheel trucks of the passenger cars are seen to be reasonably uniform. The noise level history at station 1 (Figure C-13a) does not exhibit the uniform predominant noise peaks as noted with both the Metroliner and the Turbotrain and as indicated by the vibration level history. This non-uniformity and broadness of the noise peaks, especially the noise from the cars in the last one-third of the train, suggest excess noise from the cars themselves, perhaps from noisy suspension systems.

The noise level frequency spectra at the three measurement stations of three time periods during this passenger train passby is presented. Figure C-14 contains the noise spectra generated in a 1/2-second period during the passby of the diesel locomotives; Figure C-15 contains the noise spectra generated in a 1/2-second period during a relatively quiet period mid-train; Figure C-16 contains the noise spectra generated in a 1/2-second period during a relatively noisy period at the end of the train. The time history (figure C-13) has been marked to indicate the above three periods.

Figure D-8 is the three-axis vibration spectra generated in a two-second period during the passby of the above 15-car passenger train.

The wayside noise and ground vibration level data measured during the passby of a 70-car freight train driven by five-diesel locomotives traveling west at a speed of 50 miles per hour is shown in figures C-17 and D-9, respectively. Note the noise level peaks in figure C-17a associated with the passby of the five locomotives and the two noisy areas mid-train associated with one or more noisy freight cars. Examination of figure D-9c, the y-axis vibration level history, shows that excess vibration levels were produced by the cars during these same time periods. Thus, the excess noise appears to be associated with either bad wheels or heavily loaded cars or both. Note that with the exception of the engine noise envelope, overall line source conditions have been essentially achieved at 87 feet (figure C-17c).

Figures C-18, C-19, and C-20 contain the noise level frequency spectra of data in 1/2-second periods during: the passby of the engines; a relatively noisy period mid-train; and a relatively quiet period, also mid-train.

The three-axis vibration spectra of a 2-second period during the passby of this freight train is shown in figure D-10.

3. COMMENTS

It has been shown that because of the non-uniform nature of the noise from trains, passby noise measured "in close," at an offset distance of 25 feet, contains point source noise peaks at various levels superimposed on the familiar bell-shaped noise history expected from a moving uniform line source.

Depending on the level of these peaks relative to the overall train noise, the offset distance must be increased one or more times (doublings of distance) before the noise behaves as a uniform line source. In addition as shown by Rath for a train of 510 feet in length, uniform line source conditions, once achieved, will hold to an offset distance of 162 feet ($510/\pi$) at which point the transition to point source behavior takes place. Thus care must be exercised in extrapolating data measured "in close," to large offset distances based on the assumption that the train noise behaves as from a uniform line source.

For example, using the data of figure A-4 for a 6-car Metroliner 510 feet in length, a peak level of 98 dBA is observed at 25 feet. Based on assumption that line source conditions exist at 25 feet this measured value extrapolated out to 100 feet (2 doublings of distance) yields a level of 92 dBA(98 - 2 x 3 dBA). However, a level of 88 dBA was measured at 100 feet, where it is noted line source conditions do in fact exist. Thus an error of 4 dB is observed. This error is a function of the number of doublings of distance required to achieve line source conditions times 3 dB. Where 3 dB is the difference between the rate of change of attenuation per distance doubled for point and line sources, 6 and 3 dB, respectively. Using this information, it is noted in the above example that an additional 1-1/3 (4 ÷ 3) doublings of distance are required to achieve line source conditions, i.e. at an offset distance of 67 feet away, line source condition will exist.

The number of times the distance from the source must be doubled is related to the relative fluctuation of the point source noise peaks. In the above case a peak reading of 98 dBA with 6 dB peak-to-valley fluctuations are observed.

Since the peak level noted is a combination of the excess point source noise and the overall train noise, by the technique of combining uncorrelated noise signals, it can be shown that the actual level of the point source noise is 96.7 dBA and the overall train noise (line source) is 92 dBA. Considering these two signal levels separately, and the fact that point source noise attenuates, due to spreading, at twice the rate as that for line source noise, the two signal will be attenuated down to the same level at an offset distance of 74 feet in this case. At this point the signals are indistinguishable one from the other and line source conditions can be said to exist.

This offset distance (74 feet) is consistent with and represents an error in level of less than 1 dB when compared with the calculated distance above (67 feet) which was based on the measured error at 100 feet.

Thus, by the above technique it can be shown that if the peak-to-valley point source fluctuations at 25 feet were greater than 6 dB, for example 8 dB, then an offset distance of 313 feet would be required to attain line source conditions. In this case, an error of 7.2 dB would result in extrapolating data from 25 feet under the incorrect assumption of uniform line source conditions prevailing.

A further complication is noted in figure A-9, where "in close" broad noise peaks, as from short individual line sources, are also observed superimposed on the overall bell-shaped level history expected from a line source. Thus in addition to having a situation "in close" of simultaneous point source and line source conditions, in this case multiple level line source conditions also exist. Note the first broad peak is attenuated as a line source in the first doubling of distance (25 to 50 feet) and as a point source in the second doubling of distance (50 to 100 feet). Extrapolation of "in close" readings to 100 feet based on the assumption of line source conditions yields an error in this example of 3.5 dB.

Note in the majority of noise level histories presented in this report that at 100 feet line source conditions have been approximately met. The greatest exception is the level histories for the freight trains, figures A-13 and C-17, with the extremes in excess noise levels shown.

Thus it has been shown that care must be exercised in the extrapolation of measured railroad passby noise data "in close" under the assumption of line source conditions. The extrapolated error would be minimized in a majority of cases by making the initial measurements at 100 feet.

APPENDIX A

NOISE LEVEL DATA MEASURED AT
THREE WAYSIDE LOCATIONS NEXT TO THE TRACKS OF
THE PENN CENTRAL RAILROAD
NEW YORK-TO-WASHINGTON LINE
PLAINSBORO NEW JERSEY
MAY 23, 1972

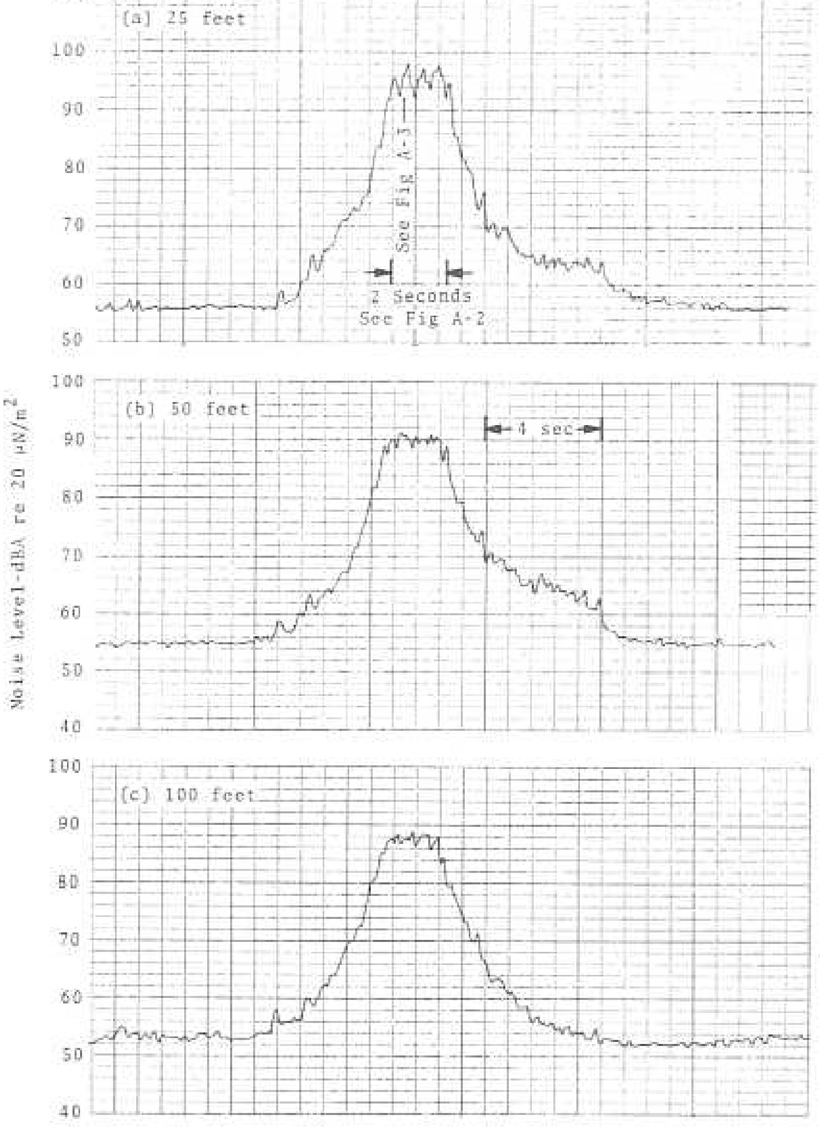


Figure A-1 Coincident Time Histories-Wayside Noise Level 25,50 and 100 ft from Centerline of Track 2. Plainsboro NJ 5/23/72, Four-Car Metroliner-Southbound-Speed 106 mph.

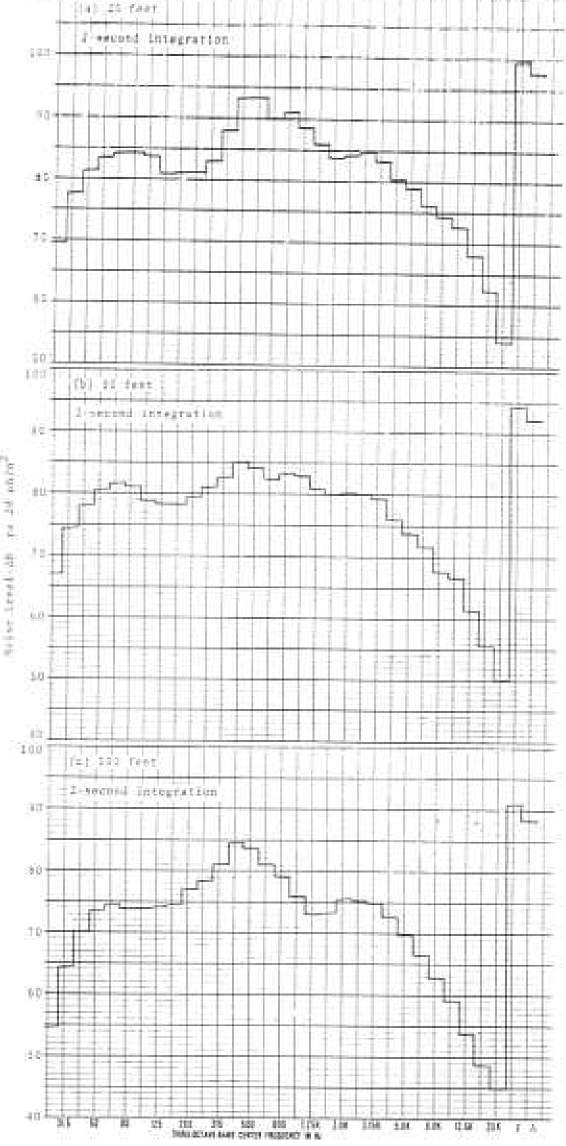


Figure A-2 Coincident Wayside Noise Spectra-Composite of Passby-25,50 and 100 ft from Centerline of Track 2. Plainsboro, NJ 5/23/72, Four-Car Metroliner-Southbound-Speed 106 mph.
See Figure A-1 to Locate Period Analyzed.

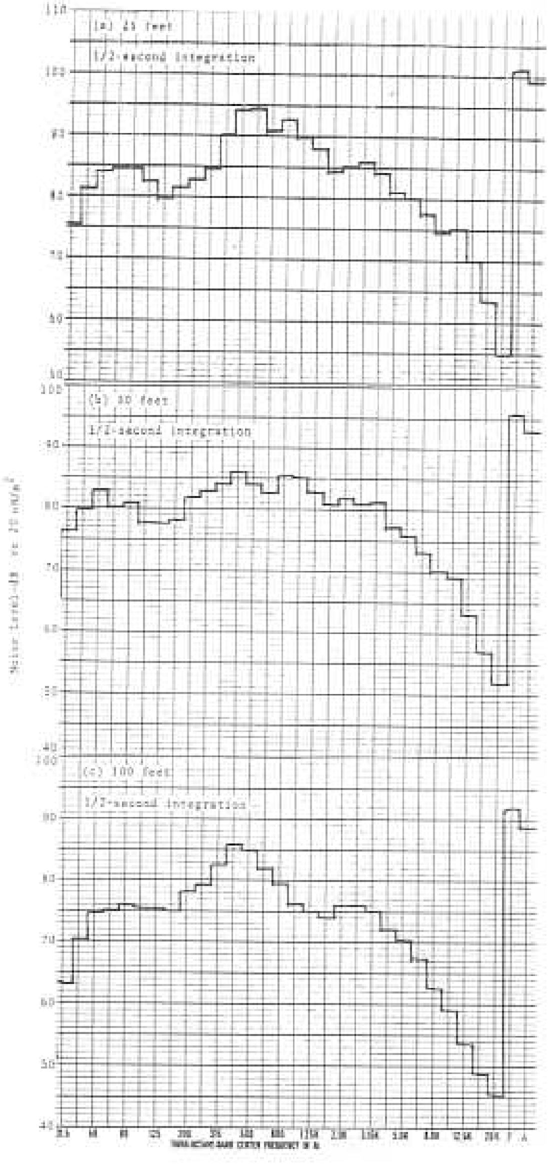


Figure A-3 Coincident Wayside Noise Spectra-Second Noise Peak-25,50 and 100 ft from the Centerline of Track 2. Plainsboro, NJ 5/23/72, Four-Car Metroliner-Southbound-Speed 106 mph. See Figure A-1 to Locate Period Analyzed.

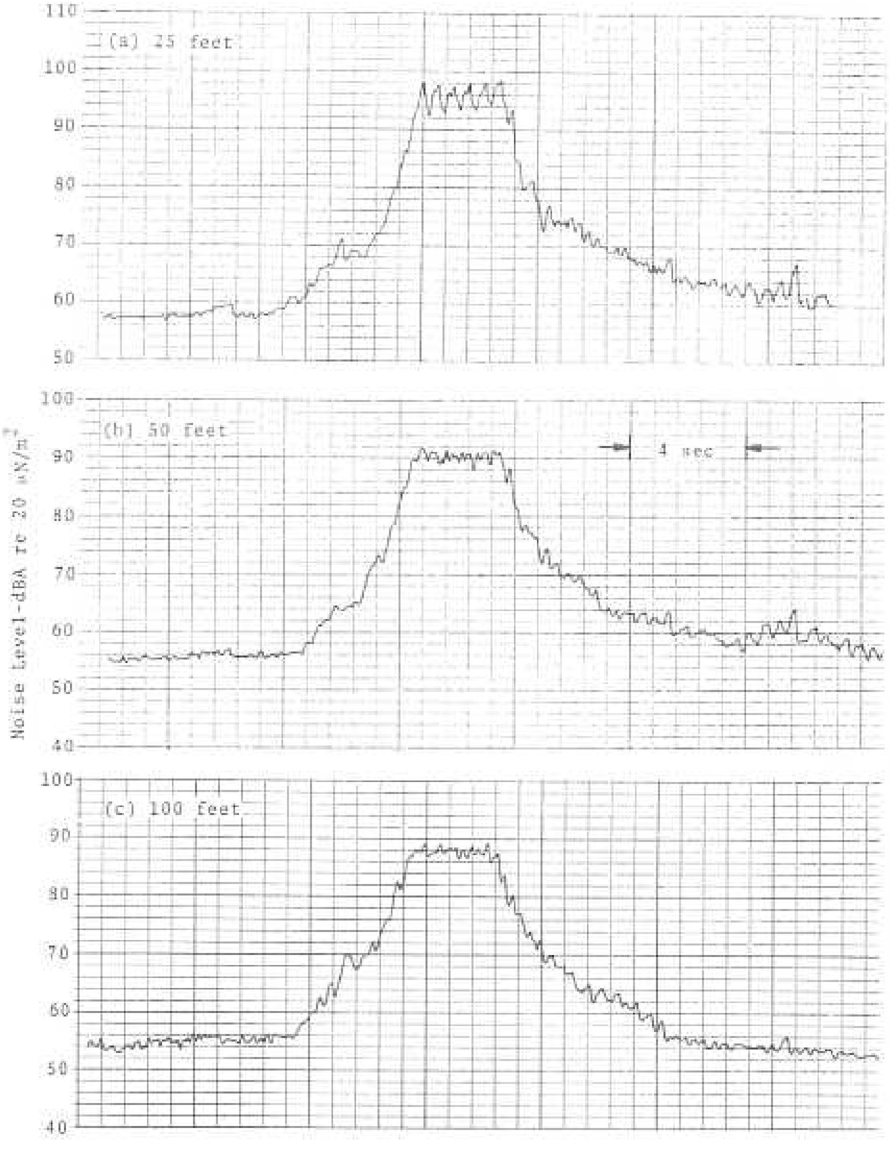


Figure A-4 Coincident Time Histories-Wayside Noise Levels 25,50, and 100 ft from Centerline of Track 2. Plainsboro, NJ 5/23/72, Six-Car Metroliner-Southbound-Speed 110 mph.

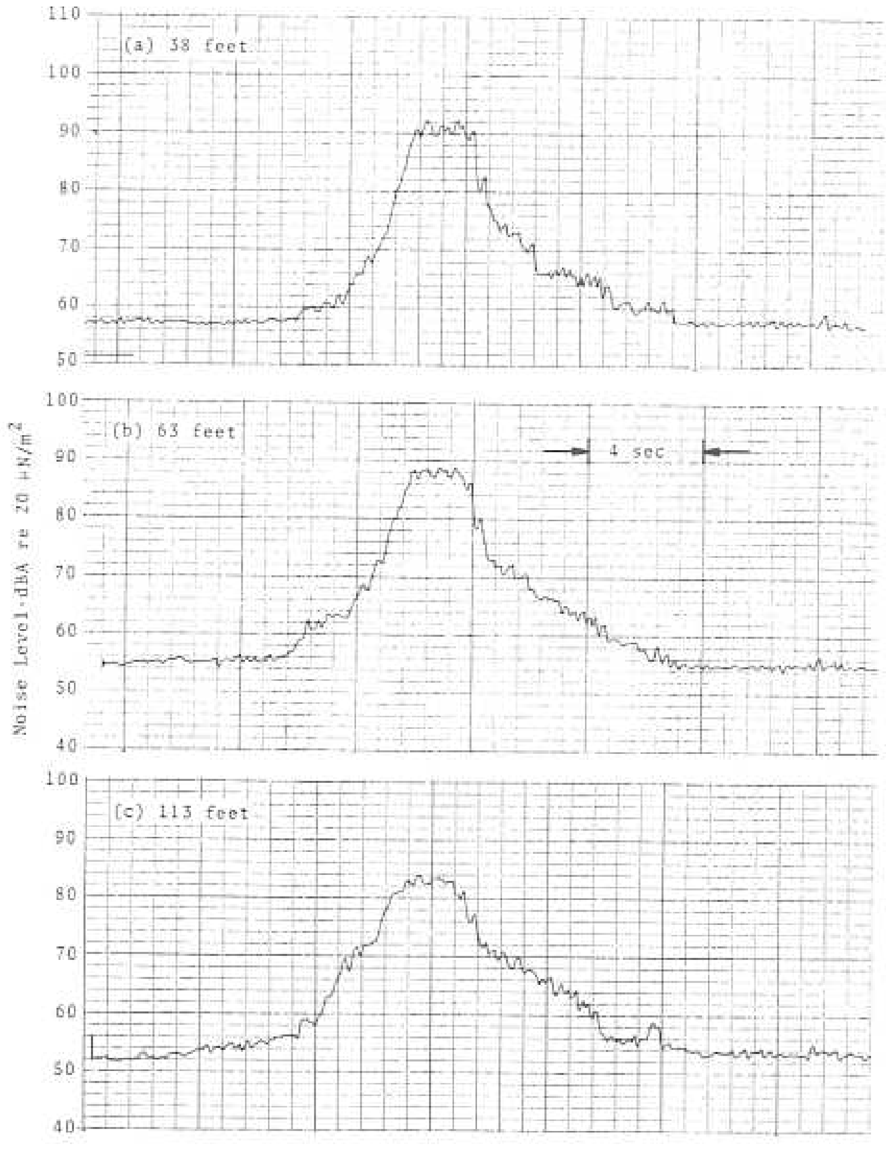


Figure A-5 Coincident Time Histories-Wayside Noise Levels 38,63 and 113 ft from Centerline of Track 3. Plainsboro, NJ 5/23/72, Four-Car Metroliner-Northbound-Speed 106 mph.

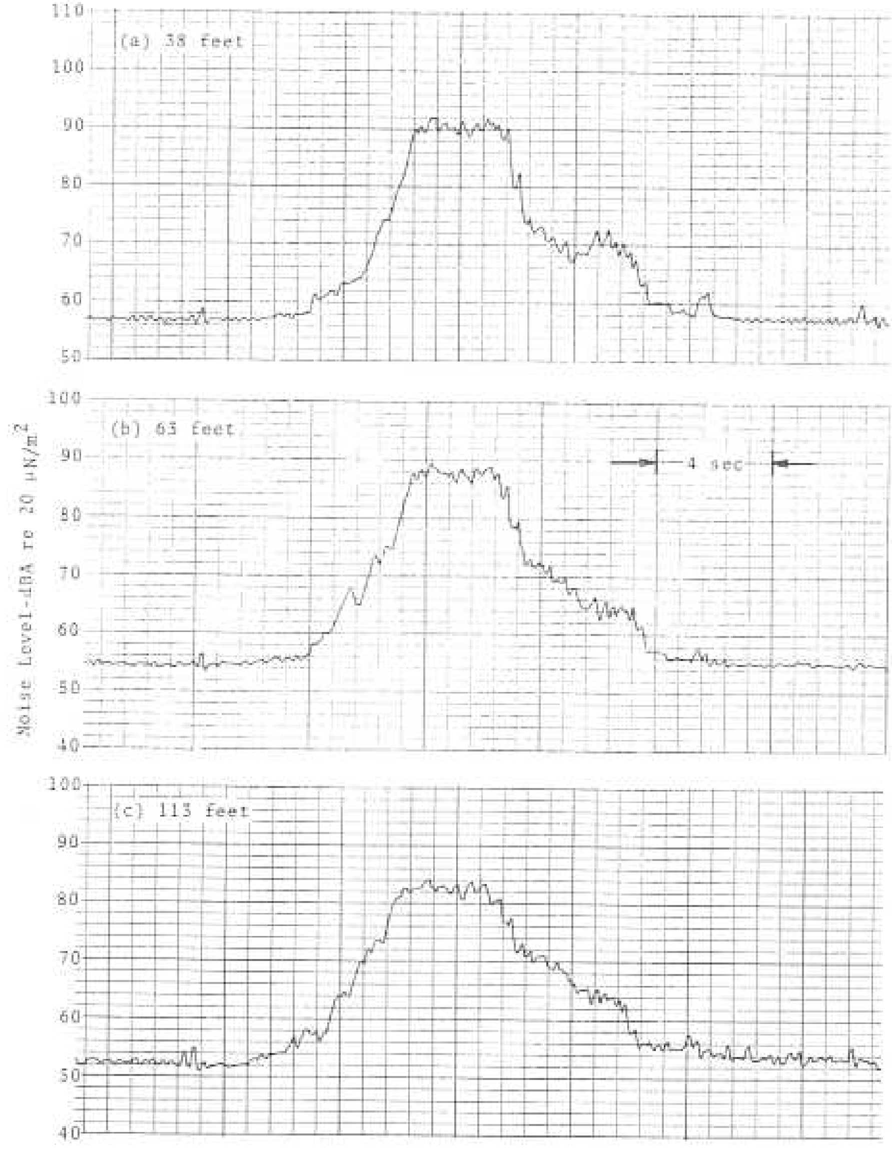


Figure A-6 Coincident Time Histories-Wayside Noise Levels at 38,63 and 113 feet from Centerline of Track 3. Plainsboro, NJ 5/23/72, Six-Car Metroliner-Northbound-Speed 110 mph.

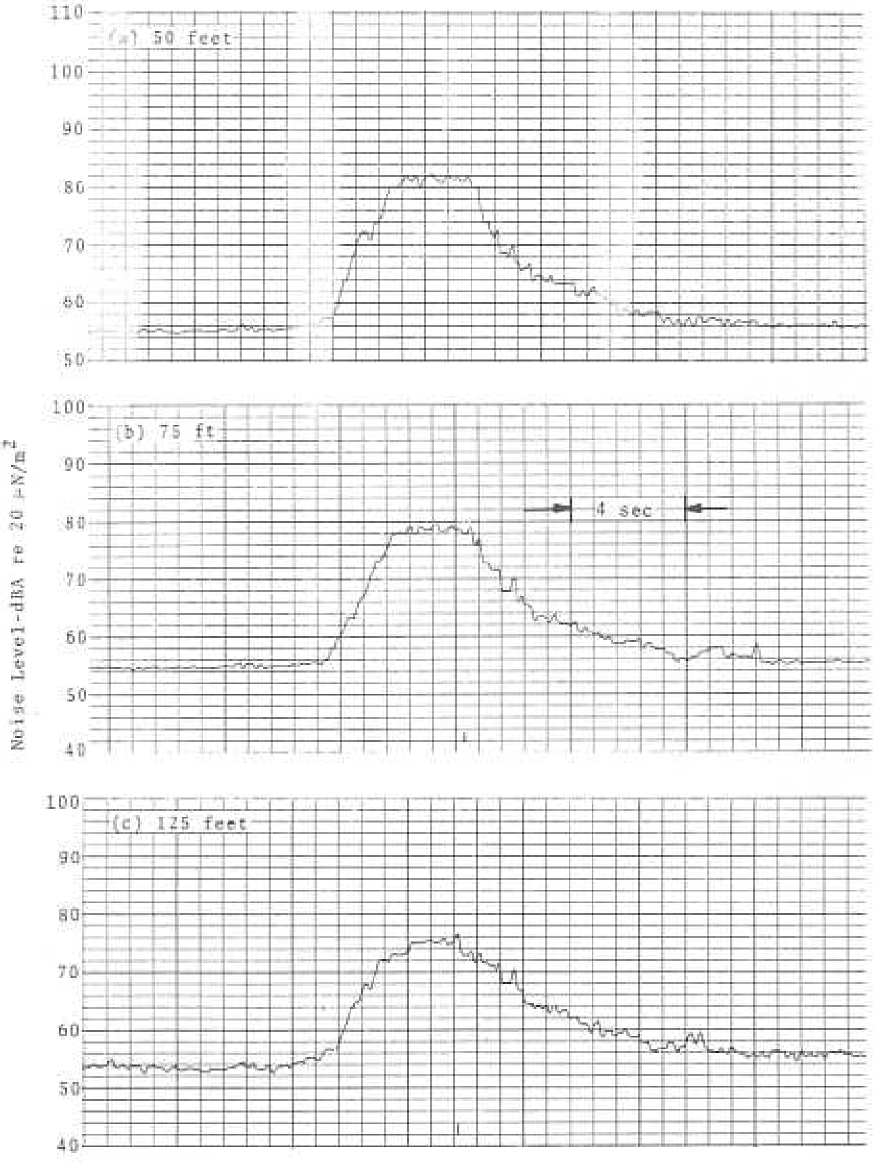


Figure A-7 Coincident Time Histories-Wayside Noise Levels at 50,75 and 125 feet from Centerline of Track 4. Plainsboro, NJ 5/23/72, Four-Car Metroliner-Northbound-Speed 80 mph.

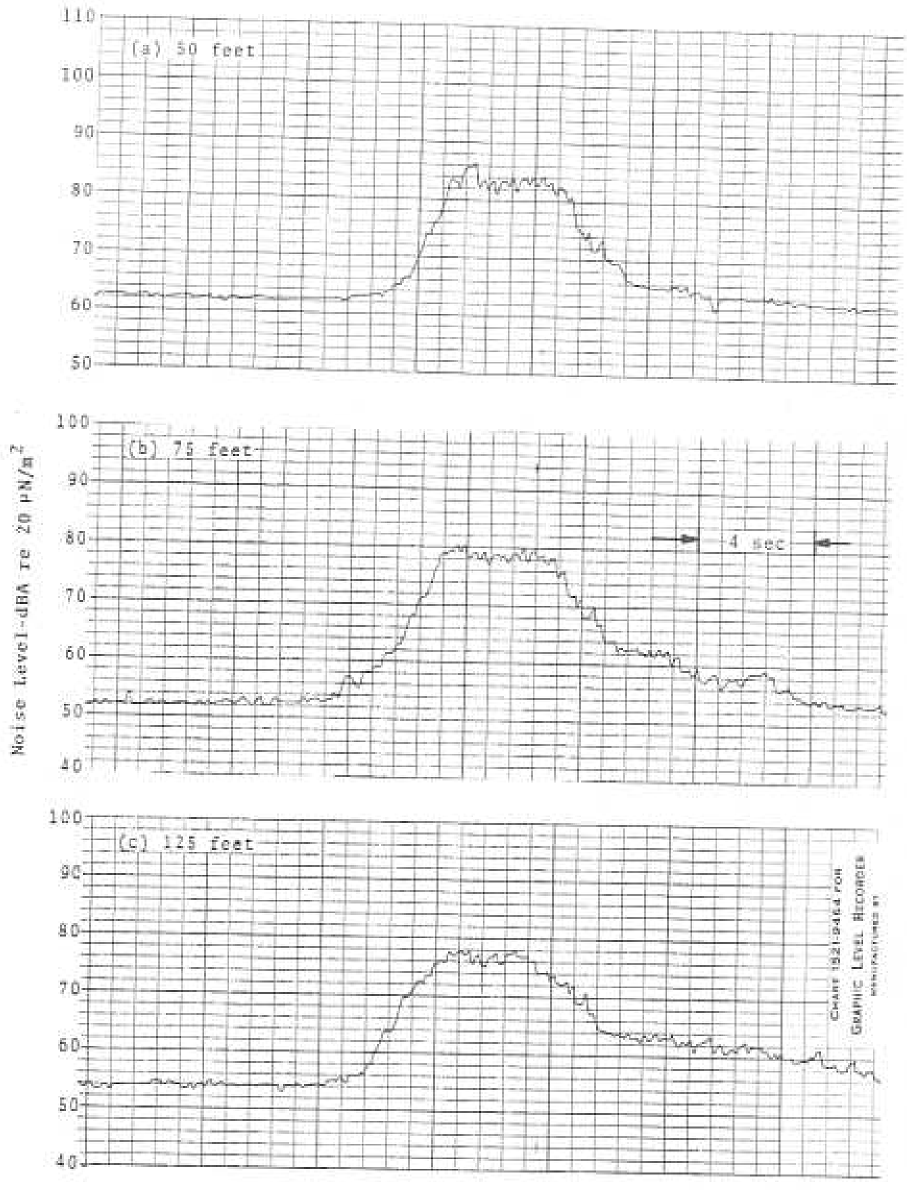


Figure A-8 Coincident Time Histories-Wayside Noise Levels at 50,75 and 125 ft from Centerline of Track 4. Plainsboro, NJ 5/23/72, Six-Car Metroliner-Northbound-Speed 84 mph.

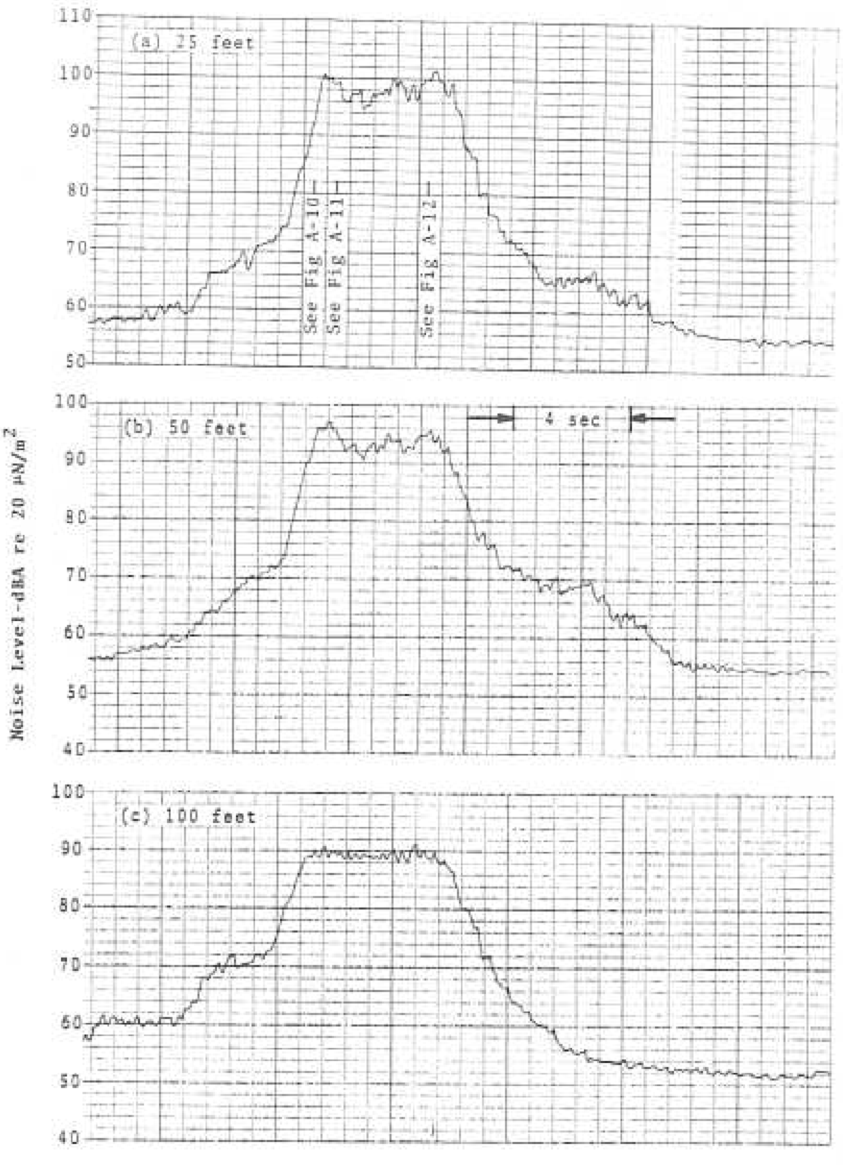


Figure A-9 Coincident Time Histories-Wayside Noise Levels at 25,50 and 100 ft from the Centerline of Track 2. Plainsboro, NJ 5/23/72, 6-Car Conventional Passenger Train with One Electric Locomotive-Southbound-Speed 84 mph.

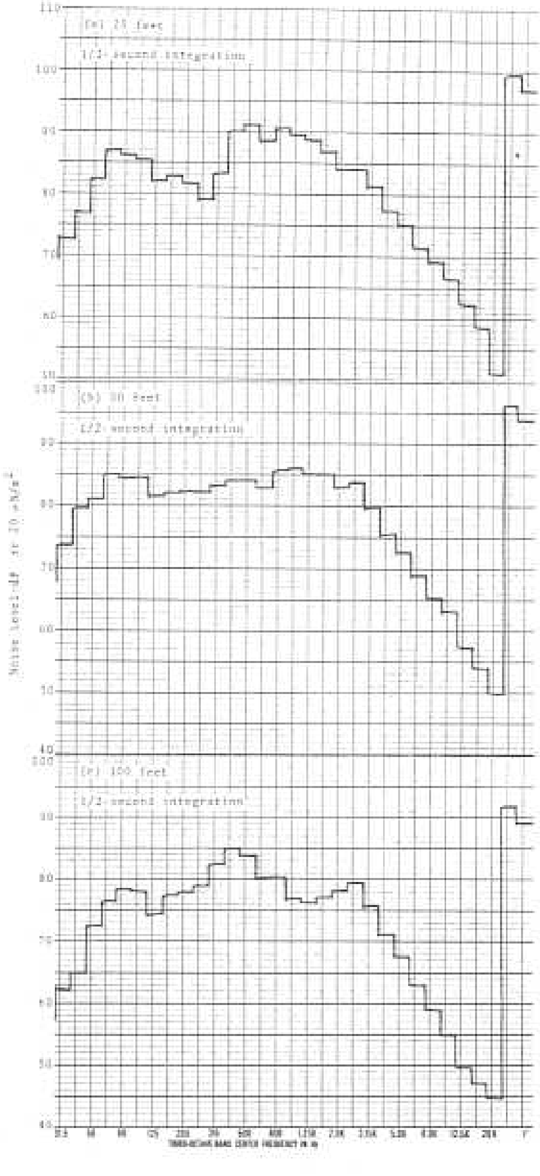


Figure A-10 Coincident Wayside Noise Spectra-Engine Passby-
at 25,50 and 100 ft from Centerline of Track 2.
Plainsboro, NJ 5/23/72,
6-car Conventional Passenger Train with One
Electric Locomotive-Southbound-Speed 84 mph.
See Figure A-9 to Locate Period Analyzed.

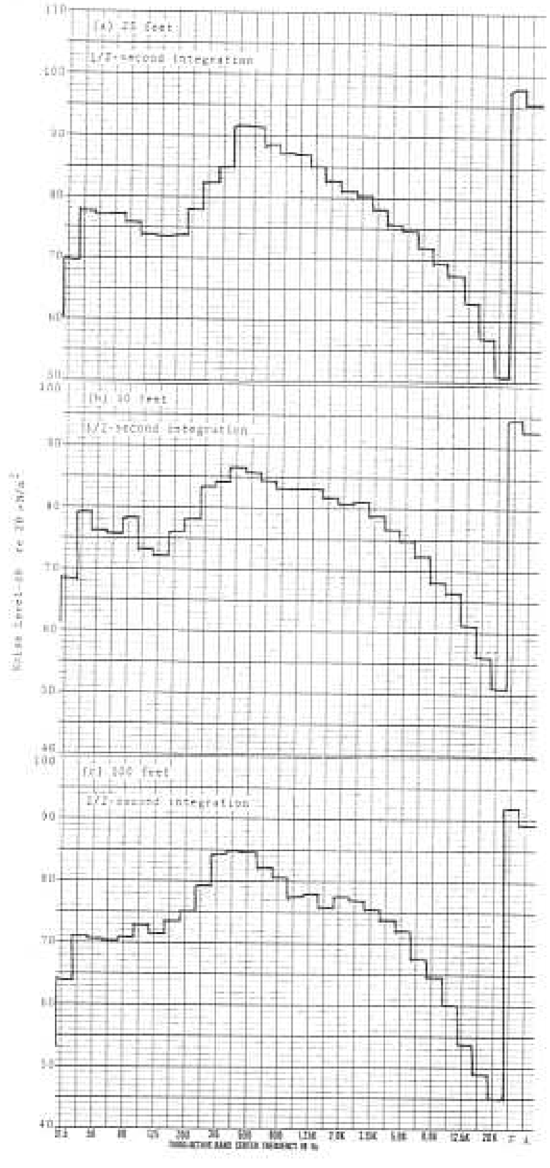


Figure A-11 Coincident Wayside Noise Spectra-Quiet Period Mid-Train at 25,50 and 100 ft from the Centerline of Track 2. Plainsboro, NJ 5/23/72, 6-Car Conventional Passenger Train with One Electric Locomotive-Southbound-Speed 84 mph. See Figure A-9 to Locate Period Analyzed.

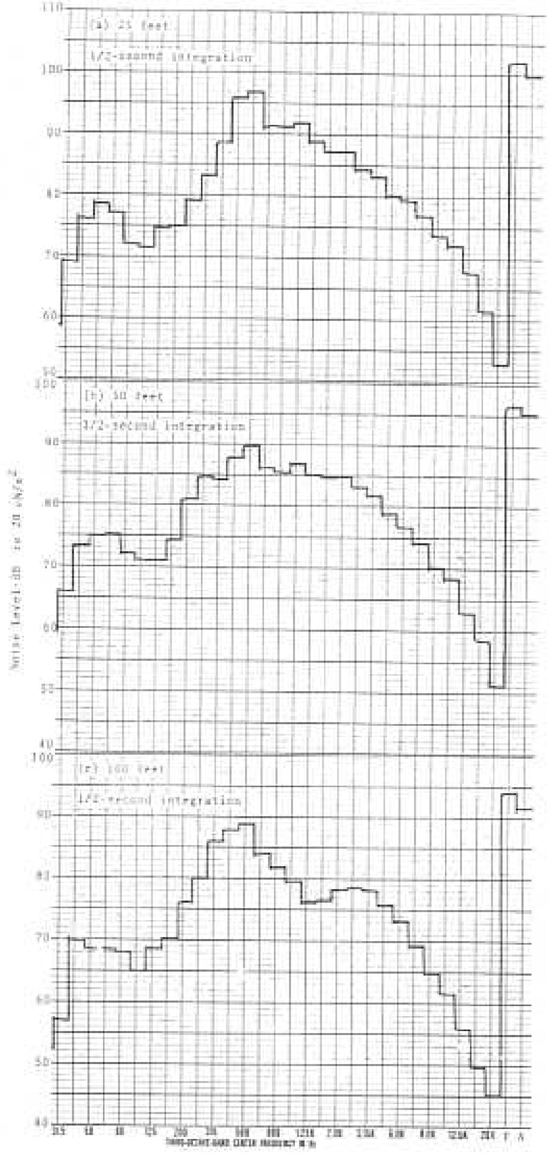


Figure A-12 Coincident Wayside Noise Spectra-Noisy Period End of Train at 25,50 and 100 ft. from the Centerline of Track 2. Plainsboro, NJ 5/23/72 6-Car Conventional Passenger Train with One Electric Locomotive-Southbound-Speed 84 mph. See Figure A-9 to Locate Period Analyzed.

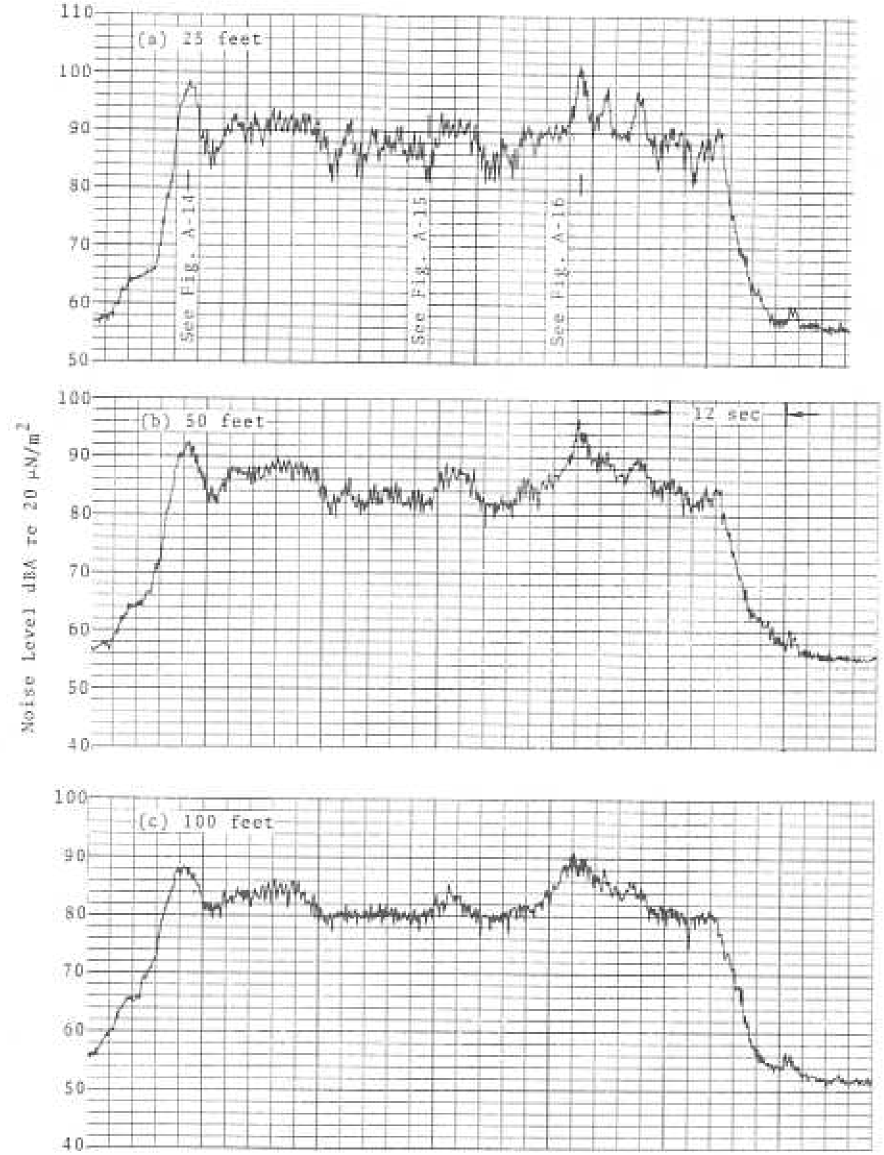


Figure A-13 Coincident Time Histories-Wayside Noise Levels at 25,50 and 100 ft from the Centerline of Track 2. Plainsboro, NJ 5/23/72, 63-Car Freight Train with 2 Electric Locomotives-Southbound-Speed 49 mph.

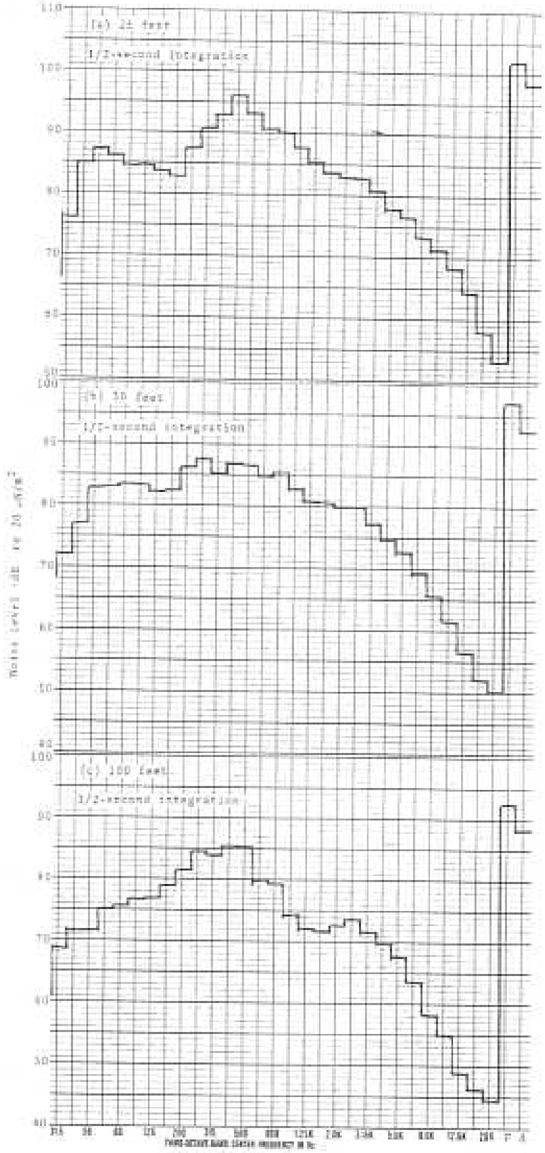


Figure A-14 Coincident Wayside Noise Spectra-Engine Passby-
at 25,50 and 100 ft from Centerline of Track 2.
Plainsboro, NJ 5/23/72,
63-Car Freight Train with 2 Electric Locomotives-
Southbound-Speed 49 mph.
See Figure A-13 to Locate Period Analyzed.

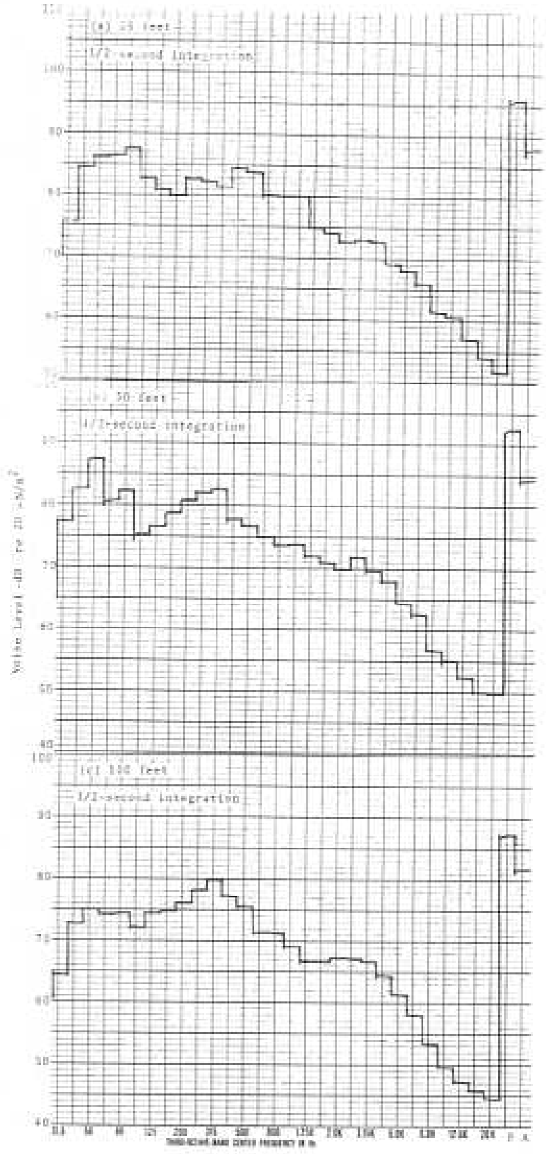


Figure A-15 Coincident Wayside Noise Spectra-Quiet Period Mid-Train at 25,50 and 100 ft from Centerline of Track 2. Plainsboro, NJ 5/23/72, 63-Car Freight Train with 2 Electric Locomotives-Southbound-Speed 49 mph. See Figure A-13 to Locate Period Analyzed.

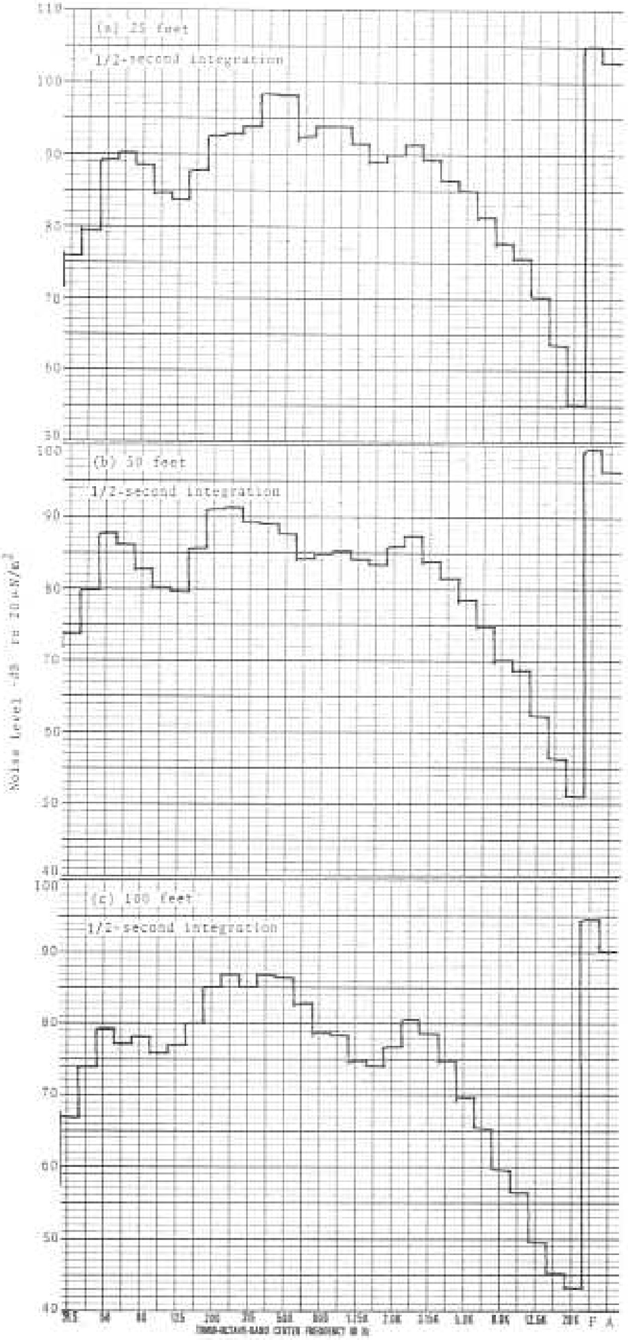


Figure A-16 Coincident Wayside Noise Spectra-Noisy Period Mid-Train at 25,50 and 100 ft from Centerline of Track 2. Plainsboro, NJ 5/23/72, 63-Car Freight Train with 2 Electric Locomotives Southbound-Speed 49 mph. See Figure A-13 to Locate Period Analyzed.

APPENDIX B

THREE-AXIS WAYSIDE GROUND VIBRATION DATA MEASURED

AT TRACKS OF PENN CENTRAL

RAILROAD NEW YORK-TO-WASHINGTON LINE,

PLAINSBORO, NEW JERSEY,

MAY 23, 1972

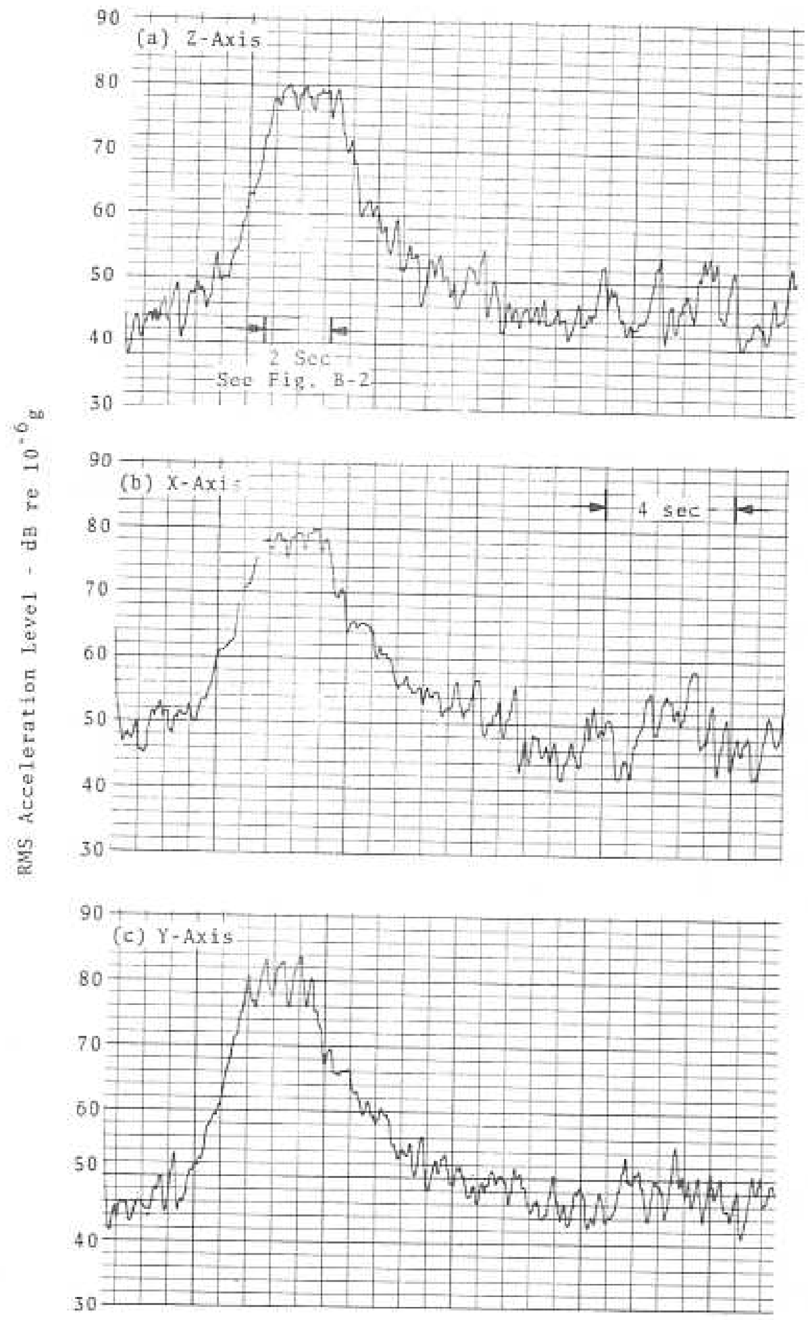


Figure B-1 Coincident Time Histories-Wayside Ground Vibration Levels in 3 Axes at a Point Offset 25 ft from the Centerline of Track 2. Plainsboro, NJ 5/23/72. Four-Car Metroliner-Southbound, Speed 106 mph.

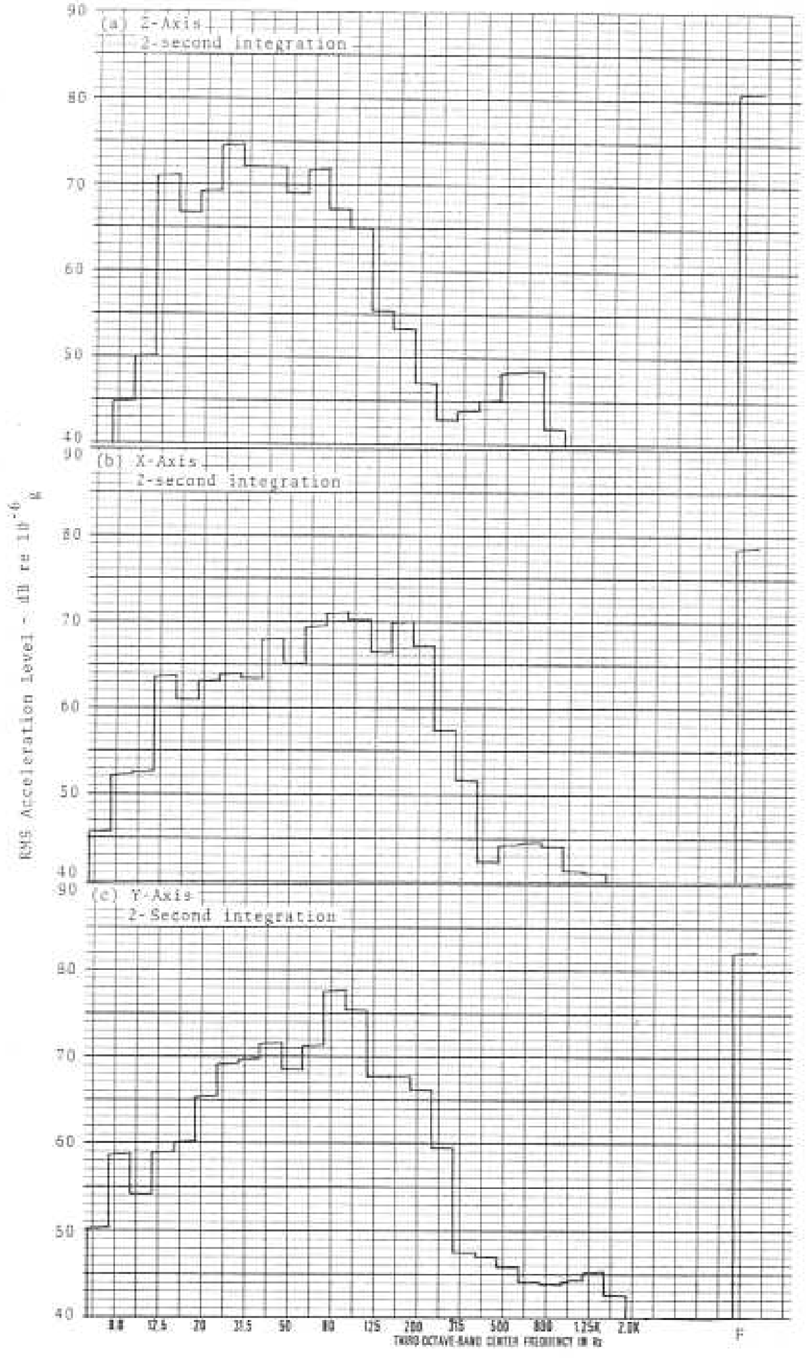


Figure B-2 Coincident Wayside Ground Vibration Spectra in 3 Axes at a Point Offset 25 feet from the Centerline of Track 2. Plainsboro NJ 5/23/72. Four-Car Metroliner-Southbound-Speed 106 mph. See Figure B-1 to Locate Period Analyzed.

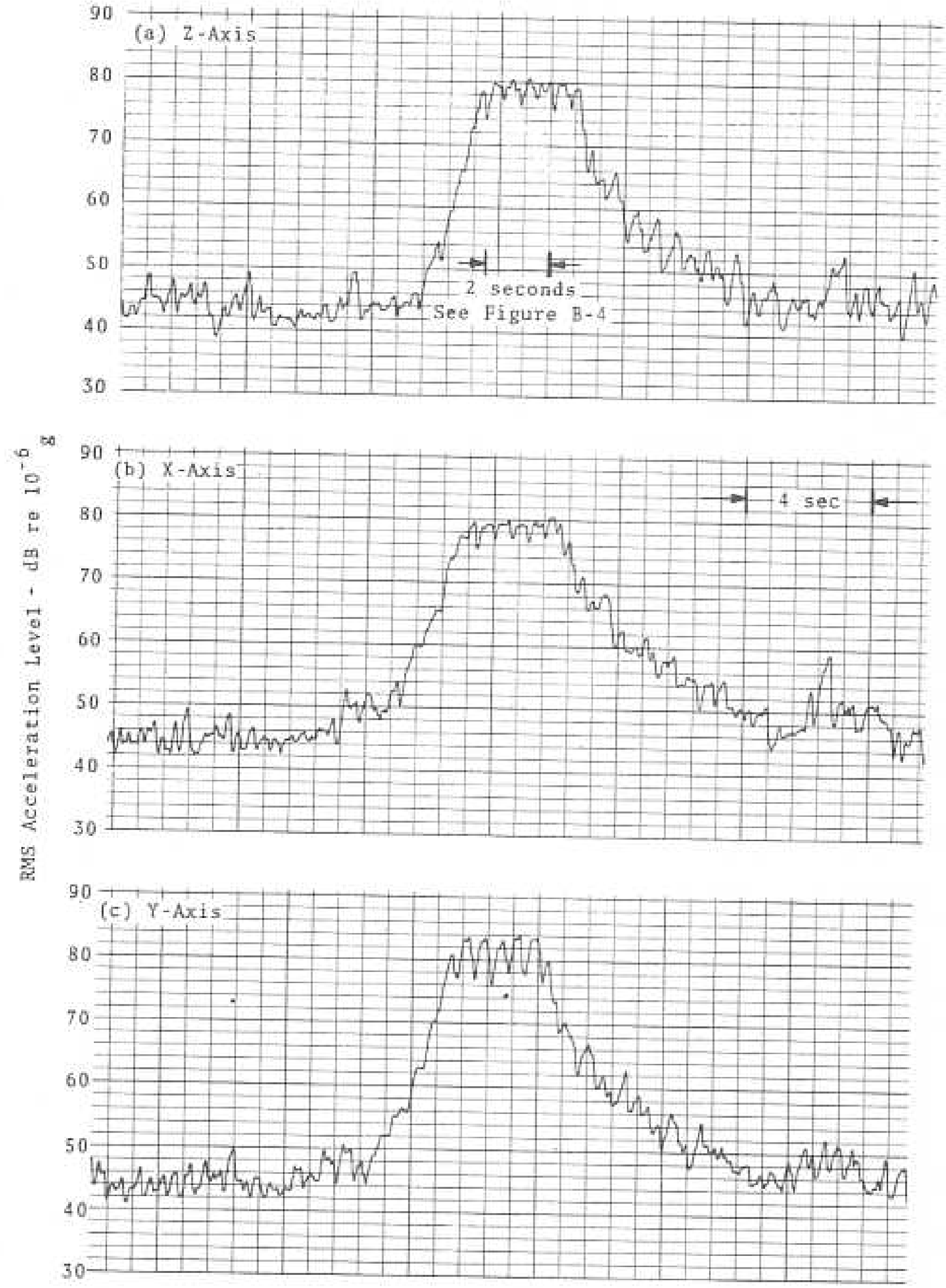


Figure B-3 Coincident Time Histories-Wayside Ground Vibration Levels in 3 Axes at a Point Offset 25 ft from the Centerline of Track 2. Plainsboro, NJ 5/23/72 Six-Car Metroliner-Southbound-Speed 110 mph.

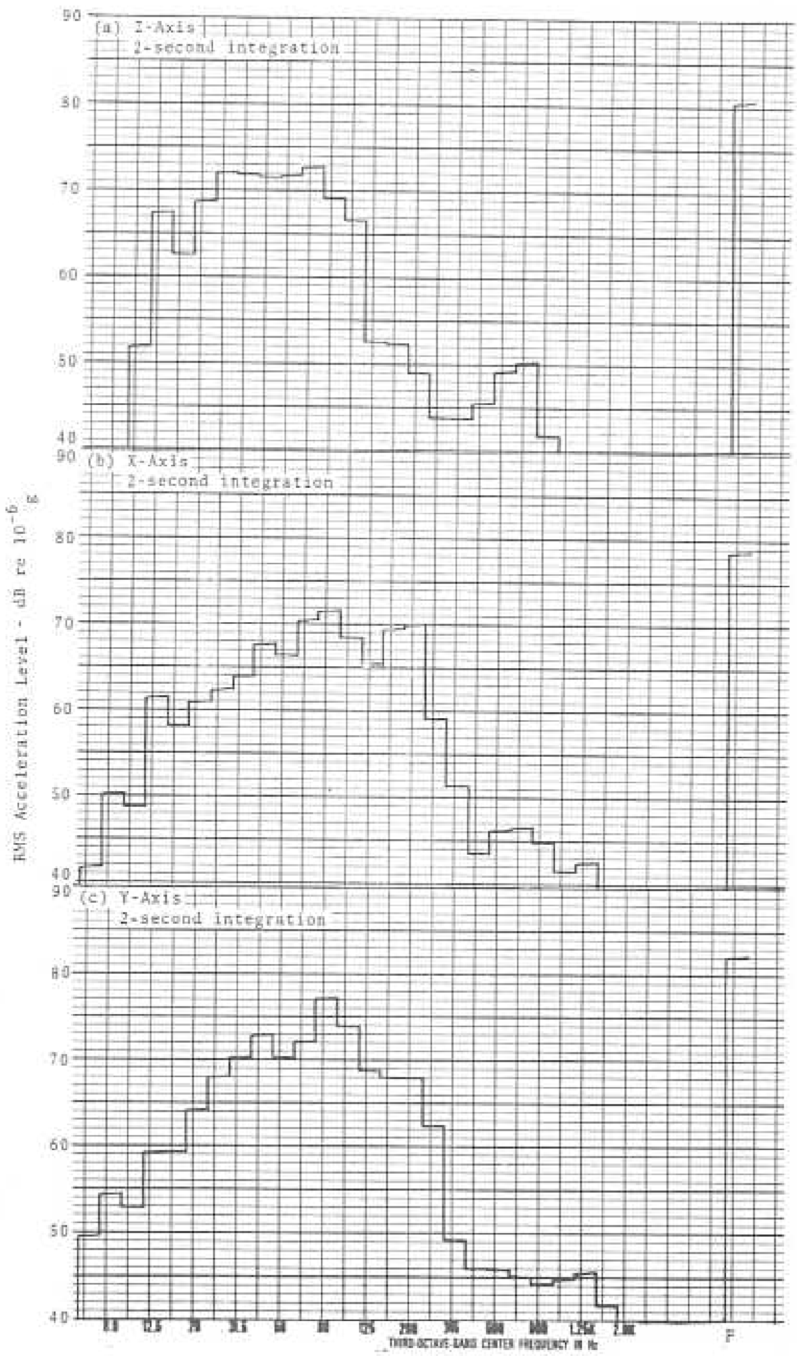


Figure B-4 Coincident Wayside Ground Vibration Spectra in 3 Axes at a Point Offset 25 ft from the Centerline of Track 2. Plainsboro, NJ 5/23/72. Six-Car Metroliner-Southbound-Speed 110 mph. See Figure B-3 to Locate Period Analyzed.

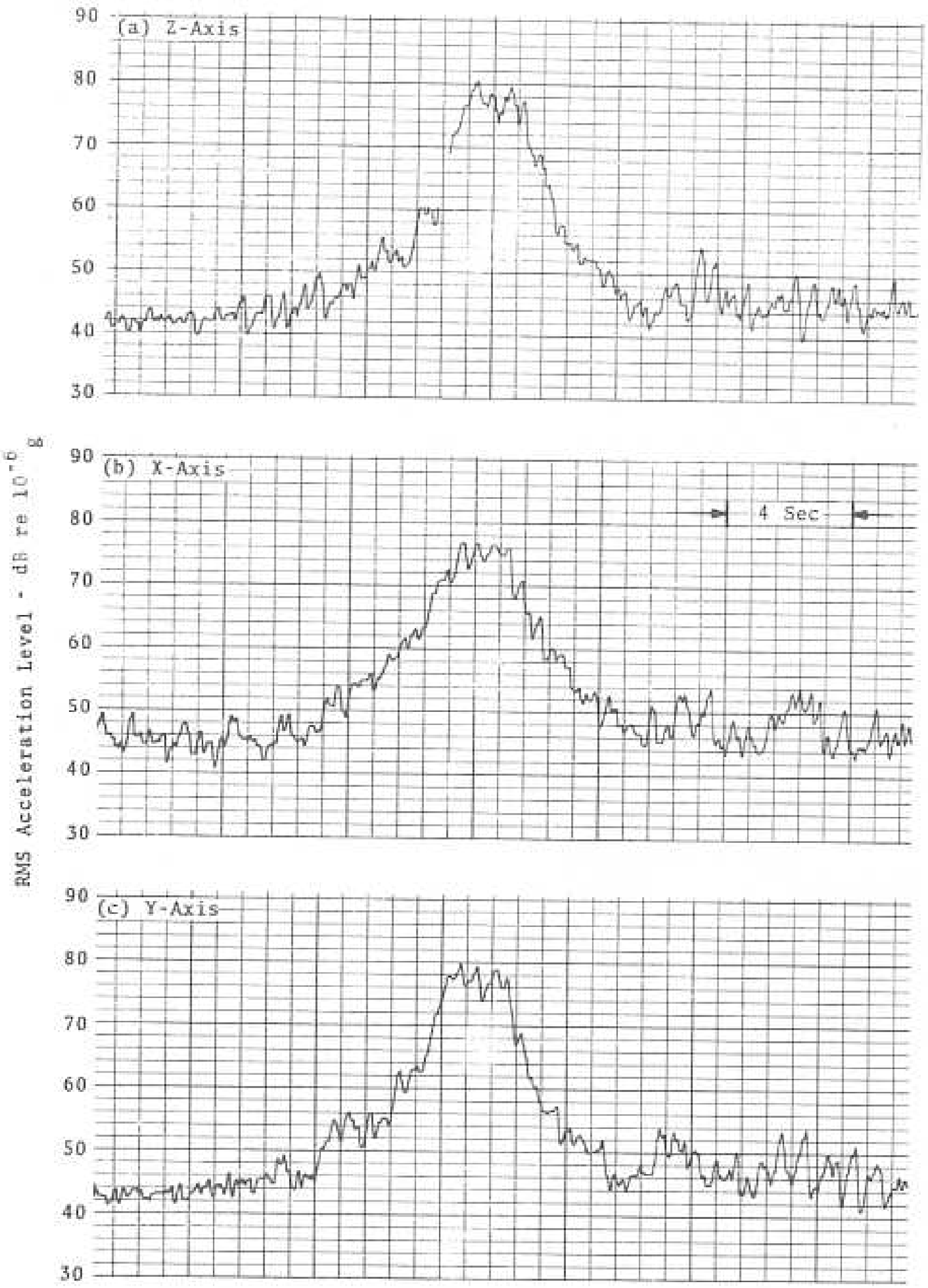


Figure B-5 Coincident Time Histories-Wayside Ground Vibration Levels in 3 Axes at a Point offset 38 ft from the Centerline of Track 3. Plainsboro, NJ 5/23/72. Four-Car Metroliner-Northbound-Speed 106 mph.

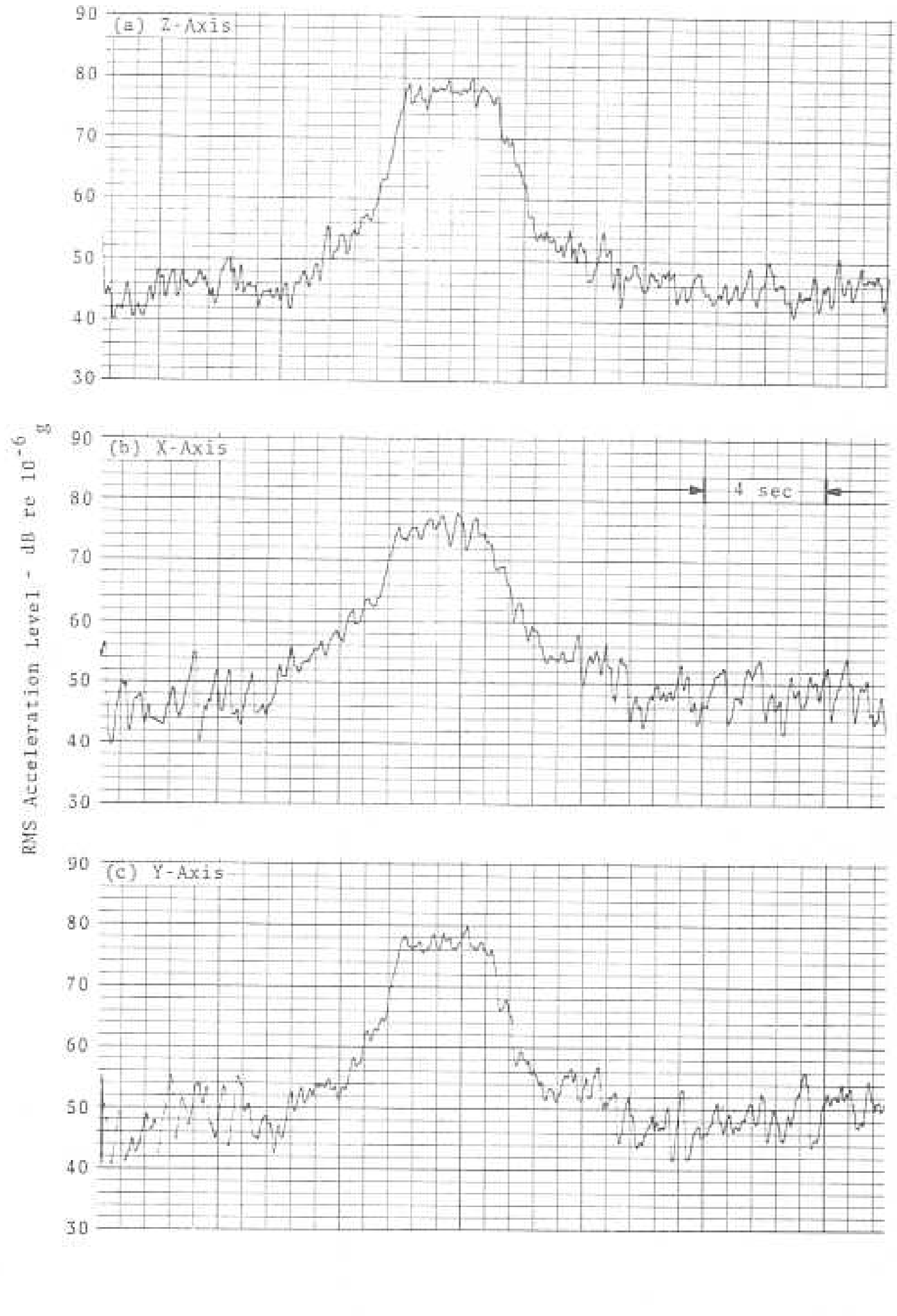


Figure B-6 Coincident Time Histories-Wayside Ground Vibration Levels in 3 Axes at a Point Offset 38 ft from Centerline of Track 3. Plainsboro, NJ 5/23/72. Six-Car Metroliner-Northbound-Speed 110 mph.

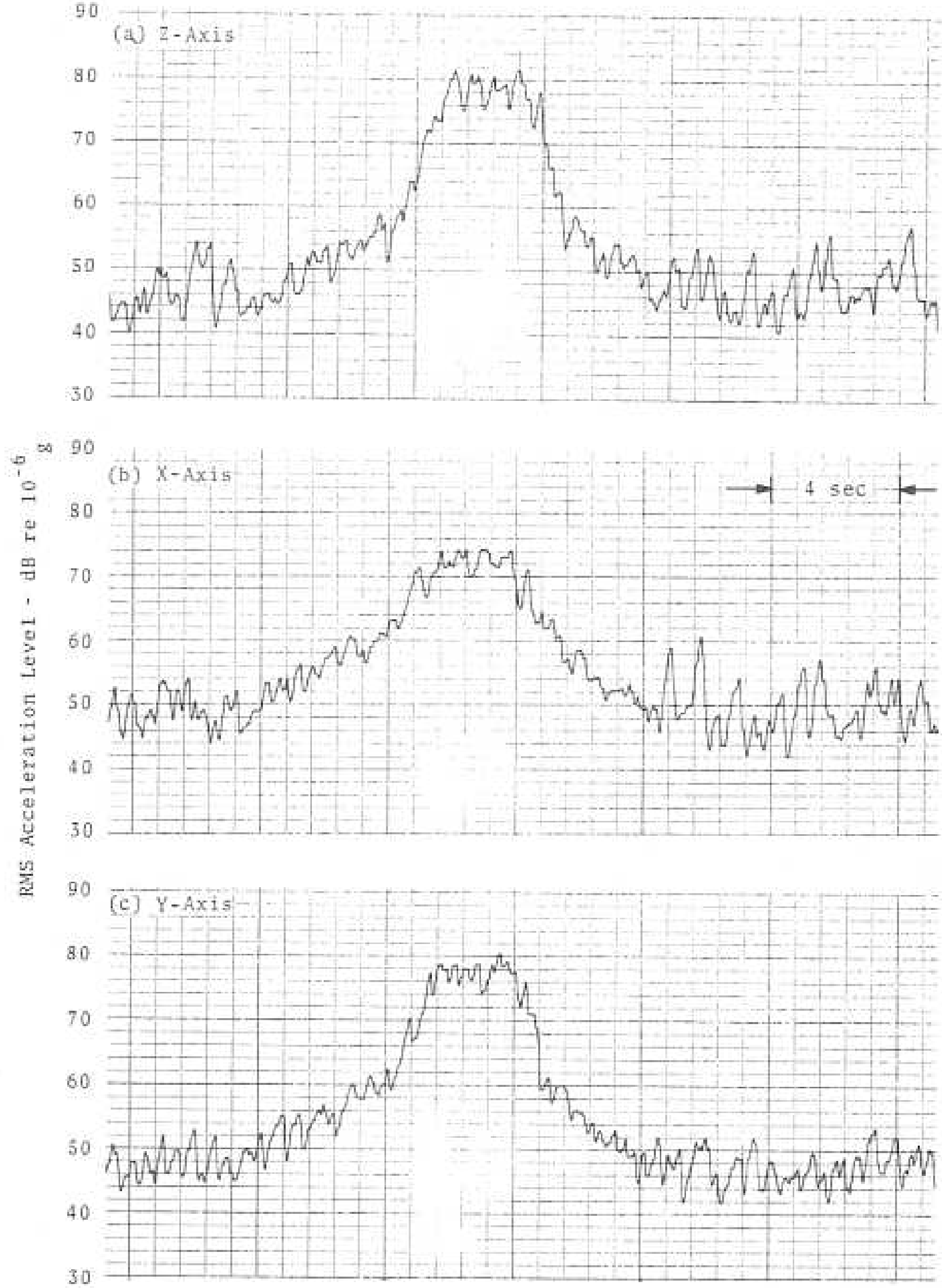
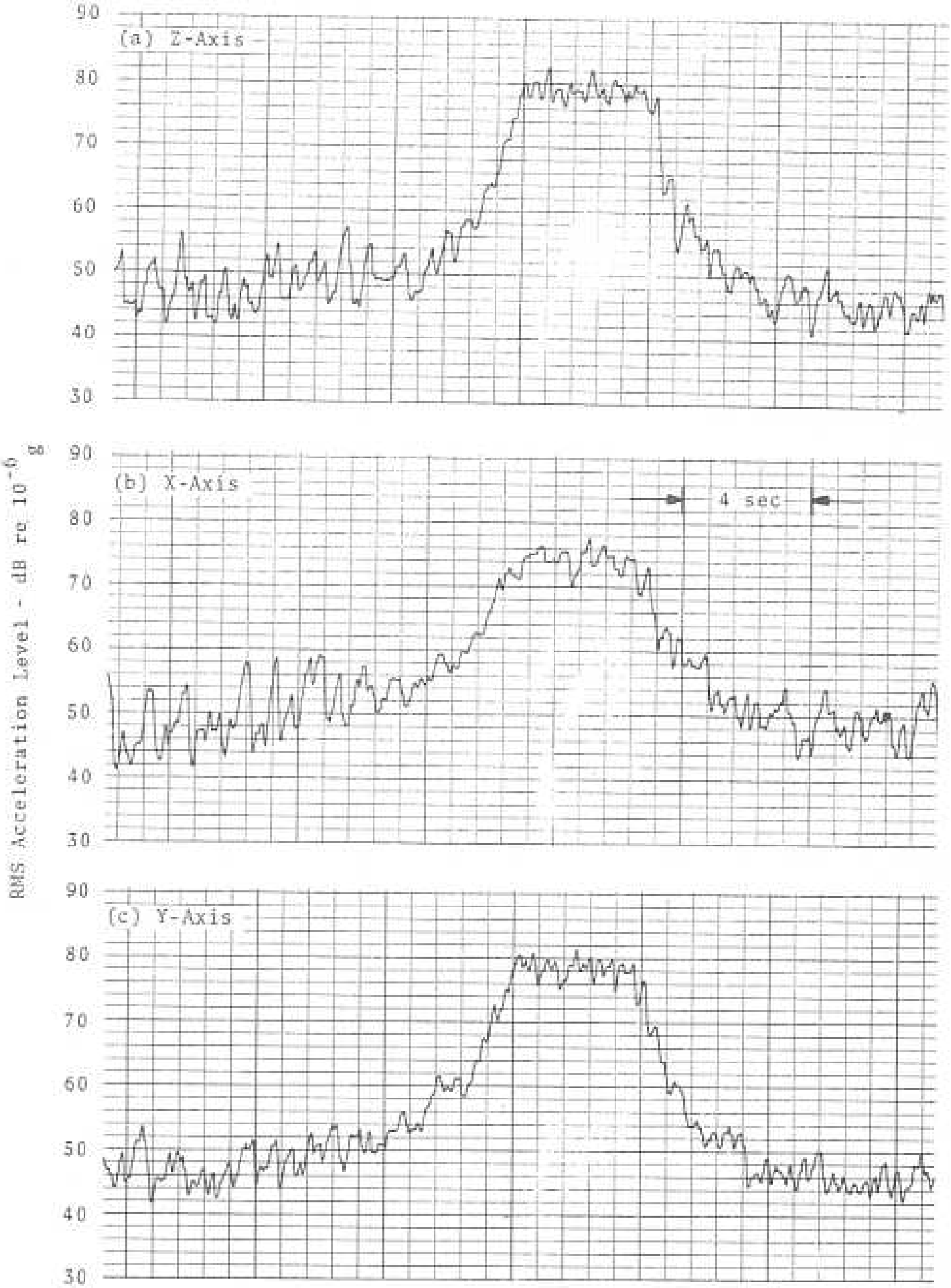


Figure B-7 Coincident Time Histories-Wayside Ground Vibration Levels in 3 Axes at a Point Offset 50 ft from the Centerline of Track 4. Plainsboro, NJ 5/23/72. Four-Car Metroliner-Northbound-Speed 80 mph.



Fibure B-8 Coincident Time Histories-Wayside Ground Vibration Levels in 3 Axes at a Point Offset 50 ft from the Centerline of Track 4. Plainsboro, NJ 5/23/72. Six-Car Metroliner-Northbound-Speed 84 mph.

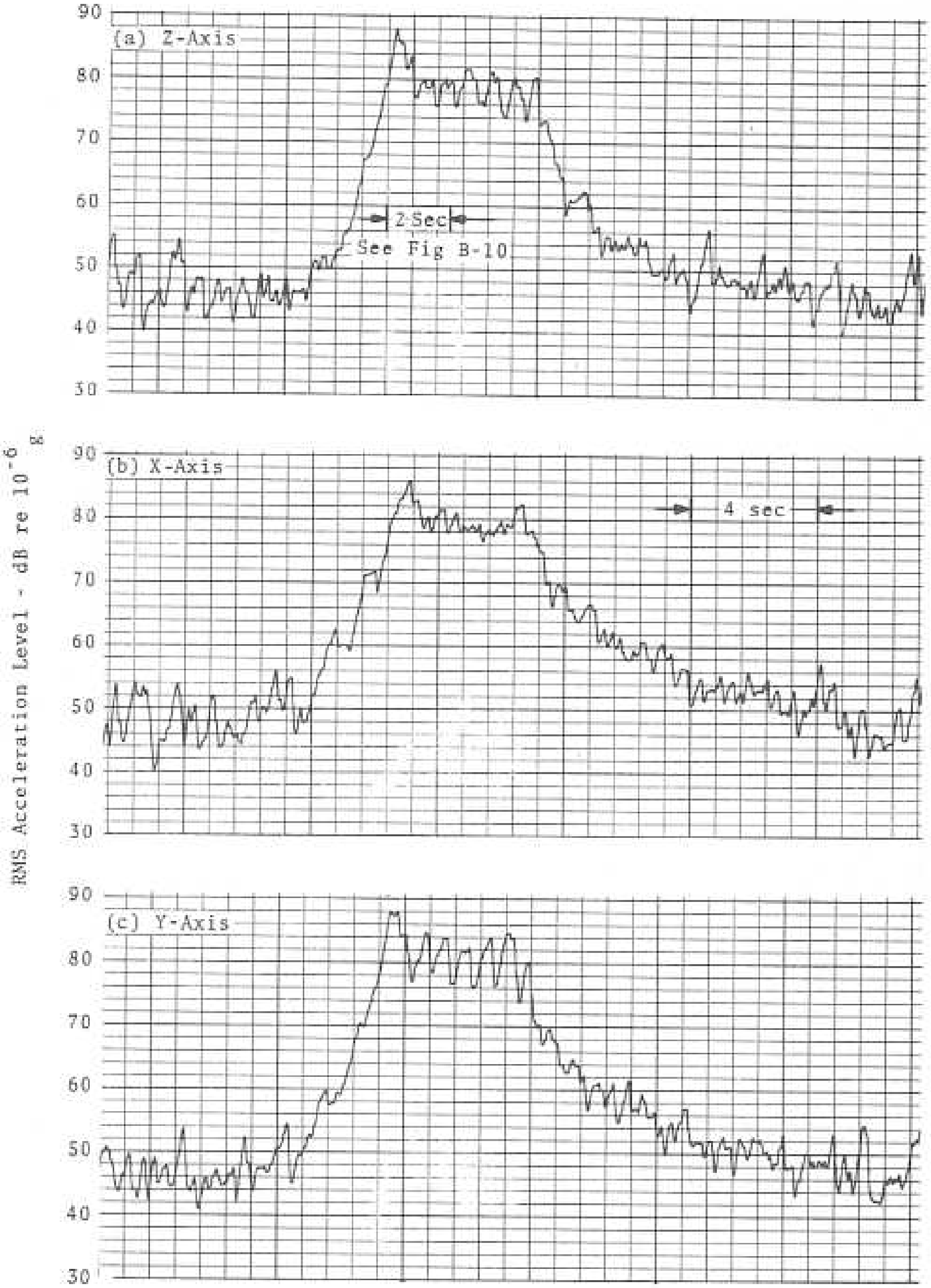


Figure B-9 Coincident Time Histories-Wayside Ground Vibration Levels in 3 Axes at a Point Offset 25 ft from the Centerline of Track 2. Plainsboro, NJ 5/23/72. 6-Car Conventional Passenger Train with One Electric Locomotive-Southbound-Speed 84 mph.

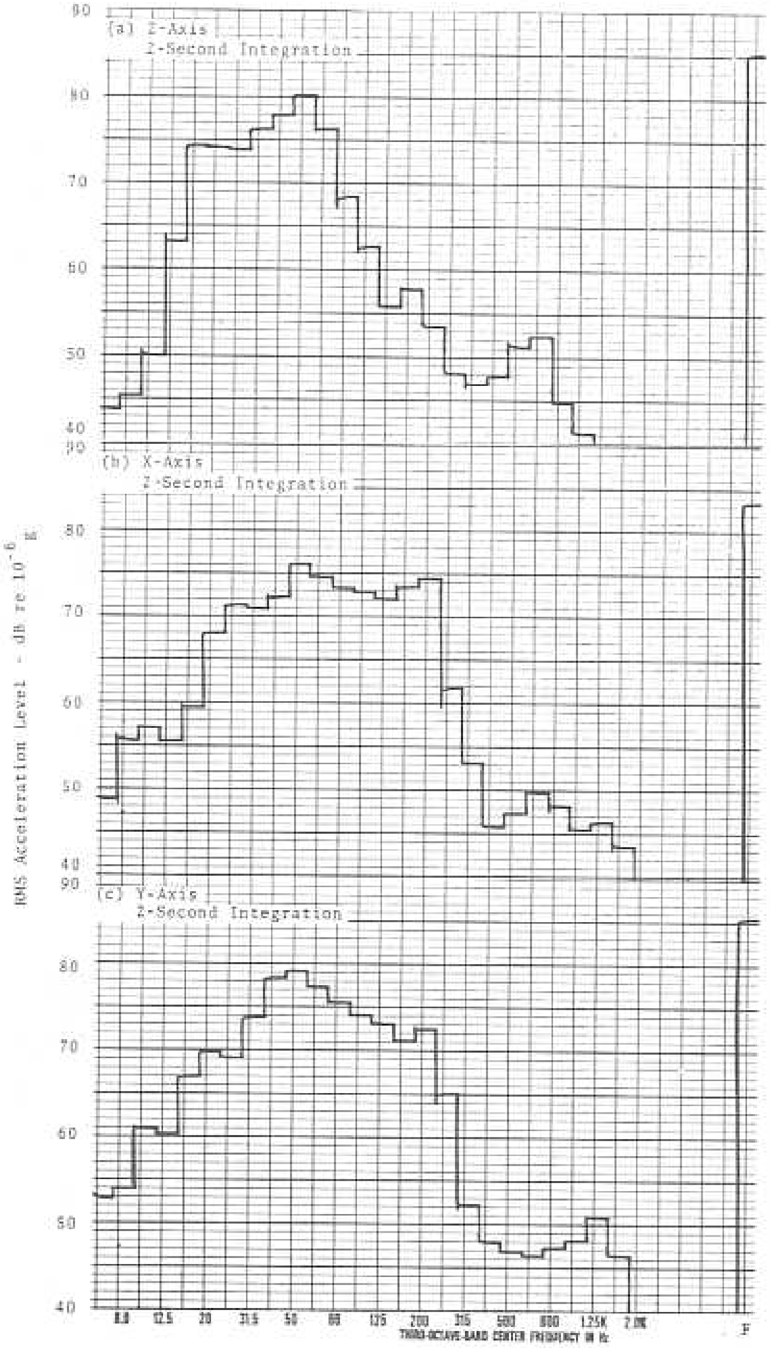


Figure B-10 Coincident Wayside Ground Vibration Spectra in 3 Axes at a Point Offset 25 ft from the Centerline of Track 2.
6-Car Conventional Passenger Train with One Electric Locomotive-Southbound-Speed 84 mph.
See Figure B-9 to Locate Period Analyzed.

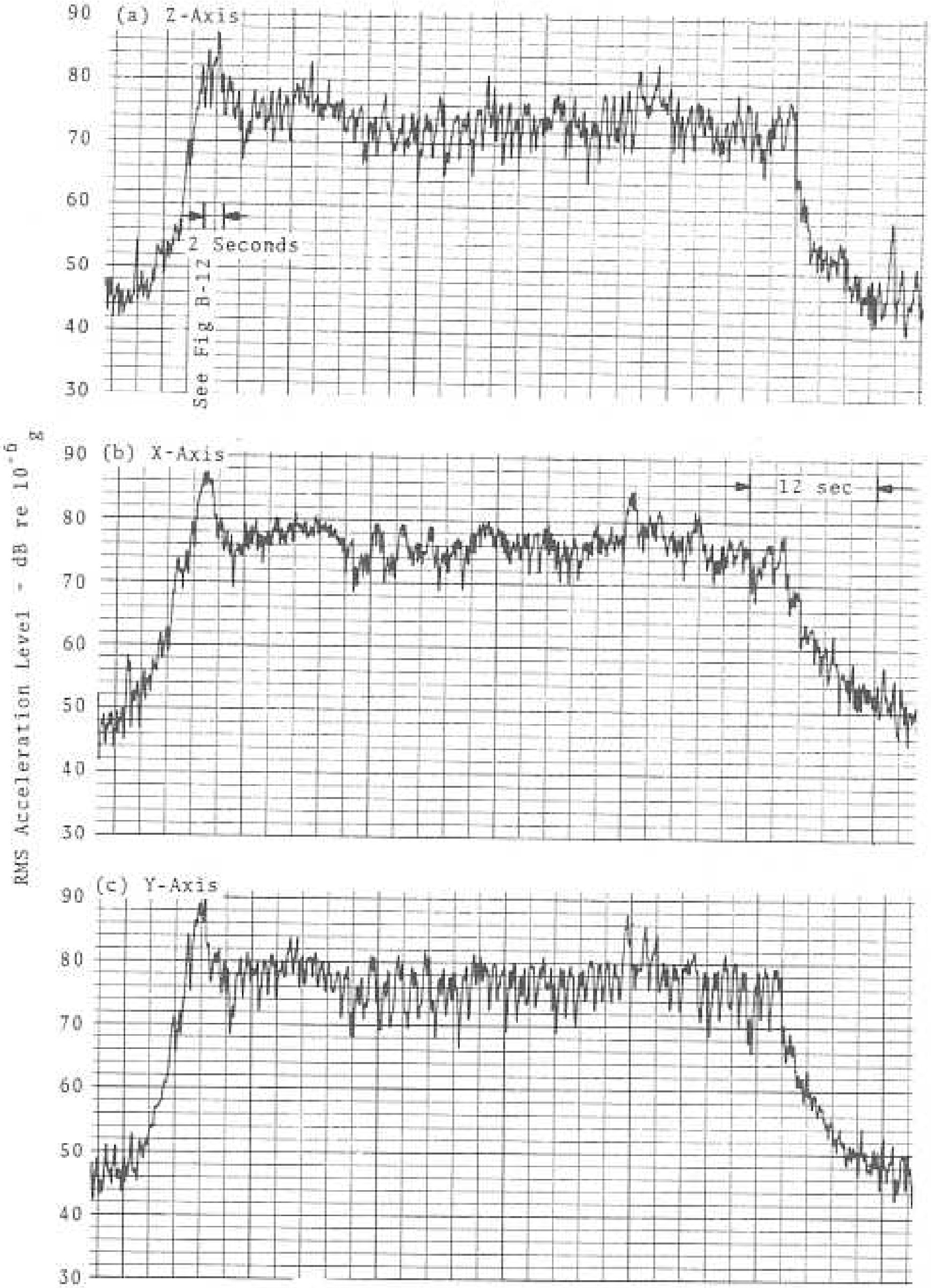


Figure B-11 Coincident Time Histories-Wayside Ground Vibration Levels in 3 Axes at a Point Offset 25 ft from Centerline of Track 2. Plainsboro, NJ 5/23/72. 63-Car Freight Train with 2 Electric Locomotives-Southbound-Speed 49 mph.

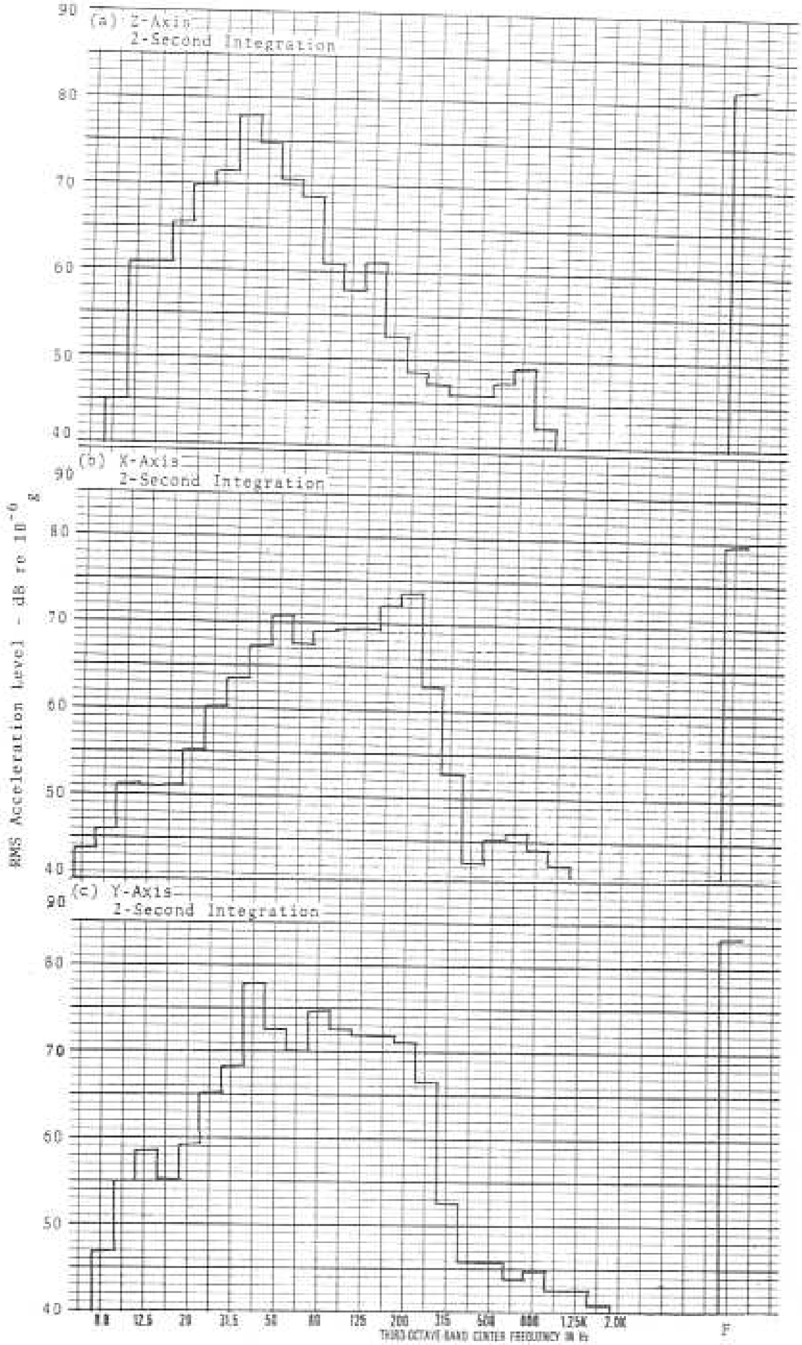


Figure B-12 Coincident Wayside Ground Vibration Spectra in 3 Axes at a Point Offset 25 ft from Centerline of Track 2. Plainsboro, NJ 5/23/72. 63-Car Freight Train with 2 Electric Locomotives-Southbound Speed 49 mph. See Figure B-11 to Locate Period Analyzed.

APPENDIX C

NOISE LEVEL DATA MEASURED AT THREE WAYSIDE LOCATIONS NEXT TO THE TRACKS OF THE PENN CENTRAL RAILROAD BOSTON-TO-NEW YORK LINE WEST MANSFIELD, MASSACHUSETTS NOVEMBER 4, 1971 AND SEPTEMBER 20 AND 26, 1972

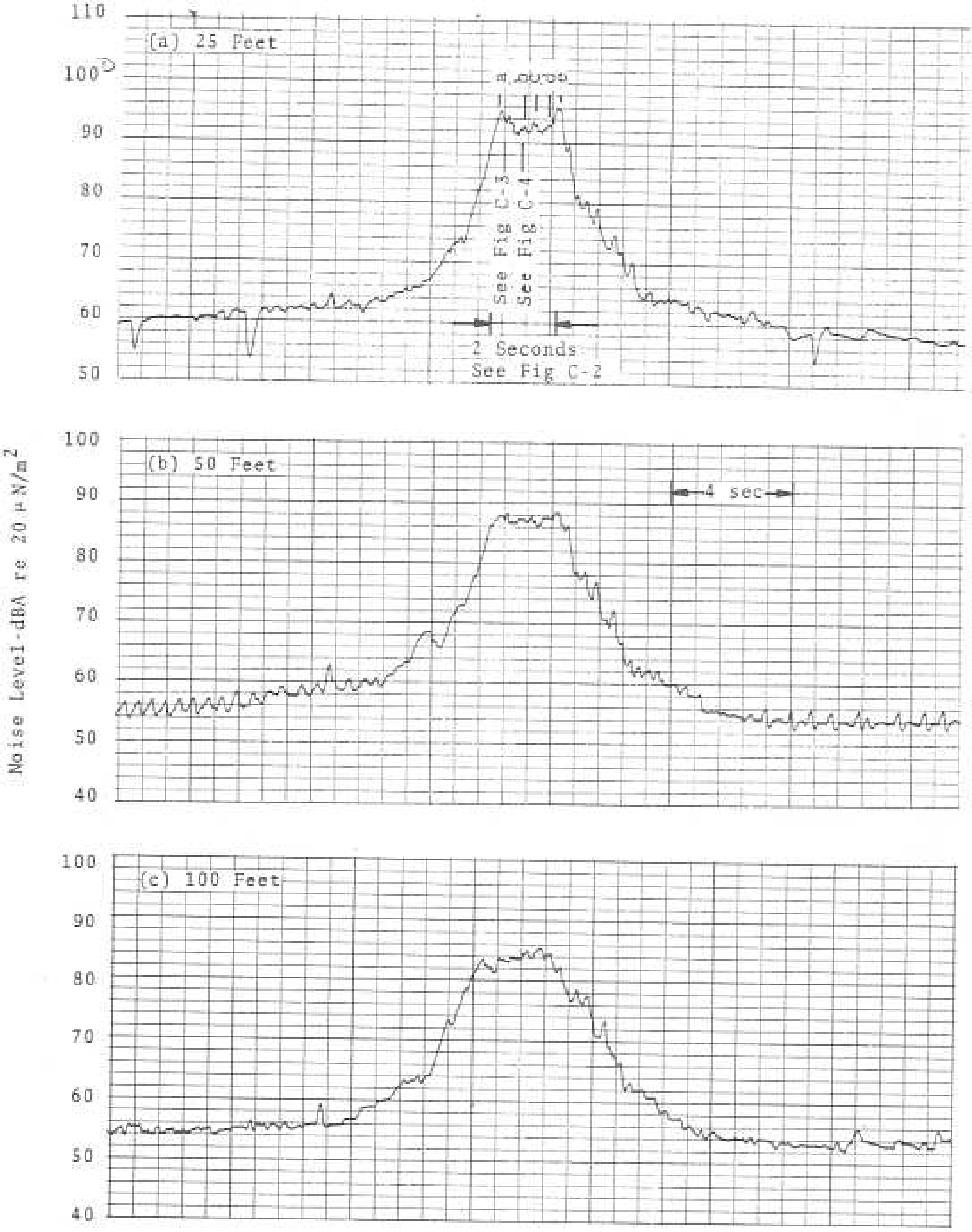


Figure C-1 Coincident Time Histories-Wayside Noise Levels 25,50 and 100 ft from Centerline of Eastbound Track, West Mansfield, MA, 9/26/72, (5-Car Turbotrain-Eastbound-Speed 97 mph.) See Figure C-5 for Westbound Data This Train.

Figure C-2 Coincident Wayside Noise Spectra Composite of Passby 25,50 and 100 ft from Centerline of Eastbound Track. West Mansfield, MA, 9/26/72 (5-Car Turbotrain-Eastbound-Speed 97 mph.) See Figure C-1 to Locate Period Analyzed.

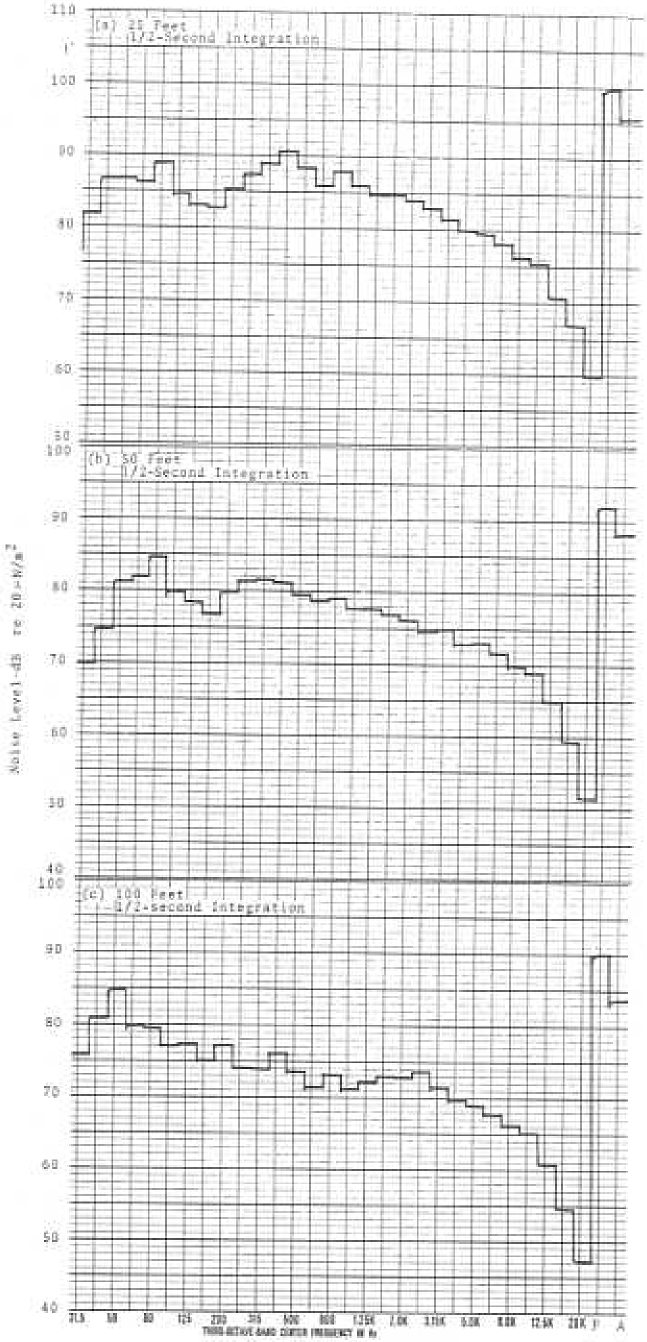


Figure C-3 Coincident Wayside Noise Spectra First Noise Peak 25,50 and 100 ft from Centerline of Eastbound Track. West Mansfield, MA, 9/26/72 (5-Car Turbotrain-Eastbound-Speed 97 mph.) See Figure C-1 to Locate Period Analyzed.

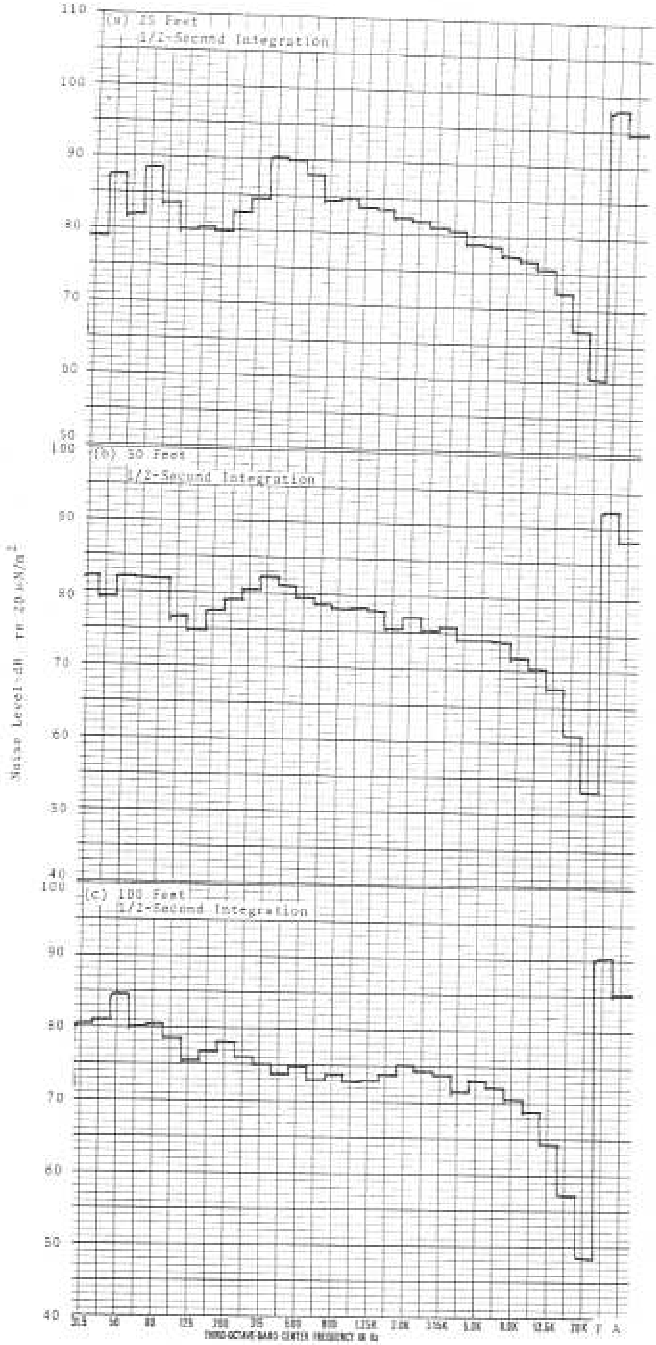


Figure C-4 Coincident Wayside Noise Spectra Quiet Period at Mid-Train 25,50 and 100 ft from Centerline of Eastbound Track. West Mansfield, MA, 9/26/72 (5-Car Turbotrain-Eastbound-Speed 97 mph.) See Figure C-1 to Locate Period Analyzed.

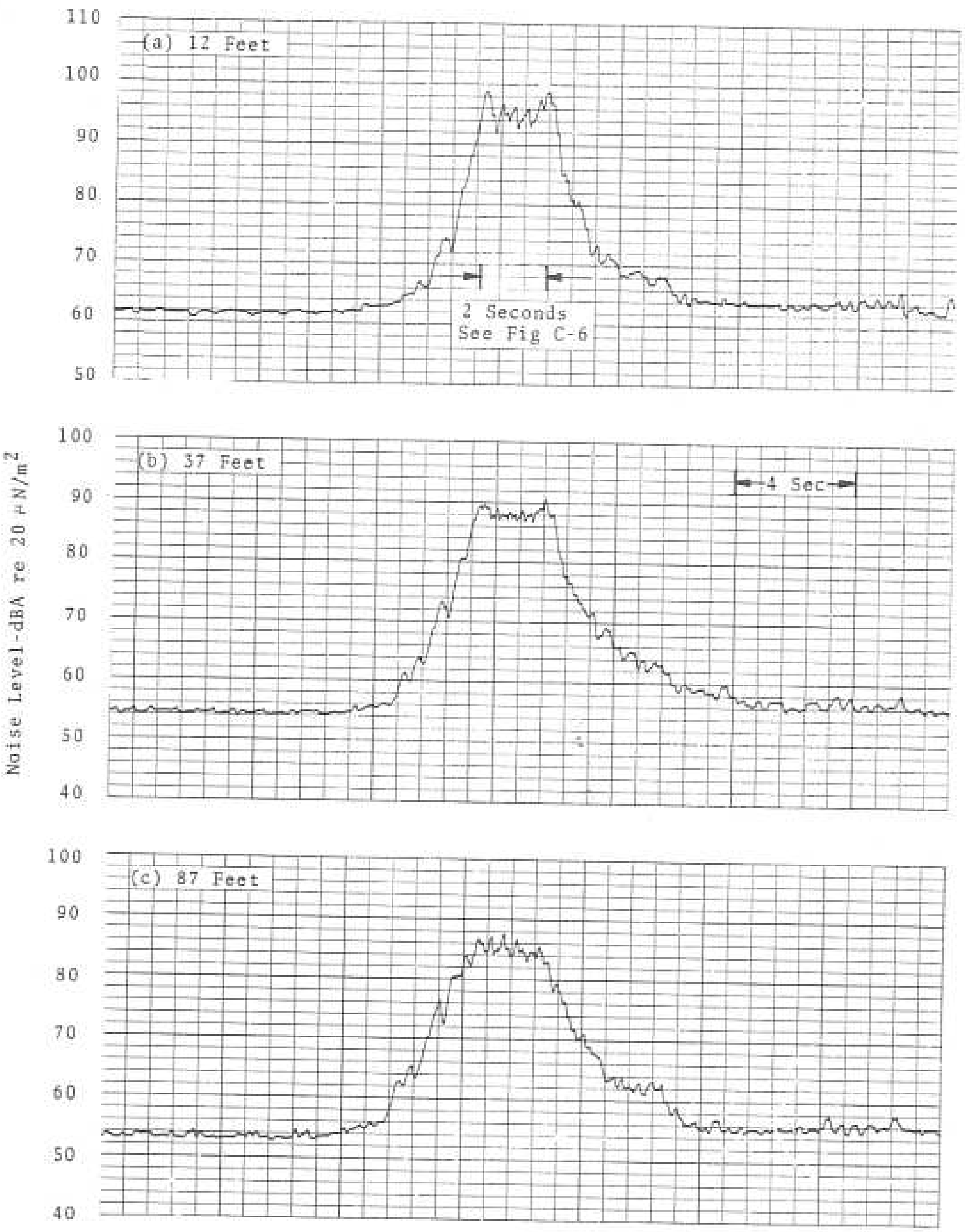


Figure C-5 Coincident Time History Wayside Noise Levels 12,37 and 87 ft from Centerline of Westbound Track. West Mansfield, MA, 9/26/72 (5-Car "Deadhead" Turbotrain-Westbound-Speed 91 mph.) See Figure C-1 for Eastbound Data This Train.

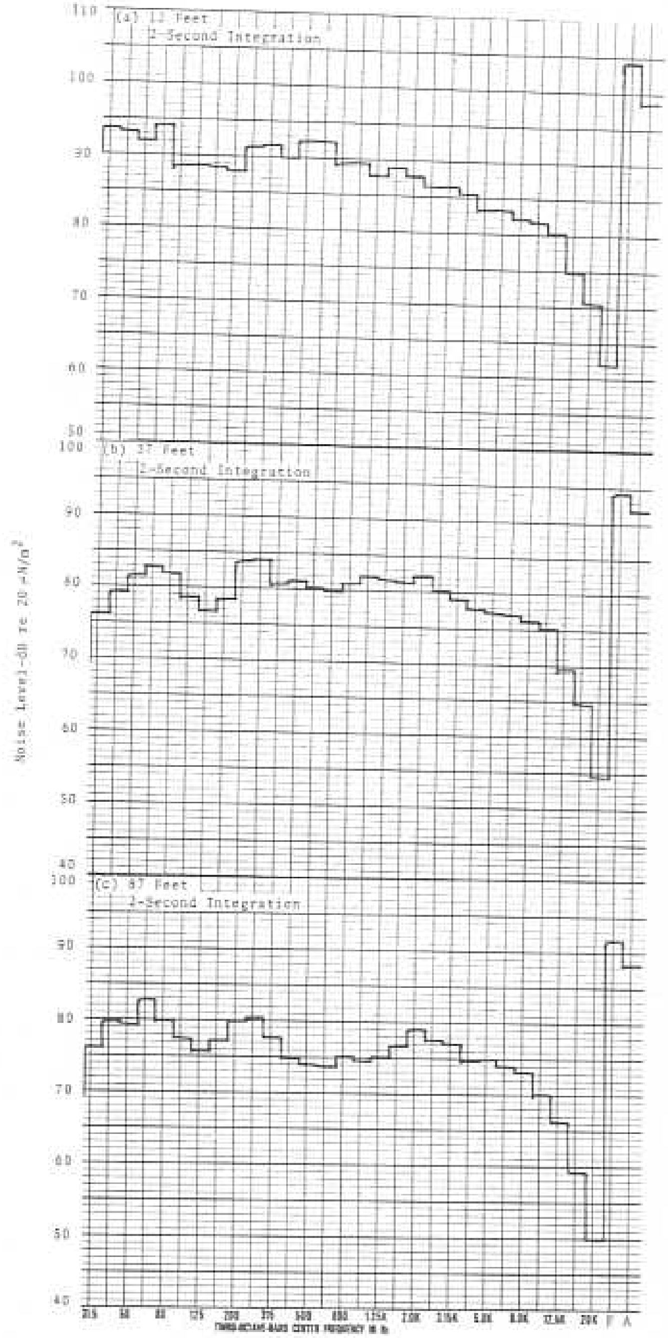


Figure C-6 Coincident Wayside Noise Spectra Composite of Passby 12,37 and 87 ft from Centerline of Westbound Track. West Mansfield, MA, 9/26/72 (5-Car "Deadhead" Turbotrain-Westbound-Speed 91 mph.) See Figure C-5 to Locate Period Analyzed.

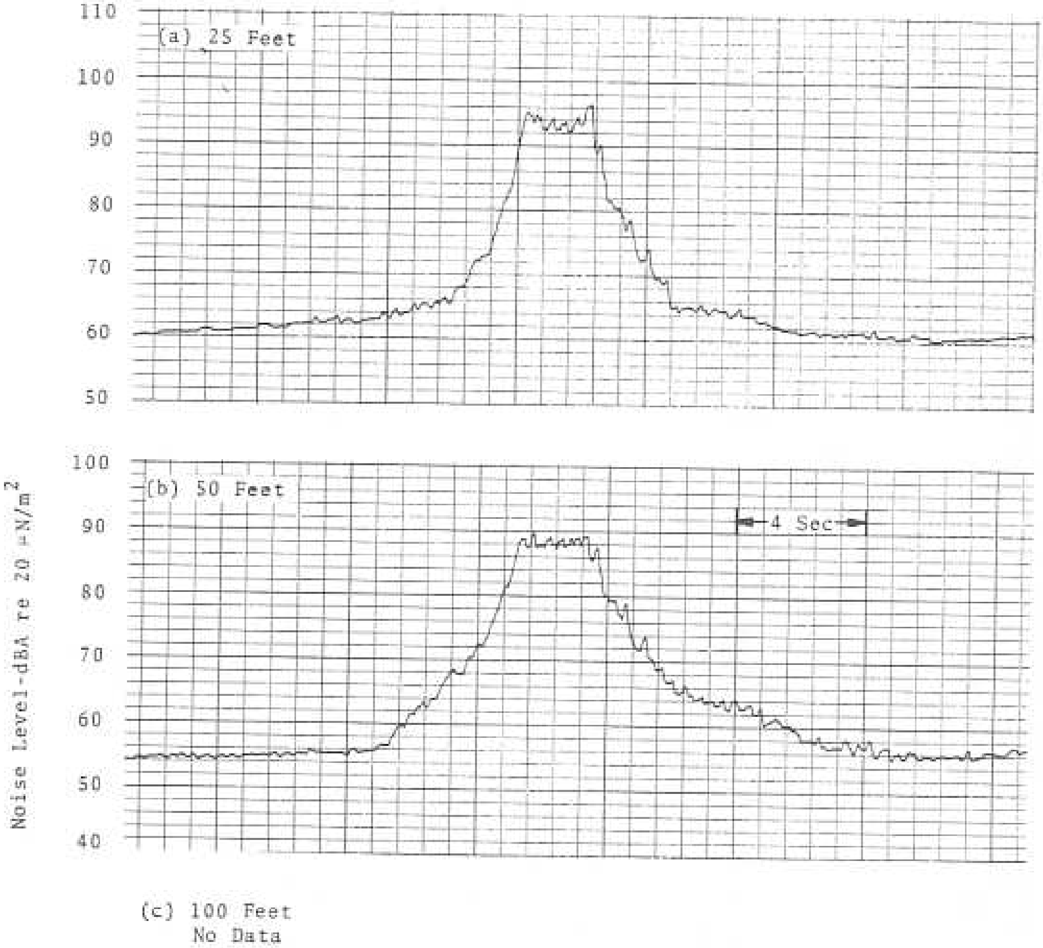


Figure C-7 Coincident Time Histories Wayside Noise Levels 25,50 and 100 ft from Centerline of Eastbound Track. West Mansfield, MA, 9/20/72 (5-Car Turbotrain-Eastbound-Speed 100 mph.) See Figure C-8 for Westbound Data This Train. See also Figure C-1 for Data This Train Measured on 9/26/72.

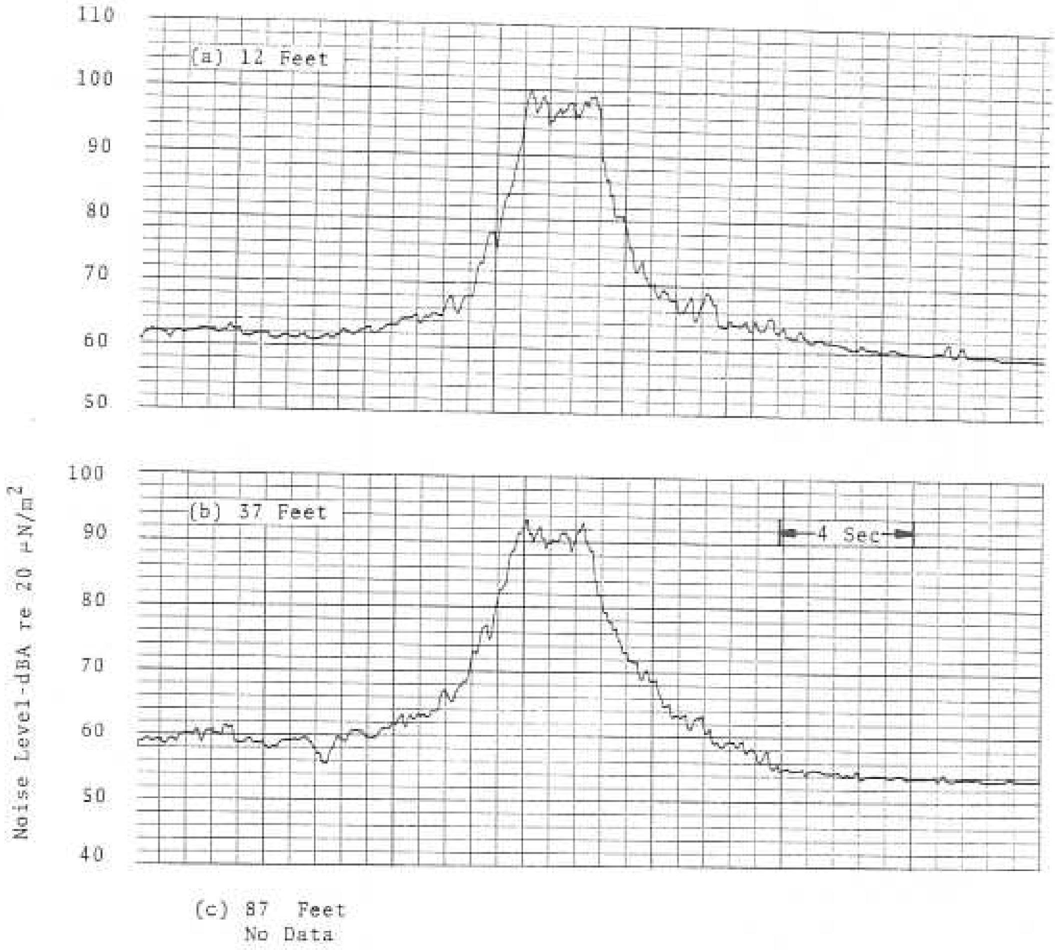
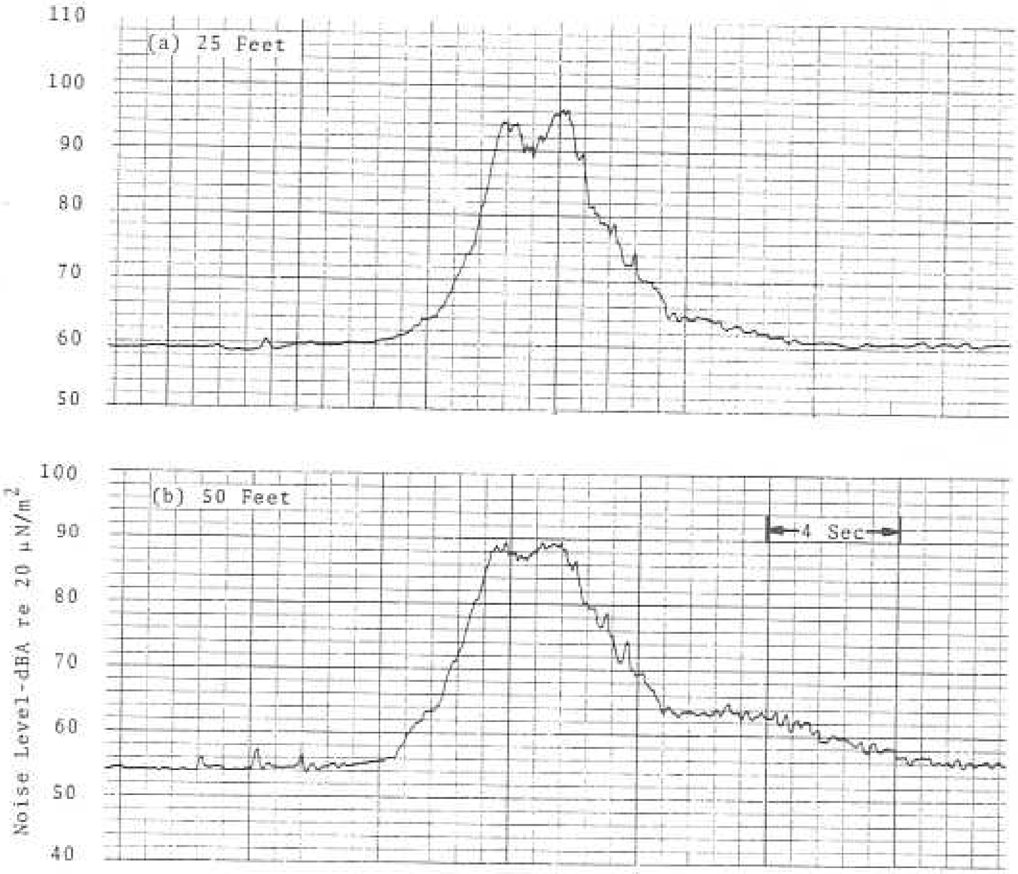


Figure C-8 Coincident Time Histories Wayside Noise Levels 12,37 and 87 ft from Centerline of Westbound Track. West Mansfield, MA, 9/20/72 (5-Car "Deadhead" Turbotrain-Westbound-Speed 97 mph) See Figure C-9 for Eastbound Data This Train. See also Figure C-5 for Data This Train Measured on 9/26/72.



(c) 100 Feet
No Data

Figure C-9 Coincident Time Histories Wayside Noise Levels 25,50 and 100 ft from Centerline of Eastbound Track, West Mansfield, MA, 9/20/72 (5-Car Turbotrain-Eastbound-Speed 90 mph.) See Figure C-10 for Westbound Data This Train.

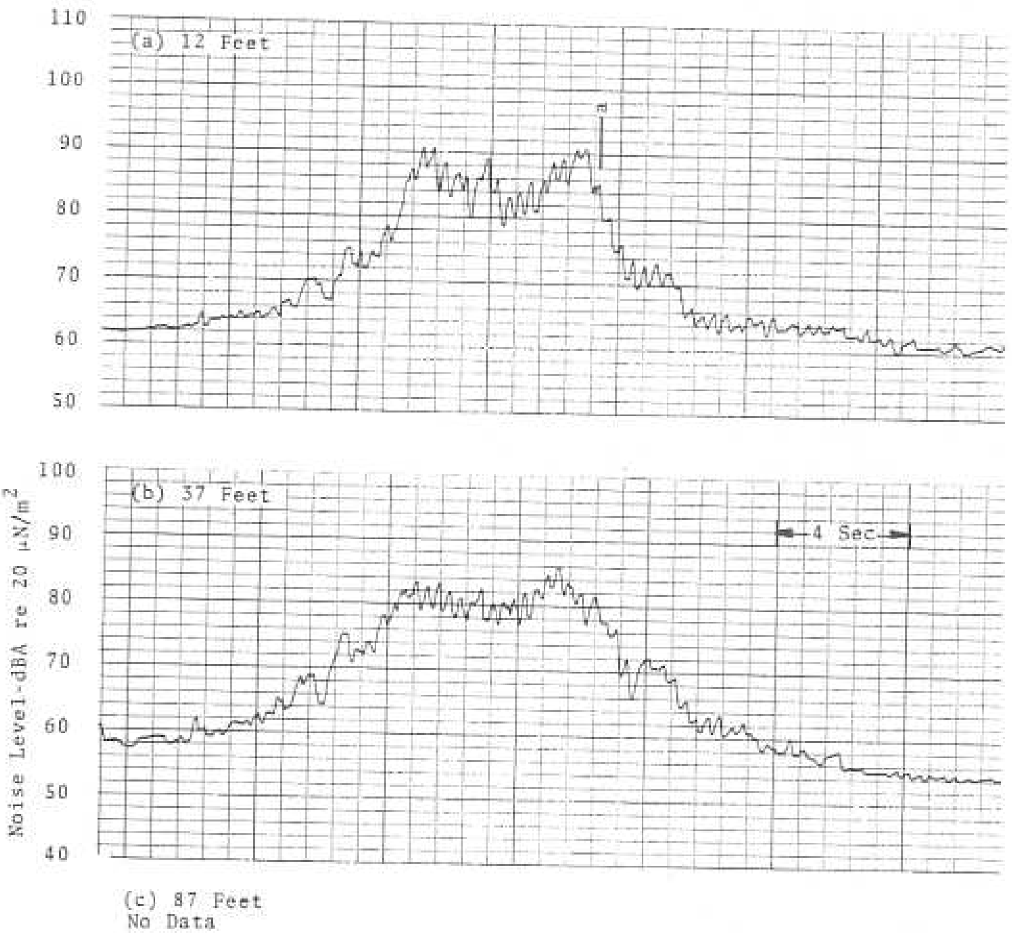


Figure C-10 Coincident Time Histories Wayside Noise Levels 25,50 and 100 ft from Centerline of Westbound Track. West Mansfield, MA, 9/20/72 (5-Car "Deadhead" Turbotrain-Westbound-Speed 40 mph) See Figure C-9 for Eastbound Data This Train.

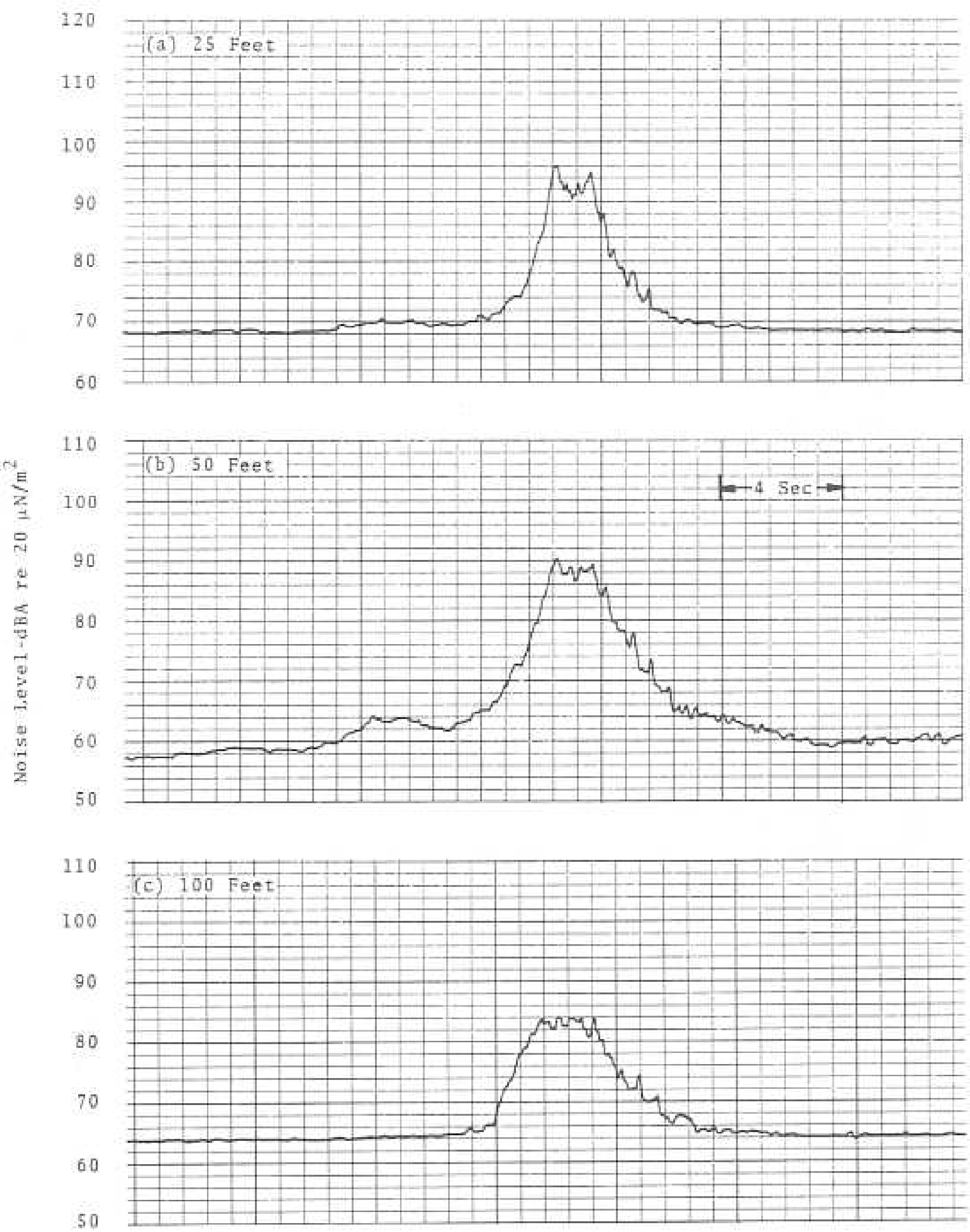


Figure C-11 Coincident Time Histories Wayside Noise Levels 25,50 and 100 ft from Centerline of Eastbound Track. West Mansfield, MA, 11/4/71 (3-Car Turbotrain-Eastbound-Speed 89 mph.) See Figure C-12 for Westbound Data This Train.

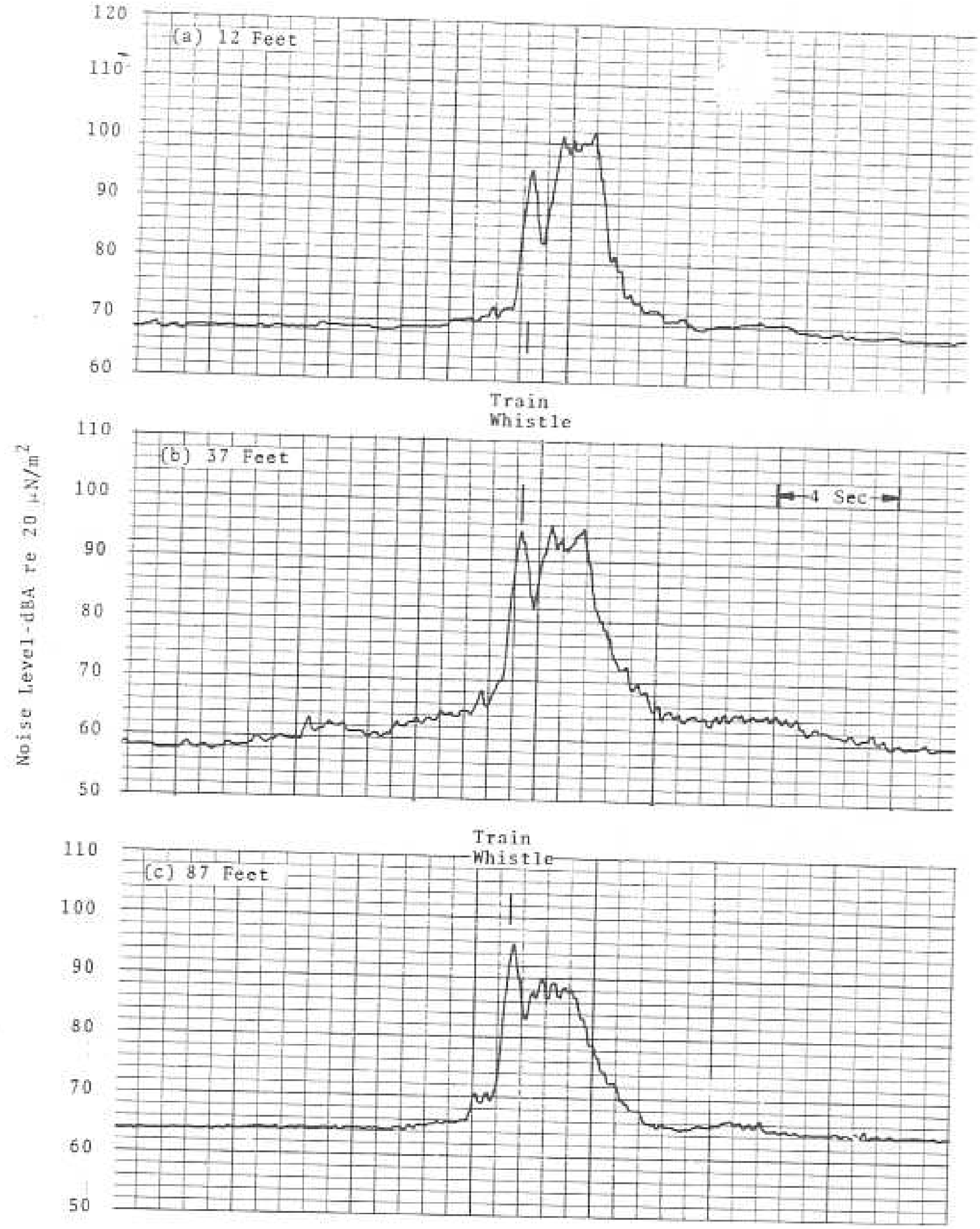


Figure C-12 Coincident Time Histories Wayside Noise Levels 12,37 and 87 feet from Centerline of Westbound Track. West Mansfield, MA, 11/4/71 (3-Car "Deadhead" Turbotrain-Westbound-Speed 104 mph.) See Figure C-11 for Eastbound Data This Train.

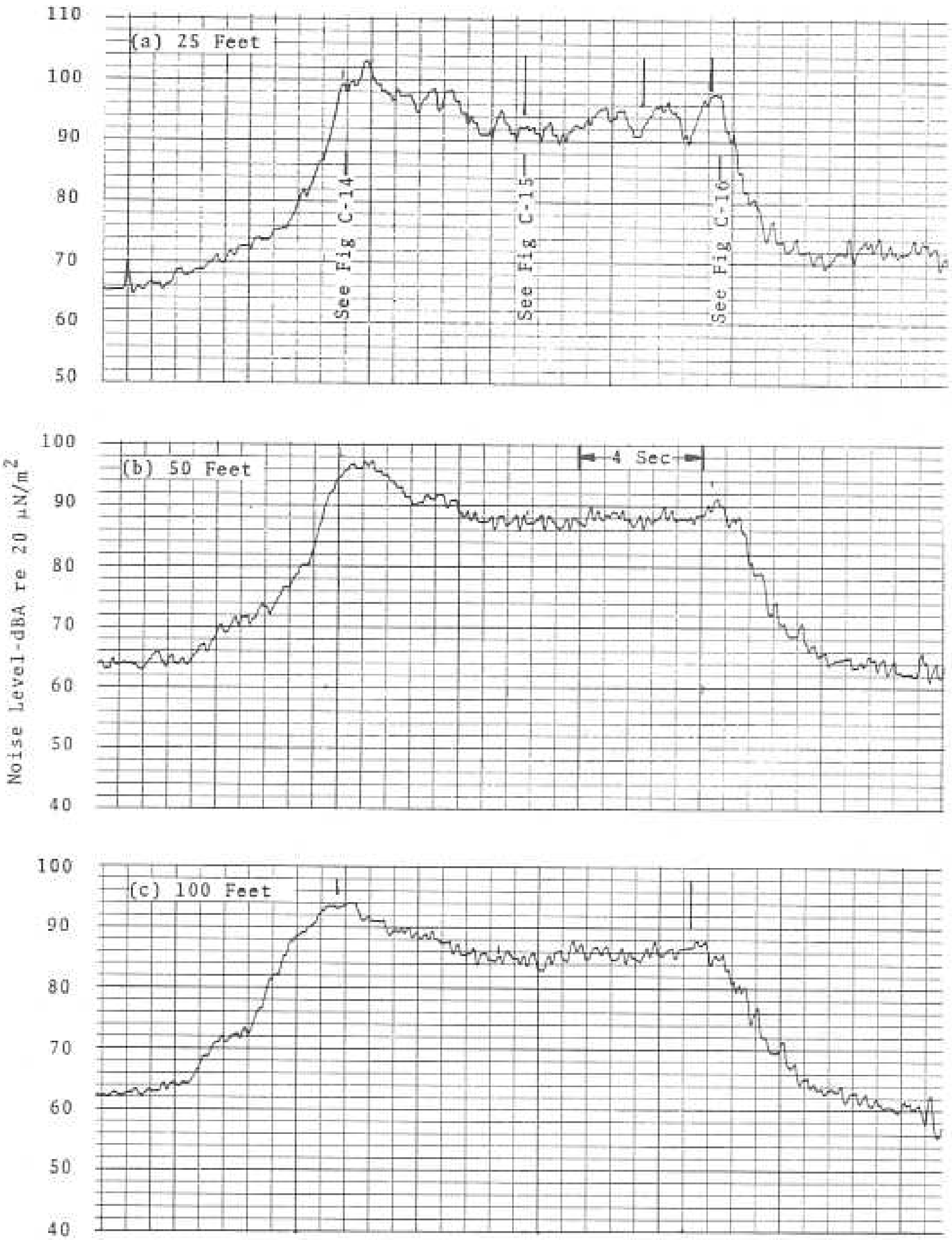


Figure C-13 Coincident Time Histories Wayside Noise Levels 25,50 and 100 ft from Centerline of Eastbound Track. West Mansfield, MA, 9/26/72 (15-Car Conventional Passenger Train with One Diesel-Powered Locomotive-Eastbound-Speed 71 mph.)

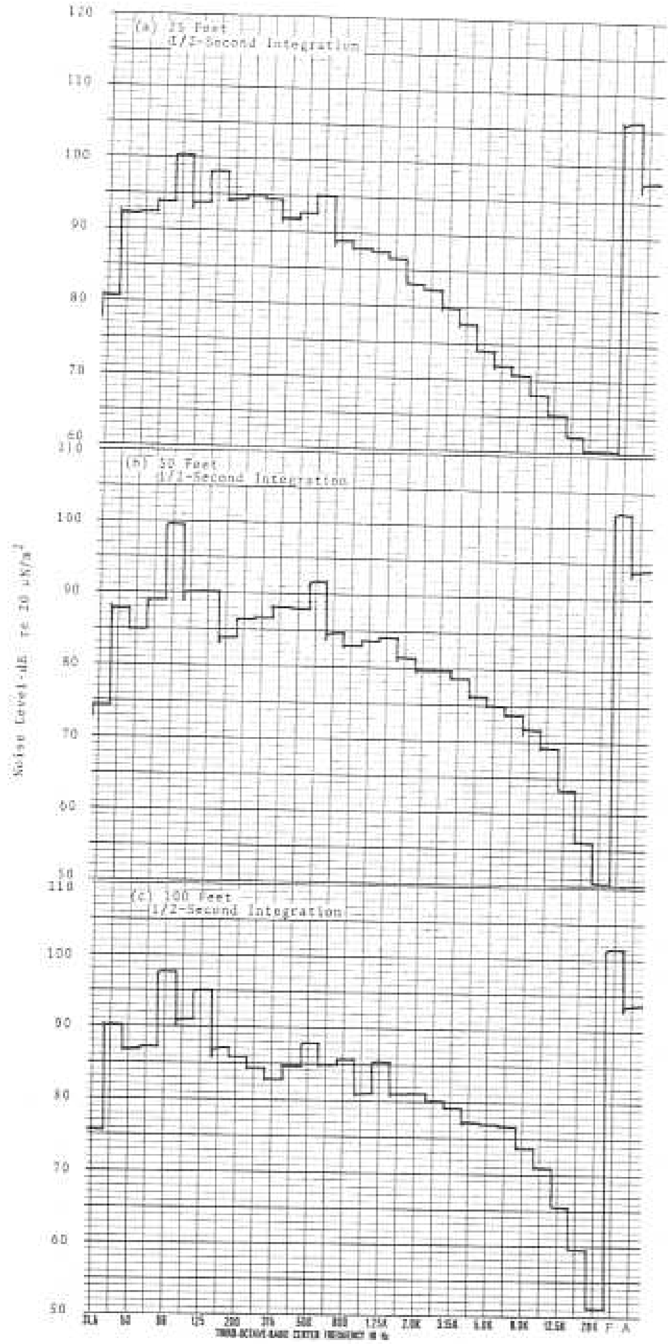


Figure C-14 Coincident Wayside Noise Spectra Engine Passby 25,50 and 100 ft from Centerline of Eastbound Track. West Mansfield, MA, 9/26/72 (15-Car Conventional Passenger Train with One Diesel-Powered Locomotive-Eastbound-Speed 71 mph.) See Figure C-13 to Locate Period Analyzed.

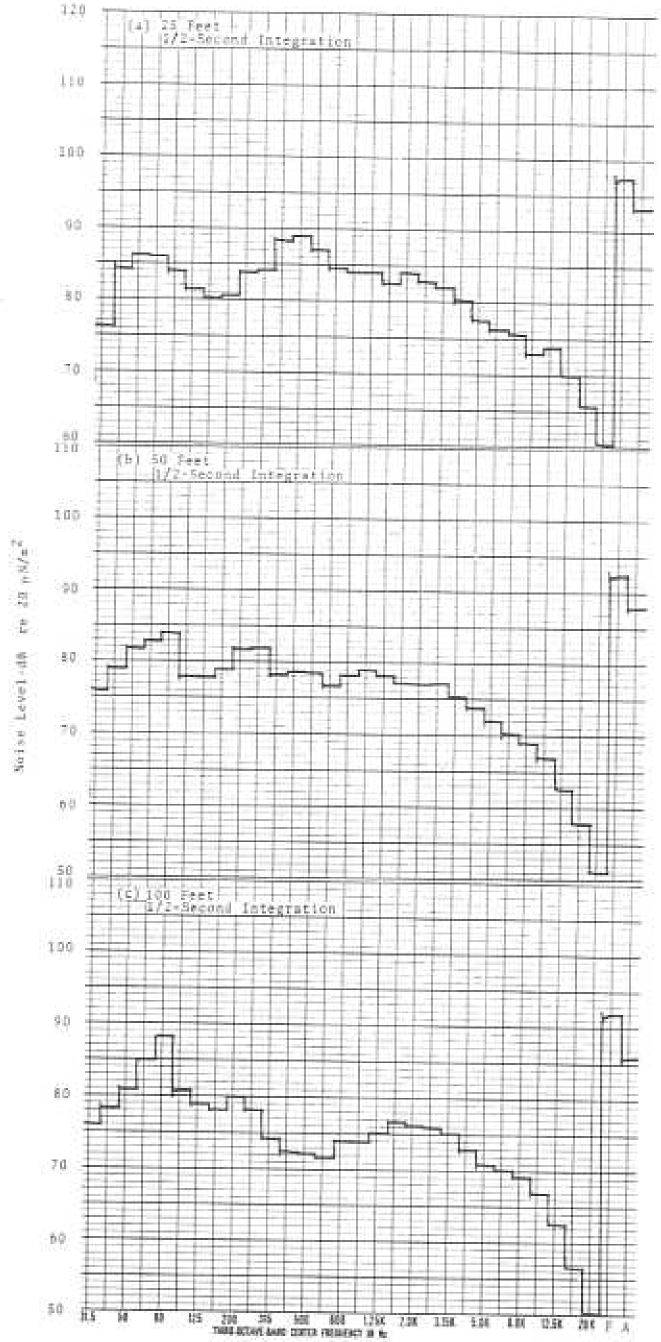


Figure C-15 Coincident Wayside Noise Spectra Quiet Period at Mid-Train 25,50 and 100 ft from Centerline of Eastbound Track. West Mansfield, MA, 9/26/72 (15-Car Conventional Passenger Train with One Diesel-Powered Locomotive-Eastbound-Speed 71 mph.) See Figure C-13 to Locate Period Analyzed.

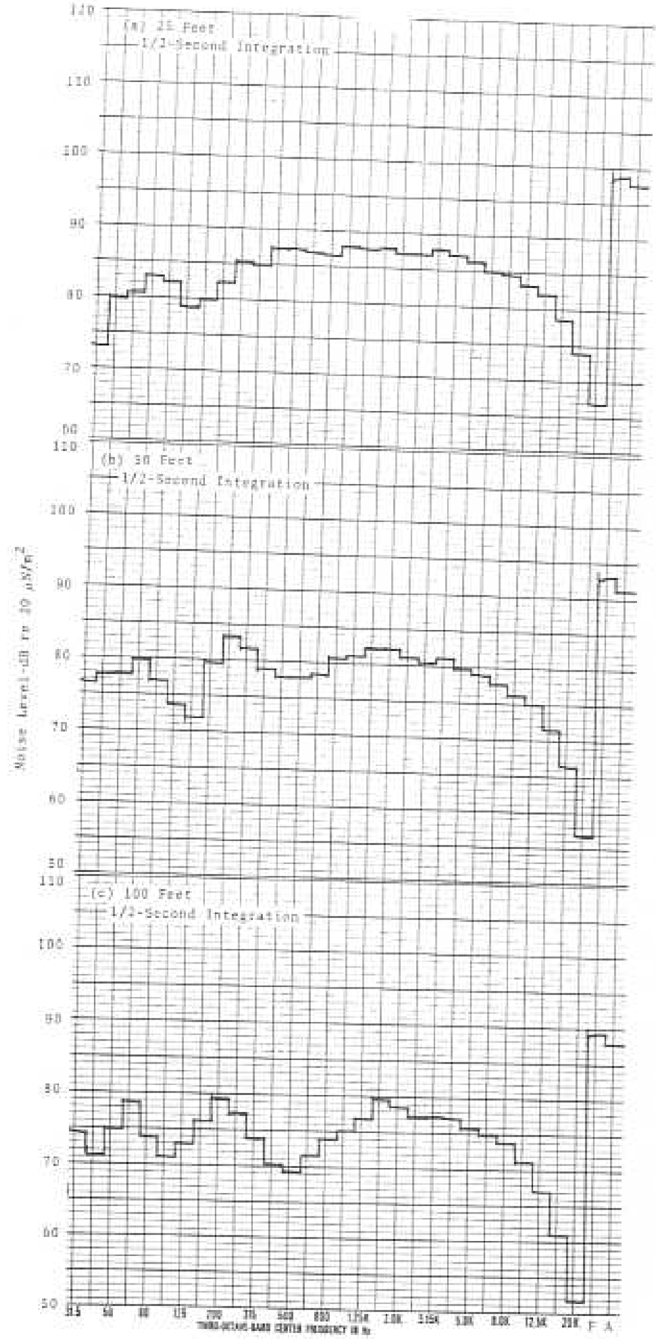


Figure C-16 Coincident Wayside Noise Spectra Noisy Period at End of Train 25,50 and 100 ft from Centerline of Eastbound Track. West Mansfield, MA, 9/26/72 (15-Car Conventional Passenger Train with One Diesel-Powered Locomotive-Eastbound-Speed 71 mph.) See Figure C-13 to Locate Period Analyzed.

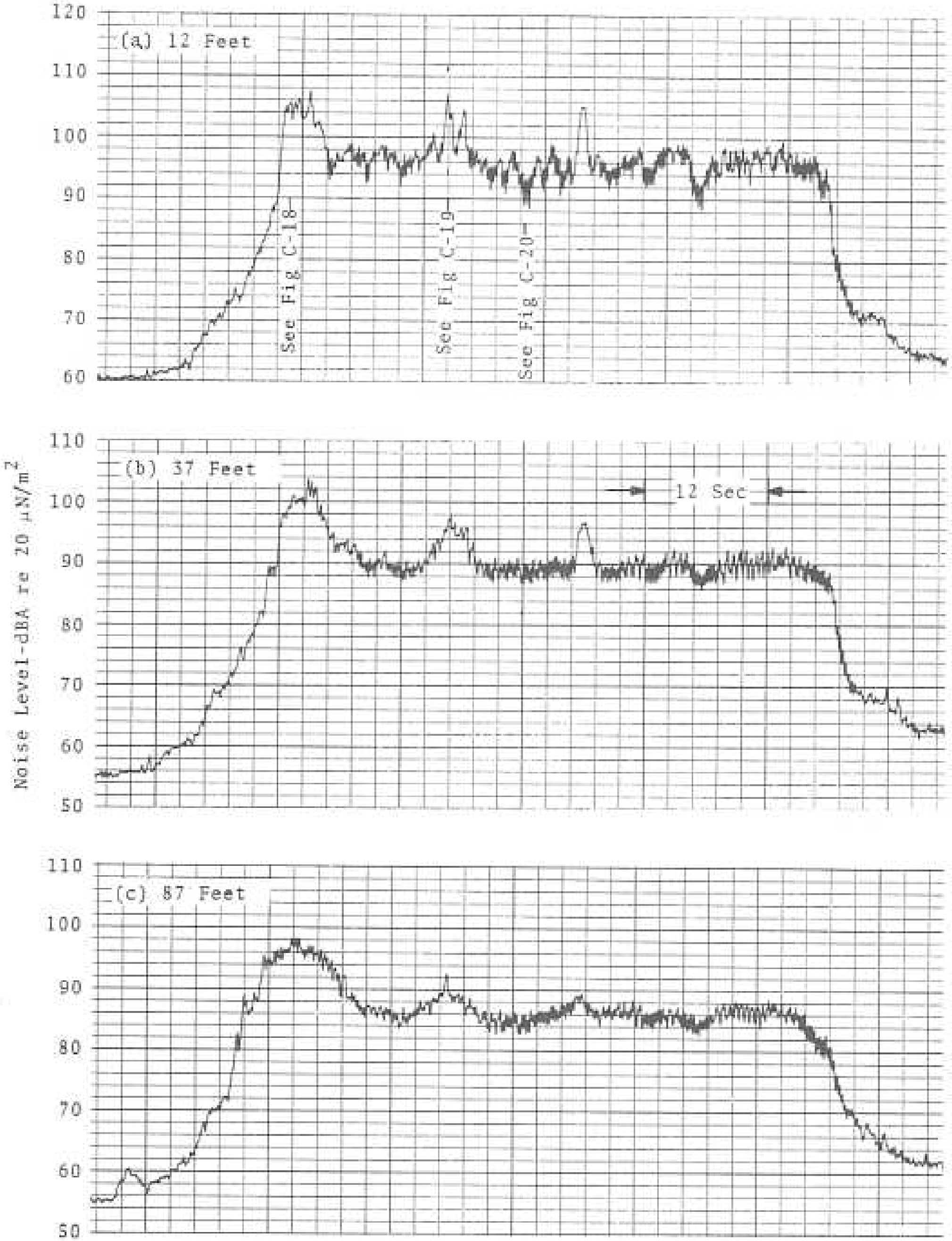


Figure C-17 Coincident Time Histories Wayside Noise Levels 12,37 and 87 ft from Centerline of Westbound Track. West Mansfield, MA, 9/26/72 (70-Car Freight Train with 5-Diesel-Powered Locomotives-Westbound-Speed 50 mph.)

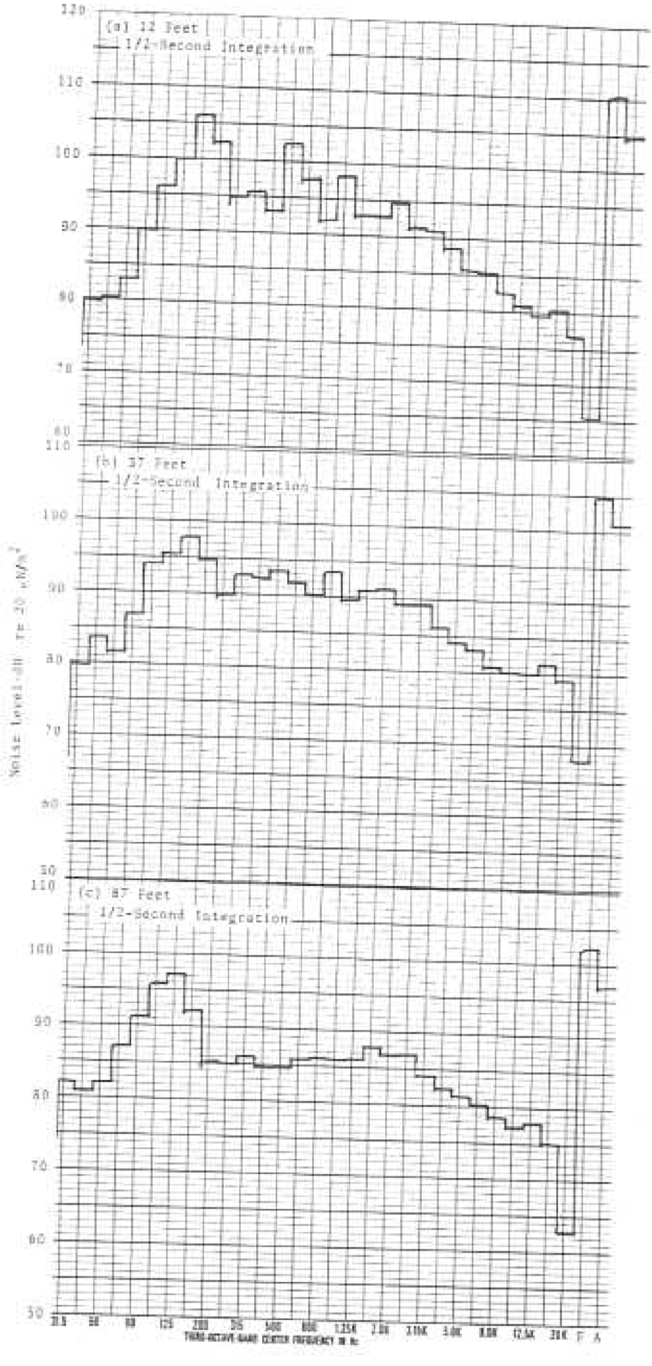


Figure C-18 Coincident Wayside Noise Spectra Engine Passby 12,37 and 87 ft from Centerline of Westbound Track. West Mansfield, MA, 9/26/72 (70-Car Freight Train with 5-Diesel-Powered Locomotives-Westbound-Speed 50 mph.) See Figure C-17 to Locate Period Analyzed.

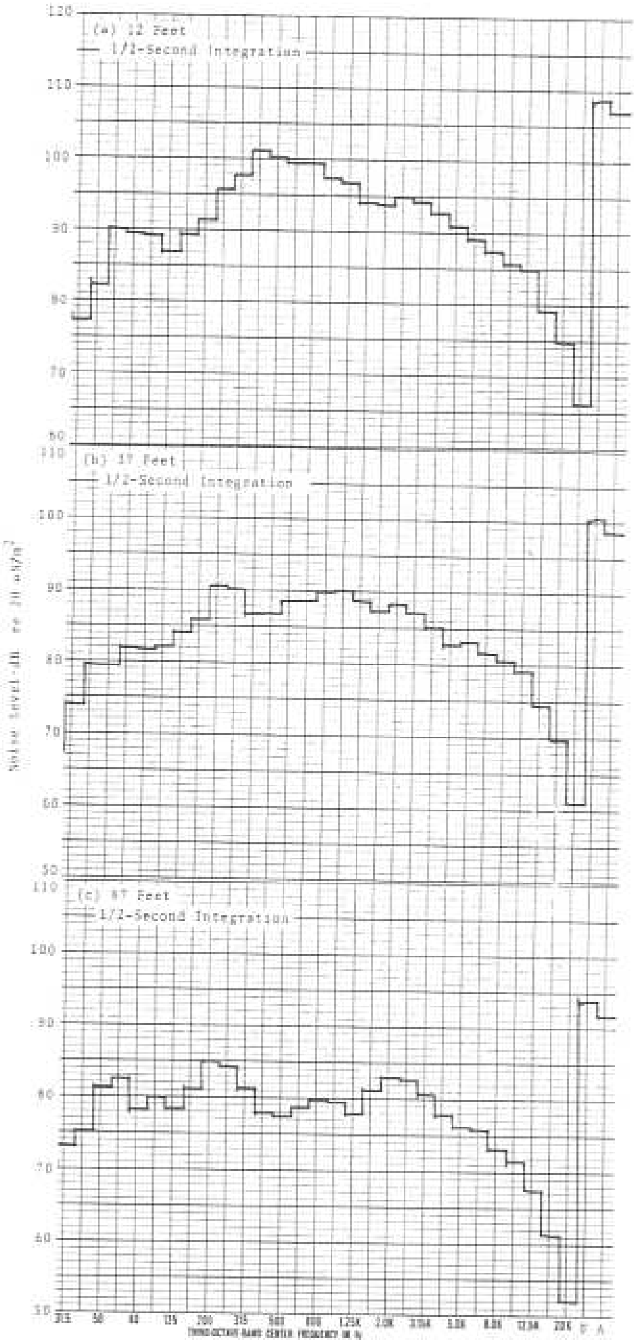


Figure C-19 Coincident Wayside Noise Level Noisy Period at Mid-Train 12,37 and 87 ft from Centerline of Westbound Track. West Mansfield, MA, 9/26/72 (70-Car Freight Train with 5-Diesel-Powered Locomotives-Westbound-Speed 50 mph.) See Figure C-17 to Locate Period Analyzed.

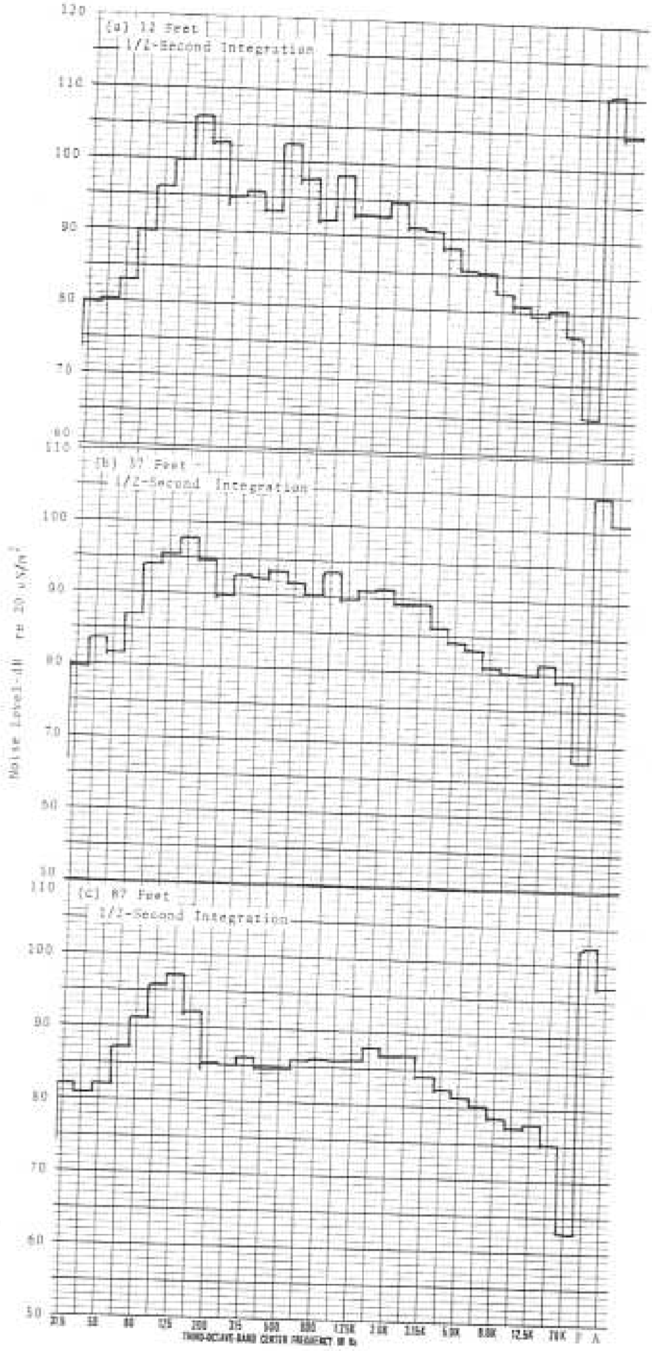


Figure C-18 Coincident Wayside Noise Spectra Engine Passby 12,37 and 87 ft from Centerline of Westbound Track. West Mansfield, MA, 9/26/72 (70-Car Freight Train with 5-Diesel-Powered Locomotives-Westbound-Speed 50 mph.) See Figure C-17 to Locate Period Analyzed.

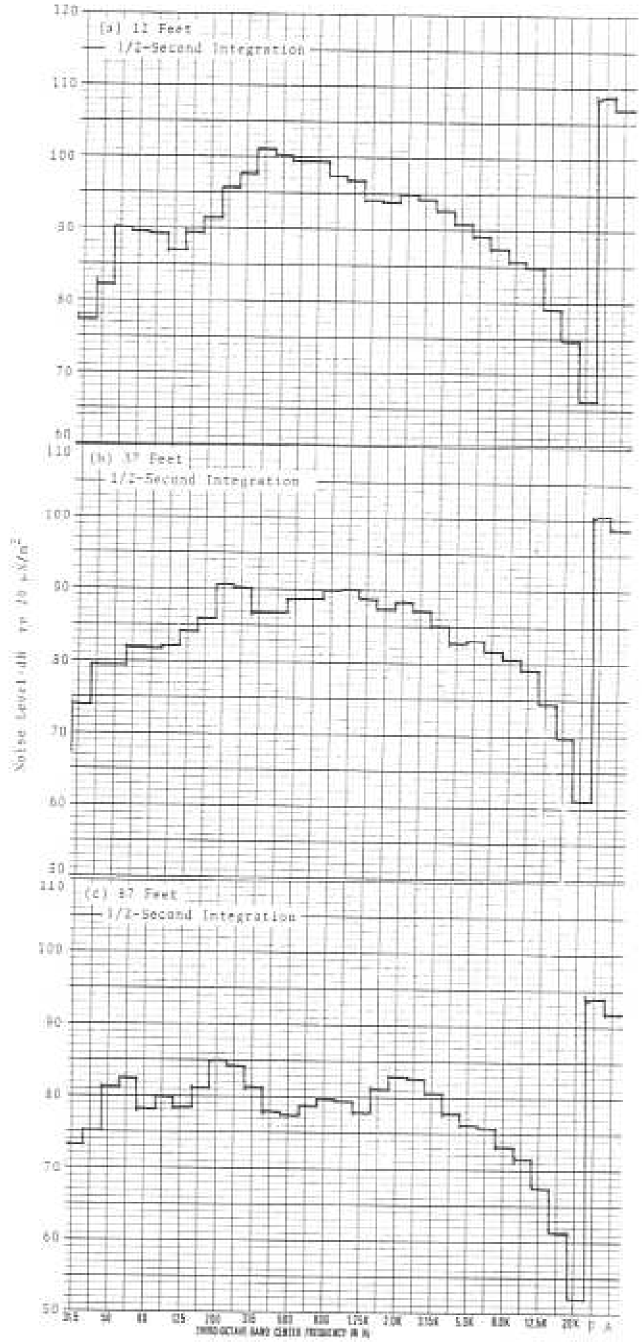


Figure C-19 Coincident Wayside Noise Level Noisy Period at Mid-Train 12,37 and 87 ft from Centerline of Westbound Track. West Mansfield, MA, 9/26/72 (70-Car Freight Train with 5-Diesel-Powered Locomotives-Westbound-Speed 50 mph.) See Figure C-17 to Locate Period Analyzed.

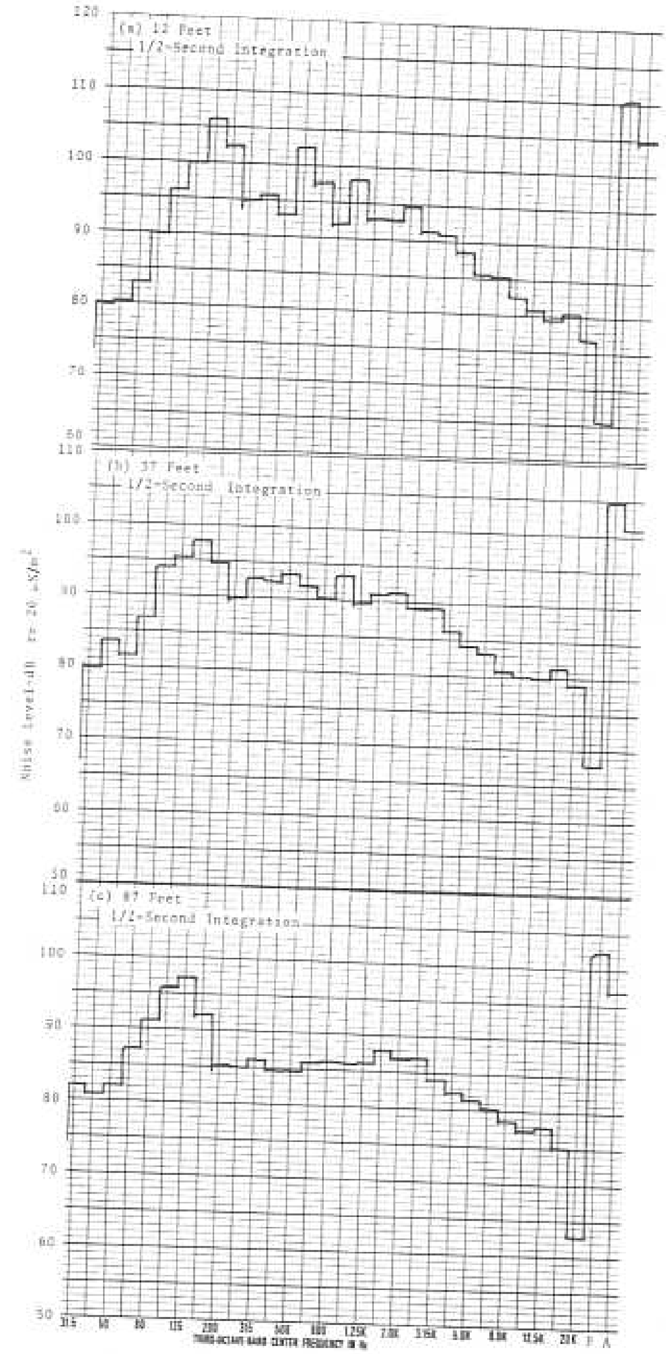


Figure C-18 Coincident Wayside Noise Spectra Engine Passby 12,37 and 87 ft from Centerline of Westbound Track. West Mansfield, MA, 9/26/72 (70-Car Freight Train with 5-Diesel-Powered Locomotives-Westbound-Speed 50 mph.) See Figure C-17 to Locate Period Analyzed.

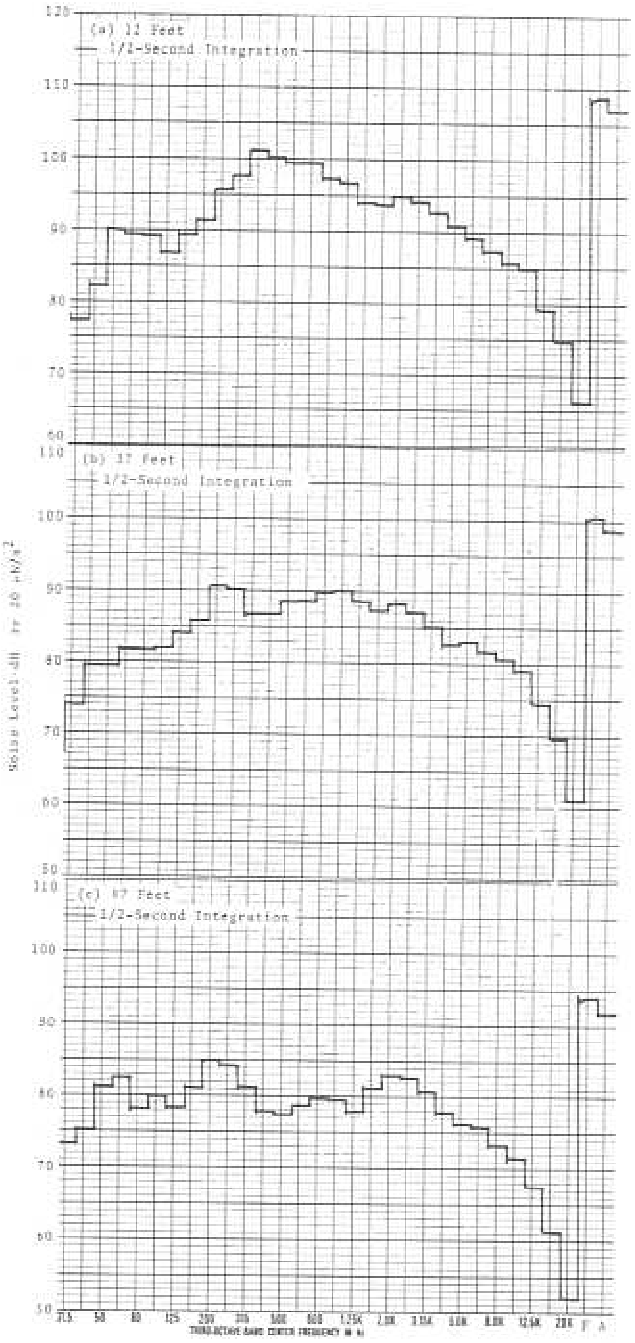


Figure C-19 Coincident Wayside Noise Level Noisy Period at Mid-Train 12,37 and 87 ft from Centerline of Westbound Track. West Mansfield, MA, 9/26/72 (70-Car Freight Train with 5-Diesel-Powered Locomotives-Westbound-Speed 50 mph.) See Figure C-17 to Locate Period Analyzed.

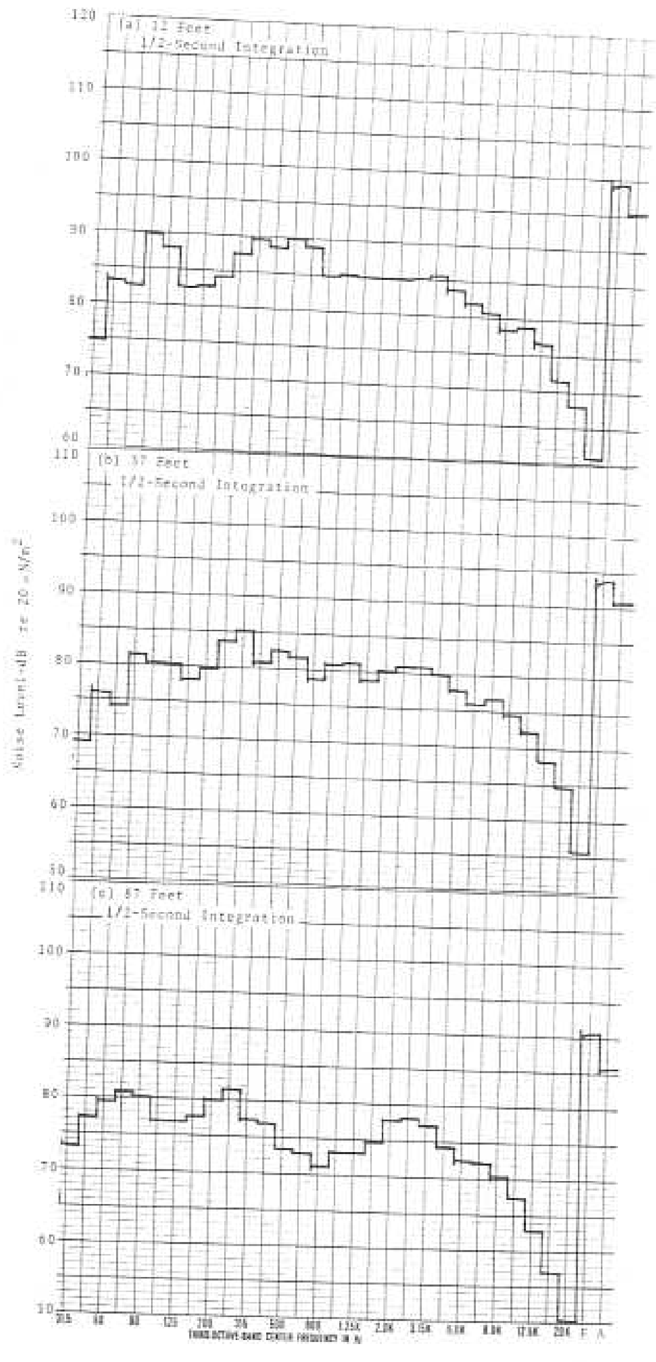


Figure C-20 Coincident Wayside Noise Levels Quiet Period at Mid-Train 12,37 and 87 ft from Centerline of Westbound Track. West Mansfield, MA, 9/26/72 (70-Car Freight Train with 5-Diesel-Powered Locomotives-Westbound-Speed 50 mph.)

APPENDIX D

THREE-AXIS WAYSIDE GROUND VIBRATION DATA

MEASURED NEXT TO THE TRACKS OF THE

PENN CENTRAL RAILROAD

BOSTON-TO-NEW YORK LINE

WEST MANSFIELD, MASSACHUSETTS

NOVEMBER 4, 1971 AND SEPTEMBER 20 AND 26, 1972

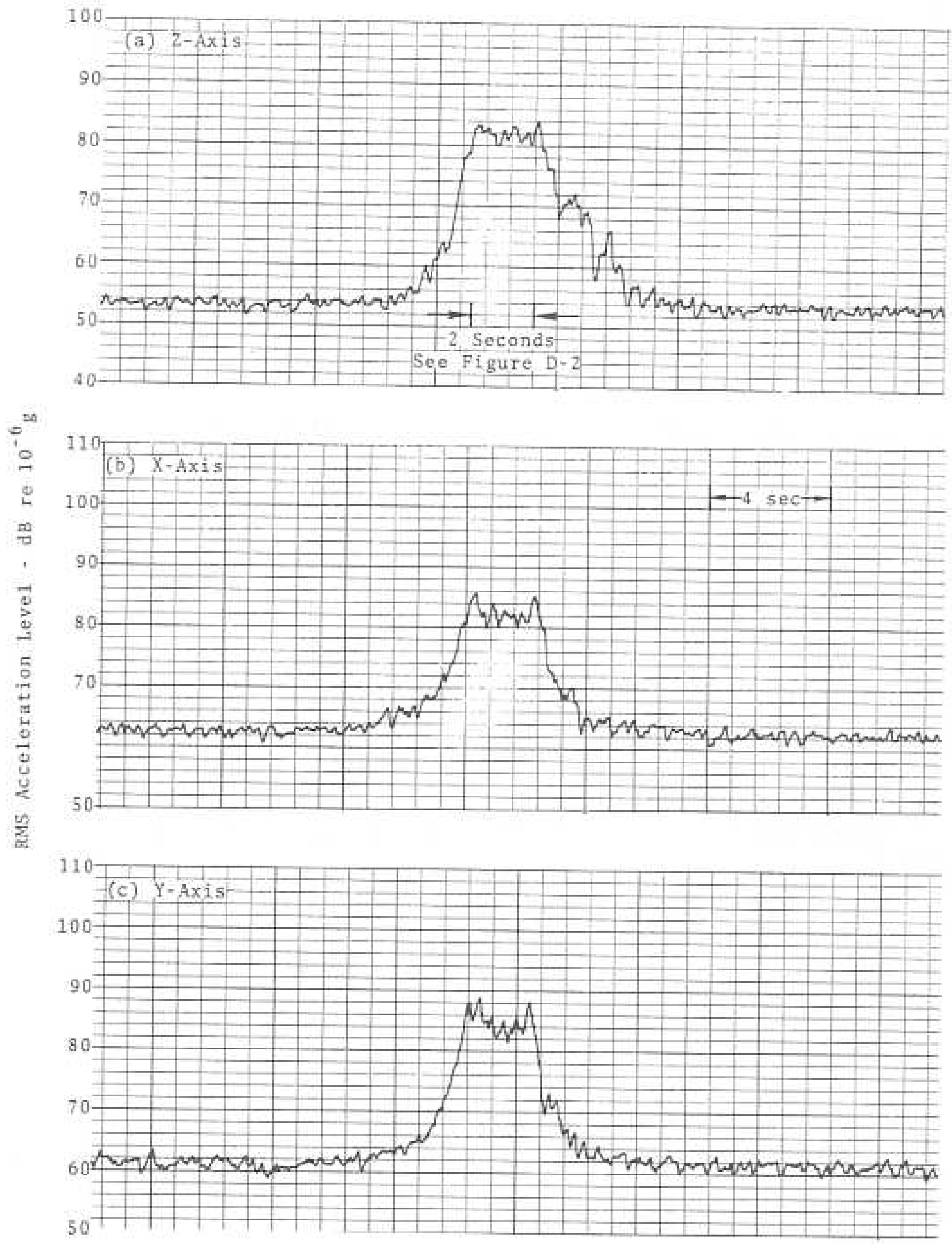


Figure D-1 Coincident Time Histories Wayside Ground Vibration Levels in 3 Axes at a Point Offset 25 ft from Centerline of Eastbound Track. West Mansfield, MA, 9/26/72 (5-Car Turbotrain-Eastbound-Speed 97 mph) See Figure D-3 for Westbound Data This Train.

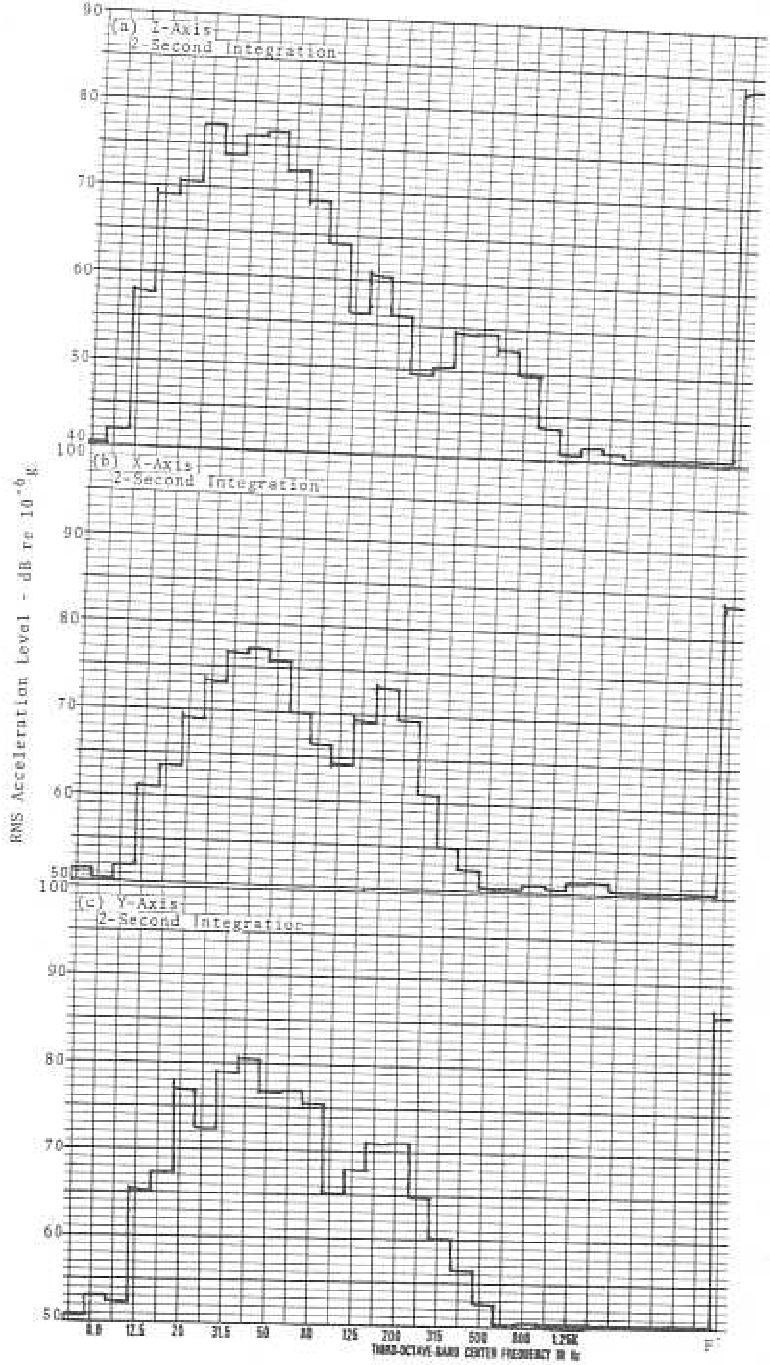


Figure D-2 Coincident Wayside Ground Vibration Spectra in 3 Axes at a Point Offset 25 ft from Centerline of Eastbound Track. West Mansfield, MA, 9/26/72 (5-Car Turbotrain-Eastbound-Speed 97 mph.) See Figure D-1 to Locate Period Analyzed.

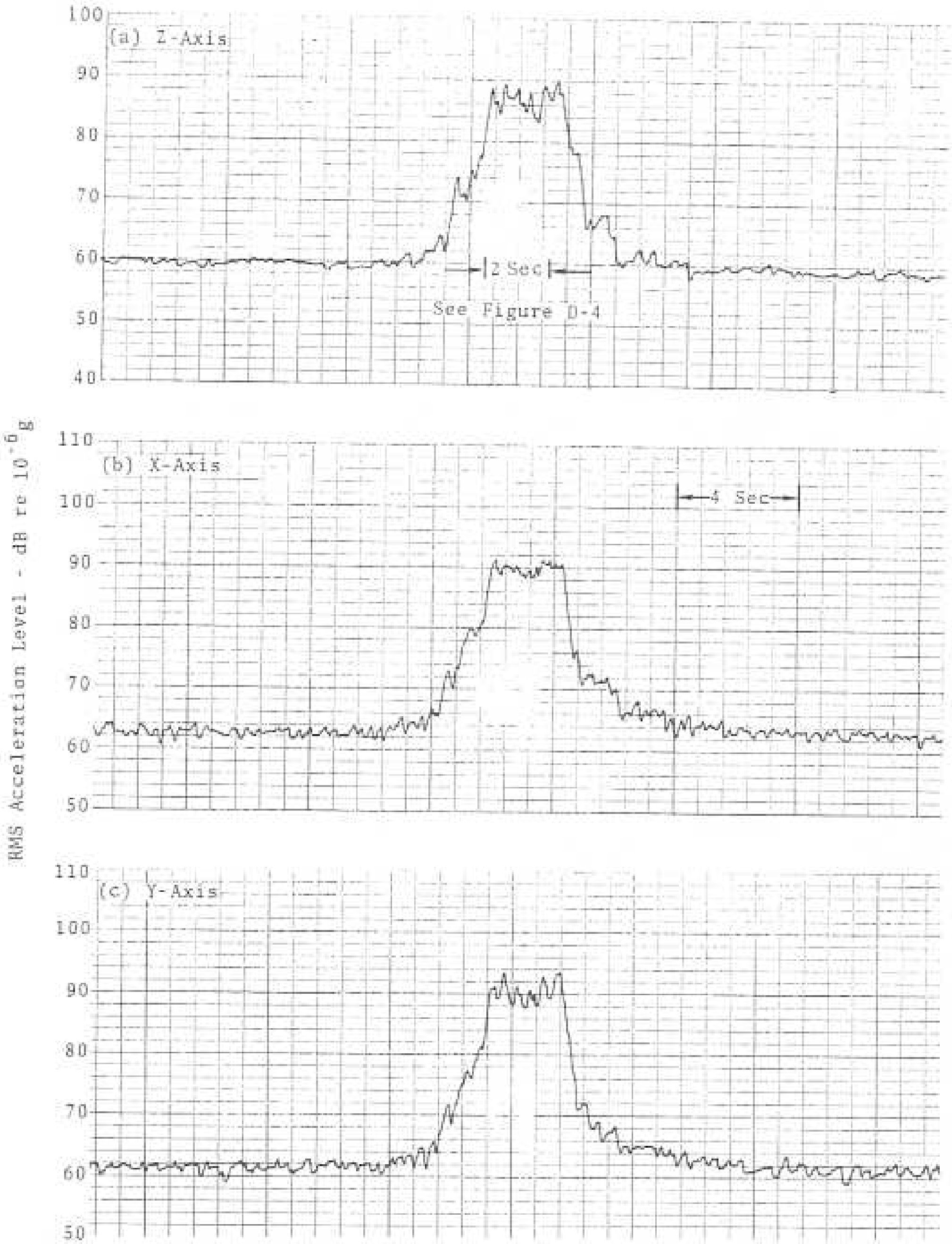


Figure D-3 Coincident Time Histories-Wayside Ground Vibration Levels in 3 Axes at a Point Offset 12 ft from Centerline of Westbound Track. West Mansfield, MA, 9/26/72 (5-Car "Deadhead" Turbotrain-Westbound-Speed 91 mph.) See Figure D-1 for Eastbound Data This Train.

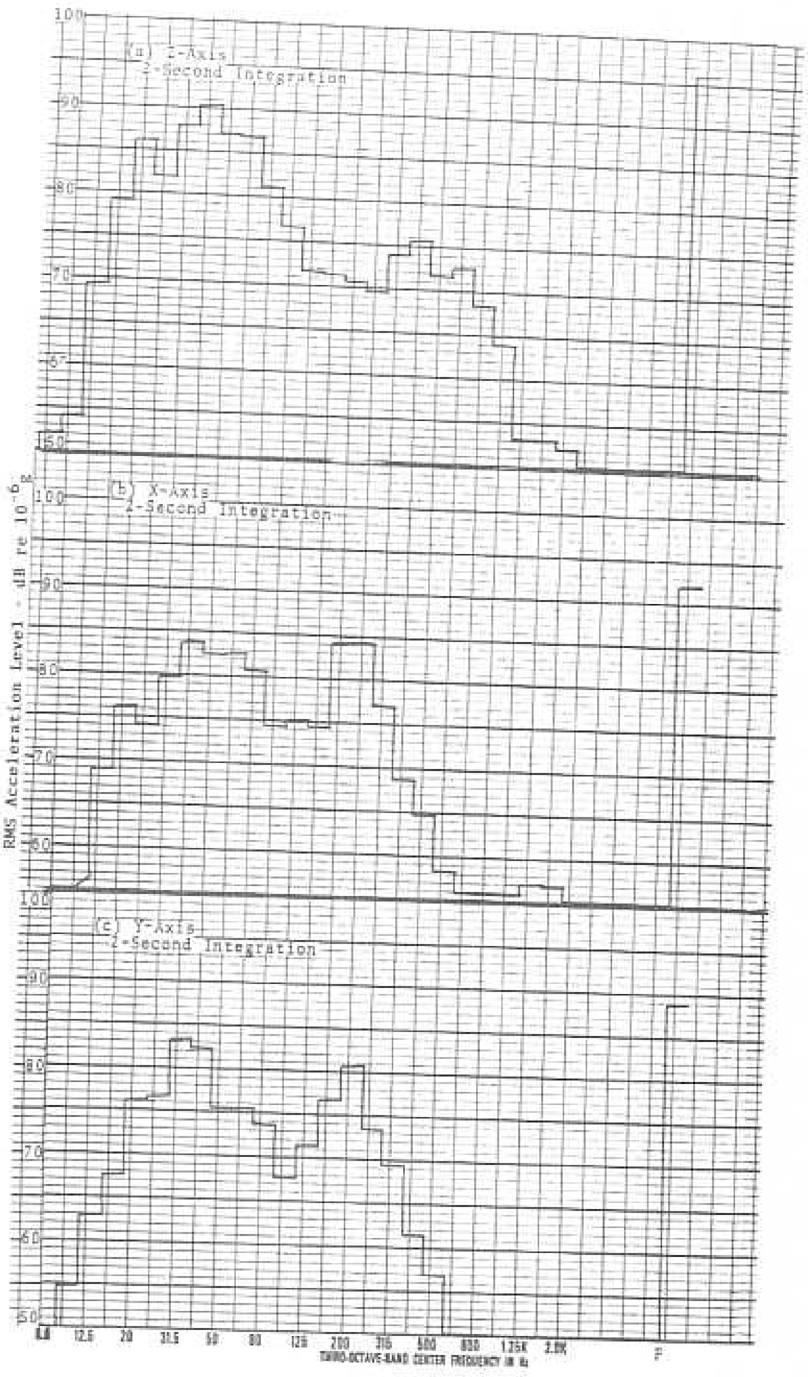


Figure D-4 Coincident Wayside Ground Vibration Spectra in 3 Axes at a Point Offset 12 ft from Centerline of Westbound Track. West Mansfield, MA, 9/26/72 (5-Car "Deadhead" Turbotrain-Westbound-Speed 91 mph.) See Figure D-3 to Locate Period Analyzed.

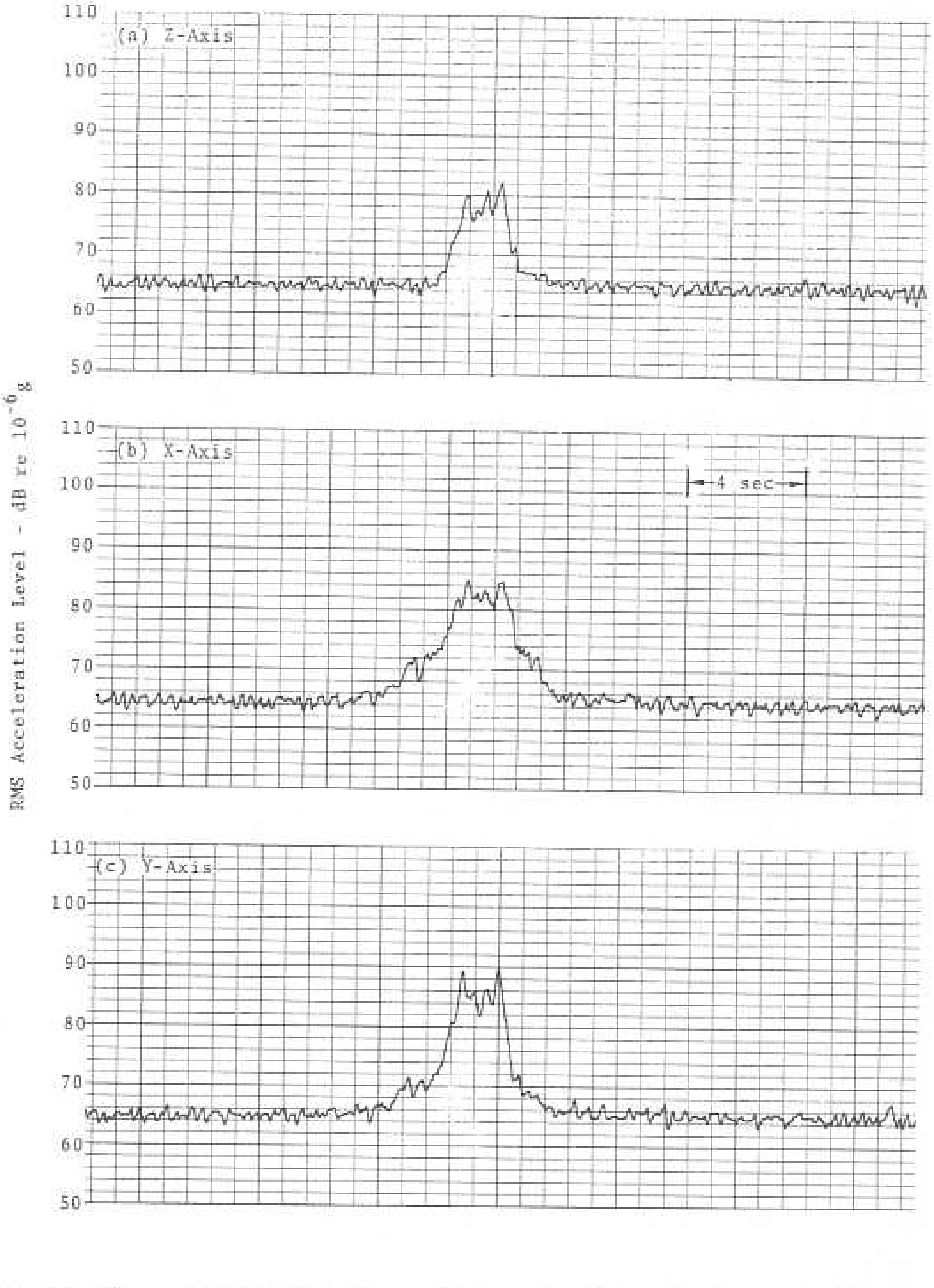


Figure D-5 Coincident Time Histories-Wayside Ground Vibration Levels in Three Axes at a Point Offset 25 feet from Centerline of Eastbound Track.
West Mansfield, MA, 11/4/71.
(3-Car Turbotrain-Eastbound-Speed 89 mph.)
See Figure D-6 for Westbound Data This Train.

Figure D-6 Coincident Time Histories-Wayside Ground Vibration Levels in 3 Axes at a Point Offset 12 feet from Centerline of Westbound Track. West Mansfield, MA, 11/4/71. (3-Car "Deadhead" Turbotrain-Westbound-Speed 104 mph.) See Figure D-5 for Eastbound Data This Train

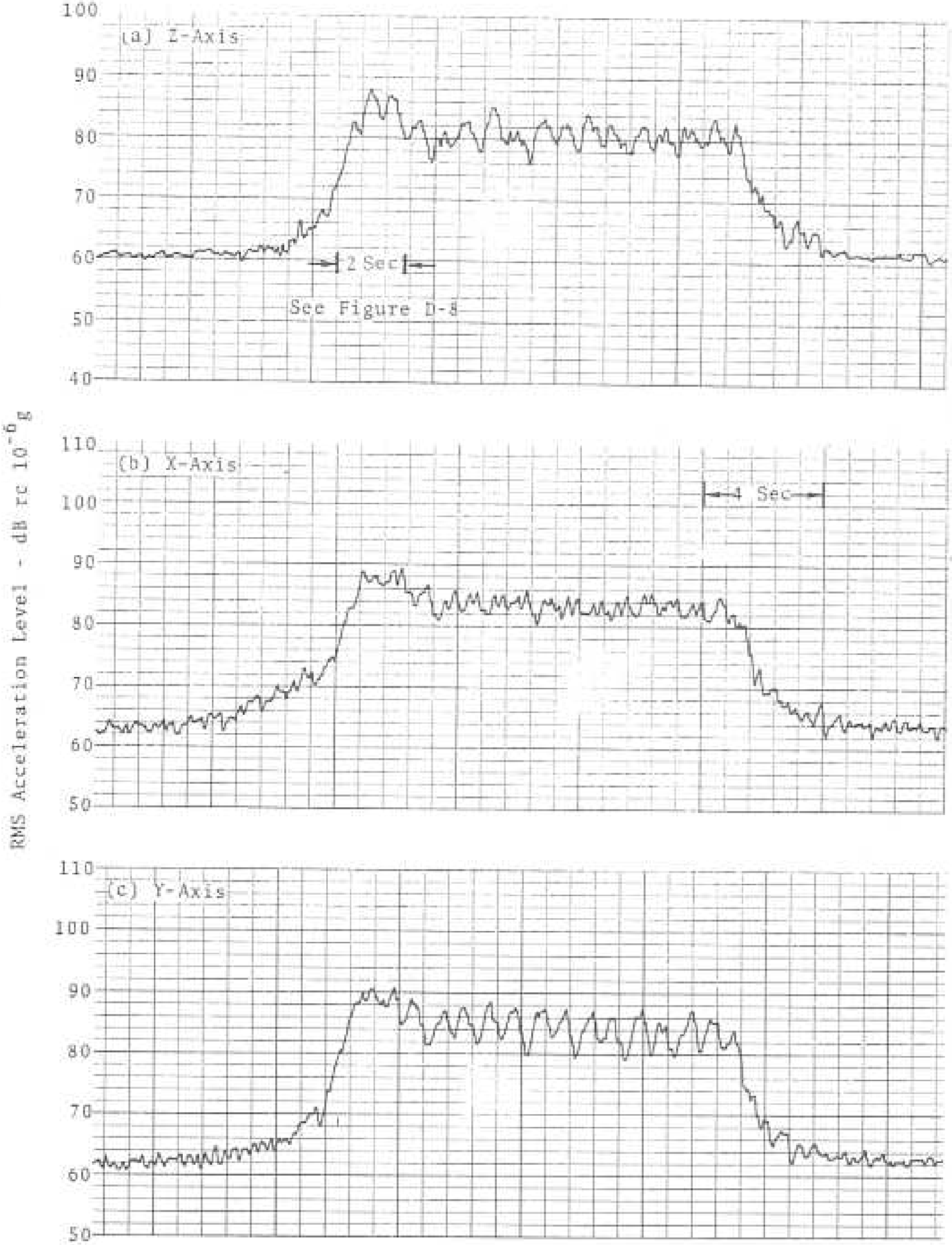


Figure D-7 Coincident Time Histories-Wayside Ground Vibration Levels in 3 Axes at a Point Offset 25 ft from Centerline of Eastbound Track. West Mansfield, MA, 9/26/72. (15-Car Conventional Passenger Train with One-Diesel-powered Locomotive-Eastbound-Speed 71 mph.)

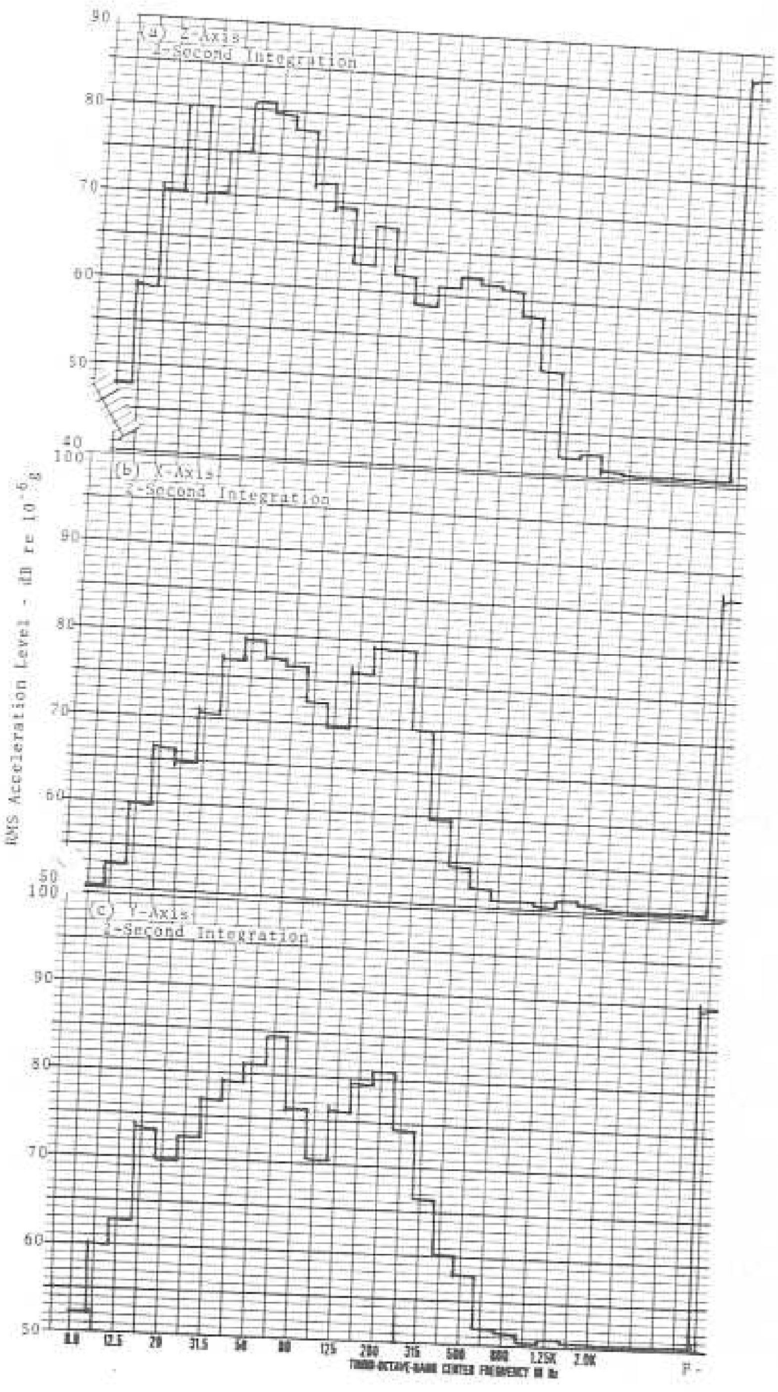


Figure D-8 Coincident Wayside Ground Vibration Spectra in Three Axes at a Point Offset 25 ft from Centerline of Eastbound Track. (15-Car Conventional Passenger Train with One-Diesel-powered Locomotive-Eastbound-Speed 71 mph.) See Figure D-7 to Locate Period Analyzed.

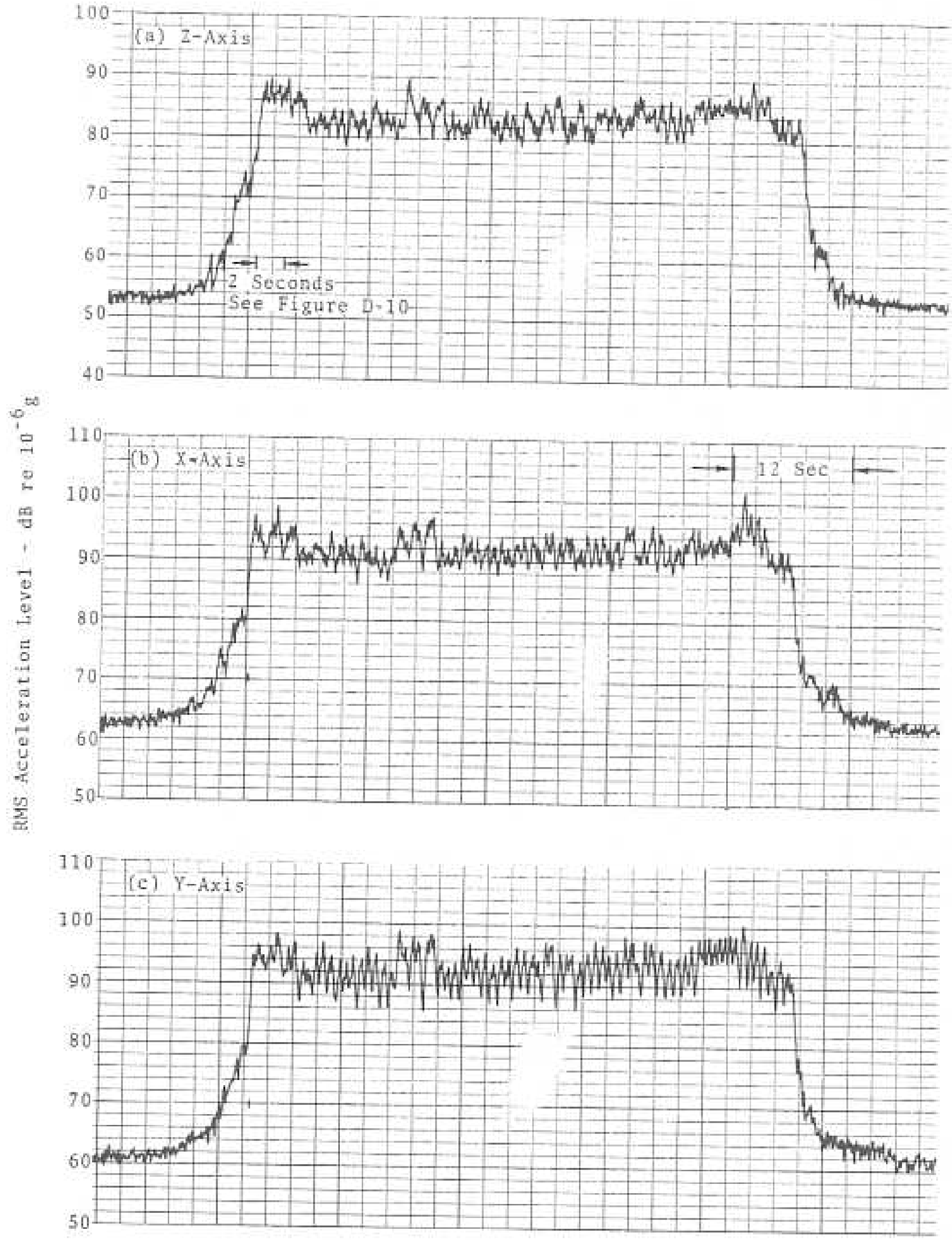


Figure D-9 Coincident Time Histories-Wayside Ground Vibration Levels in Three Axes at a Point Offset 12 feet from Centerline of Westbound Track. West Mansfield, MA, 9/26/72. (70-Car Freight Train with 5-Diesel-powered Locomotive-Westbound-Speed 50 mph.)

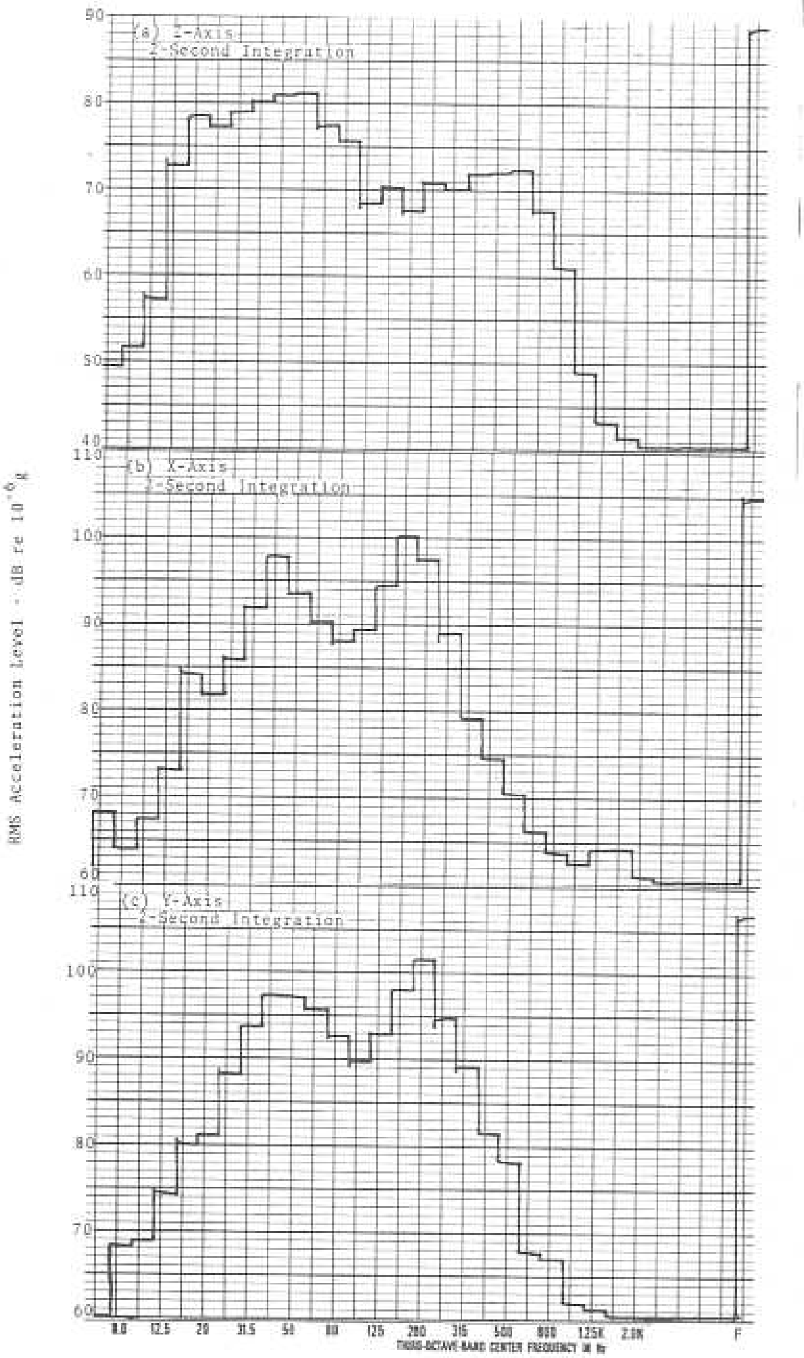


Figure D-10 Coincident Wayside Ground Vibration Spectra in 3 Axes at a Point Offset 12 ft from Centerline of Westbound Track. (70-Car Freight Train with 5-Diesel-powered Locomotives-Westbound-Speed 50 mph.) See Figure D-9 to Locate Period Analyzed.

APPENDIX E

MEASURING STATION LOCATIONS AND PHOTOGRAPHS

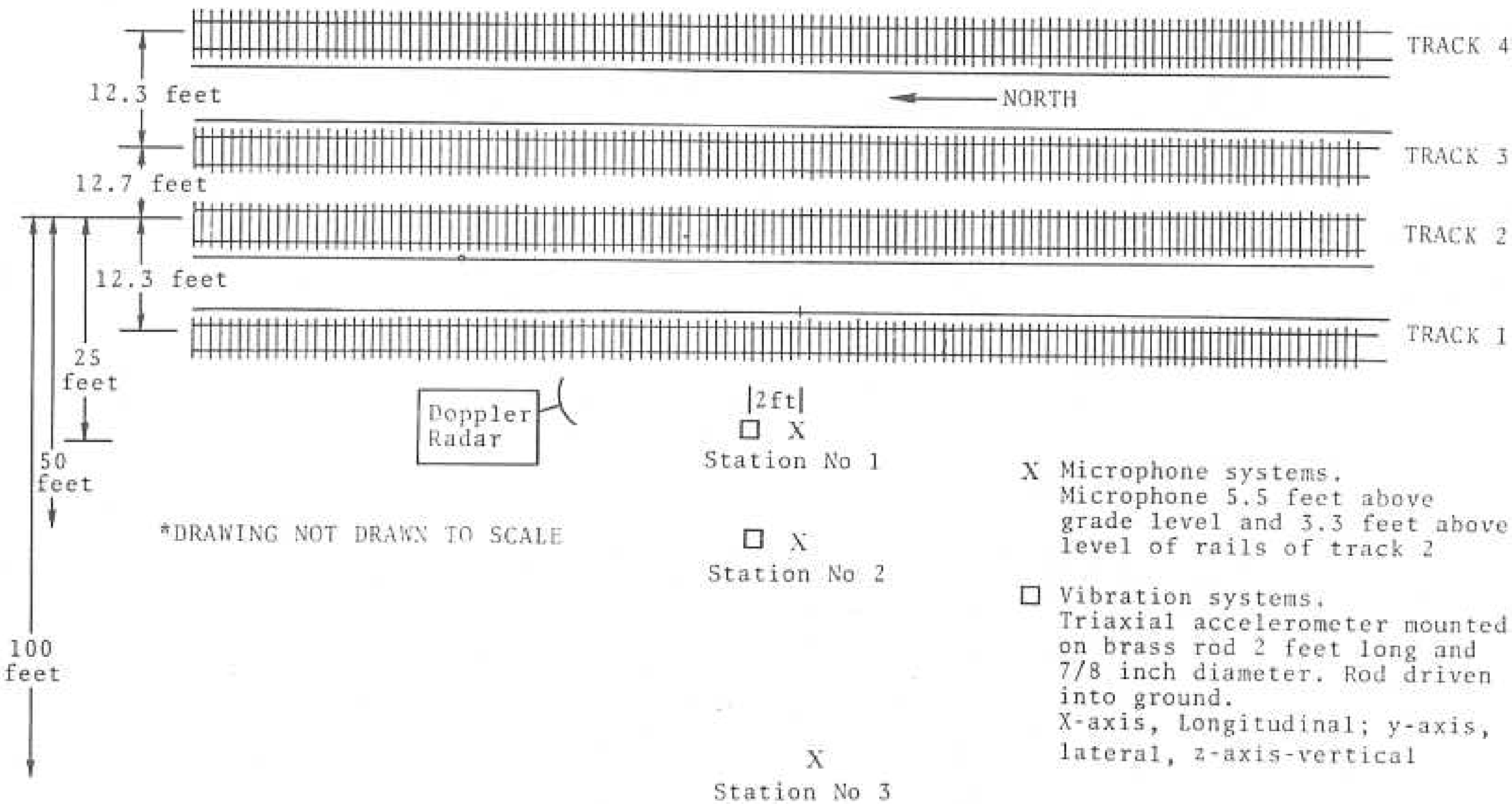


Figure E-1 Measuring System Locations-Trackside Penn Central Railroad New York-to-Washington Line, Plainsboro, New Jersey 2600 Feet North of Mile Post No. 46-May 23, 1972.

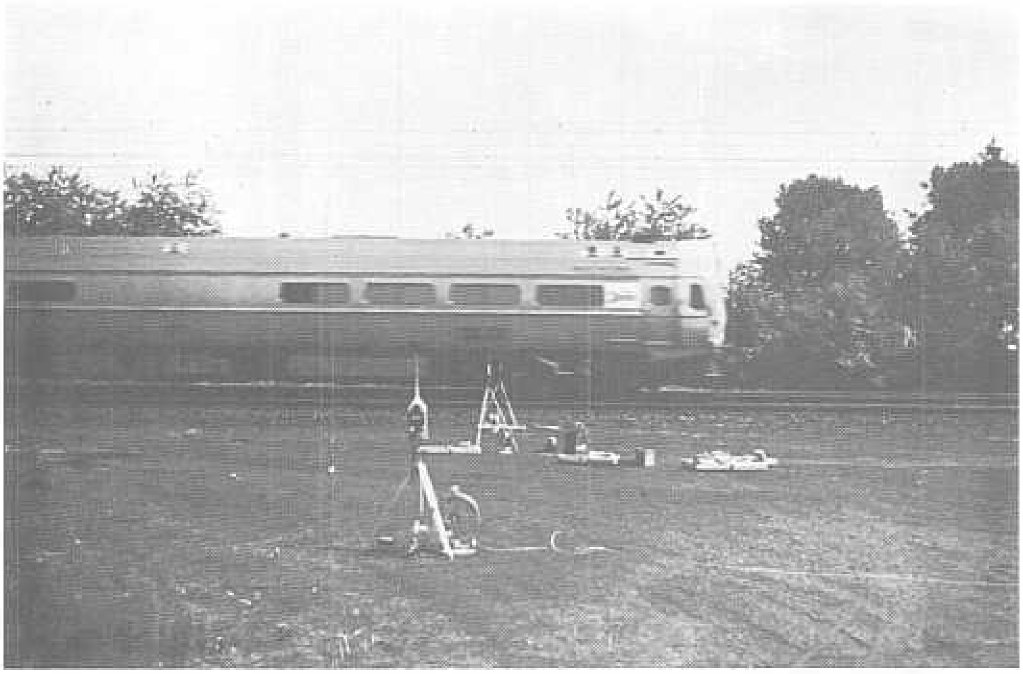


Figure E-2 View Easterly Showing Three Microphone Systems and Southbound Metroliner at Plainsboro, NJ.

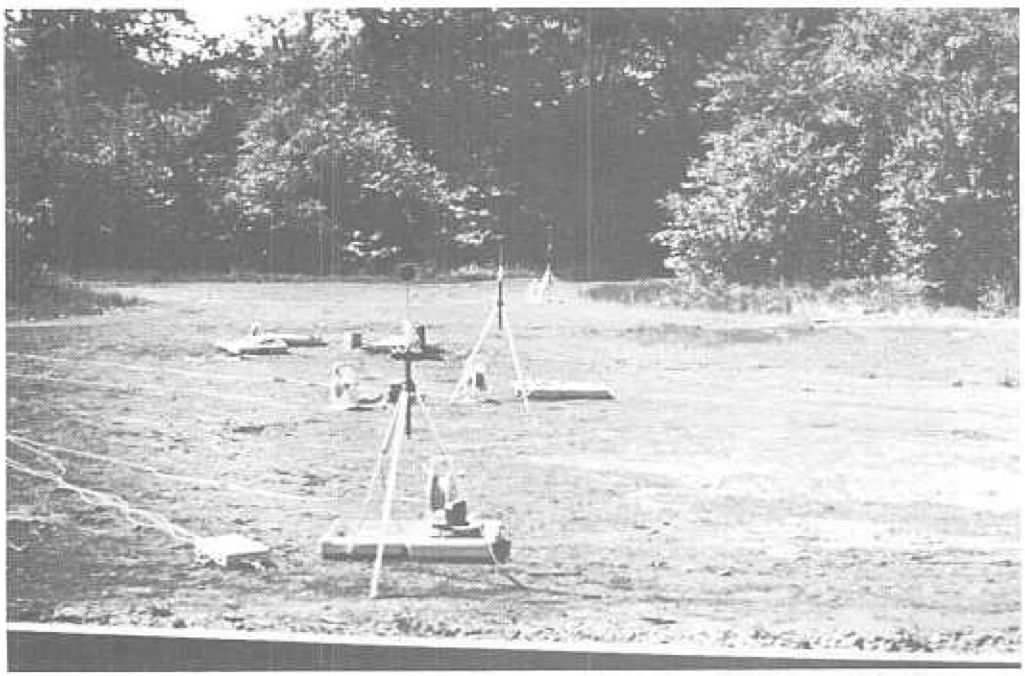


Figure E-3 View Westerly from Tracks toward Three Microphone Systems at Plainsboro, NJ.

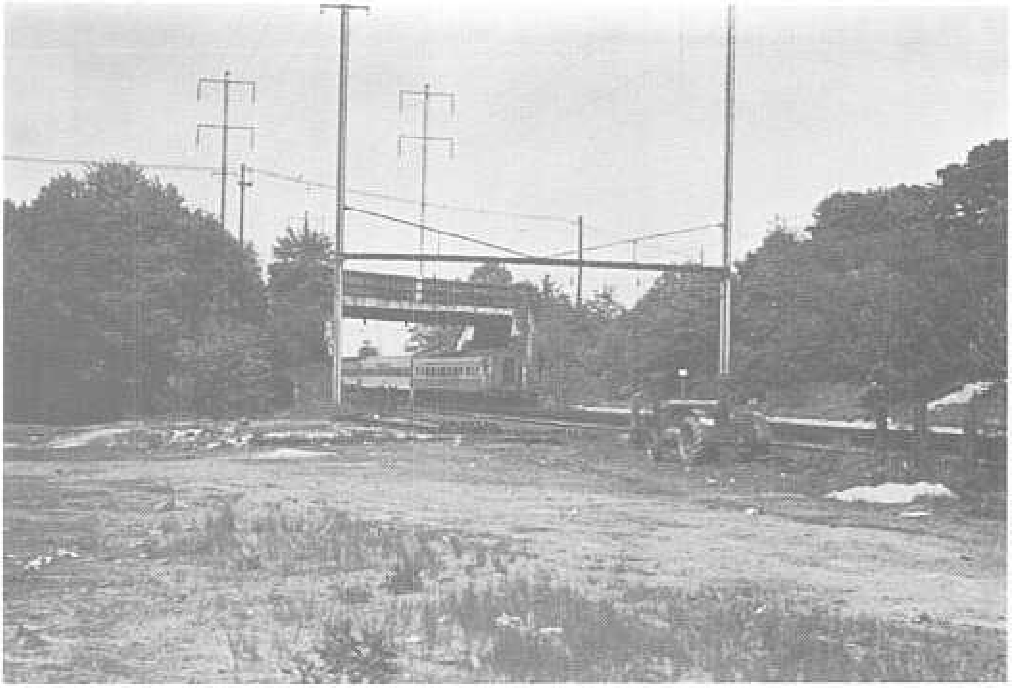


Figure E-4 View Northerly from Microphone 3 at Plainsboro, NJ.

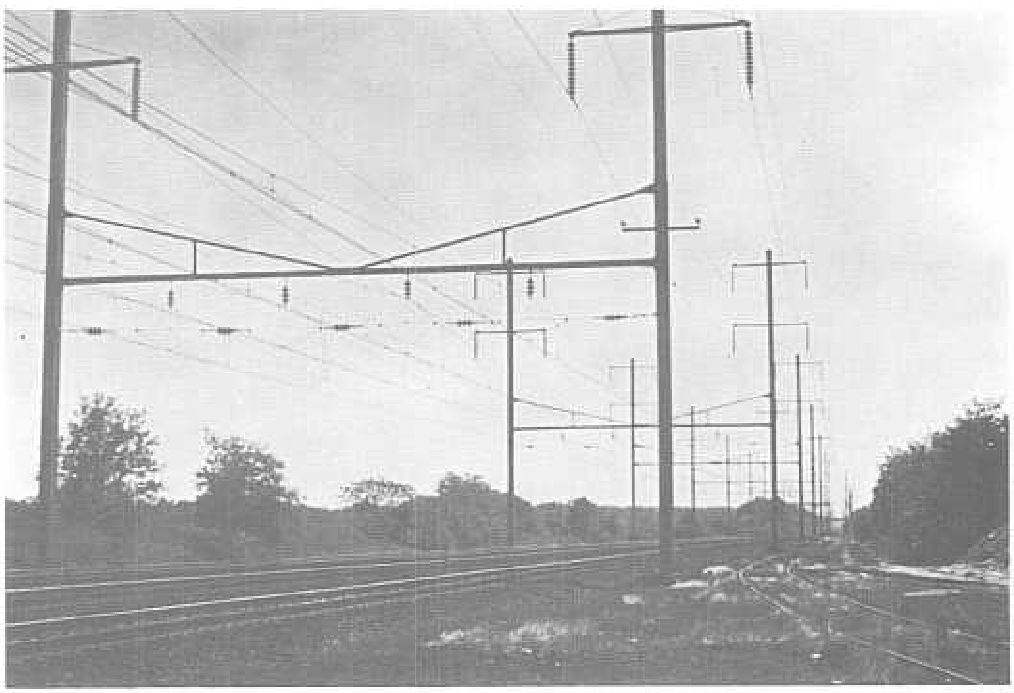


Figure E-5 View Southerly from Microphone 3 at Plainsboro, NJ.

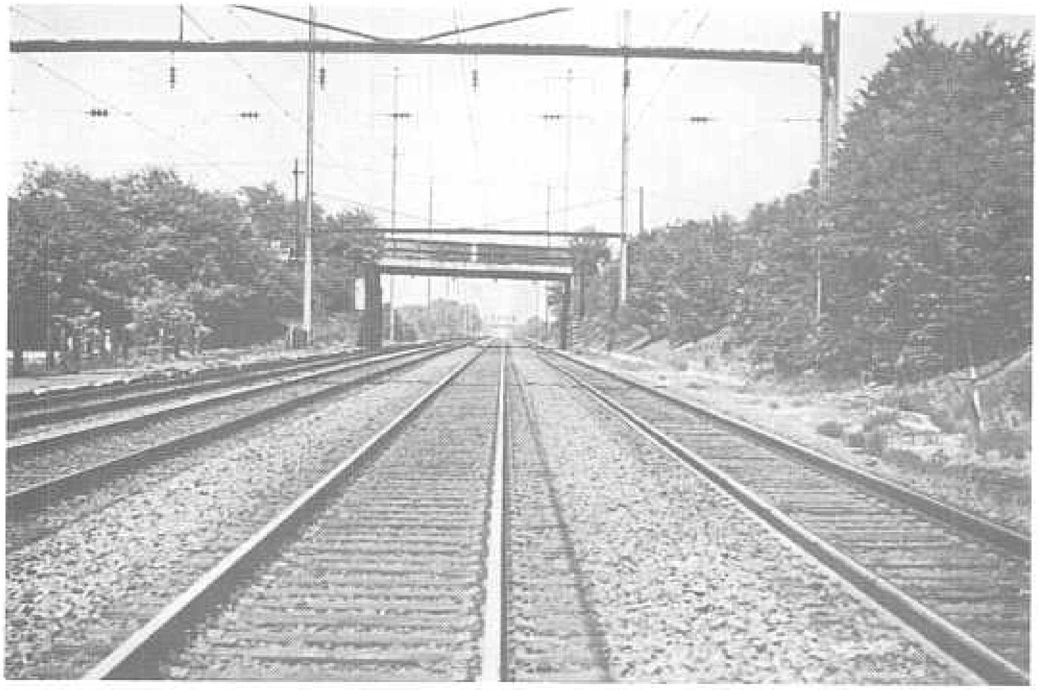


Figure E-6 View Northerly down Tracks at the Plainsboro, NJ, Measurement Site

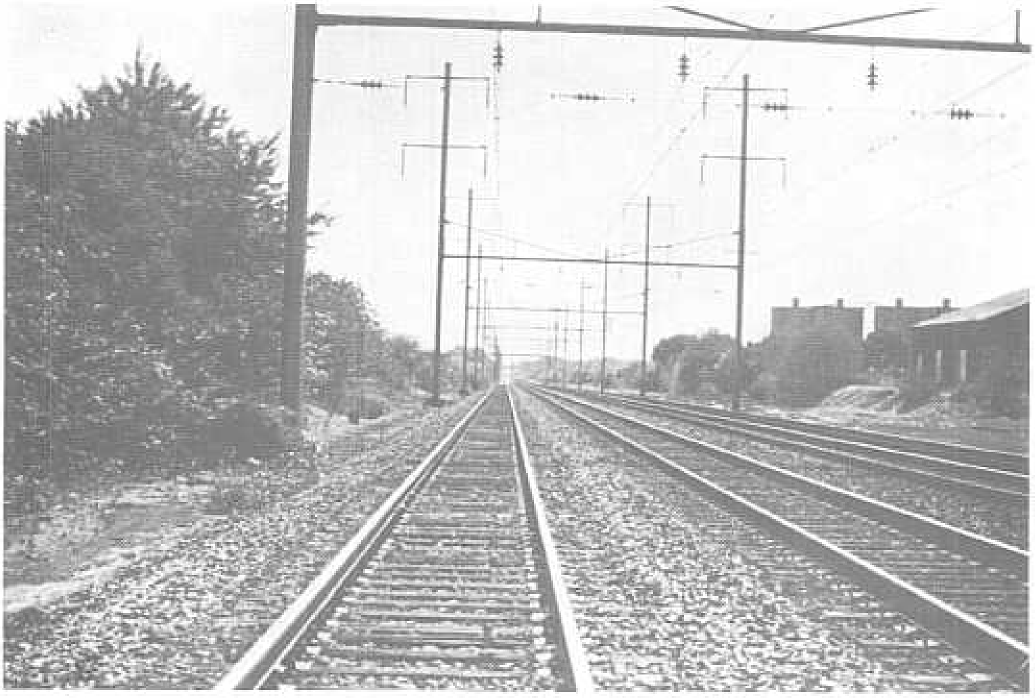


Figure E-7 View Southerly down Tracks at the Plainsboro, NJ, Measurement Site

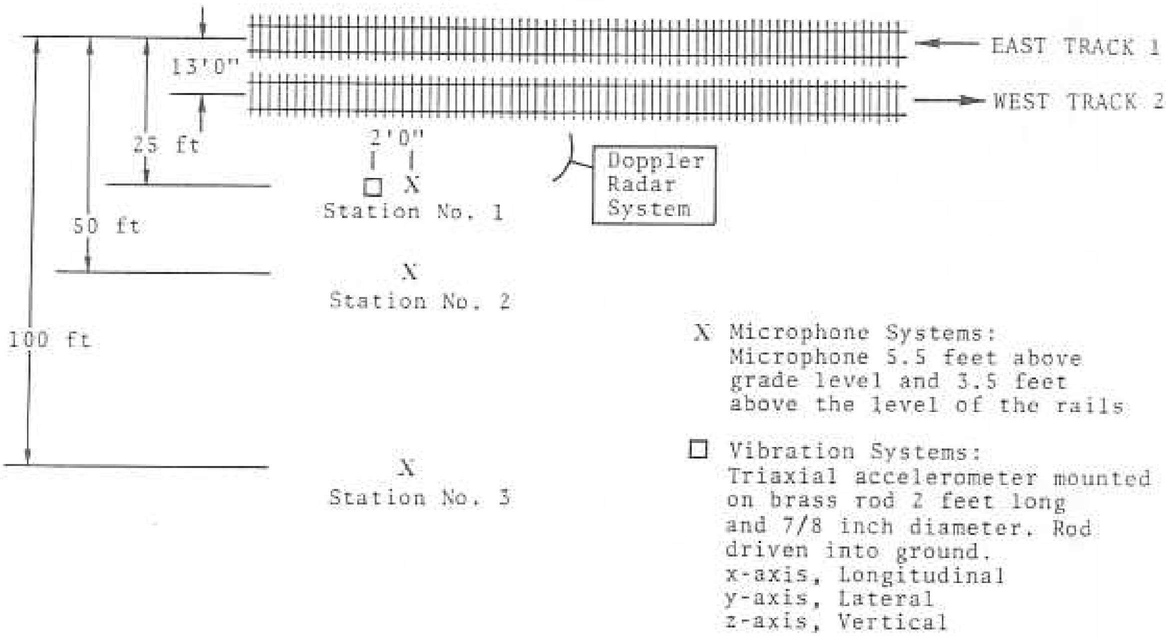


Figure E-8 Measuring System Locations-Trackside-Penn Central RR, Boston-to-New York Line, West Mansfield, MA. 1310 feet East of Mile Post No. 201-September 20 and 26, 1972.

Figure E-9 View Southerly Showing Three Microphone Systems and Eastbound Turbotrain at West Mansfield, MA.

Figure E-10 View Northerly from Tracks Toward Three Microphone Systems at West Mansfield, MA.

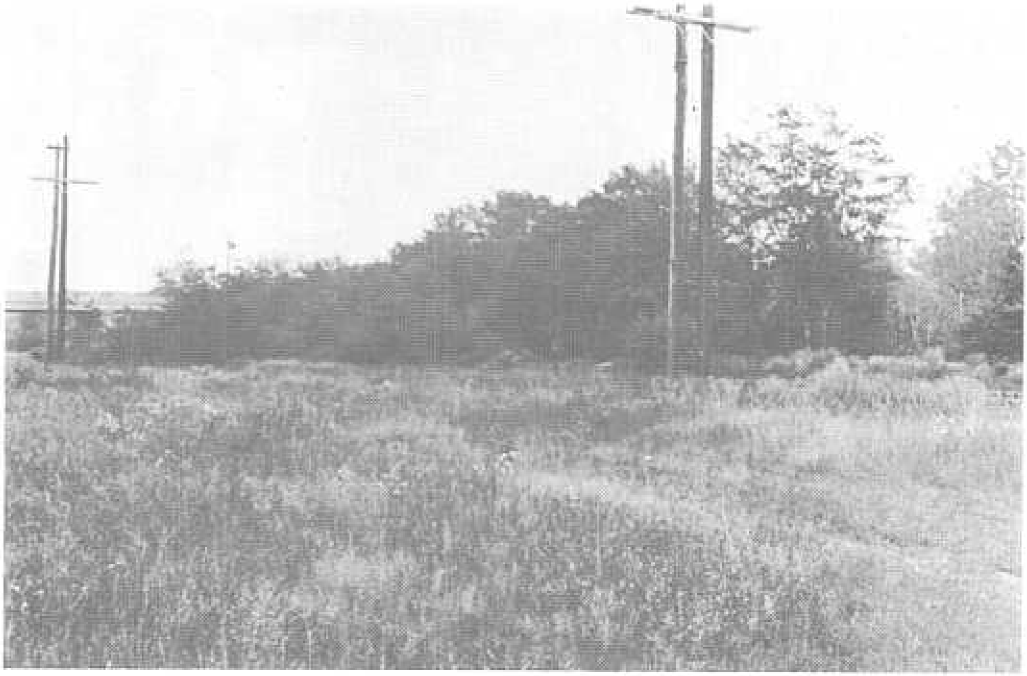


Figure E-11 View Easterly from Microphone 3
at West Mansfield, MA.

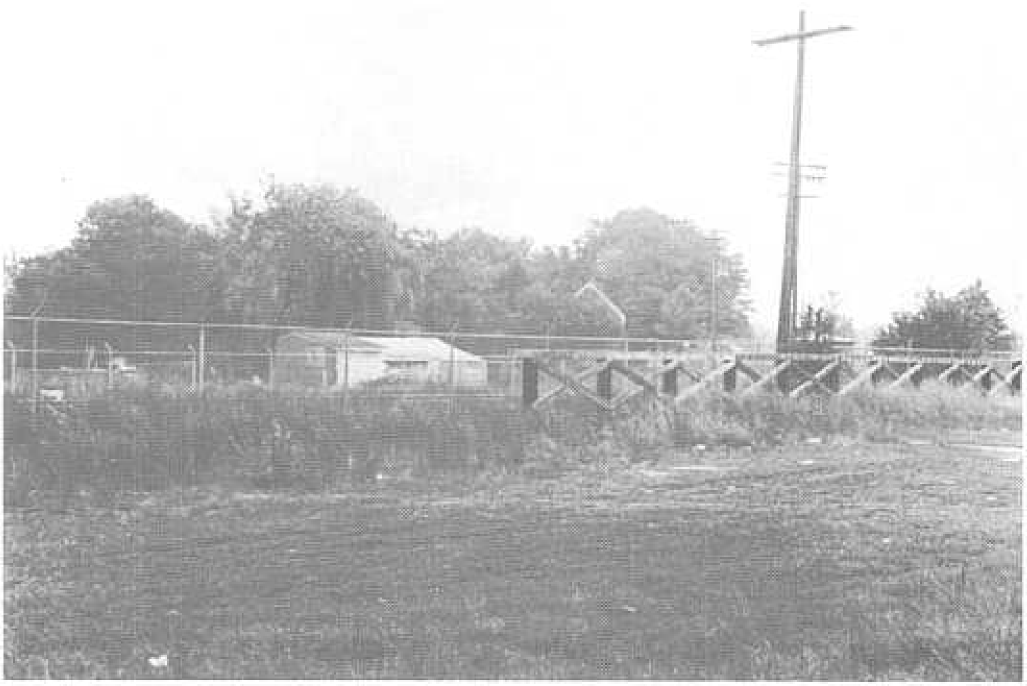


Figure E-12 View Westerly from Microphone 3
at West Mansfield, MA.

Figure E-13 View Easterly down Tracks at West Mansfield, MA. Measurement Site

Figure E-14 View Westerly down Tracks at West Mansfield, MA. Measurement Site

APPENDIX F

MEASUREMENT AND DATA REDUCTION SYSTEMS

NOISE-MEASURING SYSTEM

Figure F-1 depicts the noise-data-gathering equipment used at the three wayside-measuring stations. Figures E-1 and E-8 show the exact locations for each system at the wayside measurement sites in Plainsboro, New Jersey and West Mansfield, Massachusetts.

A magnetic tape recorder, capable of essentially flat recordings from 30 Hz to 15 kHz, was used. The recorder was operated in the direct mode at a tape speed of 3-3/4-inch per second. The dynamic range of the recorder and measuring system was 50 dB.

Prior to each run, a short verbal annotation was recorded on tape giving the following: date, time, location, tape number, tape recorder channels used, and gain setting for each channel.

A calibration signal of 1000 Hz at a level of 114 dB re 20 micronewton per square meter was recorded on tape before and after each run to provide a reference level for the data-reduction instrumentation and to detect any system instability. The calibrator used was a General Radio Model #1562A. In this calibrator, the signal is generated by a solid-state oscillator driving a small magnetic loudspeaker. The calibrator is placed on the microphone and the resultant signal at the specified sound pressure level is fed through the system and recorded on tape. In addition, a passive microphone simulator was substituted for the microphone to determine the minimum discernible sound-pressure level (Noise Floor) for the system. This signal was also preserved on tape.

The fourth channel on the recorder is for verbal annotation and to record a time code signal (hours, minutes, and seconds) to synchronize data between channels and between recorders.

The measuring and analysis systems conforms to Society of Automotive Engineers' (SAE) Standard SAE J184.

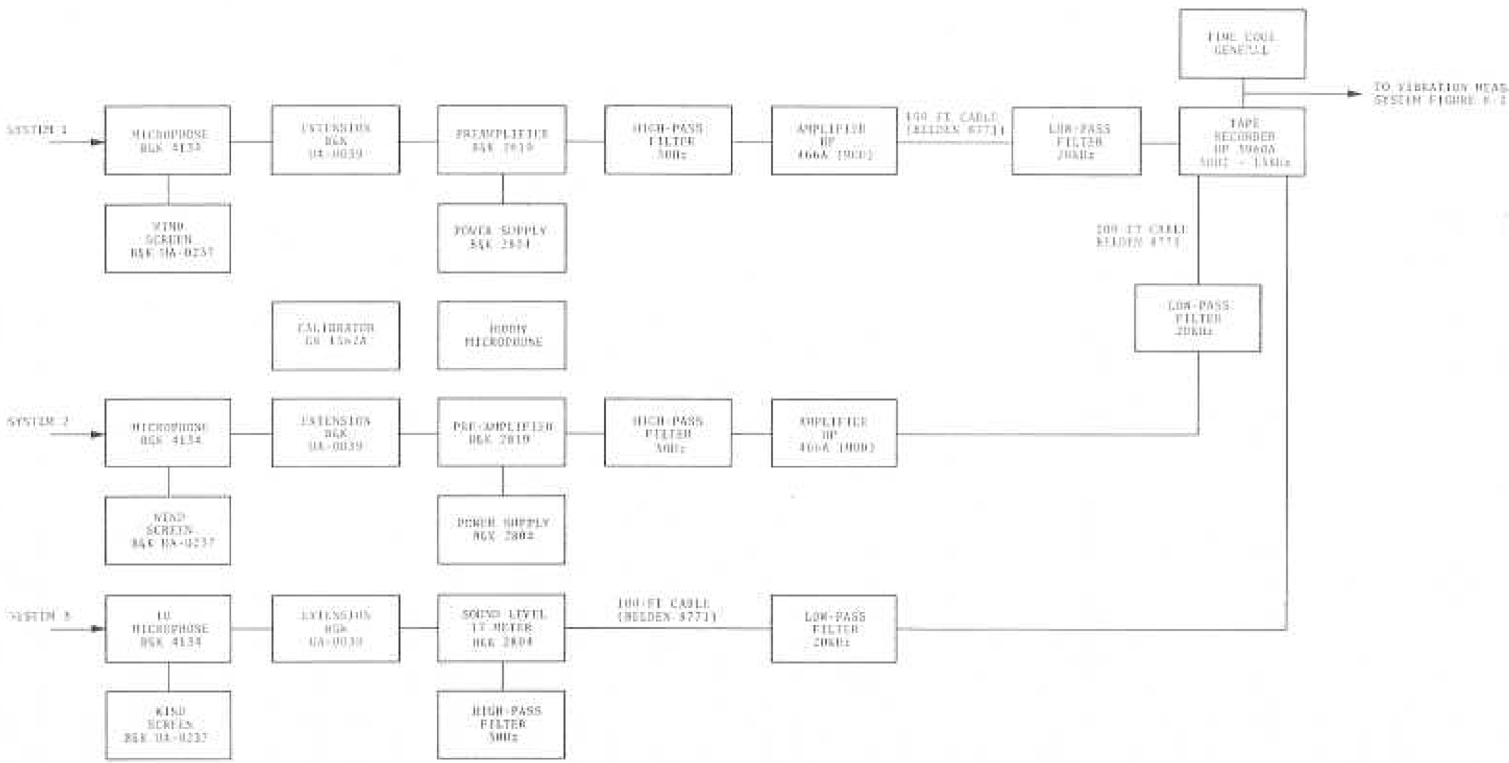


Figure F-1 Three-Microphone Noise-measuring System

VIBRATION-MEASURING SYSTEM

Figure F-2 depicts the equipment used for data gathering of ground vibration levels in three axes at the wayside measurement locations shown in Figures E-1 and E-8. The frequency response of this system is 3 to 1250 Hz.

Ground vibration measurements were made utilizing a brass rod 2-ft long and 7/8-inch wide which was driven into the ground at the measurement locations. Three accelerometers were mounted on the rod with a special adapter in a triaxial arrangement, each accelerometer was electrically insulated from one another and from the driven stake.

A magnetic tape recorder, capable of essentially flat recording from dc to 1250 Hz, was used. The recorder was operated in the FM mode at a speed of 3-3/4-inch per second. The dynamic range of the recorder and measuring system was 60 dB.

Prior to each run, a short verbal annotation was recorded on tape giving the following: date, time, location, tape number, tape recorder channels used and gain setting for each channel.

A dynamic calibration signal of 100 Hz at 1 g was recorded on tape before and after each run to provide a reference level for the data reduction instrumentation and to detect any system instability. The GR Type 1557A Vibration Calibrator was used to provide this on-the-spot calibration of the vibration-measuring system including the accelerometer. The 1557-A is a small battery-operated unit consisting of a transistorized electromechanical oscillator and a cylindrical shaker. The accelerometer of known mass is attached to the shaker and the level control adjusted to the proper mass setting. The accelerometer is then automatically subjected to an acceleration of 1 g at 100 Hz. In addition, the accelerometer is replaced by a short circuit to determine the minimum discernible acceleration level (Noise Floor) for the measuring system. This signal was also preserved on tape.

The three-axis vibration data from station 1 (z-axis vertical motion, x-axis longitudinal motion, y-axis lateral motion) was recorded on three of the four available recorder channels. The

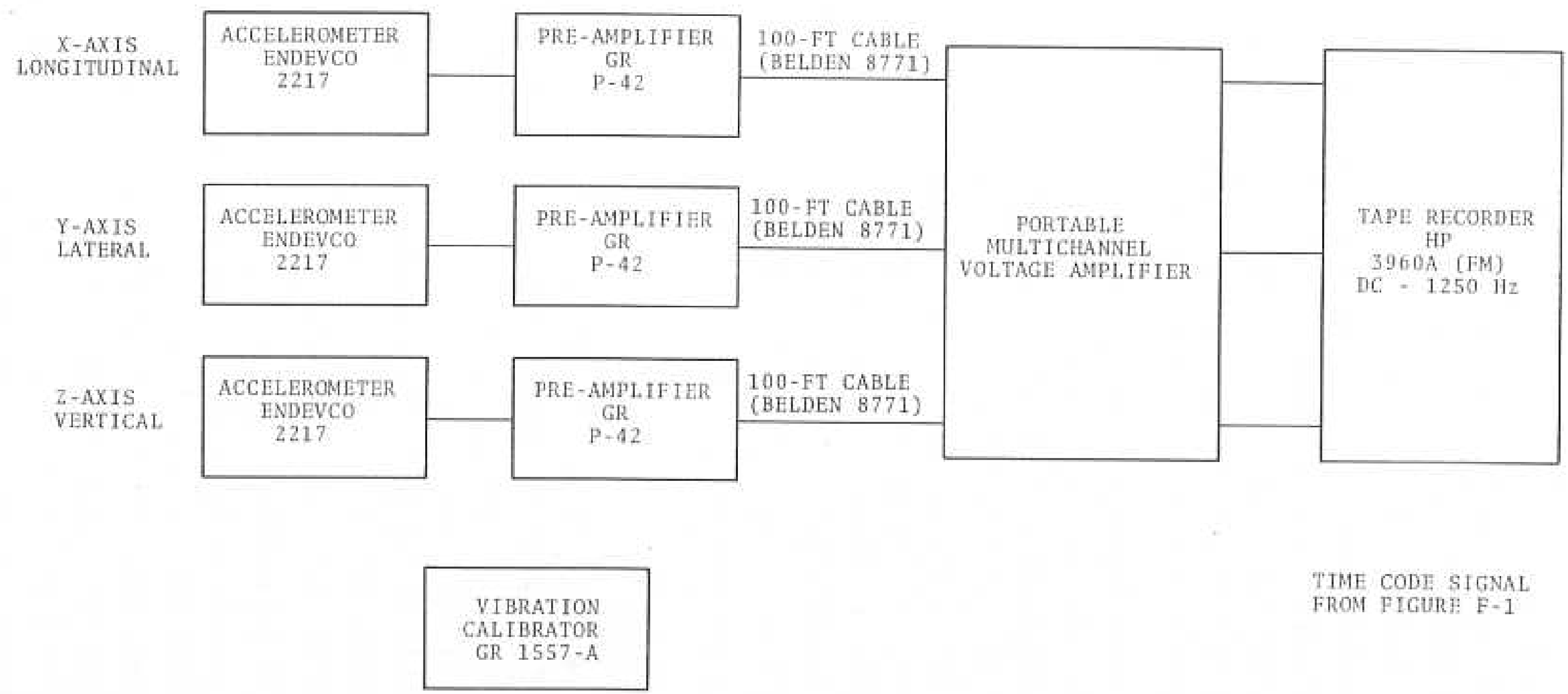


Figure F-2 Three-Axis Vibration-measuring System fourth channel was used for verbal annotation and to record a time code signal (hours, minutes and seconds) which was simultaneously being recorded on a second instrumentation recorder used to record noise data.

Since three channels of the tape recorder were being used to record the 3-axis vibration data from measurement station 1, it was possible to record one axis of data per event at station 2 by time-sharing the fourth channel of the tape recorder with the time code signal for selected events in the following manner:

The time code signal was recorded on channel 4 just prior to the event. With the recorder running, the time code signal was physically disconnected and replaced (on the FM recorder only) with the output of one accelerometer axis from station 2. Using this technique and changing the station 2 axis recorded after successive events, it was possible to record a few representative x-, y-, and z-axis acceleration levels at measurement station 2 for Metroliner and conventional passenger trains in addition to the 3-axis acceleration data measured at station 1.

These data are included in Tables 2.1 and 2.2.

Noise Data Reduction

The configuration of the noise data reduction system is shown in Figure F-3. The noise data plus the calibration signal recorded on magnetic tape at the test site were reproduced and fed to a General Radio (GR) 1921 Real Time Analyzing System made up of a GR 1925 Multifilter and a GR 1926 Multichannel RMS Detector. The necessary gain adjustments were made in the multifilter and graphic level recorder with the calibration signals.

The GR 1921 multifilter contains a set of 30 parallel 1/3-octave band filter channels ranging from 25 Hz to 20 kHz, plus additional channels with standard "A," "B," and "C" sound-level meter-weighting networks and an unfiltered channel with a flat frequency response "F". The output of the "A" weighted channel was selected and fed to the Graphic Level Recorder to produce a chart of noise level vs. time (time history) of all recorded data.

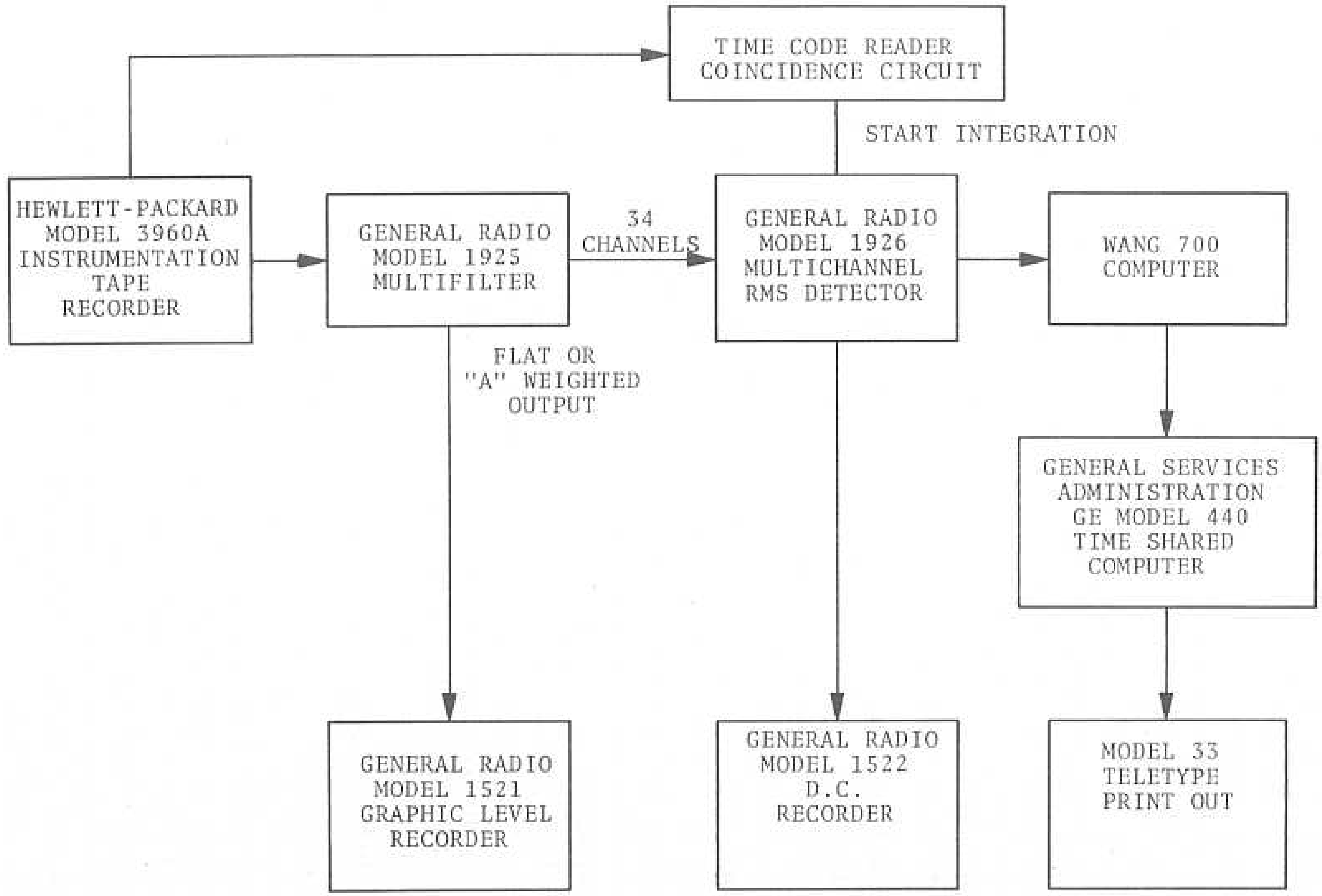


Figure F-3 Noise-and-Vibration Data-Reduction System

All 34 outputs from the multifilter are fed into the multichannel detector. The multichannel detector simultaneously computes the rms (root mean square) level for each channel and converts this level to a digital output. Single integration or measurement periods are adjustable from 1/8 to 32 seconds.

Special selected events are analyzed in detail for their 1/3-octave band frequency spectra using this equipment and the GR 1522 dc Recorder which in conjunction with the GR 1926 Multichannel RMS Detector provides a hard copy bar graph of level (dB) vs 1/3-octave frequency bands from 25 Hz to 20 kHz, including the flat (F) and "A" weighted outputs.

The multichannel detector is programmed to integrate over the time interval of the selected event or portion thereof, compute the level in dB for all 32 channels and provide a dc output to the recorder. The recorder provides a hard copy of level (dB) vs 1/3-octave bands for the event. The start of the integration period is controlled by a coincidence circuit in the time code reader; thus insuring the identical start of the integration period for events on multichannel recorders or between recorders which have been synchronized with time code signals. The graphic recorder at a pen-writing speed of 5 inches per second simultaneously provides an expanded "A" weighted level time history of the event. Time marks are manually placed on the graphic recording to show the start and end of the integration period.

Vibration Data Reduction

The configuration of the vibration data reduction system is as shown in Figure F-3. It is noted that this is the identical system described above for Noise Data Reduction. To utilize this system, which is equipped with 1/3-octave filters down to 25 Hz, for the analysis of data with frequency components down to 3 Hz, the following frequency transformation procedure was necessary. The vibration data which were originally recorded at a speed of 3-3/4-inch per second were played back at a tape speed of 15 inches per second. The recorded signal is thus scaled up in frequency by a factor of 4, and frequency components of the original signal that were in the 1/3-octave bands of 6.3 Hz, 8 Hz, 10 Hz, 12.5 Hz, etc. appear in the 25 Hz, 31.5 Hz, 40 Hz, and 50 Hz, etc., 1/3-octave bands, respectively. Thus, the data are shifted into the useable frequency range of the 20 Hz to 20 kHz data reduction system shown in Figure F-3.

The vibration data plus the 100 Hz, 1 g calibration signal recorded at 3-3/4-inch per second at the test site are reproduced at 15 inches per second and fed into the GR 1921 Real Time Analyzing system. The necessary gain adjustments are made in the multi-filter and recorders with the calibration signal now at a frequency of 400 Hz.

Special events (as in the Noise Data Reduction Section) are analyzed in detail for their 1/3-octave frequency spectra and a hard copy bargraph of level (dB) vs 1/3-octave frequency bands from 6.3 Hz to 5 KHz plus an unfiltered or flat (F) output are produced with the 1522 dc recorder in conjunction with the 1926 Multichannel Detector.

The multichannel detector is programmed to integrate over the time interval of the selected event (now occuring in 1/4 the time), compute the level in dB for all 31 channels and provide a dc output to the recorder which provides a hard copy of the level in dB vs the 1/3-octave bands from 6.3 to 1250 Hz plus flat (F) output of the vibration spectra of the event. The start of the integration period is controlled by a coincidence circuit in the time code reader, thus insuring the identical start of the integration periods for events on multichannel recorders or between recorders which have been synchronized with time code signals. The graphic recorder simultaneously provides an expanded time history of the event analyzed and time marks are manually placed on the history to show the start and end of the integration period.

APPENDIX G

DESCRIPTION METROLINER AND TURBOTRAINS

METROLINER

The high-speed Metroliner, Figure G-1, in operation on the Penn Central Railroad, New York-to-Washington DC line, was built by the Budd Company; it was placed into service on this line in 1969.

The self-propelled Metroliner has a stainless steel exterior, curved sides with reinforced plastic sheathing in some areas. Each car has four electric propulsion motors, one for each axle, capable of developing 640 horsepower each. Electric power (11 Kv nominal, 25 Hz) is obtained through a pantograph from the overhead catenary system.

Physical dimensions are as follows:

Length of car over coupler	85'0"
Distance between truck centers	59'6"
Width	10'6"
Height - running rail to roof	12'8"
Truck - wheel base	8'6"
Wheels - diameter	36"
Weight	102,200 lb.

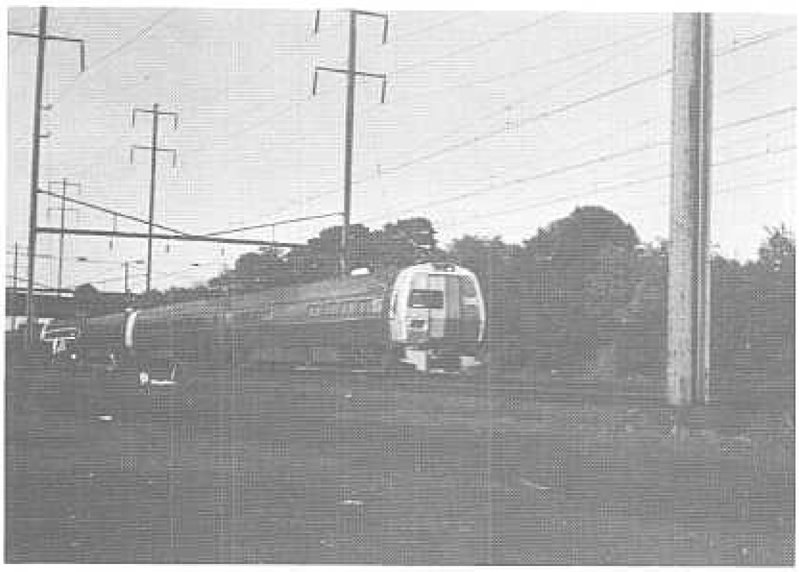


Figure G-1 High-Speed Metroliner

TURBOTRAIN

The high-speed Turbotrain, Figure G-2, in operation on the Penn Central Railroad, Boston-to-New York line, was built by United Aircraft; it was placed into operation on this line in 1969.

Each Turbotrain is comprised of two Power Dome Cars, one at each end of the train, and one or more Intermediate cars (coaches) in between. Three gas turbine engines are located under the dome section of each Power Dome car, thus each train contains six 400-horsepower engines. One engine is used to drive a 300-watt alternator for auxiliary power and the remaining five engines are used for traction power. The power is transmitted to the 2-axle power trucks of the Power Dome Cars by a direct mechanical drive system. Single-axle trucks are located between cars rather than under one end of each car (see illustration, Figure G-3). Physical dimensions are as follows:

Length overall (3-car train)	203'4"
Length overall (5-car train)	317'0"
Length Power Dome Car	73'3"
Length Intermediate Car	56'10"
Height- over Dome	12'11"
Width	10'5"
Floor level from rail	31"
Underbelly clearance	8"
Empty Weight (3-car train)	105 tons
Empty Weight (5-car train)	135 tons

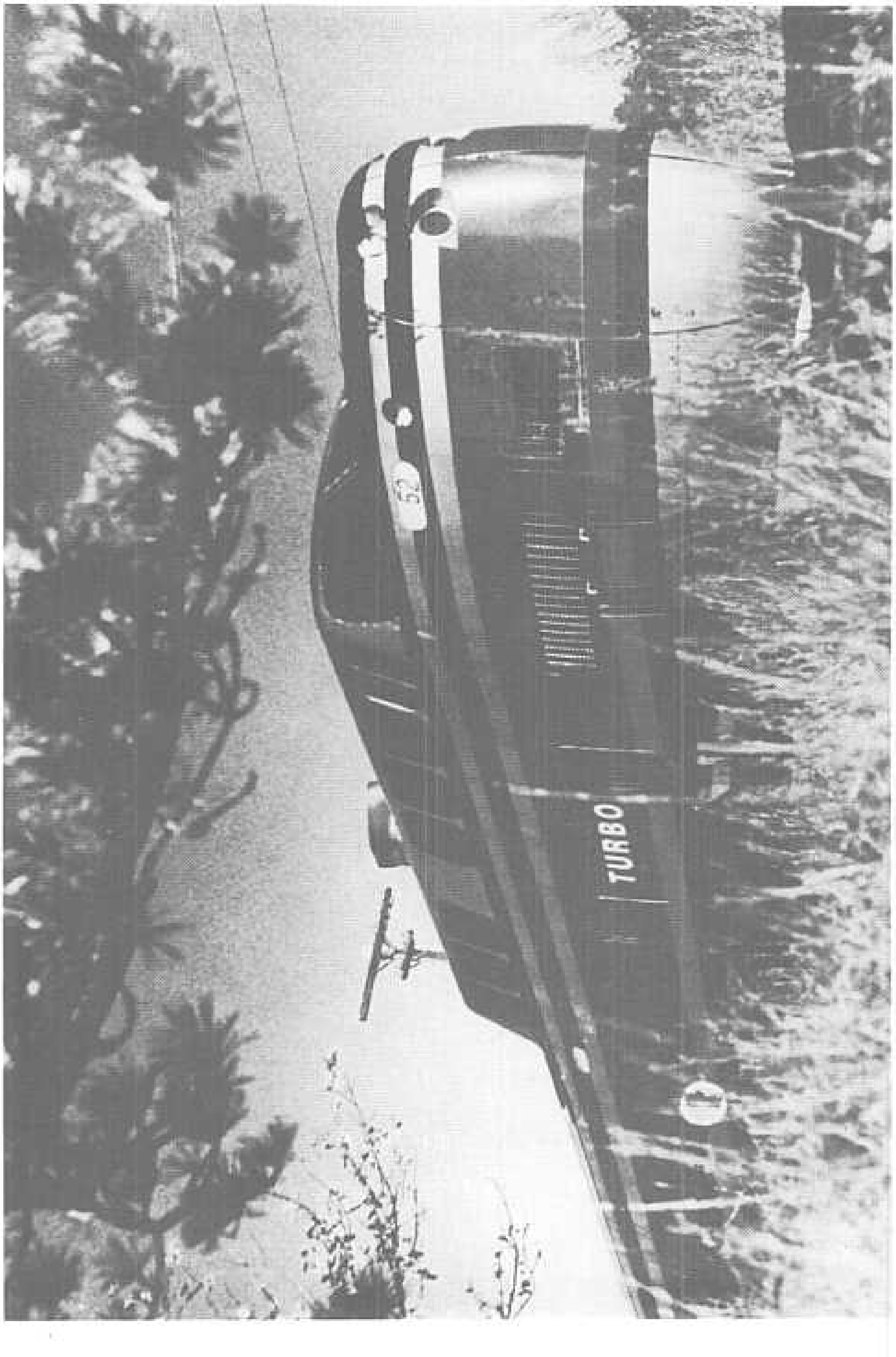


Figure G-2 Turbotrain

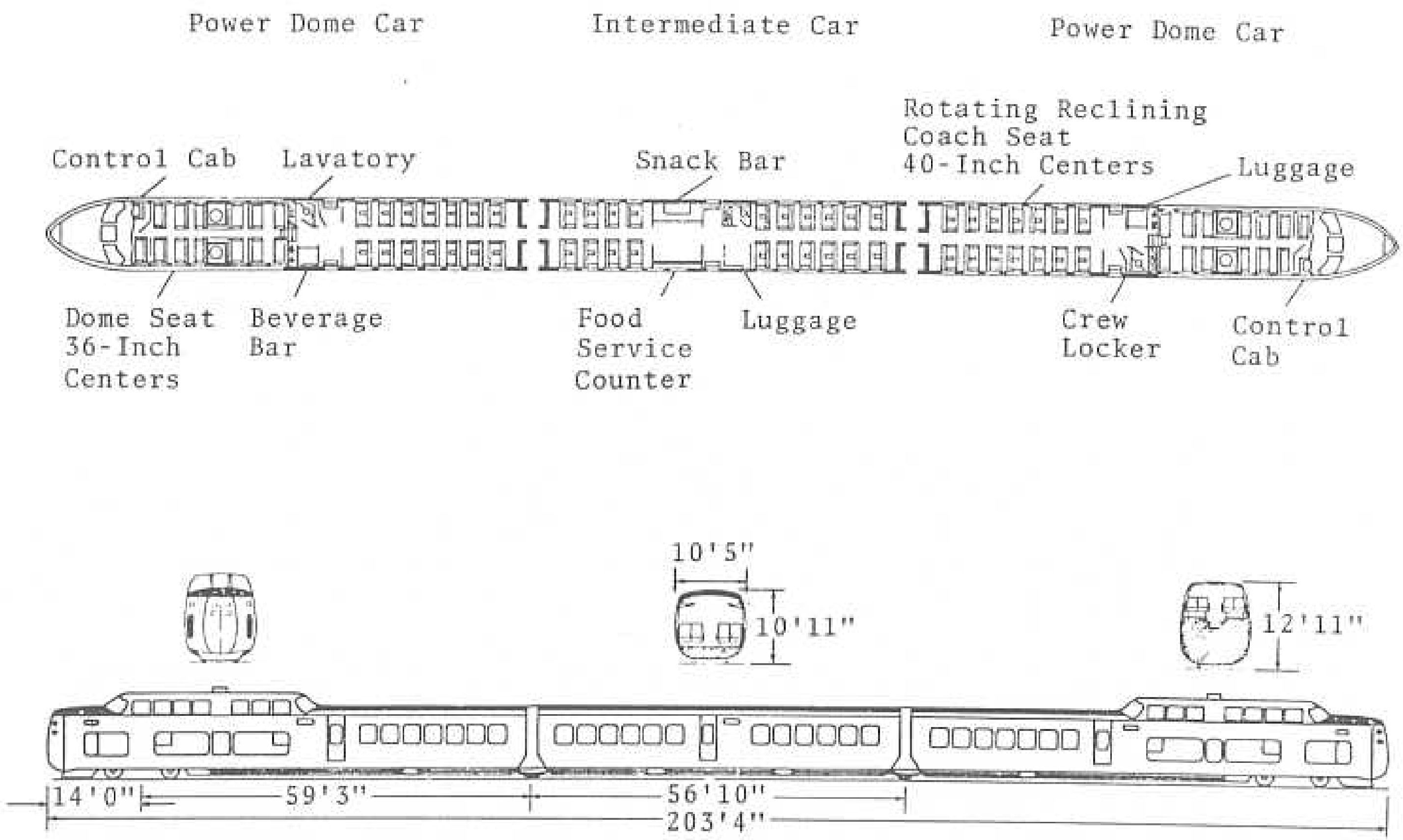


Figure G-3 Three-Car Turbotrain

APPENDIX H

ENVIRONMENTAL DATA

TABLE H-1

ENVIRONMENTAL DATA

Date	Time	Temperature	Relative Humidity	Barometric Pressure	Wind		Sky
					Velocity	Direction	
	hours	°F	percent	mm Hg	mph		
Nov 4, 1971	1900-2100	37	64	765	Calm		Clear
May 23, 1972	1000-1710	70-78	20	742	0-5	NW	Clear-Sunny
Sep 20, 1972	1800-2100	40	92	742	Calm		Clear
Sep 26, 1972	1600-2130	63-65	90	726	3-5	SW	Clear

APPENDIX I

DEFINITION OF TERMS

TABLE I-1.
DEFINITION OF TERMS

TERM	ABBREVIATION	DEFINITION
A-Weighted	dBA	Sound level obtained by measuring the sound pressure through a filter network having a frequency response (A-weight) conforming to American National Standards Institute (ANSI, S1.4, 1971).
Deadhead train		Train operating without passengers.
In-close		Relative position to a finite moving source where non uniform high level point sources exist simultaneously with noise as from a uniform line source.
Passby		Passage of vehicle by the fixed measuring stations.
Time history		Graphic recording of the variations of level measured vs. time.
Wayside		Along side the railroad right-of-way