REPORT NO. UMTA-MA-06-0025-79-5,III

SLRV ENGINEERING TESTS AT DEPARTMENT OF TRANSPORTATION TRANSPORTATION TEST CENTER FINAL TEST REPORT

Volume III - Ride Quality, Noise, and Radio Frequency Interference Tests

Prepared by

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Surface Transportation Systems
Philadelphia, PA 19142

JUNE 1979

FINAL REPORT

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Prepared for

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16. Abstract

In May 1973, Boeing Vertol Company was awarded a contract to build Light Rail Vehicles to a specification sponsored by Department of Transportation's Urban Mass Transportation Administration, and identified a Standard Light Rail Vehicle (SLRV).

Engineering testing on the SLRV was conducted by Boeing Vertol Company in accordance with the General Vehicle Test Plan GSP-064 at the Transportation Test Center, Pueblo, Colorado. The tests were conducted in conjunction with the Qualification Testing of three SLRV Production Pilot Cars (SF-0002, SF-0003, and MB-0002).

This report presents the results of the series of tests conducted in accoradance with GSP-064. Volume I contains a description of the SLRV Test Program and the vehicle, and a summary of the test results; Volume II, Performance and Power Consumption Test Data; Volume III, Ride Quality, Noise, and Radio Frequency Interference Test Data; and Volume IV, a log of all tests collated by test objective and test vehicle.

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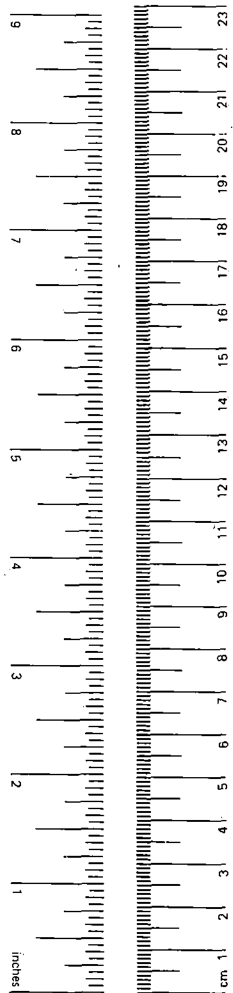
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 cm (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit	°F

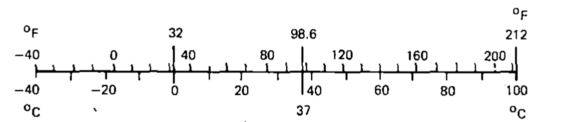


TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figure		Page

LIST OF TABLES

1. INTRODUCTION

The United States Standard Light Rail Vehicle (SLRV) is currently in production at the Boeing Vertol Company for the Massachusetts Bay Transportation Authority and the San Francisco Municipal Railway. In order to develop a data base for quantitative comparison of the SLRV with other railcars and systems, testing was performed at the Rail Transit Test Track at Pueblo to the requirements of the TSC General Vehicle Test Plans (GSP-064).

1.1 SLRV ENGINEERING TEST PROGRAM

The general objective of the SLRV engineering test program was to:

- Establish a data baseline for the SLRV obtained in accordance with the General Vehicle Test Plans
- Provide further experience in the use of the General Vehicle Test Plans in testing Urban Rail Vehicles
- Conduct GSP-064 testing, when appropriate, in conjunction with ongoing qualification testing to minimize cost of data collection

This report of the SLRV Engineering Tests is contained in four volumes:

Volume I	Introduction
Volume II	Performance and Power Consumption Tests
Volume III	Ride Quality, Noise, and Radio Frequency Interference Tests
Volume IV	Data Logs

2. RIDE ROUGHNESS TESTS

2.1 SUMMARY

Objective

The objective of the ride roughness tests was to determine the worst steady vibration level of the Standard Light Rail Vehicle operating on the test track at Transportation Test Center, Pueblo, Colorado. This data is for comparison with data recorded on other transit vehicles in similar test circumstances.

Test Procedure

The test procedure used for the ride roughness testing was that specified in the General Vehicle Test Plan (GVTP) Test Set R-1101-TT.

Test Sequence

The ride roughness testing, in accordance with the GVTP specification, was incorporated into Tests 53, 55, and 56 on the SF0002 vehicle as indicated in the following table:

TABLE 2–1. RIDE ROUGHNESS TESTING

Car Weight (lb)	Track Condition	Test Number	Record Numbers
77,540 (AW1)	Welded Rail/Concrete Tie	55	5 – 12
82,500 (AW2)	Welded Rail/Concrete Tie	56	1 – 12
100,945 (AW3)	Welded Rail/Concrete Tie	53	2 – 10
82,500 (AW2)	Jointed Rail/Wood Tie	56	17 – 30

2.2 TEST DESCRIPTION

Ride quality data was recorded and collected at two car locations over a range of car speeds and on two track sections. The locations were on the car floor centerline over an end truck and on the car floor centerline over the center truck in the articulation section. In each location recordings were taken of vertical, lateral, and longitudinal accelerations.

2.3 INSTRUMENTATION

Gulton accelerometers, type LA010265, were chosen for the vertical, lateral, and longitudinal carbody vibration measurements due to both their linear measurement in the 0 to 40 Hz frequency range and their sensitivity of ± 1.5 g. Truck-mounted accelerometers used on components between the secondary and primary suspension were Statham A5-5-350 devices which have a ± 5 g response from 0 to 190 Hz.

The ride quality accelerometer locations are noted as SA1-SA6 in Table 2-2. The parameters designated A-1 through A-5 are located on truck components.

TABLE 2–2. RIDE QUALITY INSTRUMENTATION

Parameter	Burr Brown Channel	Oscill Channel	Galvo S/N	Endevco Cond Chan	Ithaco Filter Chan	Tape Track
Time code		2-6, 3-14	10765			A-1
Flutter comp			9273			B-1
						A-2
						A-2
VS-2	2	2-3	2951	1	2	A-4
VS-3	3	2-4	4656	2	3	B-3
C/S-A	5	2-11, 3-15	402CY	4	5	A-5
			260DA			B-5
LVD	6	2-12	7563	5	6	A-7
MACD	7	2-13	16214	6	7	A-13
MFCD	8	2-14	5641	7	8	A-9
Event						
		2-17	10064			A-11
		3-18	265BT	22	23	B-13
SA1 Carbody, Vert, Over B Truck		3-8	1850	0	1	A-3
SA2 Carbody, Lat, Over B Truck		3-9	2869	18	19	A-6
SA3 Carbody, Long., Over B Truck		3-10	4458	21	22	A-8
SA4 Carbody, Vert, Over Center Truck FLOOR ℄		3-11	5417	16	17	A-10
SA5 Carbody, Lat, Over Center Truck		3-12	5448	19	20	A-12
SA6 Carbody, Long., Over Center Truck		3-13	1044	17	18	A-14
A-1 B Truck Transom Vert		3-2	21779	3	4	B-4
A-2 B Truck Transom Lat		3-3	8965	13	14	B-7
A-3 Cent. Truck Ped Vert		3-4	16005	9	10	B-8
A-4 Cent. Truck Bel Brg Vert		3-5	984CX	8	9	B-10
A-5 B Truck Ped Vert		3-6	134CO	14	15	B-11
Tests 54-56, Runs 53, 54, and 55 were Motor Vertical and Lateral						

2.4 TEST PROCEDURES

The ride quality vibration data was recorded on analog tapes and later analyzed to obtain spectrum analysis and ride roughness curves. Spectrum analysis permits identification of vibration contribution from modal characteristics of the car body structure.

Figure 2-1 shows a typical spectrum analysis curve of car body vertical vibration. These data show that peak amplitudes occur in the frequency range below 2.0 Hz and are associated with response from the rigid body pitch and vertical modes of the car body on the secondary suspension. No significant response from the car body bending modes occurs because their natural frequency is well above the maximum wheel rotational frequency. Appendix A contains the complete presentation of all the spectrum analyses for the accelerations in three axes at two locations.

The 18 Hz vertical vibration measured over the unpowered truck results from a local response of the articulation floor coverplate. Measurements made adjacent to the articulation show significantly lower levels.

The filter bandwidth for the spectrum analysis was 0.20 Hz in the 0 to 10 Hz range and 1.0 Hz for frequencies above 10 Hz.

The ride quality vibration data was further processed to produce the ride roughness data. Ride roughness is a figure-of-merit to indicate the roughness of ride experienced by a typical passenger on a moving transit vehicle.

The methodology for establishing this parameter is defined in GSP-064, General Vehicle Test Plans for Urban Rail Transit Cars. The ride roughness number is determined by obtaining the rms average of the time history for a 1-second interval with the car body acceleration applied through a system of weighting filters as supplied by TSC. The horizontal and vertical signal weighting networks specified are shown in Figures 2-2 and 2-3 respectively.

2.5 TEST DATA

The effect of vehicle speed and weight on car body acceleration levels for two car weights 77,540 pounds (AW1) and 100,945 pounds (AW3) on welded rail/concrete tie is shown in Figures 2-4 thru 2-9. Data presented are peak amplitudes at the predominant frequencies identified from the narrow band analyses.

Figure 2-10 compares SLRV ride quality data to the goal for both lateral and vertical acceleration. Compliance with this goal is required at AW1 car weight. Center car vibrations result from a local response of the articulation floor coverplate. These center and end car data show that the vehicle meets the ride quality goal.

Figures 2-11 through 2-16 present ride roughness data at AW1 and AW3 carweights at end-car and mid-car locations. The overall low ride roughness numbers reflect the smooth vehicle ride over the entire operating speed and weight range.

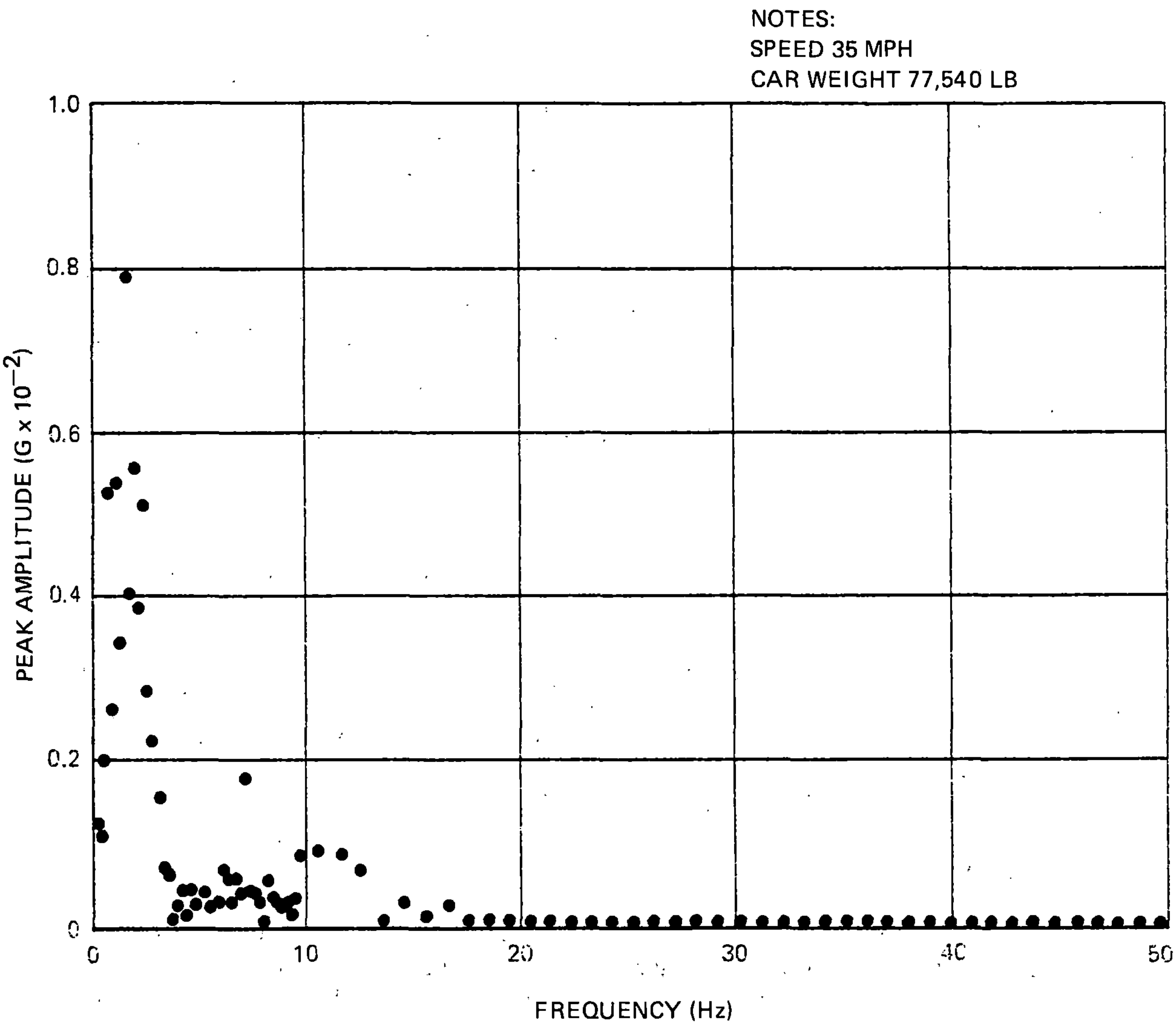


Figure 2–1. Typical Spectrum Analysis – Car Body Vertical Vibration

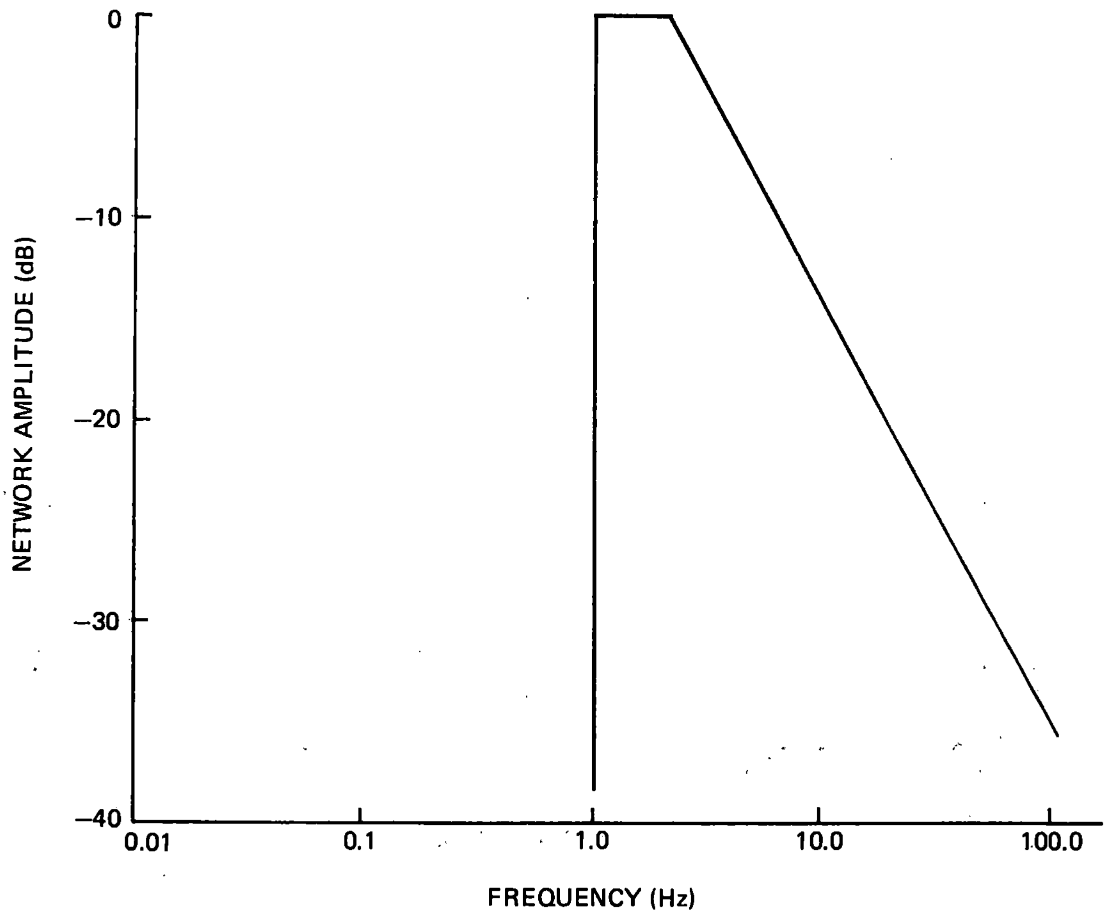


Figure 2–2. Weighting Network Frequency Response for Horizontal Ride Roughness

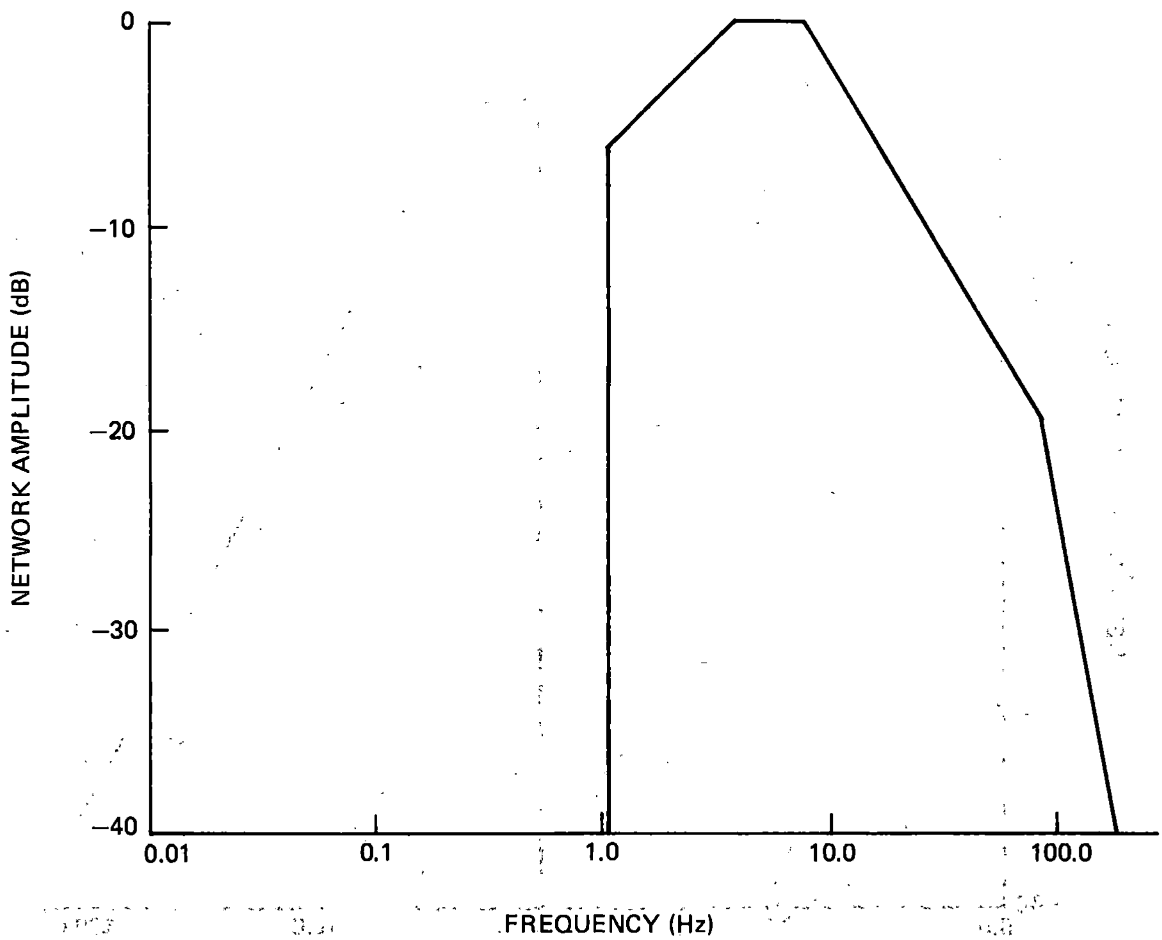


Figure 2–3. Weighting Network Frequency Response for Vertical Ride Roughness

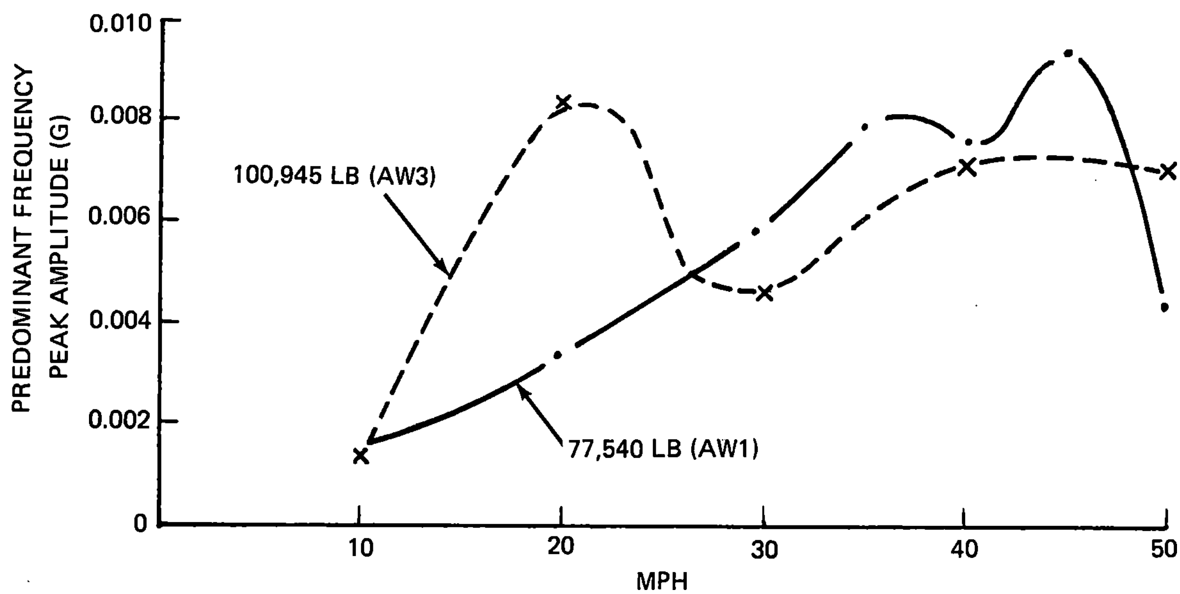


Figure 2–4. Effect of Speed and Weight on Vertical Ride Roughness, End Car

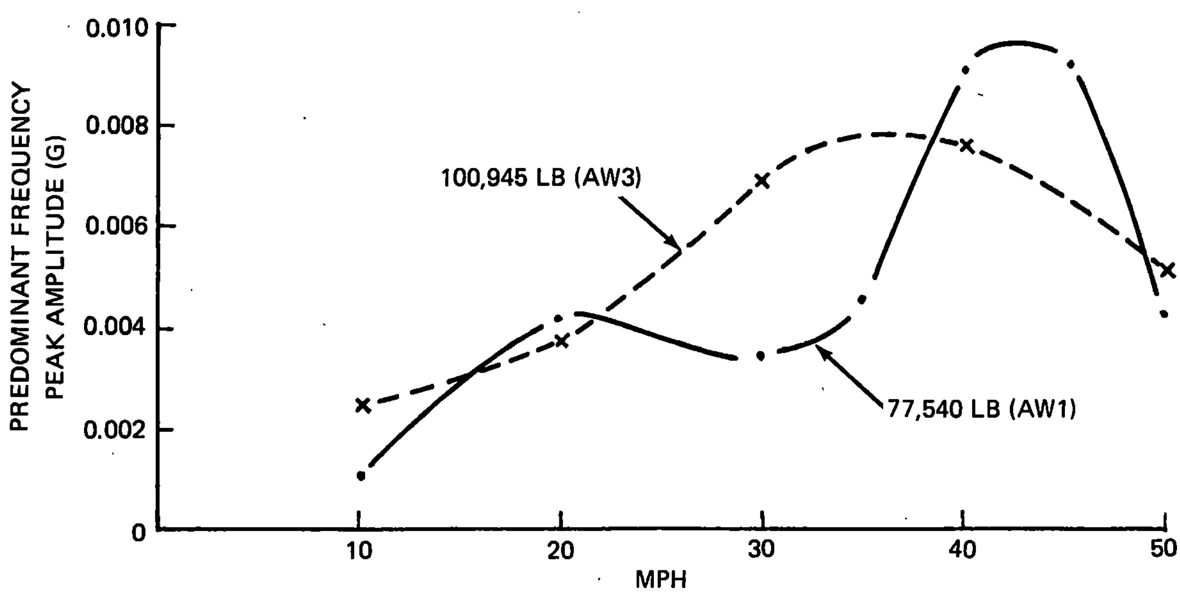


Figure 2–5. Effect of Speed and Weight on Lateral Ride Roughness, End Car

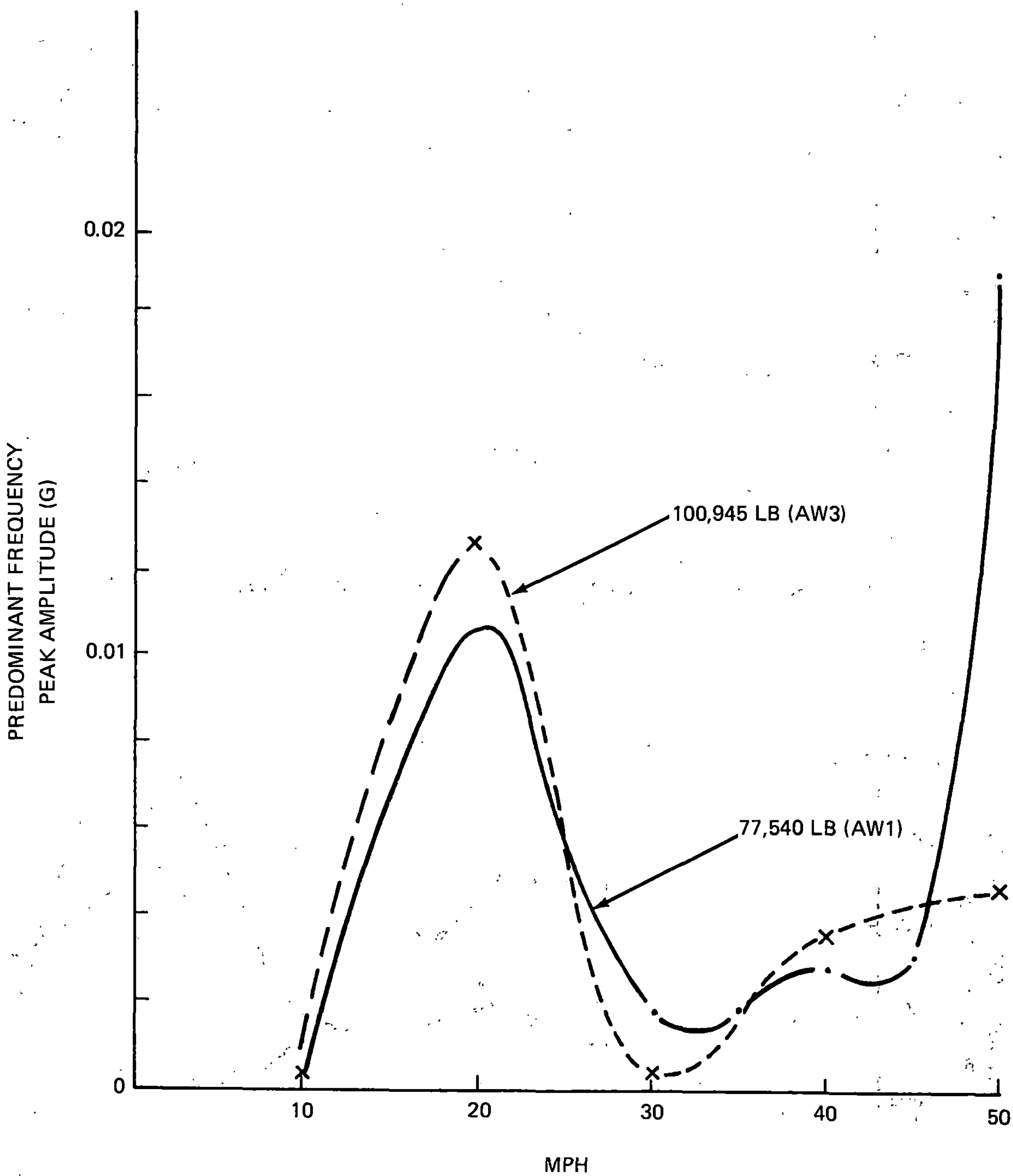


Figure 2–6. Effect of Speed and Weight on Longitudinal Ride Roughness, End Car

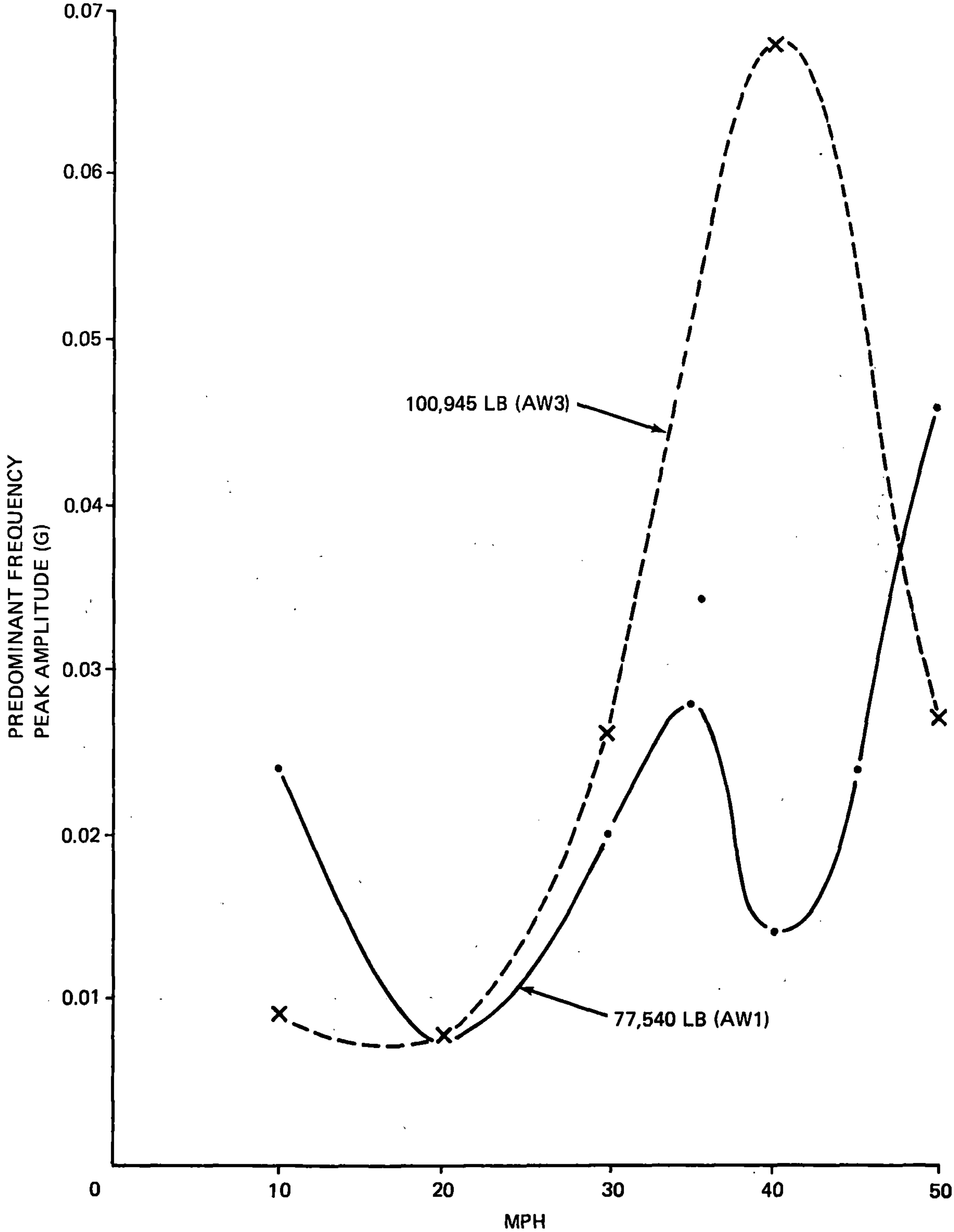


Figure 2–7. Effect of Speed and Weight on Vertical Ride Roughness, Mid Car

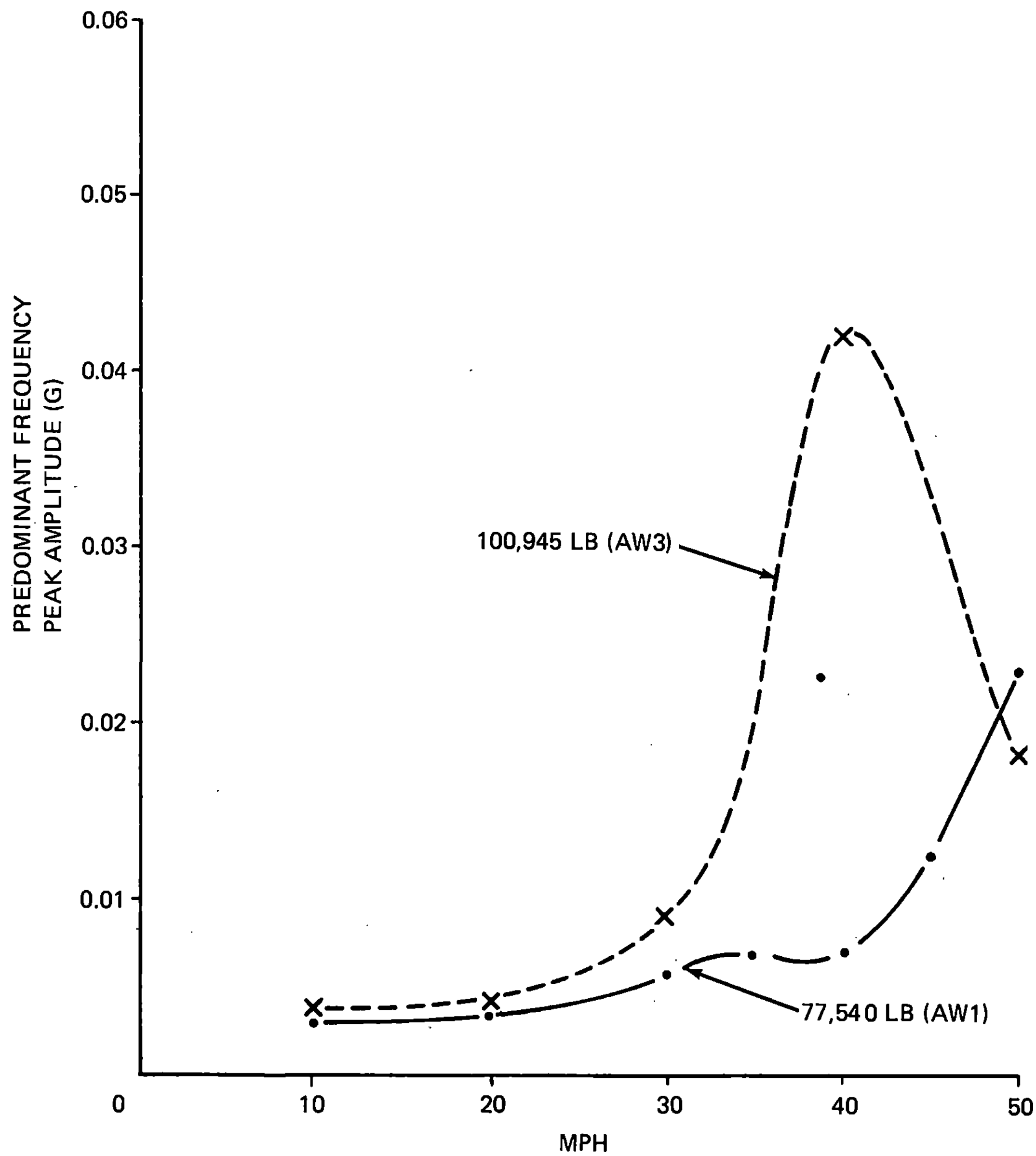


Figure 2–8. Effect of Speed and Weight on Lateral Ride Roughness, Mid Car

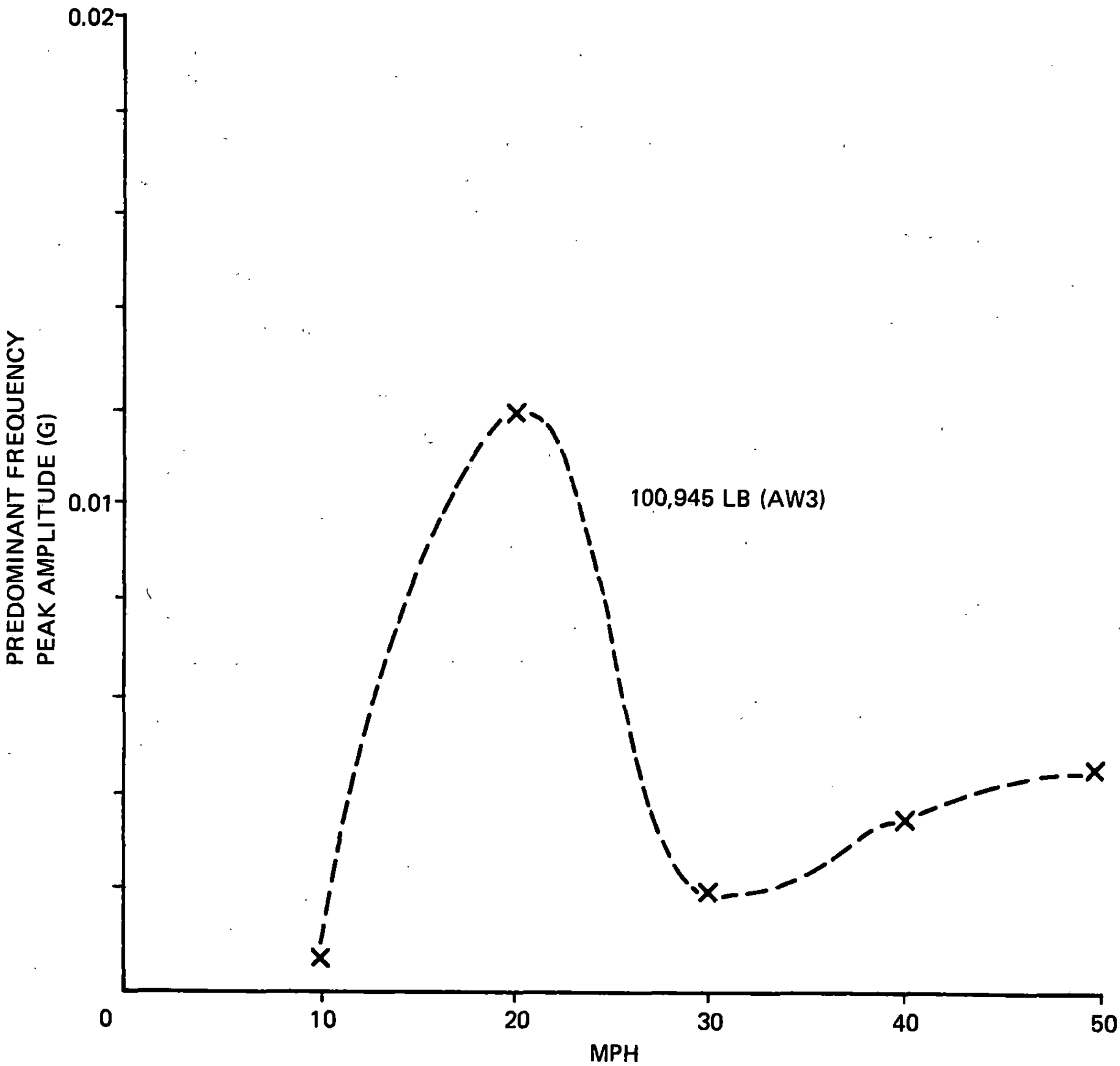


Figure 2–9. Effect of Speed on Longitudinal Ride Roughness, Mid Car

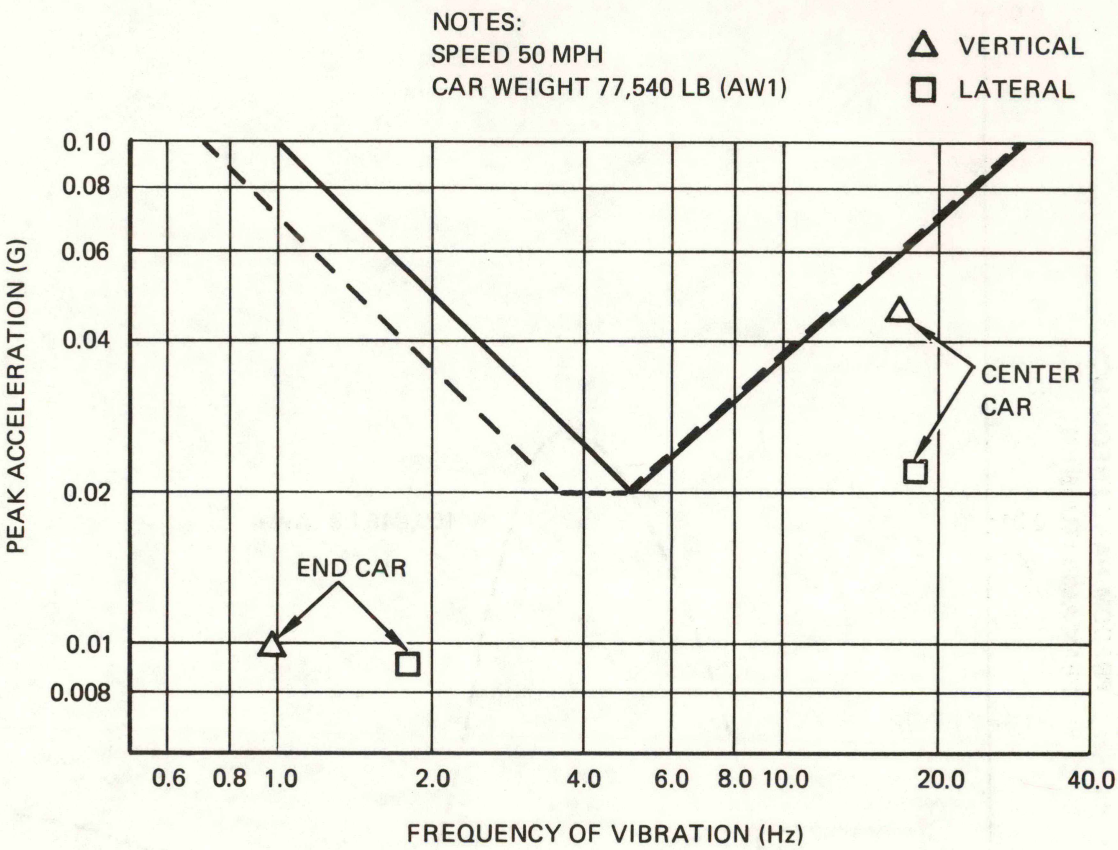


Figure 2–10. Vibration Data Versus Ride Quality Goal

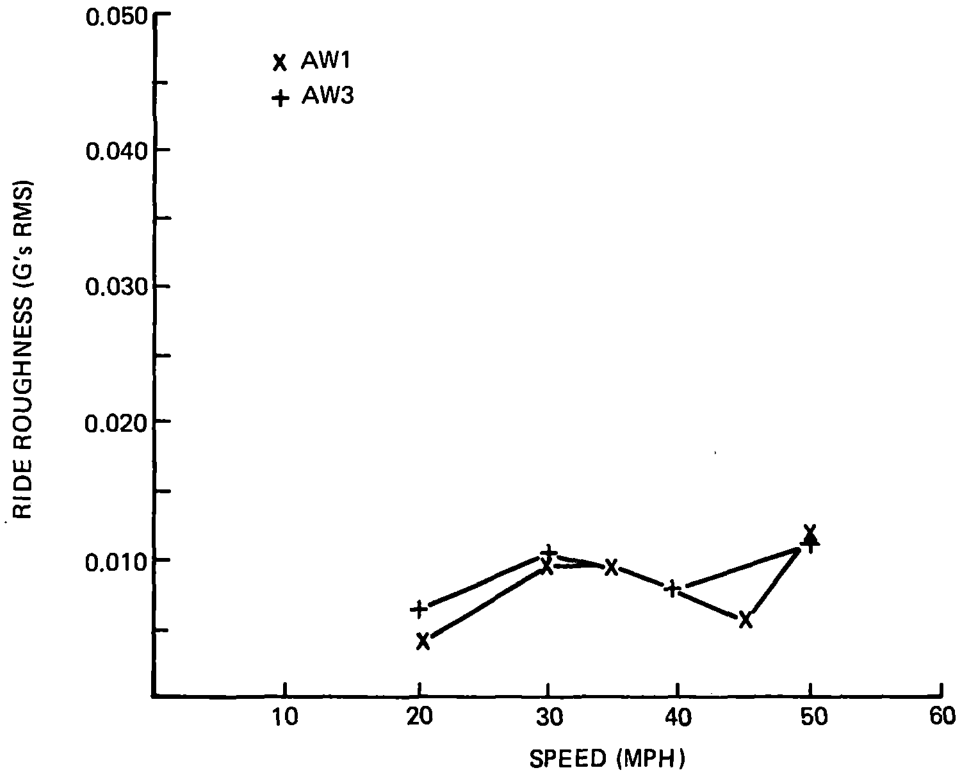


Figure 2–11. Effects of Speed and Weight on Vertical Ride Roughness, End Car

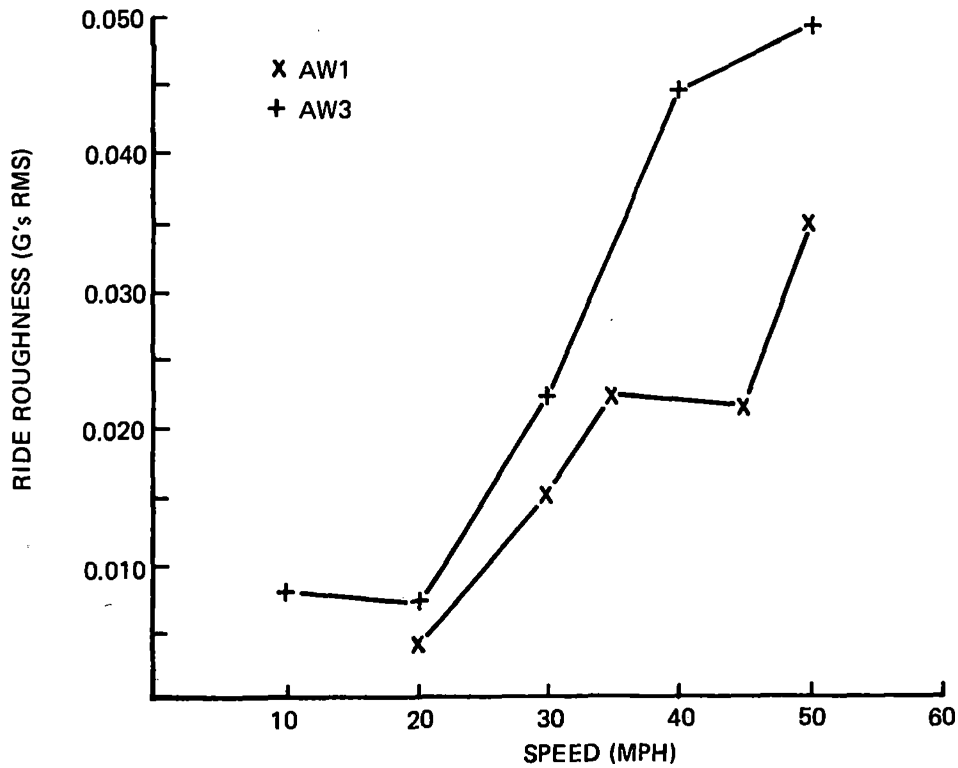


Figure 2–12. Effects of Speed and Weight on Vertical Ride Roughness, Mid Car

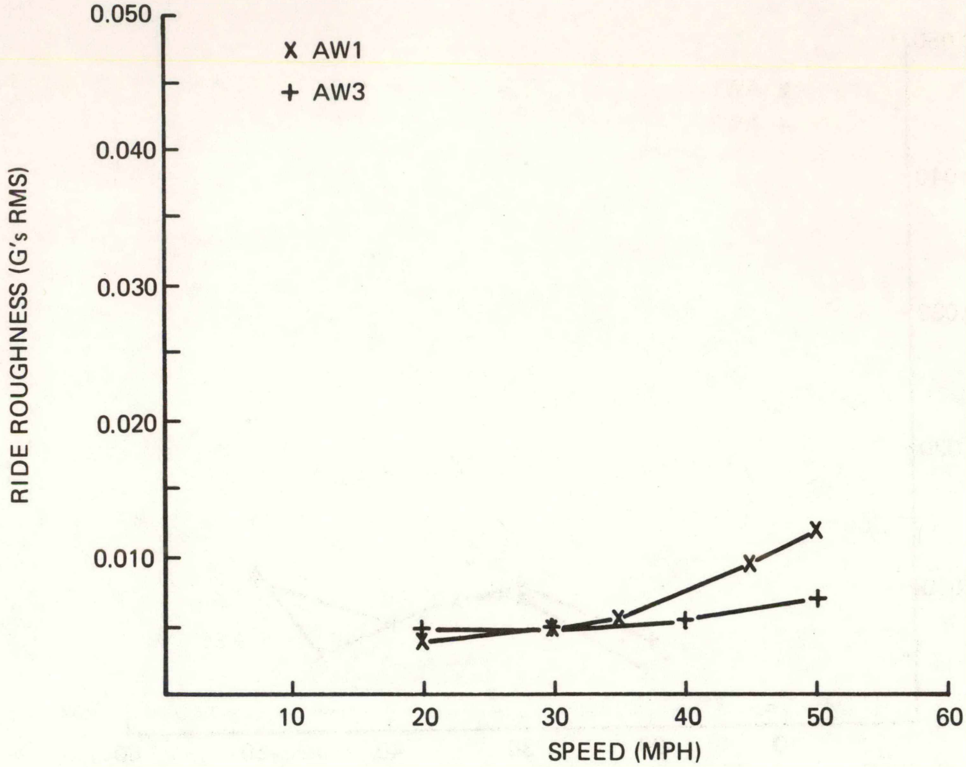


Figure 2–13. Effects of Speed and Weight on Lateral Ride Roughness, End Car

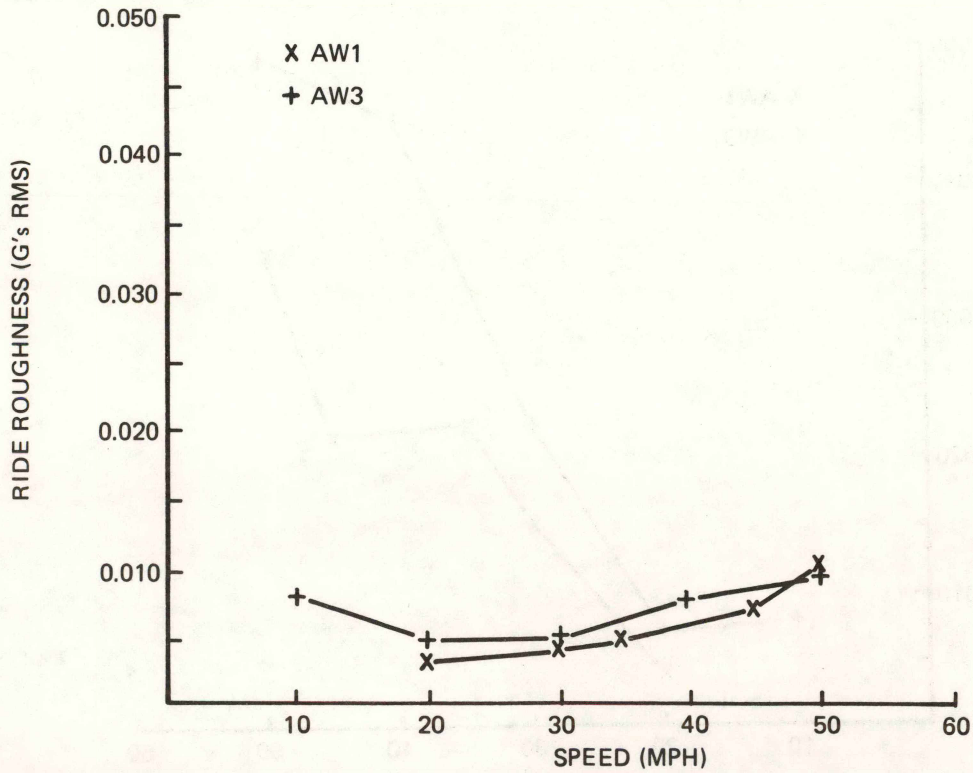


Figure 2–14. Effects of Speed and Weight on Lateral Ride Roughness, Mid Car

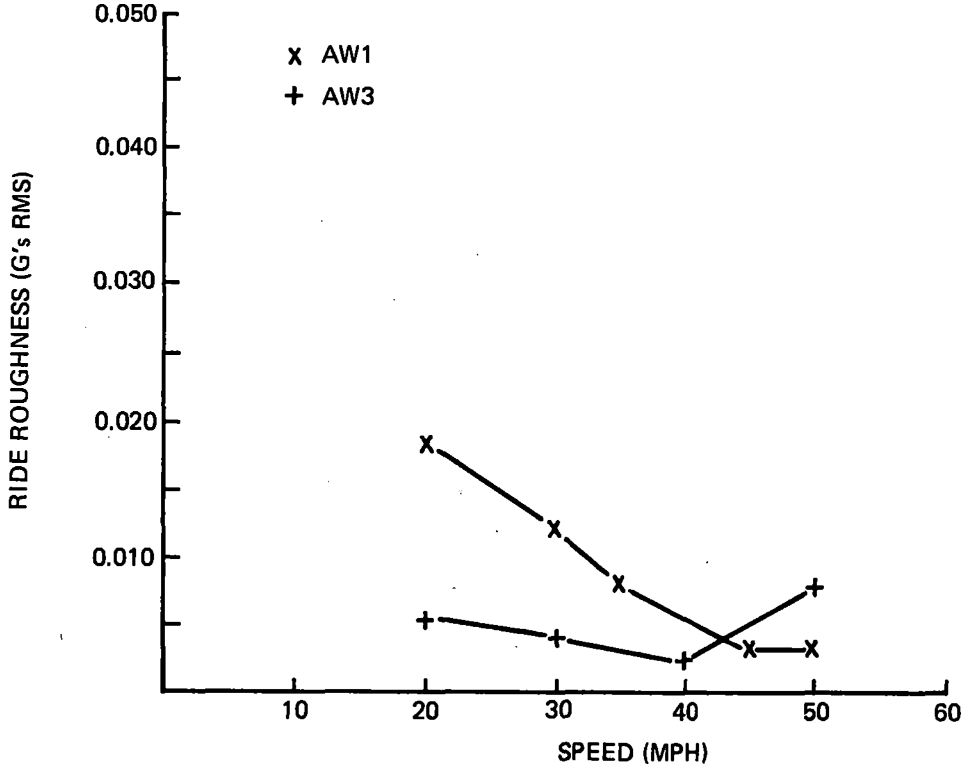


Figure 2–15. Effect of Speed and Weight on Longitudinal Ride Roughness, End Car

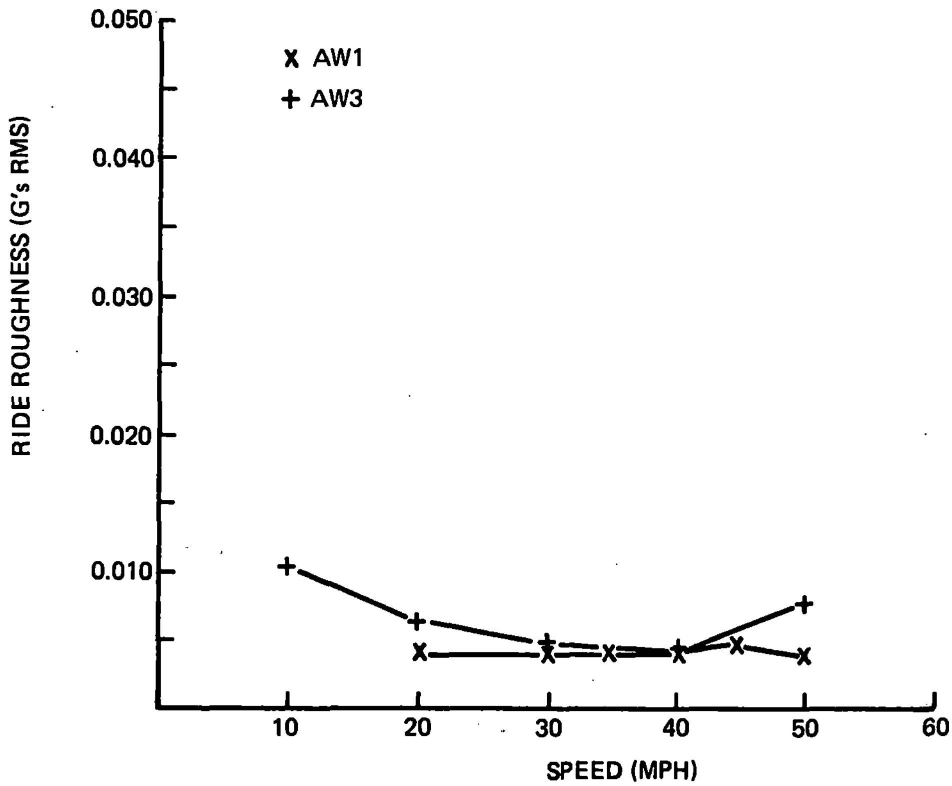


Figure 2–16. Effect of Speed and Weight on Longitudinal Ride Roughness, Mid Car

3. NOISE TESTS

3.1 SUMMARY

Objective

The objective of the noise testing was to survey the interior and wayside noise levels of the SLRV in both the MBTA and SFMR configurations in order to assess the acoustic environment of the passenger inside the car as well as the contribution of the SLRV to community noise.

Procedures

The test procedures adopted for the noise surveys are those recommended by the General Vehicle Test Plan for Urban Rail Transit Cars (Report Number UMTA-MA-06-0025-75-14, September 1975). The following test sets were utilized: Equipment Noise Survey – Wayside, Effect of Car Speed on Wayside Noise, Effect of Speed – On Car, Interior Noise Survey, Acceleration Effect – On Car, and Deceleration Effect – On Car.

Test Sequence

Wayside and interior noise surveys of the SFMR vehicle were conducted at the Transportation Test Center, Pueblo, Colorado, on continuous welded rail (Track Section IV of the Transit Oval). The noise survey of the MBTA vehicle was conducted on the MBTA's Green Line on at-grade track and continuous welded rail.

Status

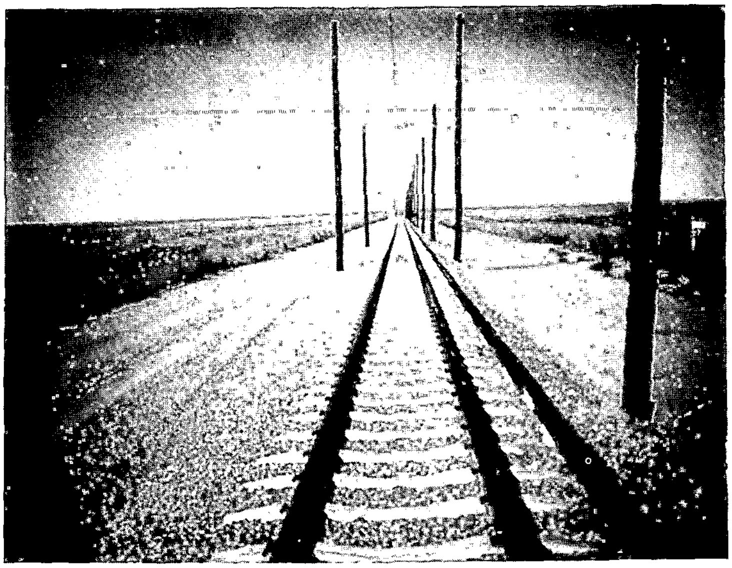
The SFMR noise surveys were made in February 1976 on cars SF0002 and SF0003. The tests on the MBTA vehicle were conducted on car 3402 in Boston in June and August 1976. A revision to the SFMR air comfort blower design speed was made after tests were completed on this vehicle. This revision results in lower interior noise levels for the SFMR vehicle than those identified by this report. Tests have not been conducted on the SFMR vehicle in this final configuration.

3.2 WAYSIDE NOISE TEST DESCRIPTION

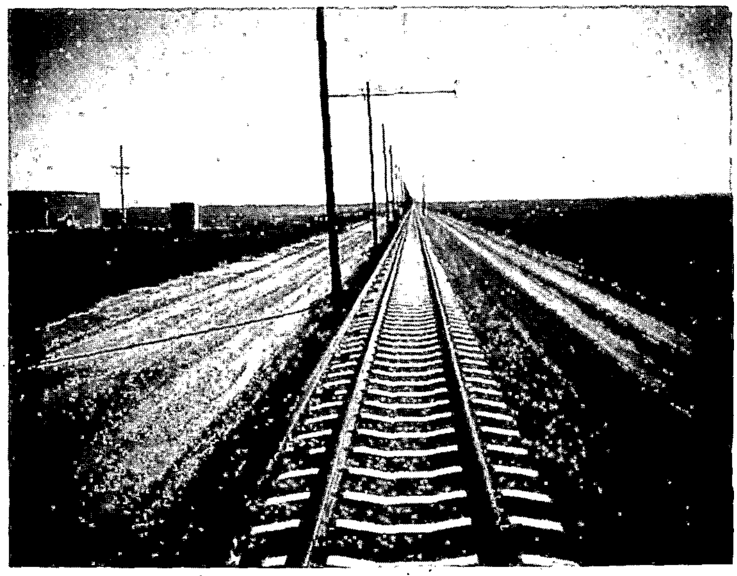
A noise survey was conducted on vehicles representing both the SFMR and MBTA configurations. Data on the SFMR car was obtained at the Transportation Test Center, Pueblo, and for the MBTA configuration, data was taken on the MBTA's Green Line near the Riverside Station in Newton, Mass.

The test area at the Transportation Test Center is known as Track Section IV, and for wayside noise measurements, the survey was conducted adjacent to tangent track. The track consists of 119-pound continuously welded rails set on concrete ties imbedded in stone ballast and spaced at 30 inches. The microphones were located opposite station 369, approximately midway in the tangent portion of Section IV which is 8,000 feet in length. There is a 0.7 percent upgrade in the northbound direction (see Figure 3-1).

The test region on the MBTA Green Line was a section of track near the Riverside terminal. The right-of-way in this area was bordered by a golf course which presented grassy terrain between the track and the microphone.



VIEW NORTHBOUND



VIEW SOUTHBOUND

Figure 3–1. Track Section IV Used for Noise Survey

The track consisted of 115-pound continuously welded rails set on timber ties spaced at inches imbedded in stone ballast. For the passby noise survey, the car moved past the microphone in the same direction for all speeds.

The wayside noise survey included measurements of undercar equipment operating individually with the microphone positioned at the center of the stopped car, located at a distance of 50 feet from the track centerline and 4 feet above top-of-rail.

For the wayside passby noise surveys, the microphone was also at a distance of 50 feet from the track centerline and at a height of 4 feet above top-of-rail.

Ambient noise levels were, in all cases, 10 dB or more below the equipment or car noise being measured.

Figure 3-2 is a plan view of the SLRV showing the location of the undercar equipment items surveyed.

3.3 INSTRUMENTATION

A portable microphone/recorder data system was used to survey noise levels of the SLRV in both the MBTA and SFMR configurations. The instrumentation consisted of 1/2-inch condenser microphones and 1/4-inch magnetic tape recorders. Figure 3-3 is a block diagram of the data acquisition and reduction systems. Acquisition system A was used for the recording of all data with the exception of the SFMR wayside passby survey of two cars. For this test system B was employed. The record/playback system characteristics were similar for both recording systems over the frequency range of 50–100 kHz. During all tests, a sound level meter was used to document A-weighted sound levels at the same locations as the tape recordings.

Calibration

The recorders were calibrated prior to testing using a swept frequency sinusoidal insert voltage over the range 20 Hz to 20 kHz. The entire record/reproduce system frequency response, including the microphone; was evaluated during this calibration, with the microphone diaphragm actuated electro-statically. During field tests, a known signal (e.g., 94 dB at 1,000 Hz) was recorded on each tape to establish system sensitivity and a reference level.

System Accuracy

The frequency response of the 2-channel noise recording system had an electrical frequency response linearity as shown in Figure 3-4 for a range of signal voltage levels corresponding to input sound levels of 50 dB to 120 dB at the microphone.

The frequency response characteristics of Channel 2 of the NAGRA IV when operated at 3-3/4 ips accentuate sound levels at frequencies above 2 kHz. The correction shown in Table 3-1 should be applied to all data recorded on this channel as noted. Data recorded on this channel is identified in the applicable figure or table.

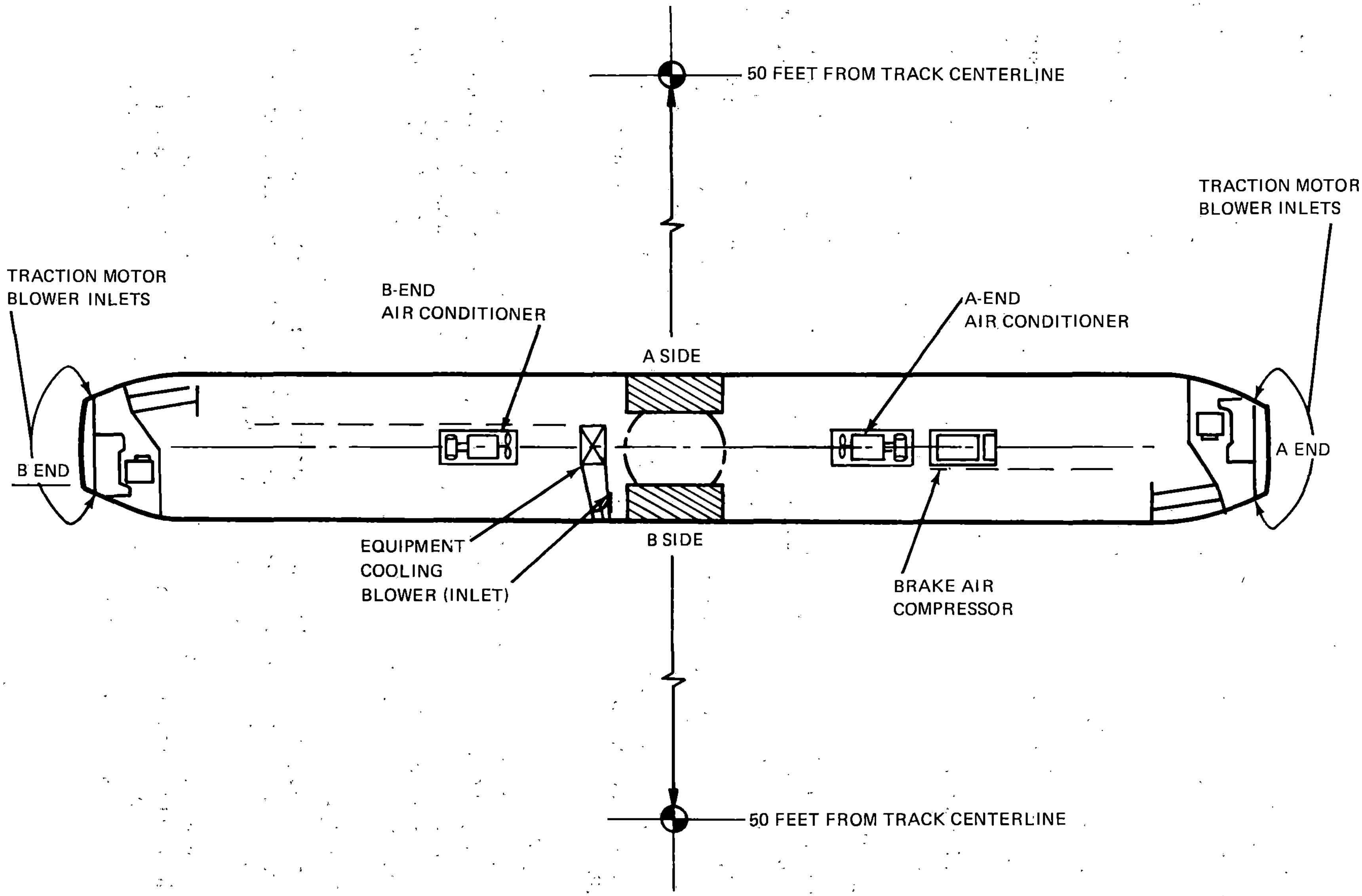


Figure 3–2. SLRV Undercar Equipment Measured for Wayside Noise

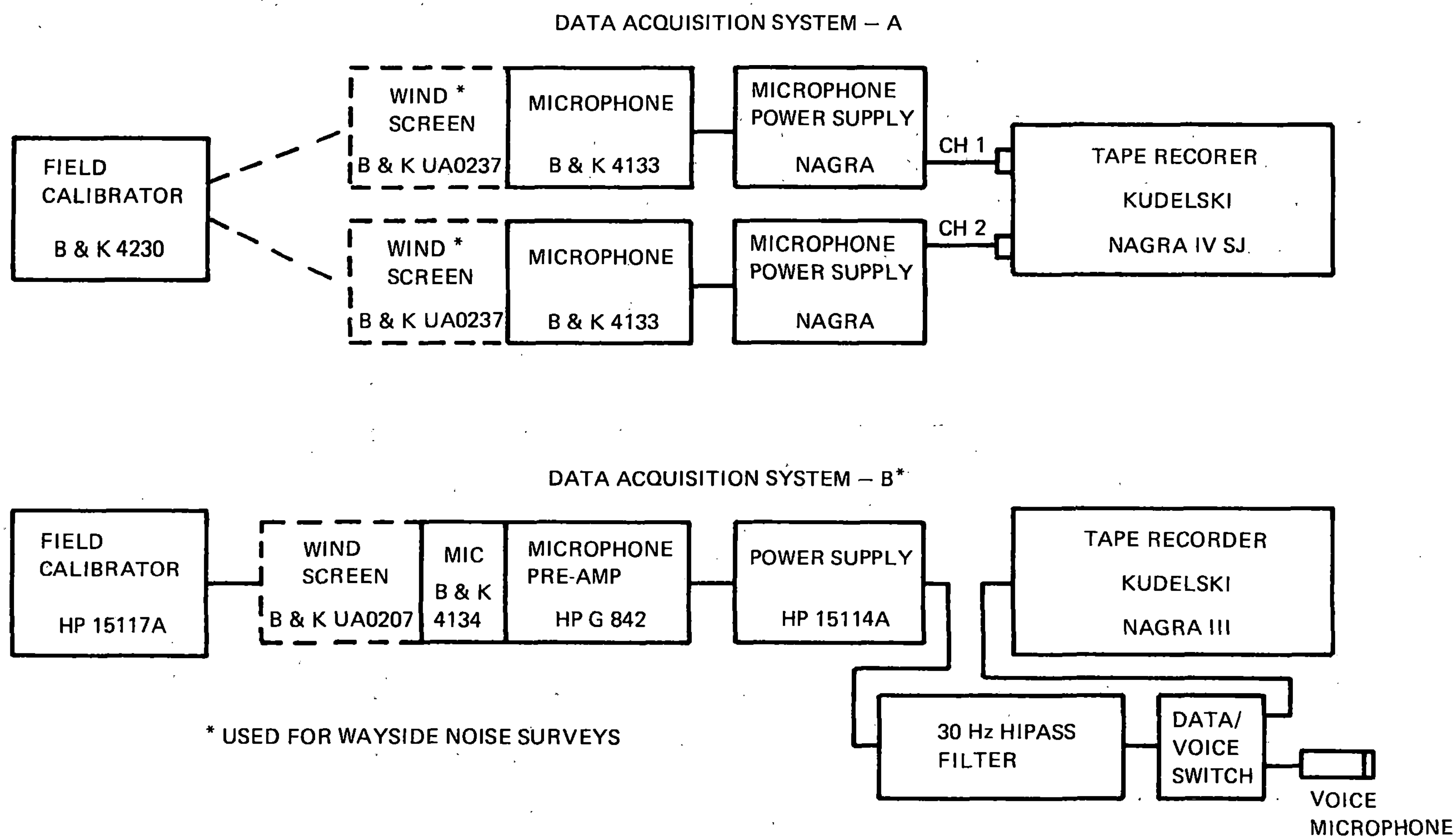


Figure 3–3. Block Diagram for Data Acquisition and Reduction Systems (Sheet 1 of 2)

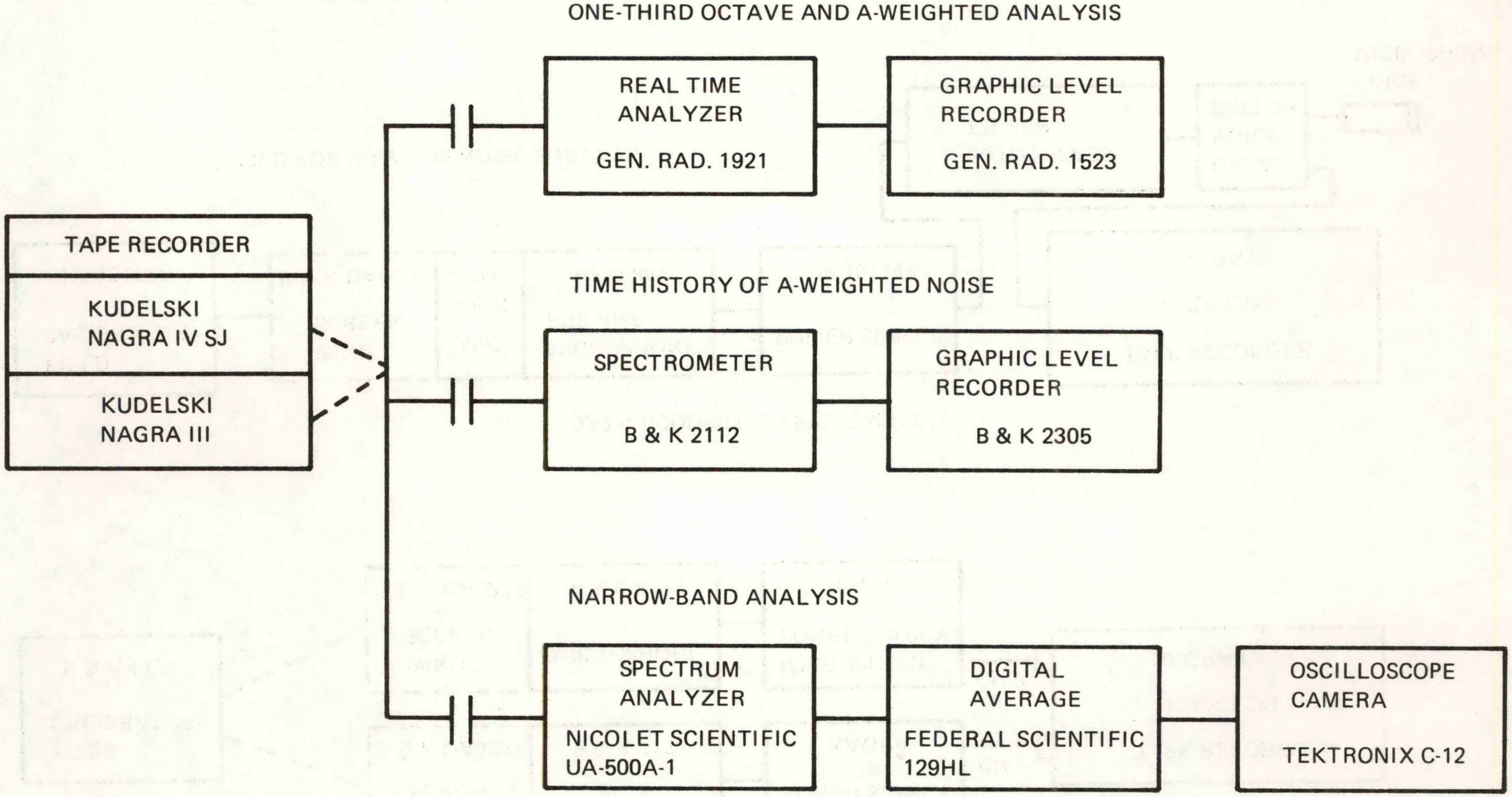


Figure 3–3. Block Diagram for Data Acquisition and Reduction Systems (Sheet 2 of 2)

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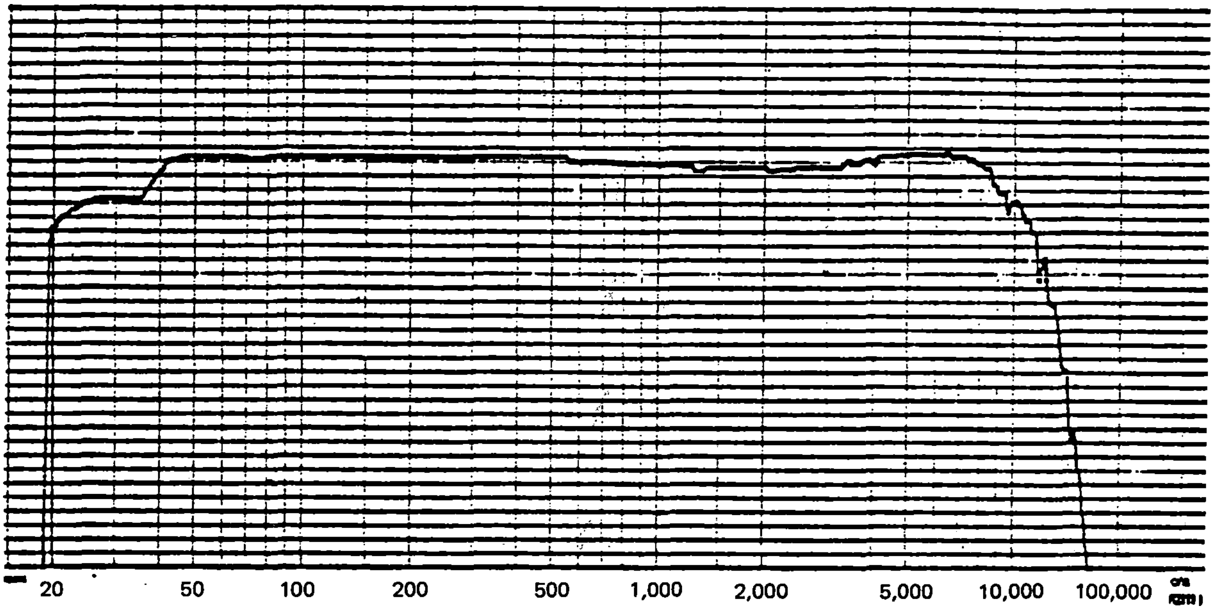
NAGRA IV S/N 1353   3 3/4 IPS

CHANNEL 1 RECORD/REPRODUCE RESPONSE



CHANNEL 2 RECORD/REPRODUCE RESPONSE

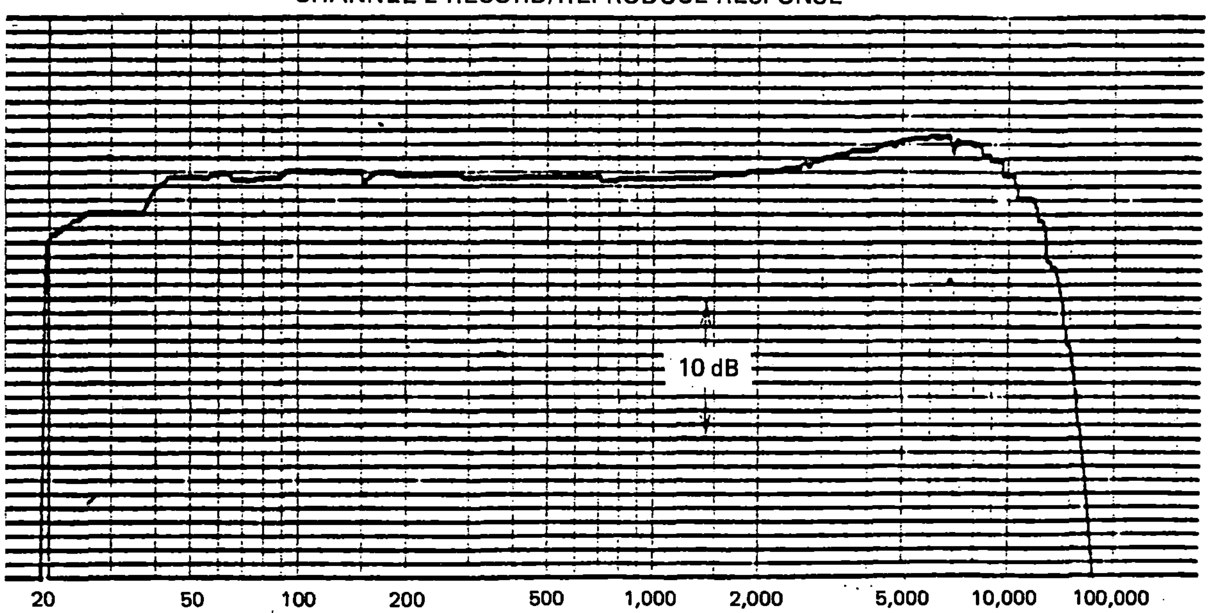


Figure 3–4. NAGRA IV System Frequency Response

TABLE 3–1. CORRECTION FOR CHANNEL 2 DATA

2,000 And Below	2,500	3,150	4,000	5,000	6,300	8,000	10,000	Frequency
0	–1	–1.5	–2	–2.5	–3	–2.5	0	dB Correction

The total harmonic distortion of the assembled noise measurement and recording equipment did not exceed four percent over the measurement dynamic range.

The single channel NAGRA III has frequency response and harmonic distortion characteristics similar to Channel 1 of the NAGRA IV system.

The Boeing Vertol Company operates a Calibration/Certification Laboratory to insure maintenance of instrumentation standards traceable to the National Bureau of Standards. Analyzer characteristics such as filter bandwidths and microphone calibrators are checked twice yearly. Frequency response characteristics of recording systems are typically run prior to each test program.

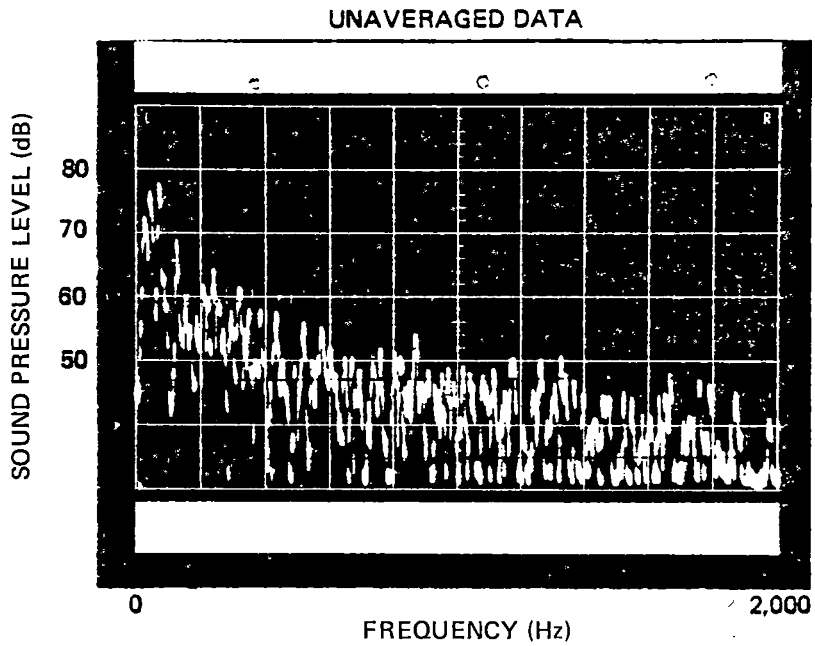
Data Reduction

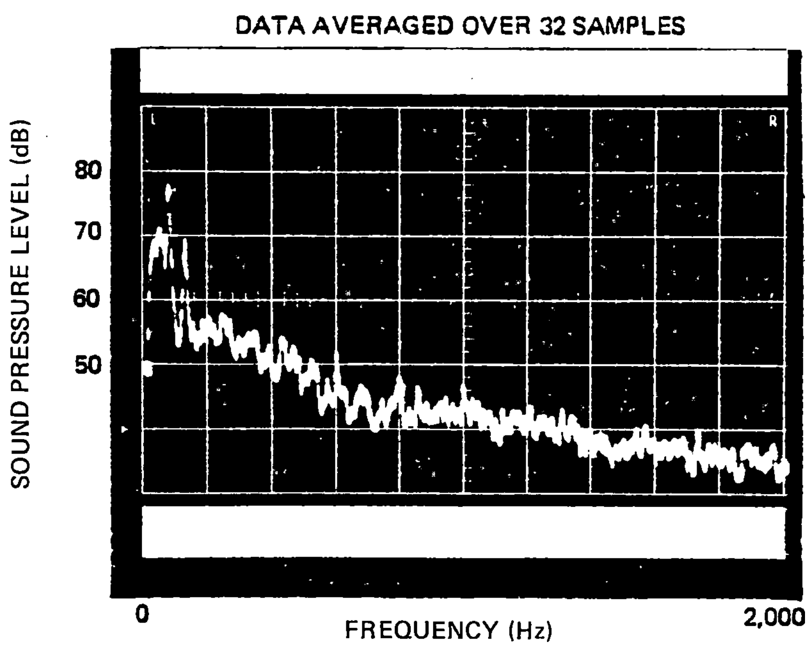
The basic analysis of all data recorded during the program consists of a frequency analysis using an A-weighting filter. For reduction of data where a graphic level recorder was used, such as wayside and interior time histories, the level recorder was set at control positions which reproduced sound level meter readings set on the slow scale.

All steady-state data points have been analyzed using real-time digital processing and are presented both as one-third-octave band and narrow-band spectra. The data presented in one-third-octave spectra represent rms levels which have been integrated over sampling times of at lease 8 seconds, and frequency 16 seconds. The sampling times are presented on each chart. Where one-third-octave band analyses were performed, the A-weighted level was determined by the analyzer during the same processing time. Therefore, all steady-state A-weighted sound levels reported correspond to the identical sampling periods as for one-third-octave analysis. A-weighted sound levels reported for wayside passbys are instantaneous maximum values determined from the graphic level recorder time histories.

The narrow-band frequency spectra presented in this report were analyzed over several frequency ranges in order to display each acoustic signature with a useful spectral resolution. The frequency ranges selected for narrow-band analysis were 0 to 1,000 Hz, 0 to 2,000 Hz, 0 to 5,000 Hz, and 0 to 10,000 Hz.

The frequency analyses presented are not instantaneous spectra but the average of 32 samples analyzed from the magnetic tape record. When averaged over many samples, the frequency components which are random with time tend to cancel and the resulting averaged spectra represent the continuous noise environment for the particular operating conditions. The effect which this averaging technique has on data is shown in Figure 3-5. The unaveraged data is an instantaneous snapshot of one sample, and the averaged data has been summed over 32 samples.





**SFMR INTERIOR NOISE, POSITION 8, 40 MPH
ALL SYSTEMS ON**

Figure 3–5. Comparison of Averaged and Unaveraged Narrow-band Spectra

The analysis time for each sample, τ, is then related to the filter band-width β by,

$$\tau = \frac{1}{\beta}$$

The filter bandwidth and sampling time for each frequency range selected for data reduction are shown in Table 3-2.

TABLE 3–2. FREQUENCY RANGE, BANDWIDTHS, AND SAMPLING TIMES

Frequency Range (Hz)	0–1,000	0–2,000	0–5,000	0–10,000
Filter Bandwidth (Hz)	2	4	10	20
Single Sample Time (sec)	0.5	0.25	0.1	0.05
Time for 32 Samples (sec)	16	8	3.2	1.6

3.4 WAYSIDE NOISE TEST PROCEDURES

Equipment Noise Survey, Wayside Noise, CN-0001-TT

The equipment noise survey was conducted on MBTA Car No. 3402 at the Riverside test location on August 19, 1976. The noise of the SLRV is essentially uniform with regard to right and left sides of the car, and for this survey the microphone was on the left side of the car, as determined from the A end operator's seat. When positioned for minimum reflection from far-field objects, the SLRV was centered over a macadam crosswalk between tracks which was approximately 10 feet wide. It is expected that this hard-surfaced walkway contributed to sound levels which were increased by perhaps 1–2 dBa over those which would have been measured with the equipment over ballast and tie track. This comment applies to the equipment cooling blower and the A-unit air conditioner only. Other items of undercar equipment were above ballast and tie track. No correction has been made to the data to account for the crosswalk reflection.

The following noise data were recorded during this test for a minimum of 15 seconds:

Acoustical Ambient
Brake Air Compressor (130–150 psi)
Equipment Cooling Blowers
Traction Motor Blowers
A-Unit Air Conditioner (both cylinders of the 2-cylinder compressor were operating)

Effect of Car Speed on Wayside Noise, CN-1001-TT

Wayside passby noise surveys were conducted on both the air-conditioned and non-air-conditioned cars. The air-conditioned car survey was conducted on Car No. 3402 near the Riverside station on August 19, 1976. The passbys were run with the A-end leading for each speed evaluated. All normal car systems were operating for these records. The test vehicle was at AWO.

The non-air-conditioned car was surveyed at the Transportation Test Center, Pueblo, on February 17, 1976. For this test, noise levels of the car were measured for both directions of travel on the track. All systems were operating on the car (SF0002). Testing was conducted at both AW0 and AW3.

Data for the two-car train also were obtained at the Transportation Test Center. For this test, cars SF0002 and SF0003 were coupled and data recorded for passbys on both sides of the car. Both cars were at AW0 weight for this test.

For each passby, the vehicle was accelerated to test speed and held to this speed for at least 10 seconds prior to and after passing the microphone.

3.5 WAYSIDE NOISE TEST DATA

See Table 3-3 and Figures 3-6 through 3-12.

3.6 INTERIOR NOISE TEST DESCRIPTION

The on-car noise survey was conducted on both the SFMR and MBTA configuration vehicles. Data on the SFMR car was obtained at the Transportation Test Center, Pueblo, Colorado, and for the MBTA configuration data was taken on the MBTA's Green Line between Riverside and Fenway Park on at-grade track.

The test section at the Transportation Test Center is known as Track Section IV and consists of 119-pound continuously welded rail set on concrete ties in stone ballast. There is a 0.7 percent upgrade in the northbound direction. Power was supplied by the overhead catenary. The test area on the MBTA Green Line was the at-grade section of the line, approximately 9 miles in length, between Riverside and Fenway Park stations. Data was taken on the tangent track sections free of special trackwork or way structures, during both inbound and outbound running.

Interior data was surveyed at locations representative of both seated and standing passengers as well as at operator's seat ear level. The height of the microphone for seated locations was 1.4 meters and for standing ear level, 1.6 meters above floor height. Figure 3-13 illustrates the microphone locations within the car for both the SFMR and MBTA configurations.

Wheels on all cars were smooth, with no slid flats visible or audible. A clear, dry atmosphere existed for all testing.

The noise survey in the SFMR vehicle (Figure 3-14) was conducted on an early production SLRV for San Francisco in February 1976. The SFMR vehicle does not include an air conditioning unit, but uses a two-speed overhead blower system to provide for interior cooling and heating. The early production cars were designed to a specification which required an airflow of 6,000 cfm for cooling and 3,000 cfm for heating. The cooling flow of 6,000 cfm later was determined to be unacceptably high and a revised airflow schedule was designed for the SFMR car after the vehicles returned from the Pueblo test center. The new schedule reduces interior noise by reducing the airflows to 4,200 cfm for cooling and 2,100 cfm for heating. The impact of this new blower schedule on interior noise has not been documented in detail to date, as revised production schedules do not require building or delivery of SFMR vehicles until 9 months after the time of writing. However, preliminary measurements on a developmental car indicate that maximum noise levels with high speed blowers are reduced from 75 dBa to 70 dBa during car static conditions. Thus, data reported in the following section are more severe than will be experienced in any production SFMR car which will operate in San Francisco.

3.7 INTERIOR NOISE TEST INSTRUMENTATION

The same instrumentation was used for interior noise testing as for the wayside noise testing (see Section 3.3).

3.8 INTERIOR NOISE TEST PROCEDURES

Effect of Speed – On Car, PN-1001-TT

The interior survey to determine the effect of speed on noise in the passenger and operator areas of the SLRV was conducted on an MBTA vehicle (Car 3402) and an SFMR vehicle (SF0002). Both cars were at a weight of AW0. Four locations in one-half of the car were surveyed along the centerline of the car. These locations (see Figure 3-13) were the operator's seat (Position 1), over the powered truck (Position 5), at the centerline between side doors (Position 8), and in the articulated section (Position 12). Microphone height was at seated ear level at the operator's seat and at standing ear level for other positions. A minimum of 15 seconds of data was recorded at each location for each speed. All systems were on for the survey including the air conditioner for the MBTA tests and the overhead blowers (on high?) for the SFMR test.

Interior Noise Survey, PN-1301-TT

The interior noise survey was conducted in the SFMR vehicle (SF0002) at AWO and a speed of 40 mph to determine variations in noise in the longitudinal, lateral, and vertical directions. The longitudinal survey included the following locations: (See Figure 3-13) Positions 1, 2, 3, 4, 5, 6, 7, 9, and 12. The lateral survey included all seats at Position 6. The vertical survey was conducted at a position in the forward section of the car under the air comfort system distribution diffusers. The three heights surveyed included, 1 foot from the ceiling, seated ear level, and 1 foot from the floor.

Acceleration Effect – On Car, PN-2001-TT

Time histories of interior noise were taken during acceleration of the SLRV from 0–20 mph and from 0–50 mph. The rate of acceleration produced a car speed of 20 mph in approximately 13 seconds, and a speed of 50 mph in approximately 40 seconds. These rates average 1.5 mph/sec and 1.25 mph/sec, respectively. The time histories were recorded at car locations 5 and 8 (see Figure 3-57).

Deceleration Effect – On Car, PN-3001-TT

Time histories of interior noise were taken during deceleration of the SLRV from 20–0 mph and from 50–0 mph. The deceleration rates were approximately 2 mph/sec and 2.5 mph/sec, respectively. The time histories were recorded at car locations 5 and 8 (see Figure 3-58).

3.9 INTERIOR NOISE TEST DATA

See Table 3-4 and Figures 3-15 through 3-58.

TABLE 3–3. WAYSIDE NOISE DATA

Car	Mike Dist From Track ℄ (ft)	Speed (mph) and Dir	No. of Cars	Test Condition	Test Weight	Side of Car Toward Microphone	Weighted Sound Level (dBa)
SFMR (SF0002)	50	0	1	All Systems On	AW0		59
		10 S					61
		20 N					65
		20 S					64.5
		30 N					68
		30 S					68
		40 N					70
		40 S					70
		50 N					73.5
		50 S					73.5
(SF0002)	50	10 N	1	All Systems On	AW3		60
		10 S					60
		20 N					65
		20 S					64
		30 S					67
		40 N					70
		40 S					69
		50 S					72.5
SFMR (SF0002, SF0003)	50	0	2	All Systems On	AW0	1	63.5
		10 N					
		10 S					64.5
		20 N					67
		20 S					
		30 N					
		30 S					69

TABLE 3–3. Continued

Car	Mike Dist From Track ℄ (ft)	Speed (mph) and Dir	No. of Cars	Test Condition	Test Weight	Side of Car Toward Microphone	Weighted Sound Level (dBa)
		40 N					73
		40 S					
		50 N					75.5
		50 S					
		0				2	61.5
		10 N					65
		10 S					64
		20 N					67
		20 S					67.5
		30 N					70
		30 S					70.5
		40 N					75
		40 S					73
		50 N					76.5
		50 S					76
MBTA (3402)	50	0	1	All Systems On	AW0	A	65
		10					66
		20					67
		30					69
		40					72
		50					74
MBTA	50	0	1	Equipment Blower	AW0	A	55
		0		Equipment Blower		B	57
		0		Brake Air Comp		A	48
		0		Traction MTR Blwrs		A	59
		0		A-End Air Cond		A	61

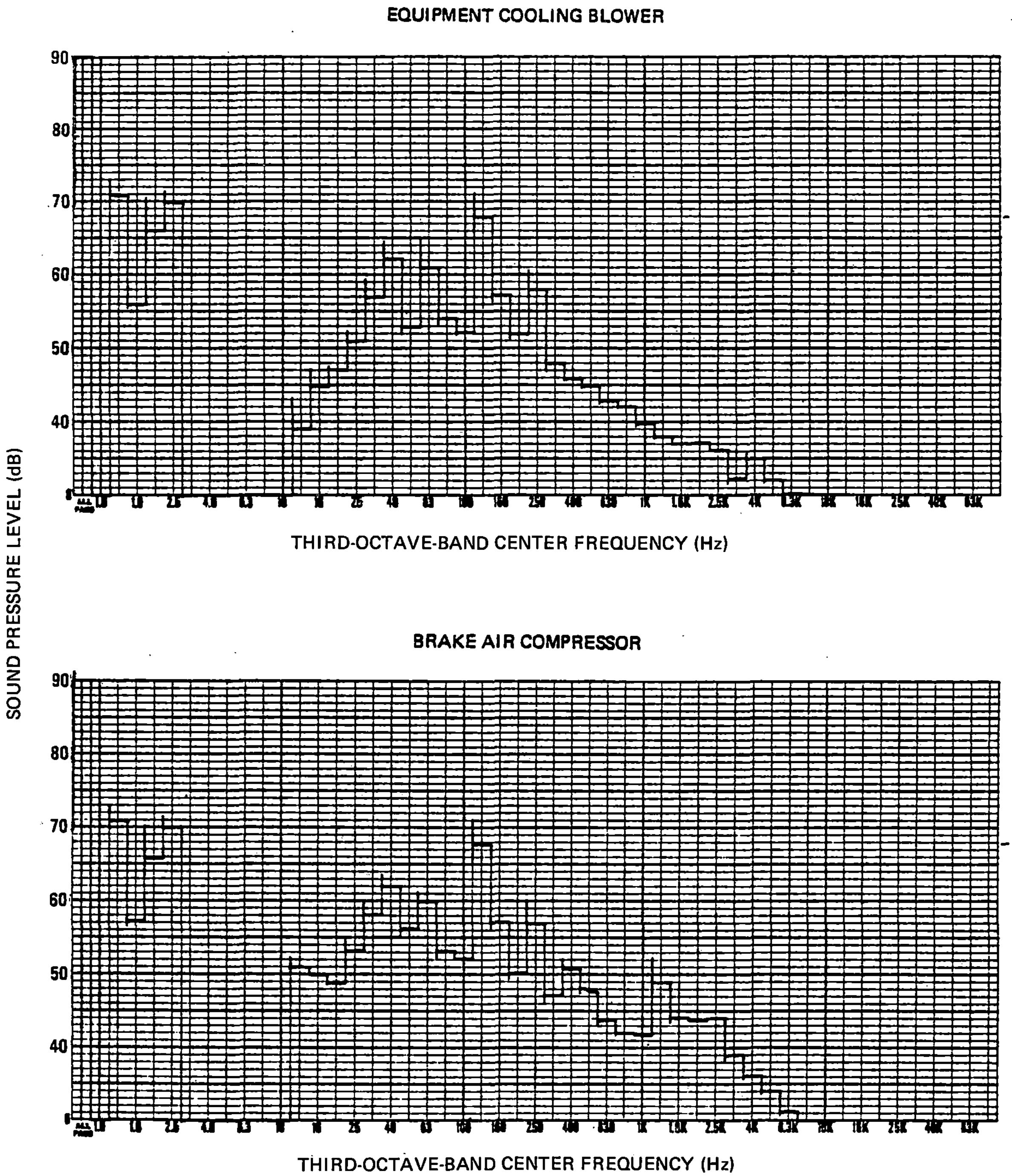


Figure 3–6. SLRV Equipment Noise, 50-Ft Wayside, Third-Octave Analysis

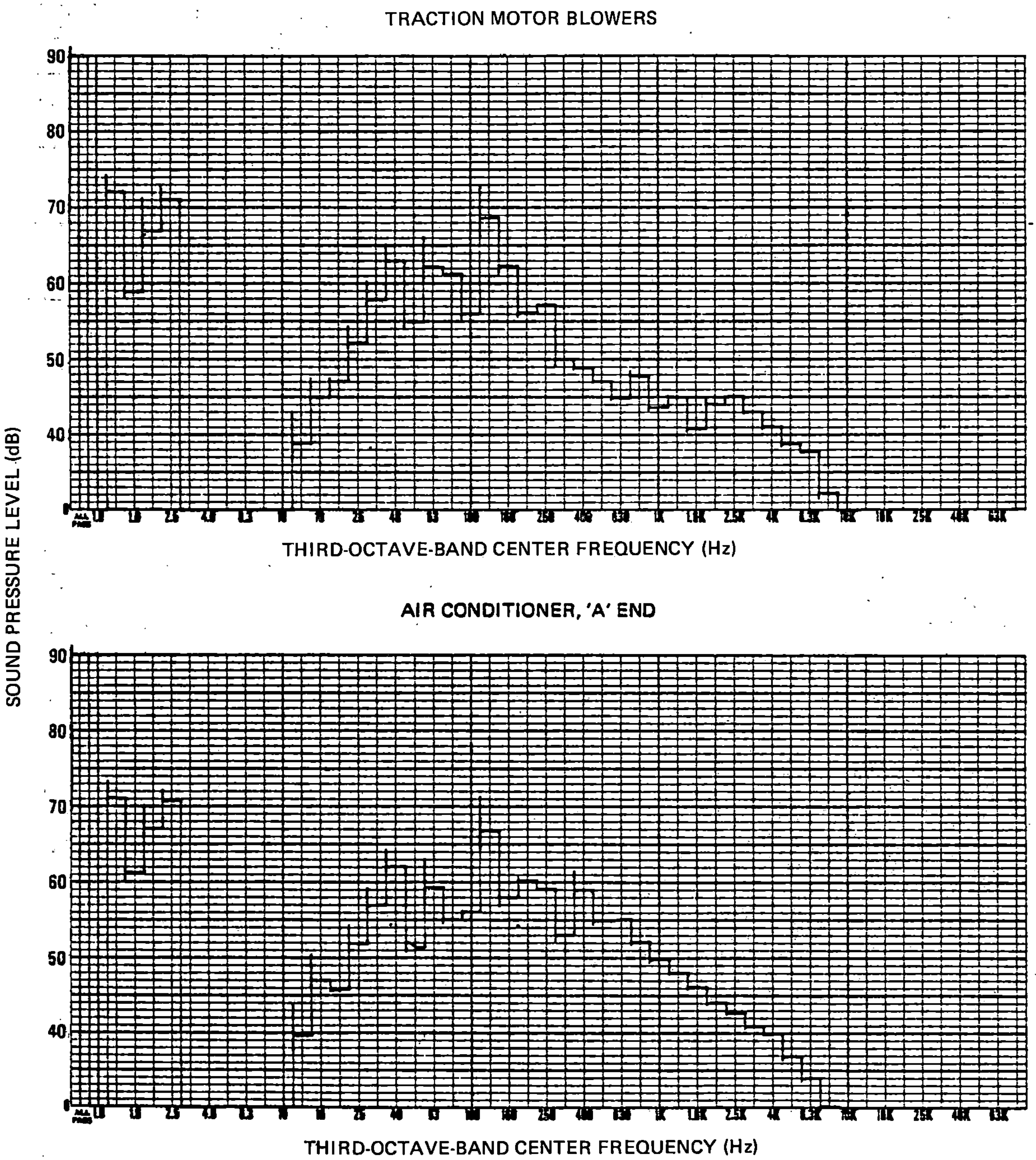


Figure 3–7. SLRV Equipment Noise, 50-Ft Wayside, Third-Octave Analysis

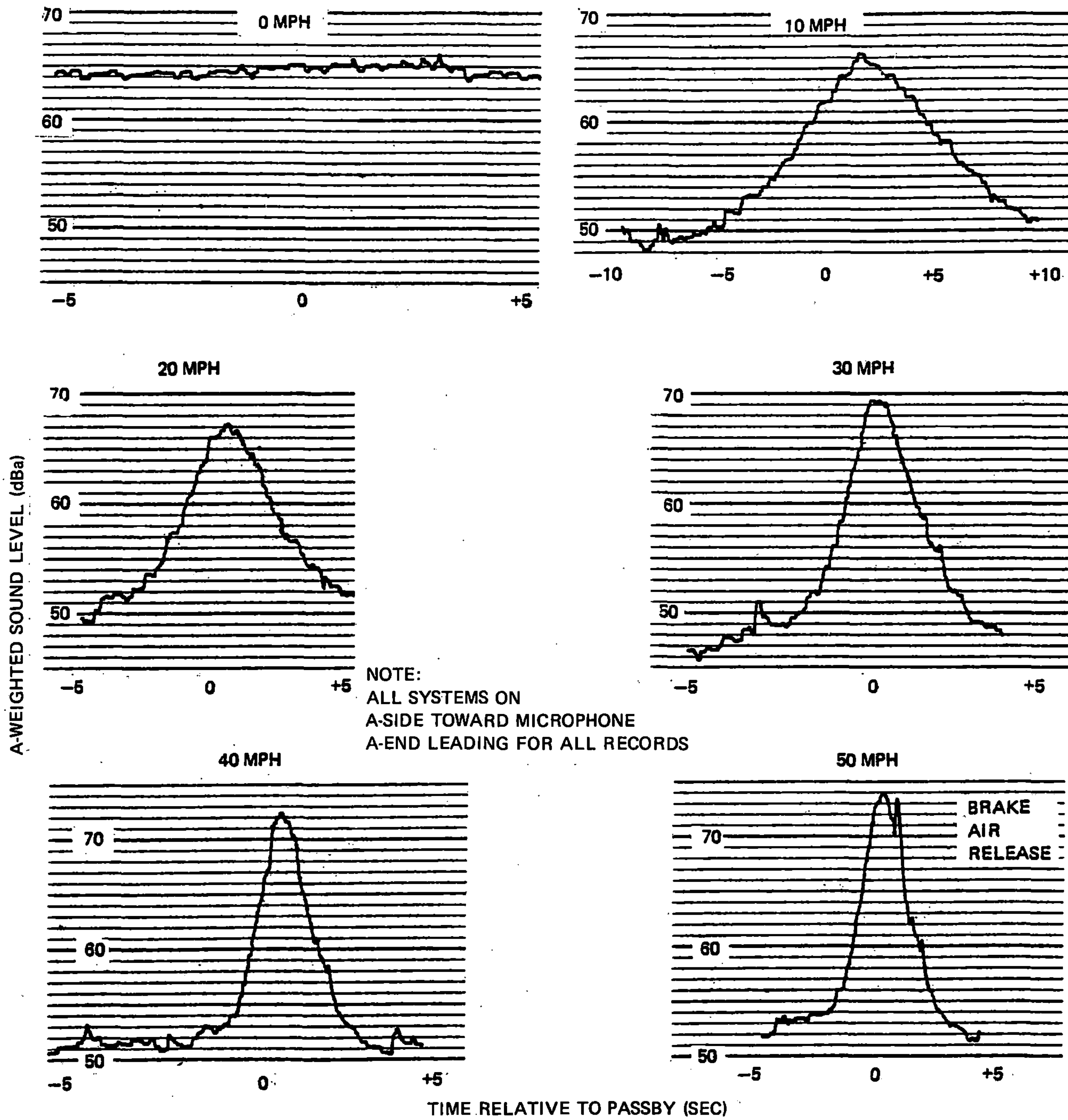


Figure 3–8. SLRV Wayside Noise Time Histories, 50-Ft Single Car, MBTA Configuration, AWO

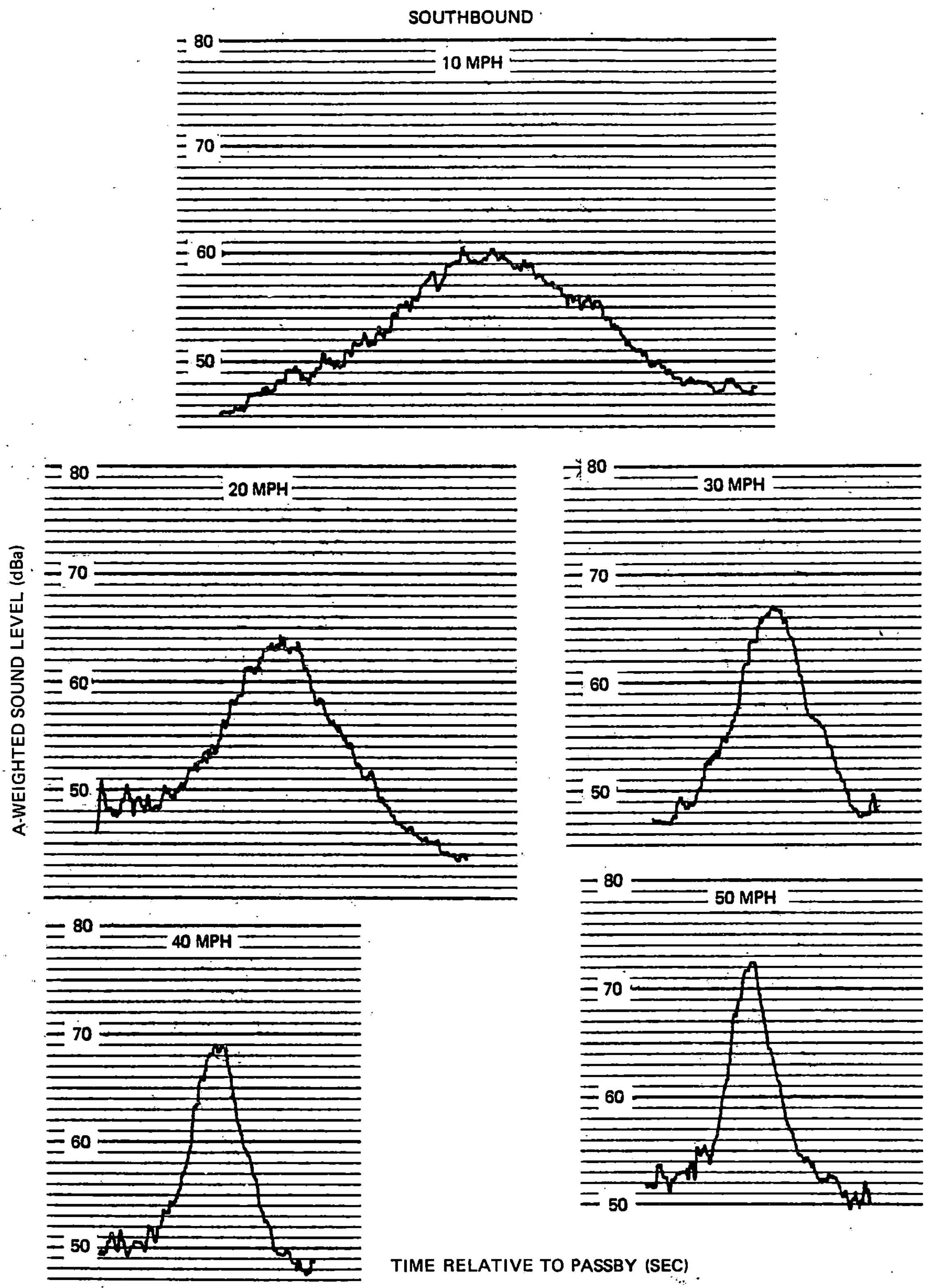


Figure 3–9. SLRV Wayside Noise Time Histories, 50-Ft, Single Car, SFMR Configuration, AW3

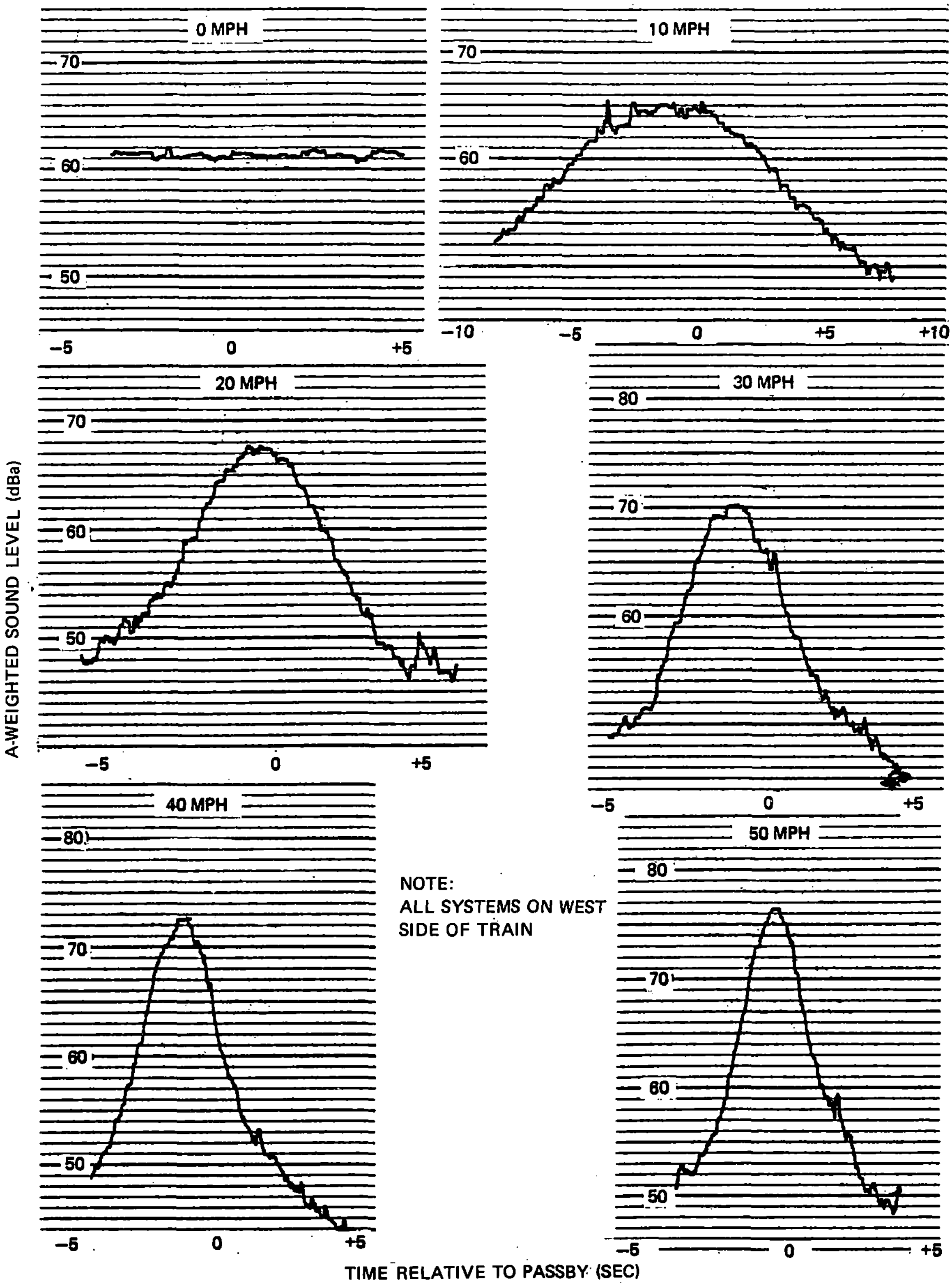


Figure 3–10. SLRV Wayside Noise Time Histories, 50-Ft, Two-Car Train, SFMR Configuration, AWO

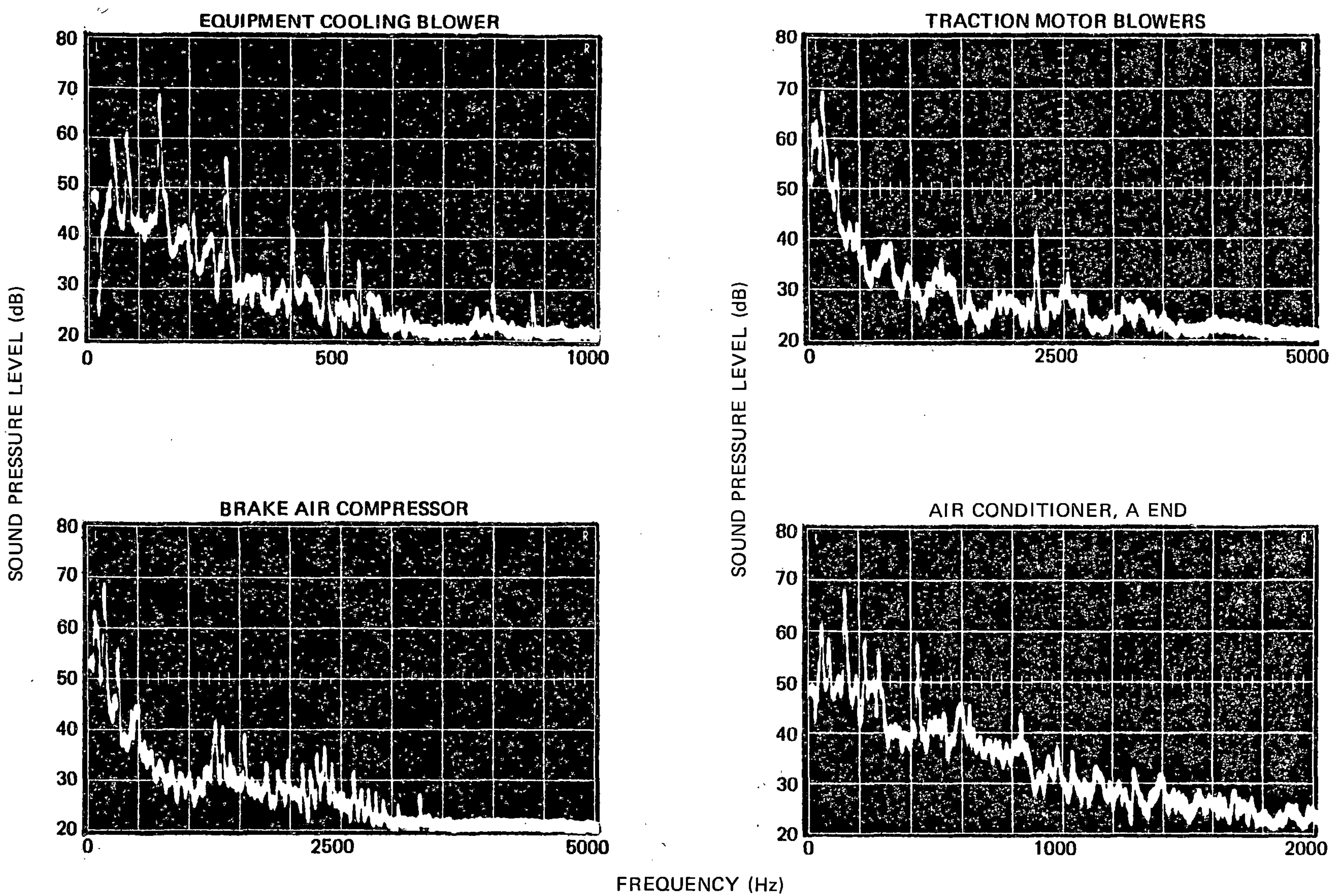


Figure 3—11. SLRV Equipment Noise, 50-Ft Wayside, Narrow-band Analysis

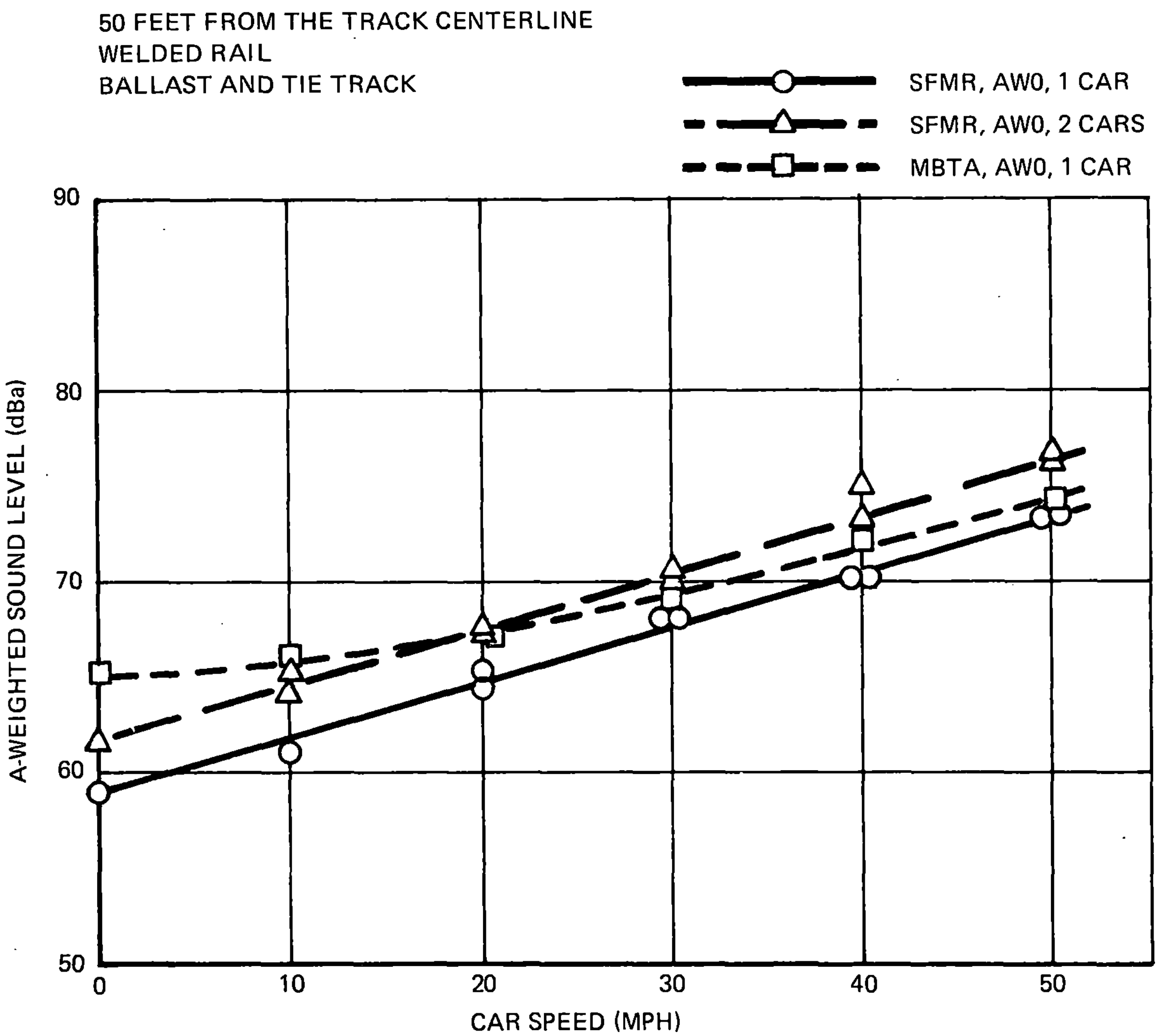


Figure 3–12. SLRV Wayside Passby Noise at Different Speeds

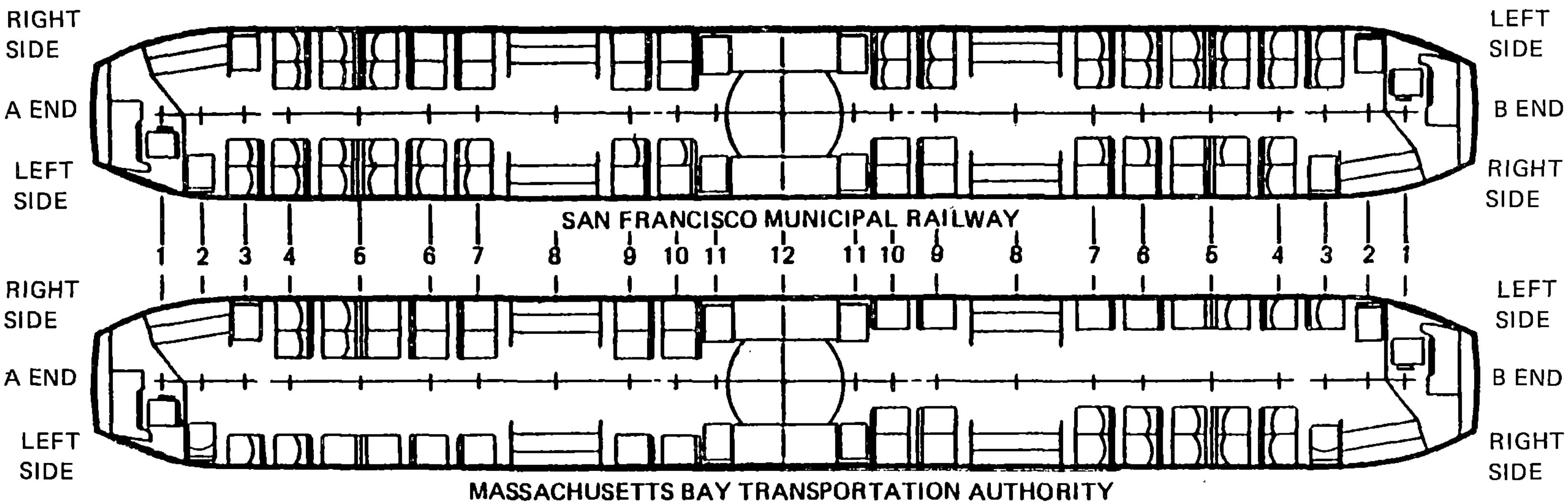


Figure 3–13. Measurement Locations for SLRV Interior Noise Survey

Figure 3–14. Interior of SLRV in SFMR Configuration – Noise Survey Vehicle

TABLE 3–4. INTERIOR NOISE DATA

Car	Test Weight	Speed (mph) and Dir	Microphone Position *	Test	Weighted Sound Level (dBa)	Remarks
SFMR	AW0	0	1, X, ℄	Effect of Speed – On Car	75.5	All Systems On
(SF0002)		15 N			75	
		15 S			75	
		25 N			75	
		25 S			74.5	
		35 N			75.5	
		35 S			75	
		50 N			74.5	
		50 S			77	
		0	5, X, ℄	Effect of Speed – On Car	72.5	All Systems On
		15 N			73	
		15 S			72	
		25 N			73	
		25 S			72.5	
		35 N			73	
		35 S			74	
		50 N			74	
		50 S			74.5	
		0	8, X, ℄	Effect of Speed – On Car	70	All Systems On
		15 N			70.5	
		15 S			70.5	
		25 N			70.5	
		25 S			70.5	
		35 N	8, X, ℄	Effect of Speed – On Car	70.5	All Systems On
		35 S			71.5	
		50 N			72.5	
		50 S			73	

* Δ = 1 Ft From Ceiling; X = Ear Level, Standing; 0 = Ear Level, Seated; ☐ = 1 Ft From Floor

TABLE 3–4. Continued

Car	Test Weight	Speed (mph) and Dir	Microphone Position *	Test	Weighted Sound Level (dBa)	Remarks
			3, X, ℄		74	
			3, Δ, ℄			
			3, □, ℄			
			4, 0, LHS – Aisle		74	
			5, 0, LHS – Aisle			
			5, X, ℄		73	
SFMR	AW0	40	6, 0, LHS – Window	Interior Noise Survey	72	All Systems On
(SF0002)			6, 0, LHS – Aisle		72	
			6, 0, RHS – Aisle		72	
			6, 0, RHS – Window		72	
			7, 0, LHS – Aisle		71	
			8, X, ℄		72	
			9, 0, LHS – Window		71	
			9, 0, LHS – Aisle		71	
			10, 0, LHS – Aisle			
			12, X, ℄		75.5	

* Δ = 1 Ft From Ceiling; X = Ear Level, Standing; 0 = Ear Level, Seated; □ = 1 Ft From Floor

NOTES: *Aisle* and *Window* are seat locations
RHS = Right Hand Side
LHS = Left Hand Side

TABLE 3–4. Continued

Car	Test Weight	Speed (mph) and Dir	Microphone Position *	Test	Weighted Sound Level (dBa)	Remarks
SFMR (SF0002)	AW0	0	12, X, ℄	Effect of Speed – On Car	70	All Systems On
		15 N			70	
		15 S			70	
		25 N			71.5	
		25 S			71	
		35 N			73	
		35 S			73	
		50 N			76	
		50 S			76	
MBTA (3402)	AW0	15	1, X, ℄	Effect of Speed – On Car	69	All Systems On
		25			71	
		35			76	
		50			75	
		15	5, X, ℄	Effect of Speed – On Car	72	All Systems On
		25			73	
		35			75	
		50			75	
		15	8, X, ℄	Effect of Speed – On Car	71	All Systems On
		25			71	
		35			74.5	
		50			75.5	
		15	12, X, ℄	Effect of Speed – On Car	73	All Systems On
		25			74	
		35			75	
		50			79	
SFMR (SF0002)	AW0	40	1, O, ℄	Interior Noise Survey	75	All Systems On
			2, X, Dr.		76	

* Δ = 1 Ft From Ceiling; X = Ear Level, Standing; 0 = Ear Level, Seated; ☐ = 1 Ft From Floor

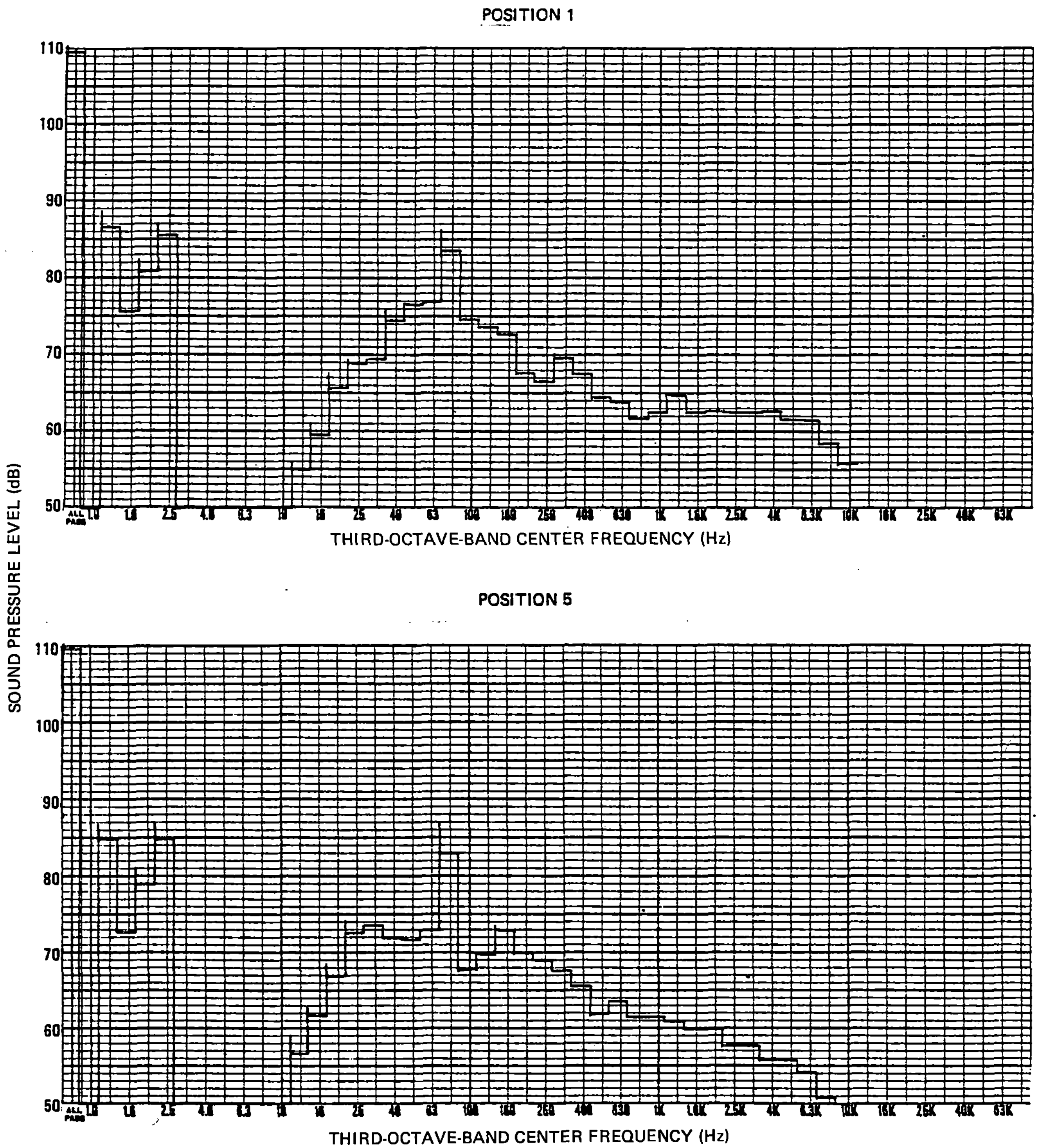
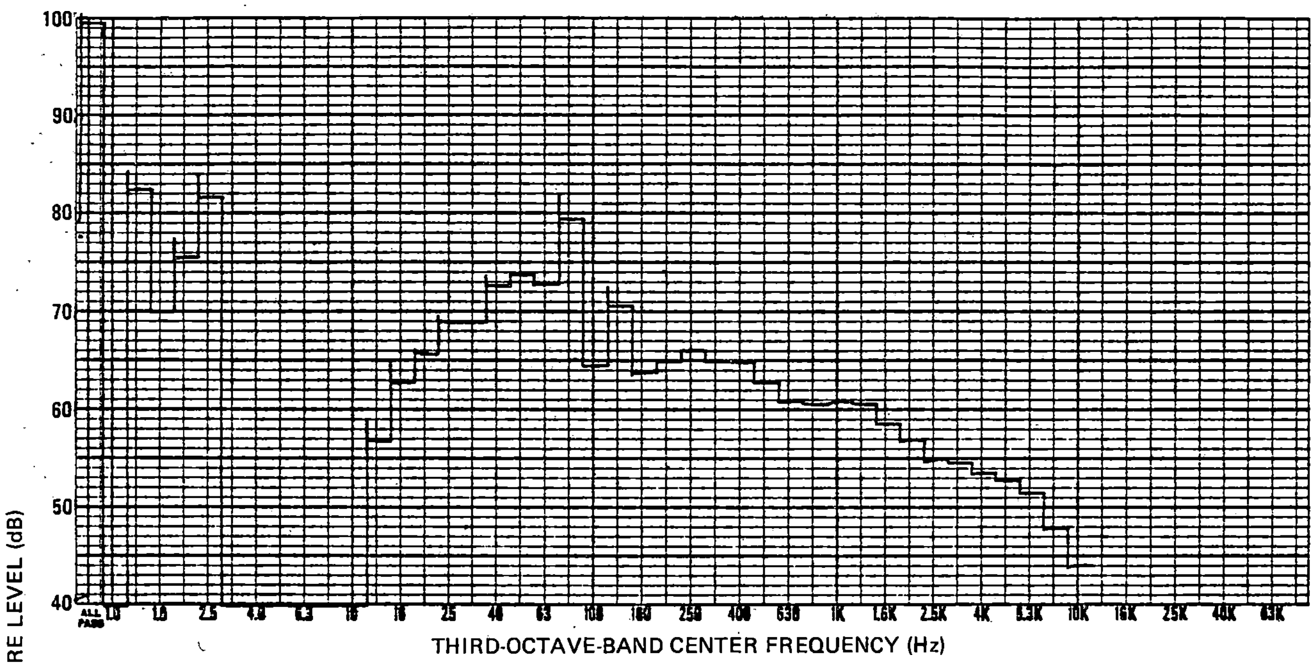


Figure 3–15. Third-Octave-Band Analysis of SFMR Interior Noise, AWO, 0 mph

POSITION 8



POSITION 12

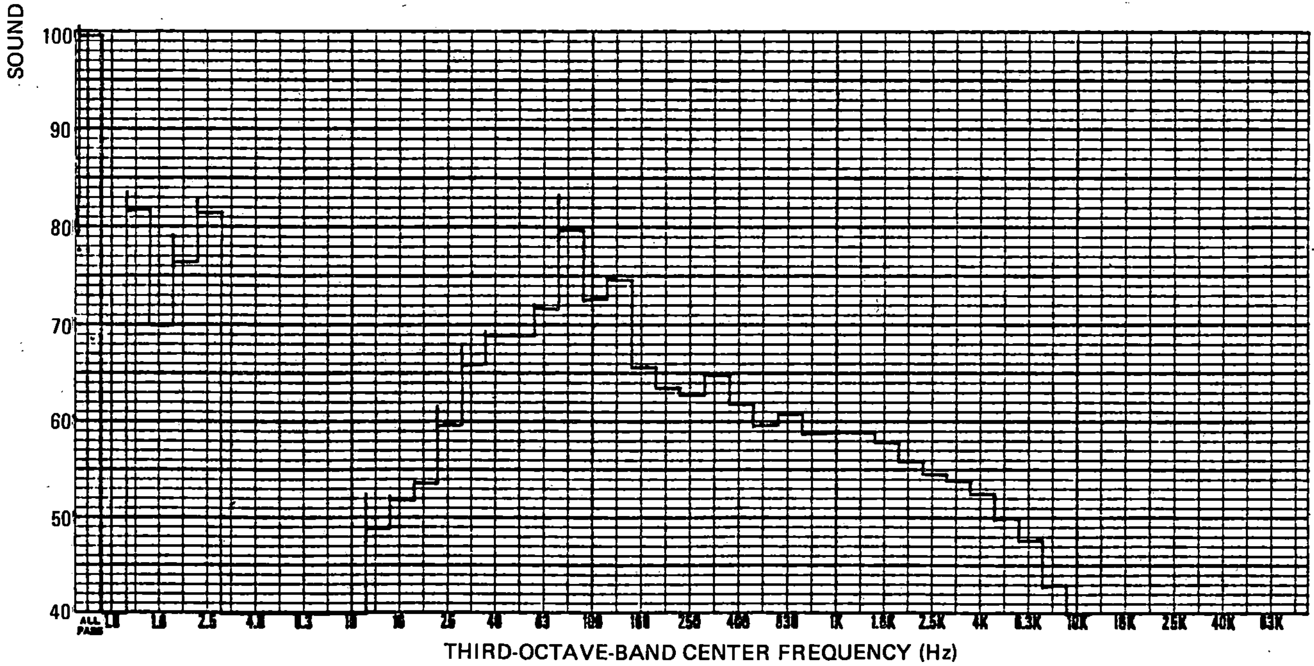
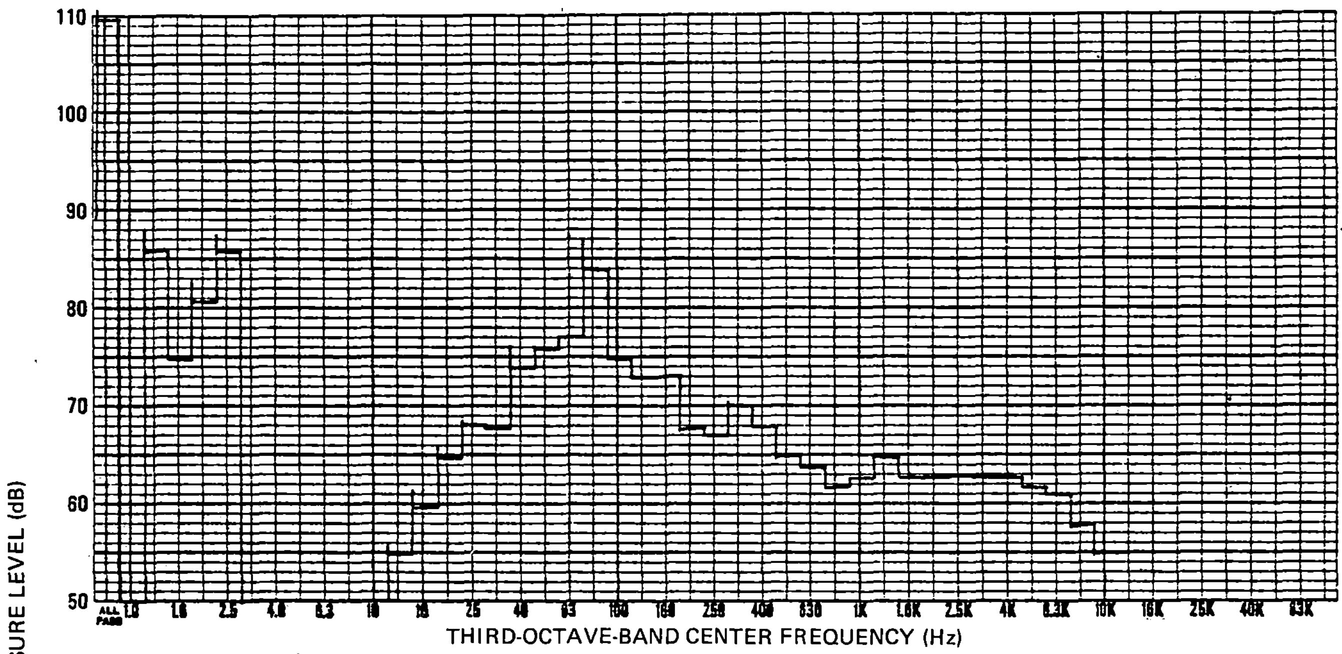


Figure 3–16. Third-Octave-Band Analysis of SFMR Interior Noise, AWO, 0 mph

POSITION 1



POSITION 5

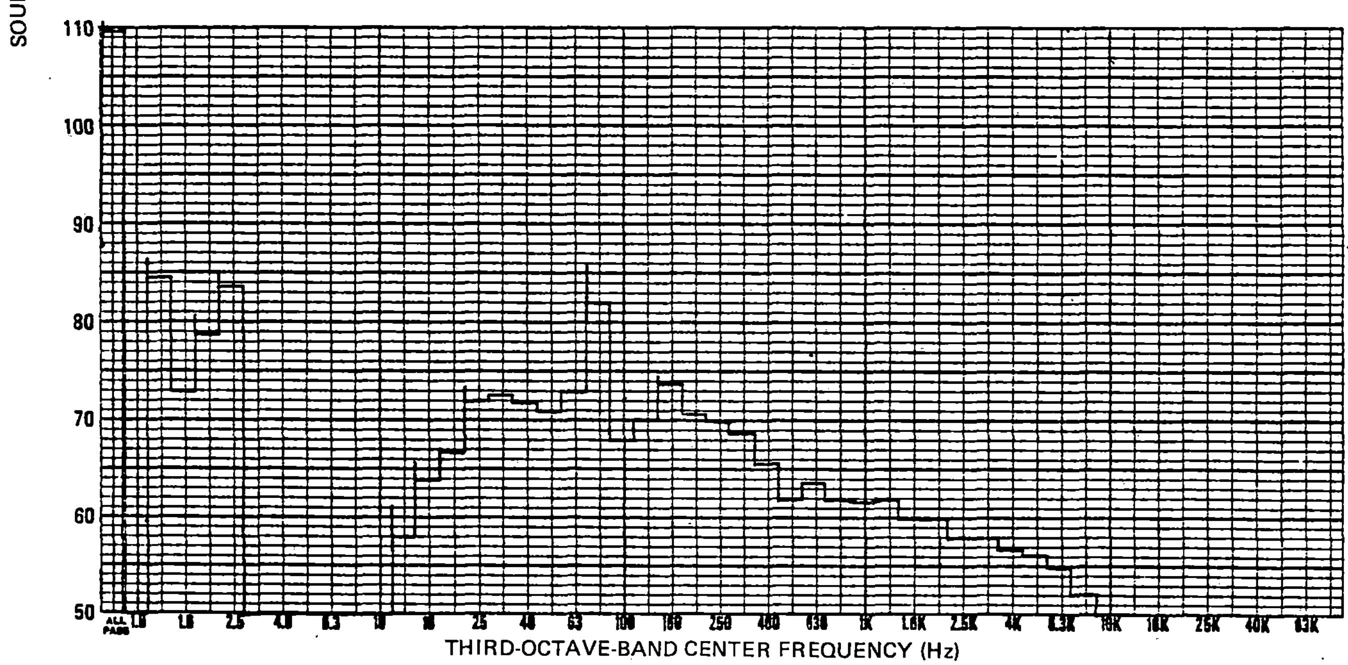


Figure 3–17. Third-Octave-Band Analysis of SFMR Interior Noise, AWO, 15 mph

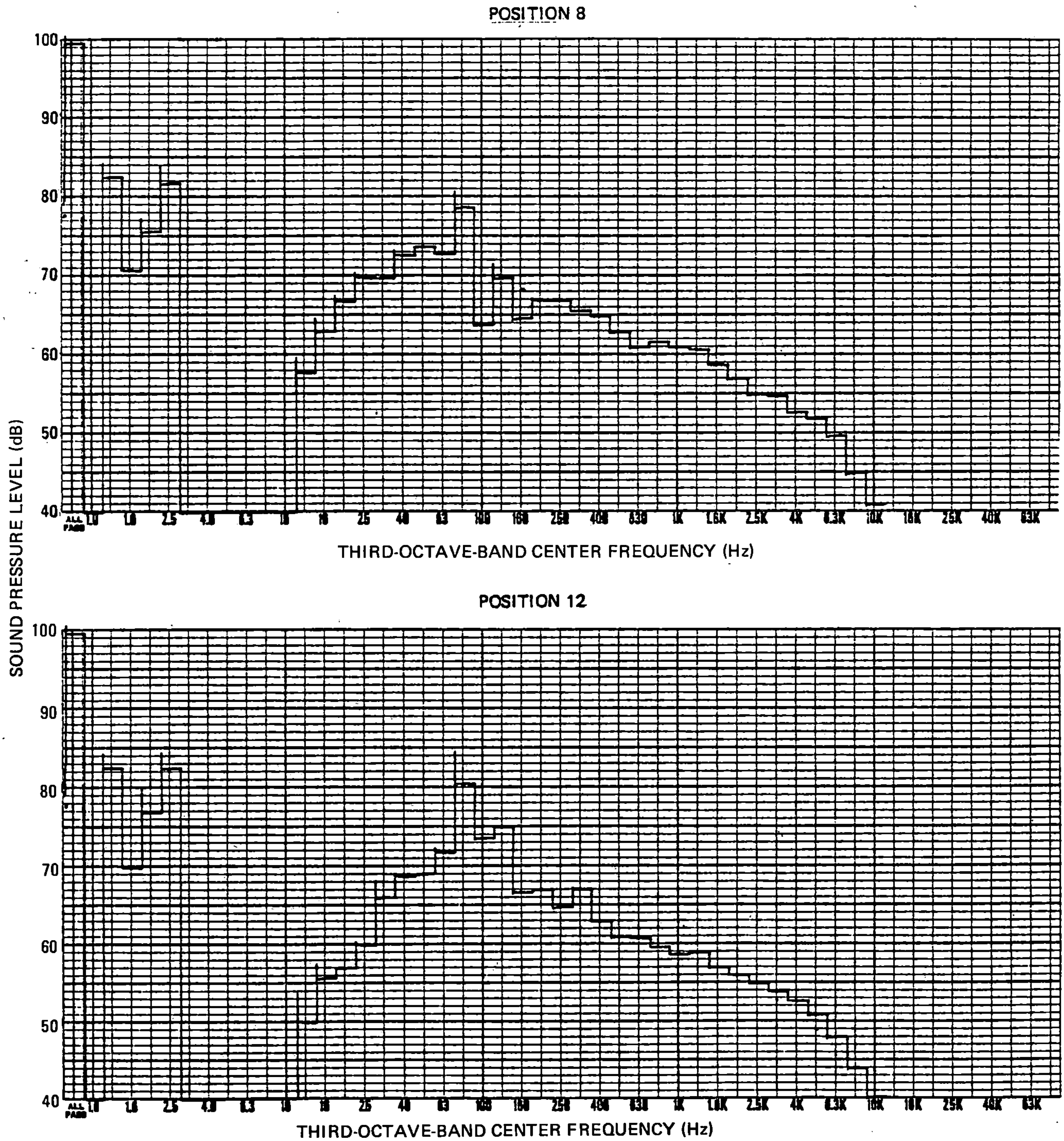


Figure 3–18. Third-Octave-Band Analysis of SFMR Interior Noise, AWO, 15 mph

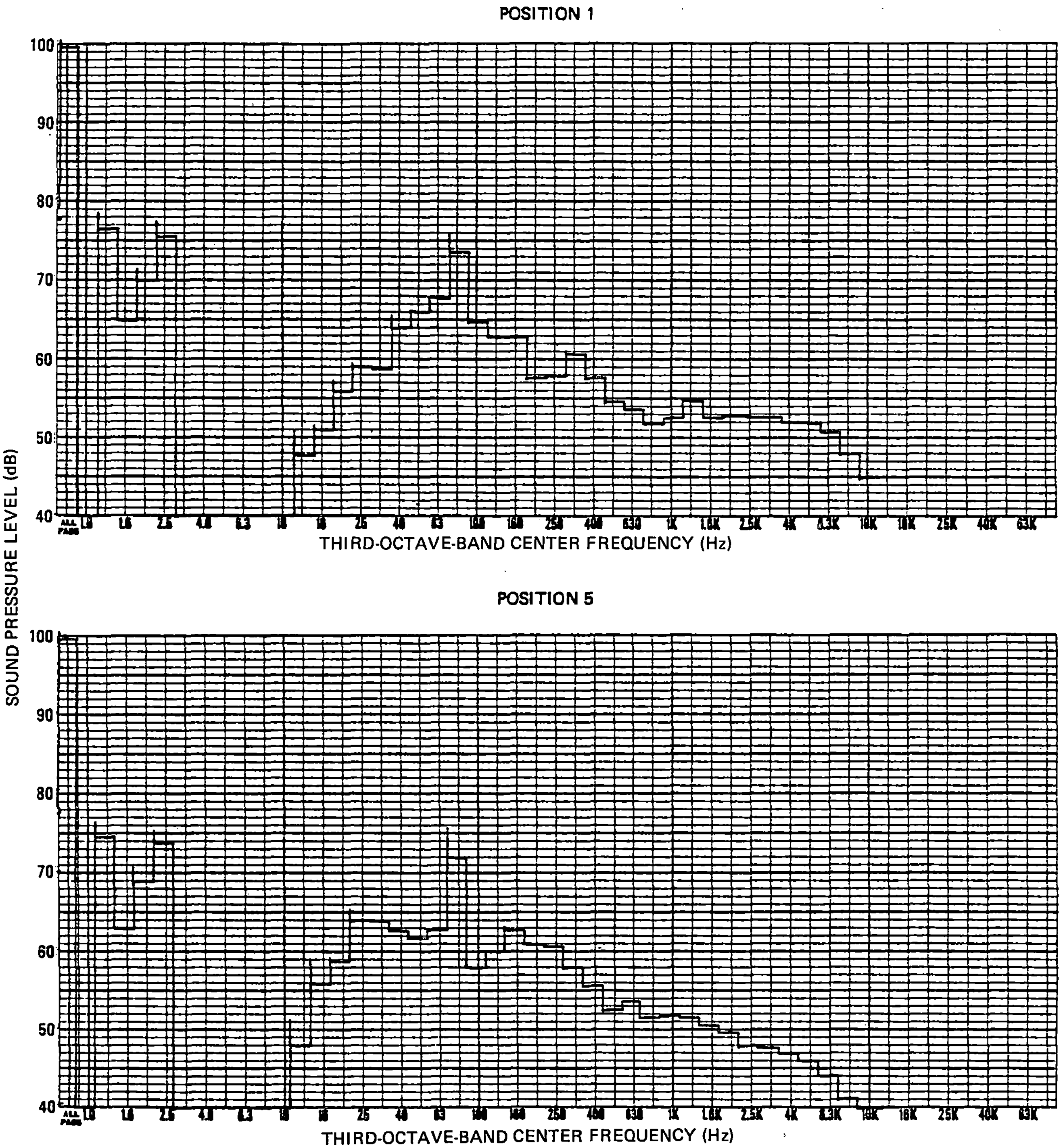


Figure 3–19. Third-Octave-Band Analysis of SFMR Interior Noise, AWO, 25 mph

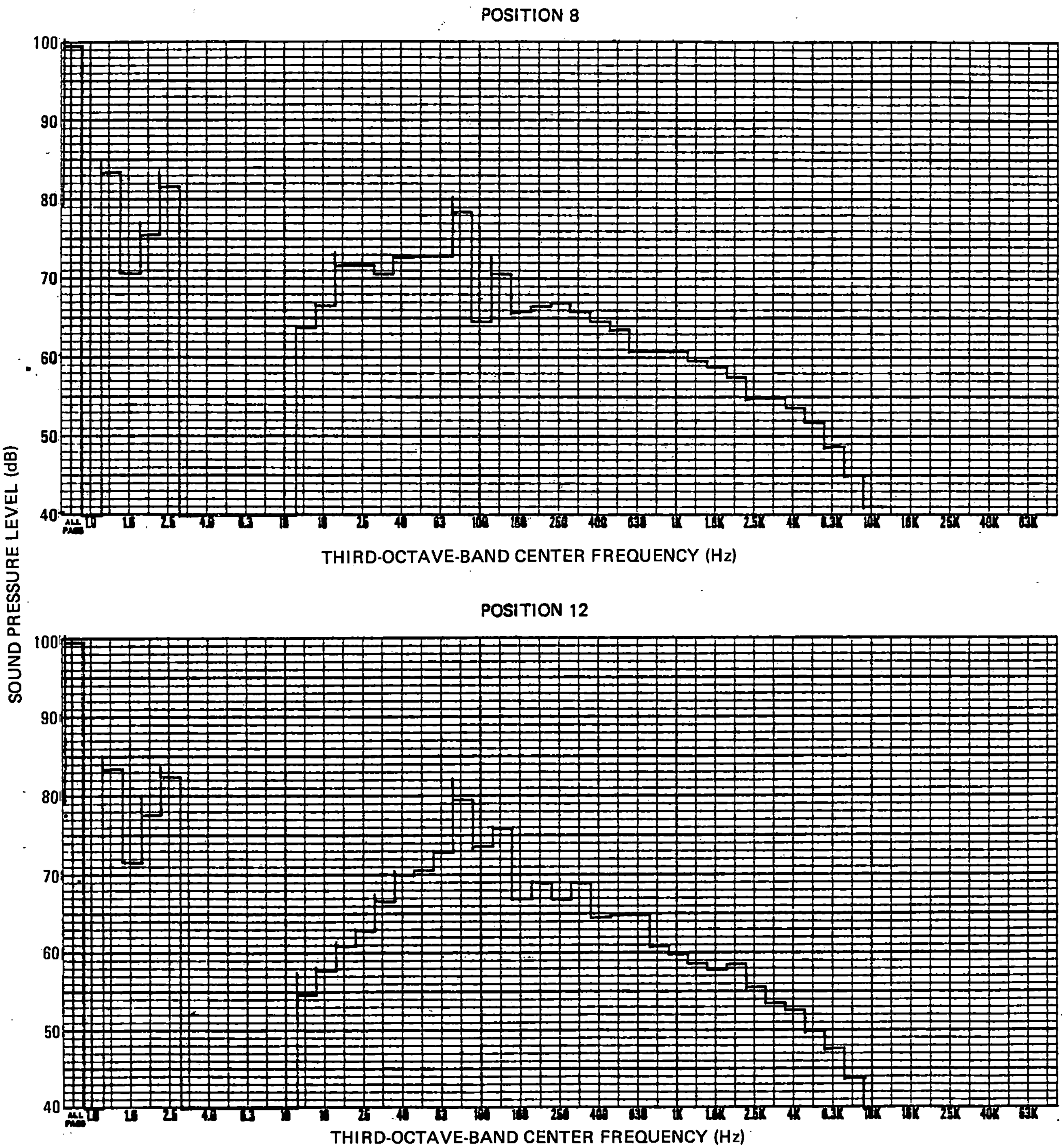


Figure 3–20. Third-Octave-Band Analysis of SFMR Interior Noise, AWO, 25 mph

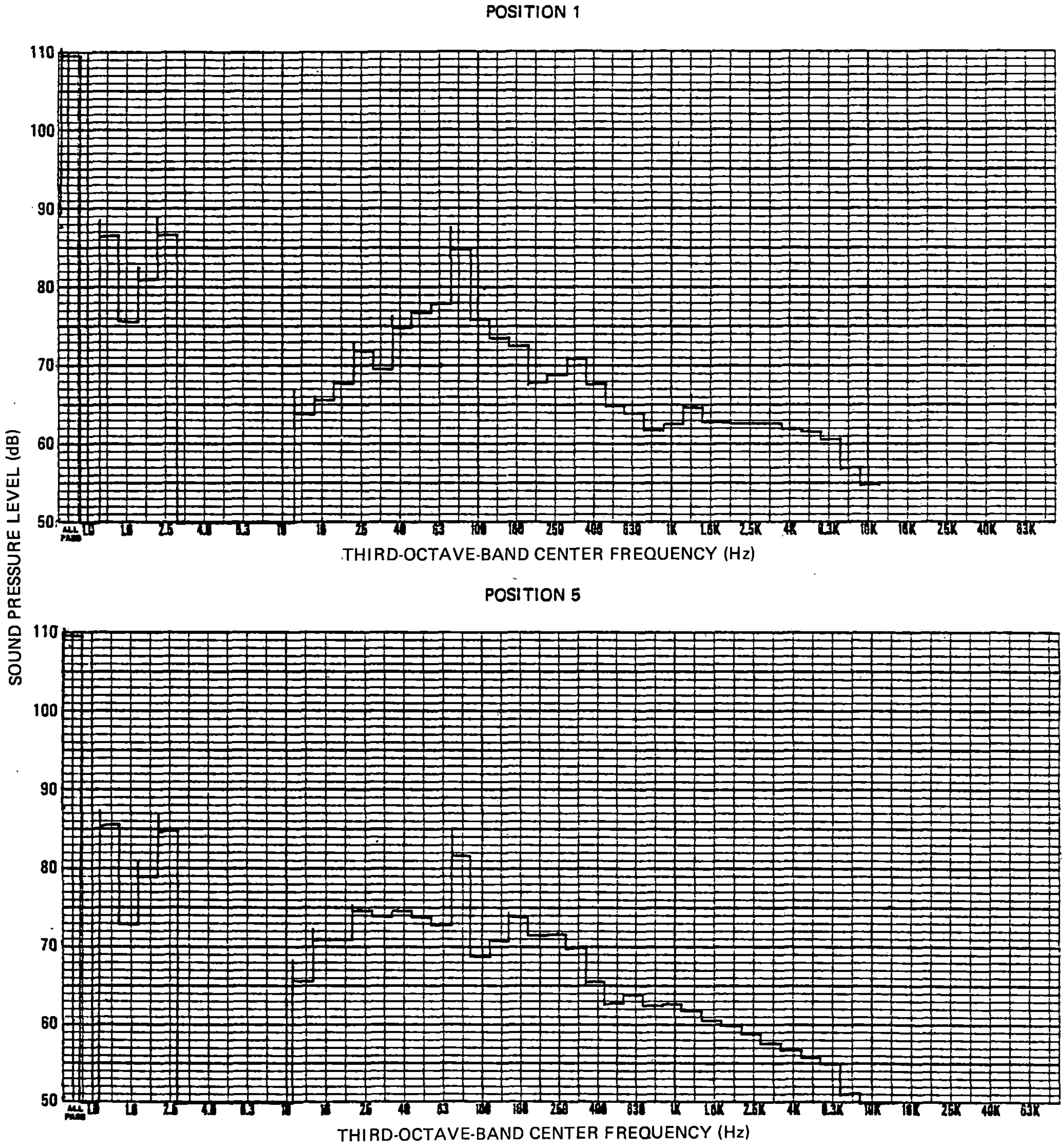


Figure 3–21. Third-Octave-Band Analysis of SFMR Interior Noise, AWO, 35 mph

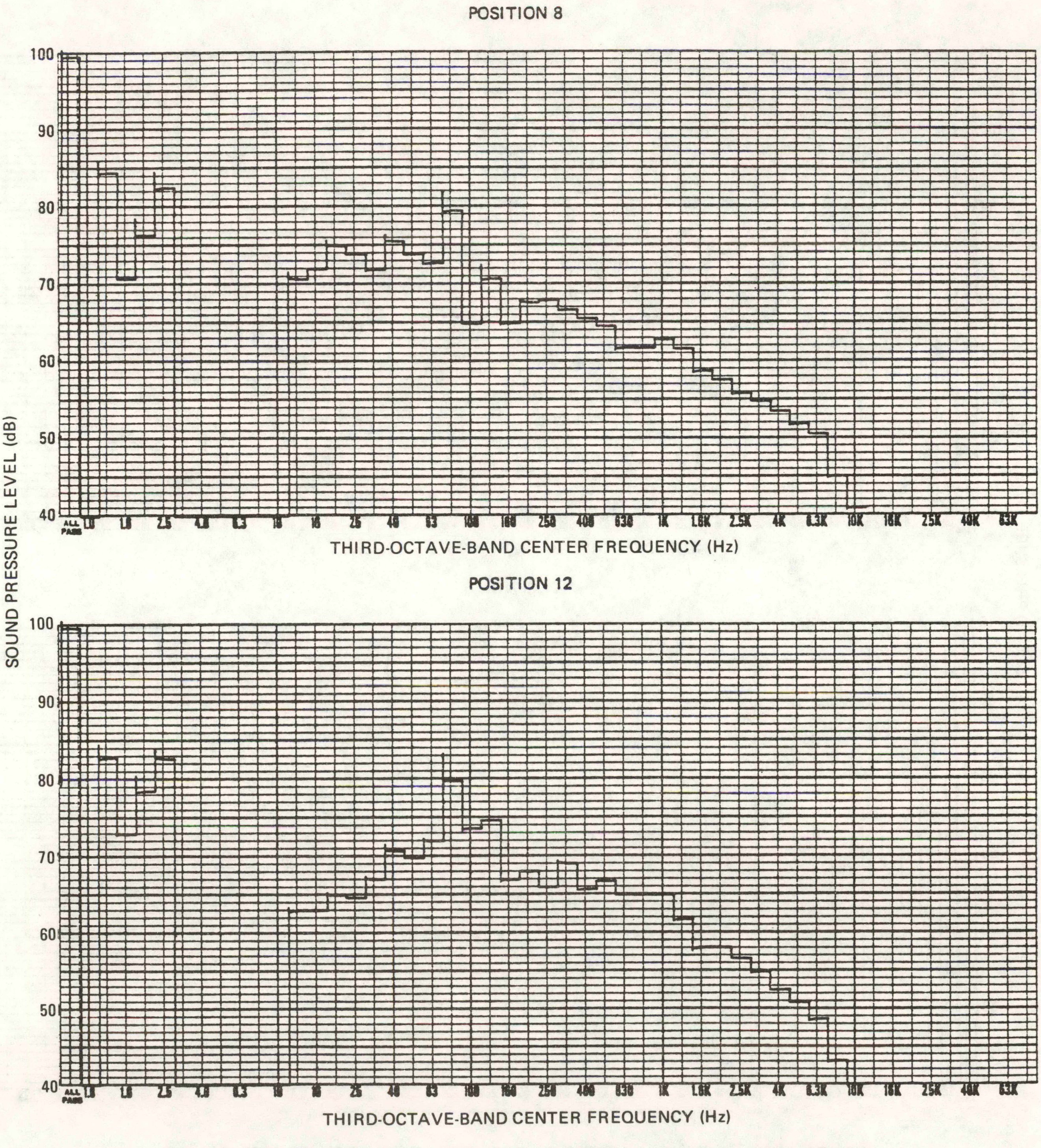


Figure 3–22. Third-Octave-Band Analysis of SFMR Interior Noise, AWO, 35 mph

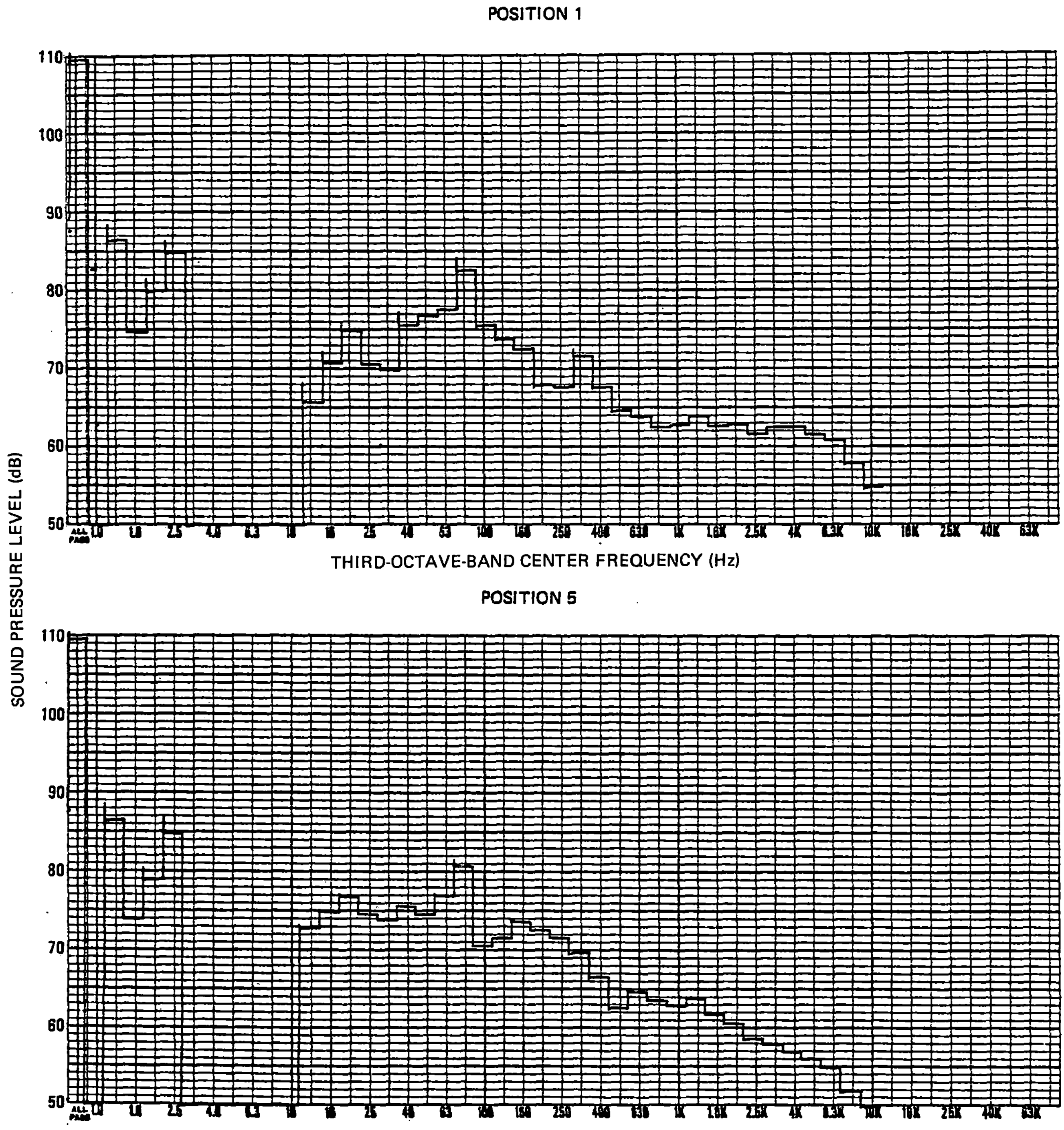


Figure 3–23. Third-Octave-Band Analysis of SFMR Interior Noise, AWO, 50 mph

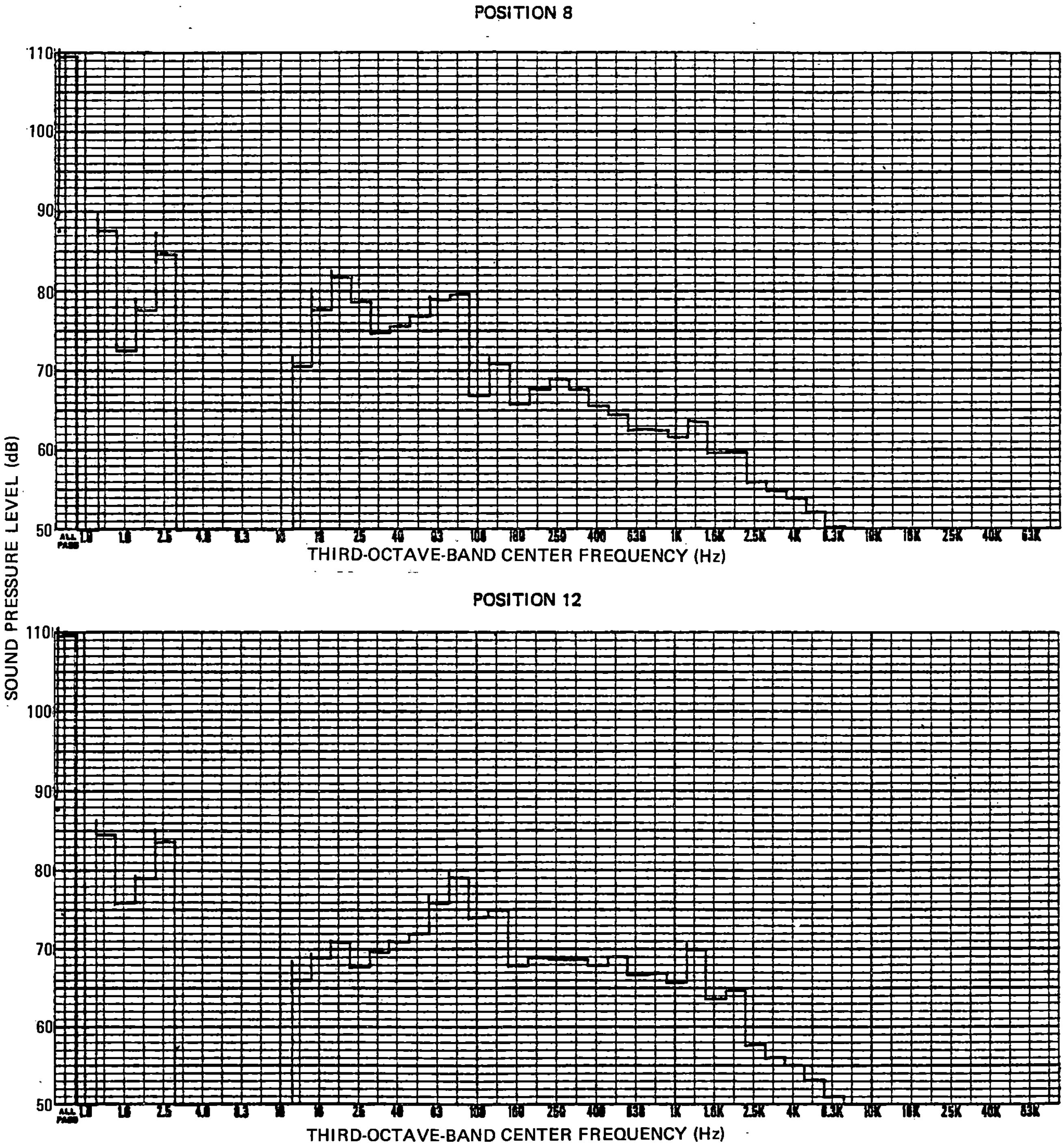


Figure 3–24. Third-Octave-Band Analysis of SFMR Interior Noise, AWO, 50 mph

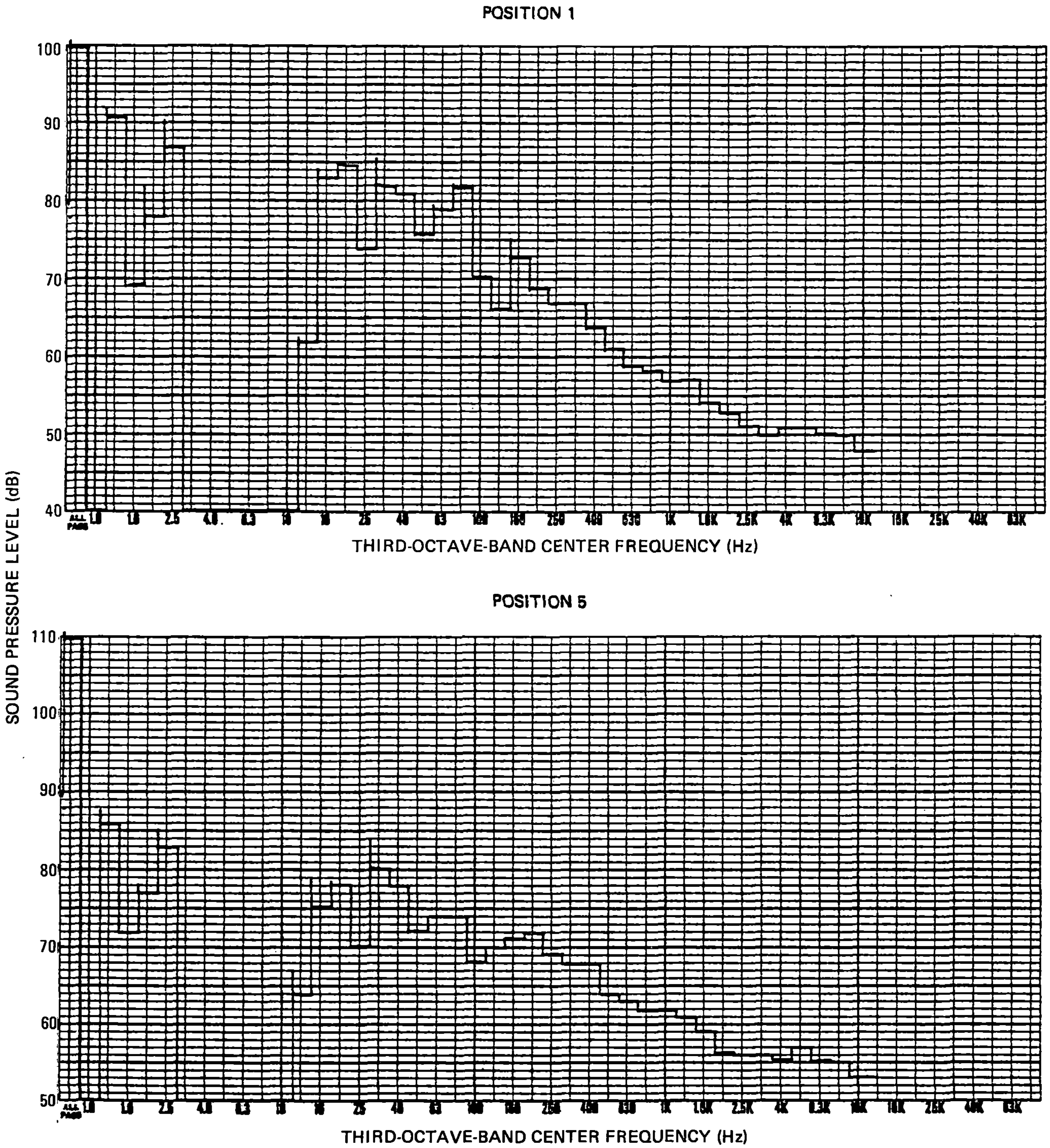


Figure 3–25. Third-Octave-Band Analysis of MBTA Interior Noise, AWO, 15 mph

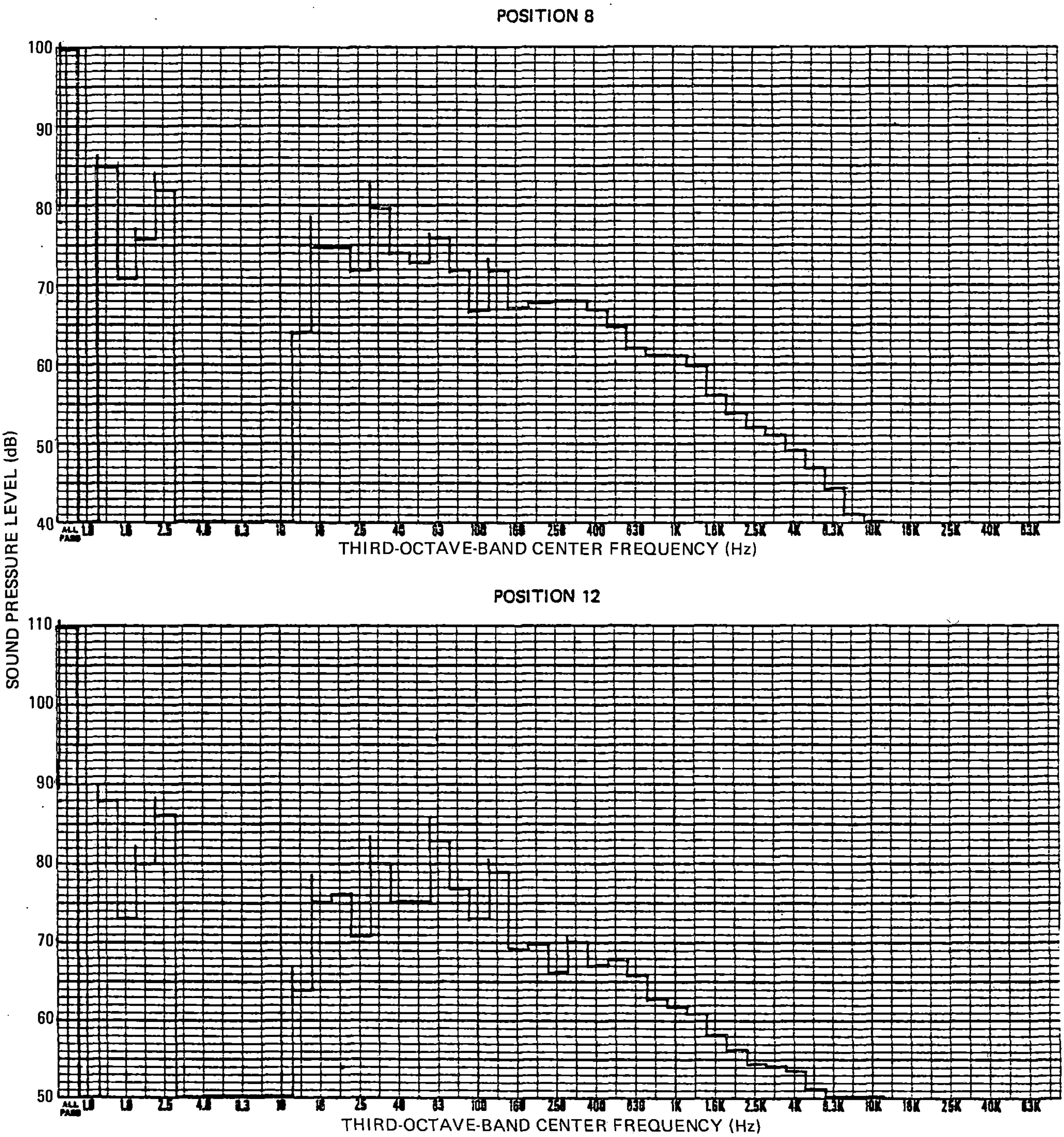
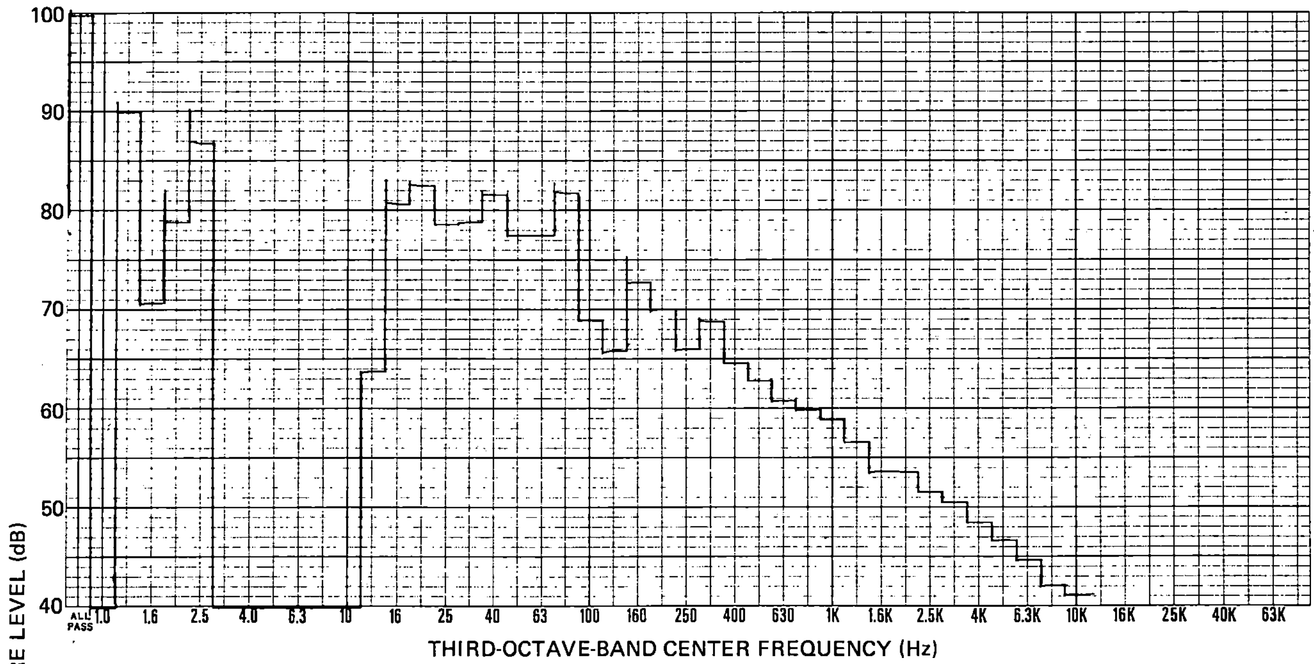


Figure 3–26. Third-Octave-Band Analysis of MBTA Interior Noise, AWO, 15 mph

POSITION 1



POSITION 5

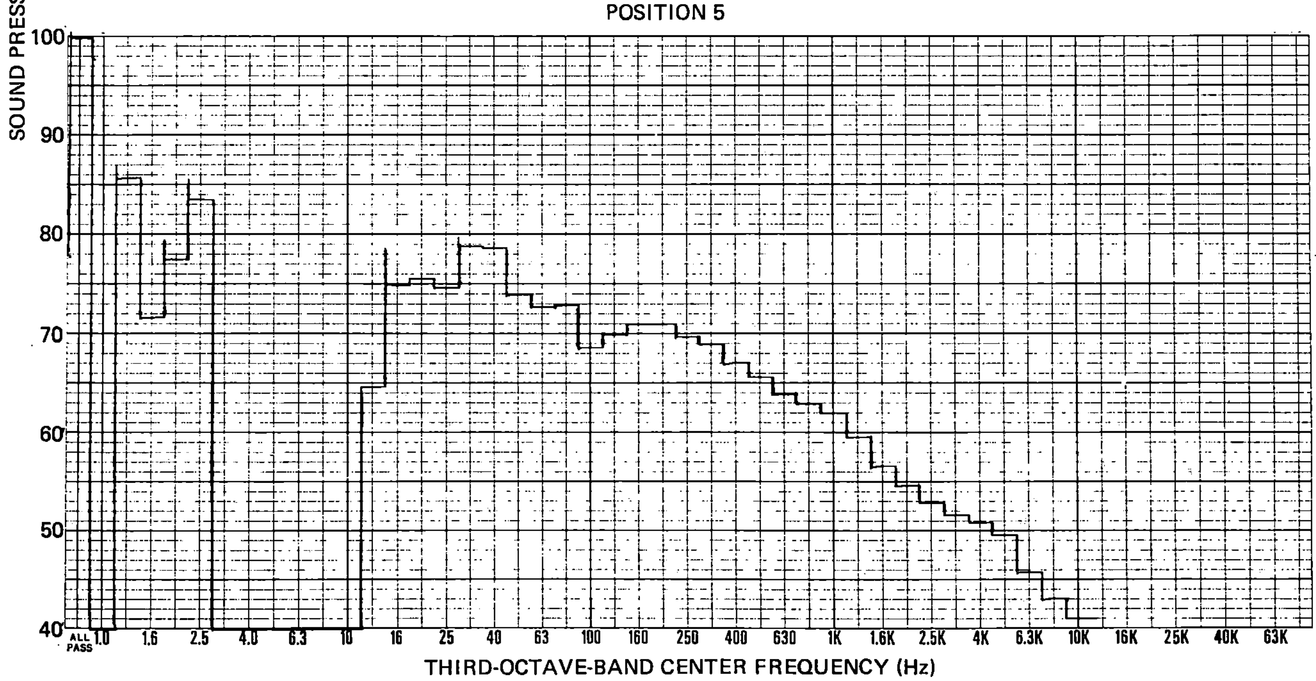


Figure 3–27. Third-Octave-Band Analysis of MBTA Interior Noise, AWO, 25 mph

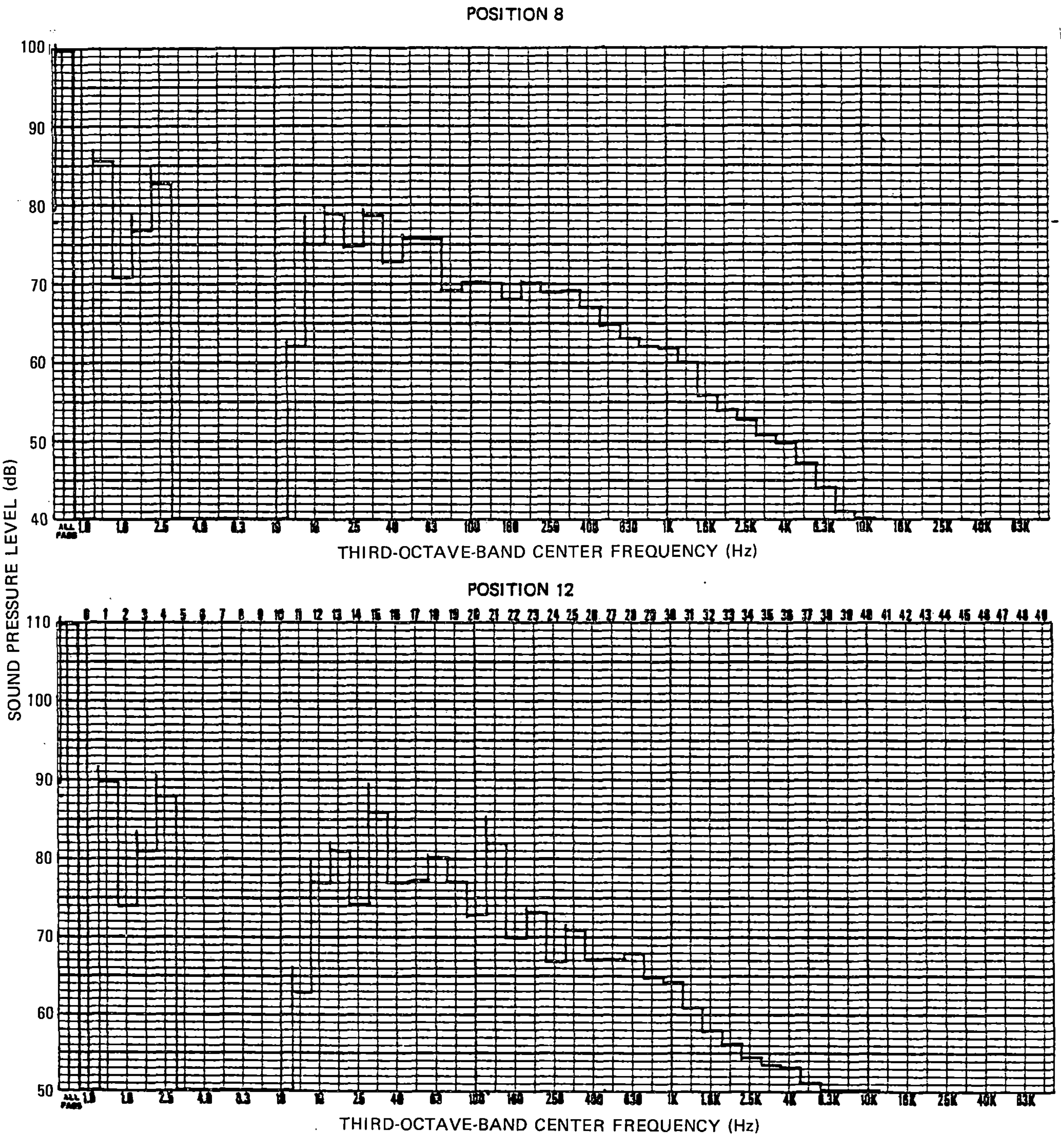


Figure 3–28. Third-Octave-Band Analysis of MBTA Interior Noise, AW0, 25 mph

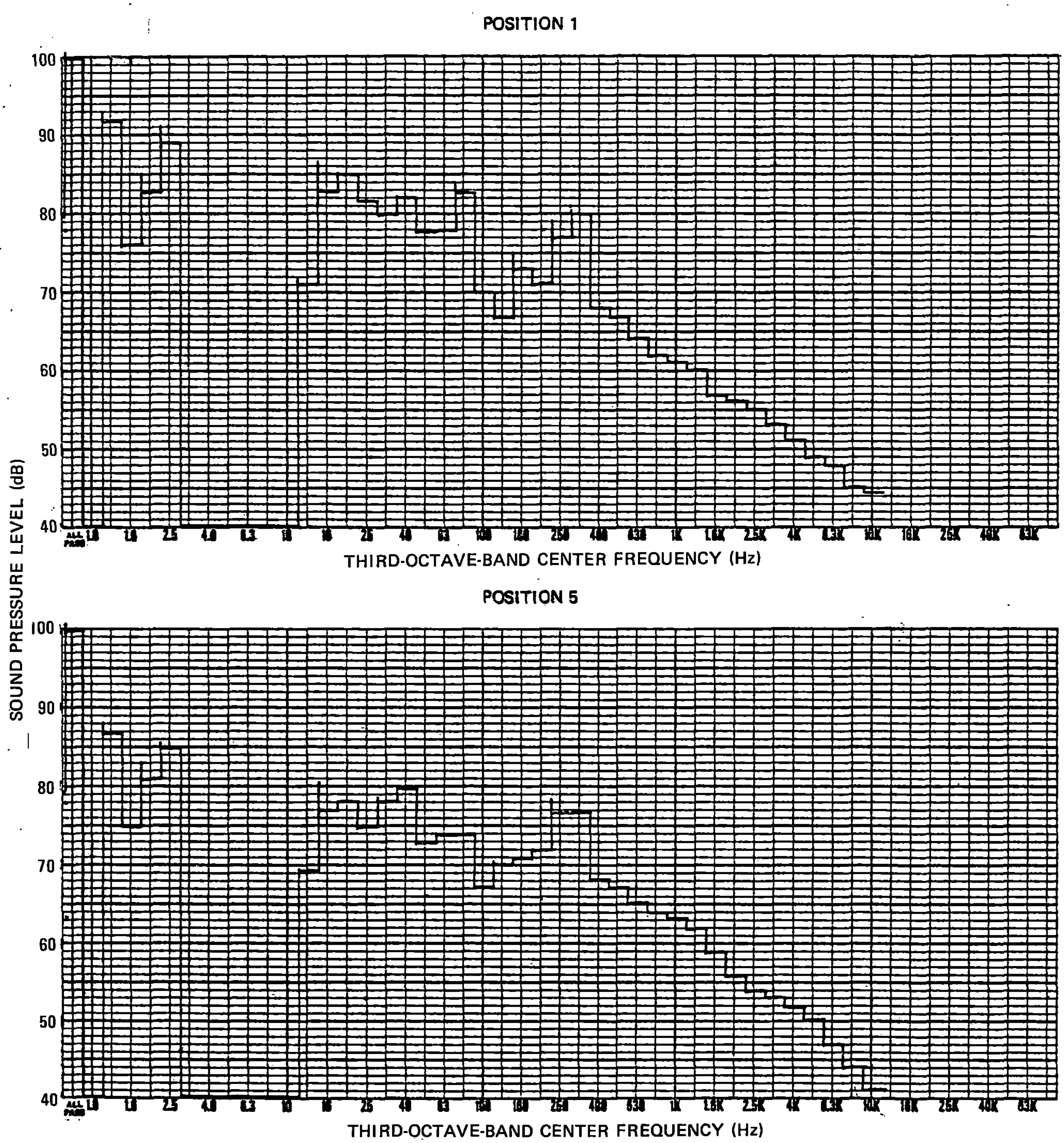


Figure 3–29. Third-Octave-Band Analysis of MBTA Interior Noise, AW0, 35 mph

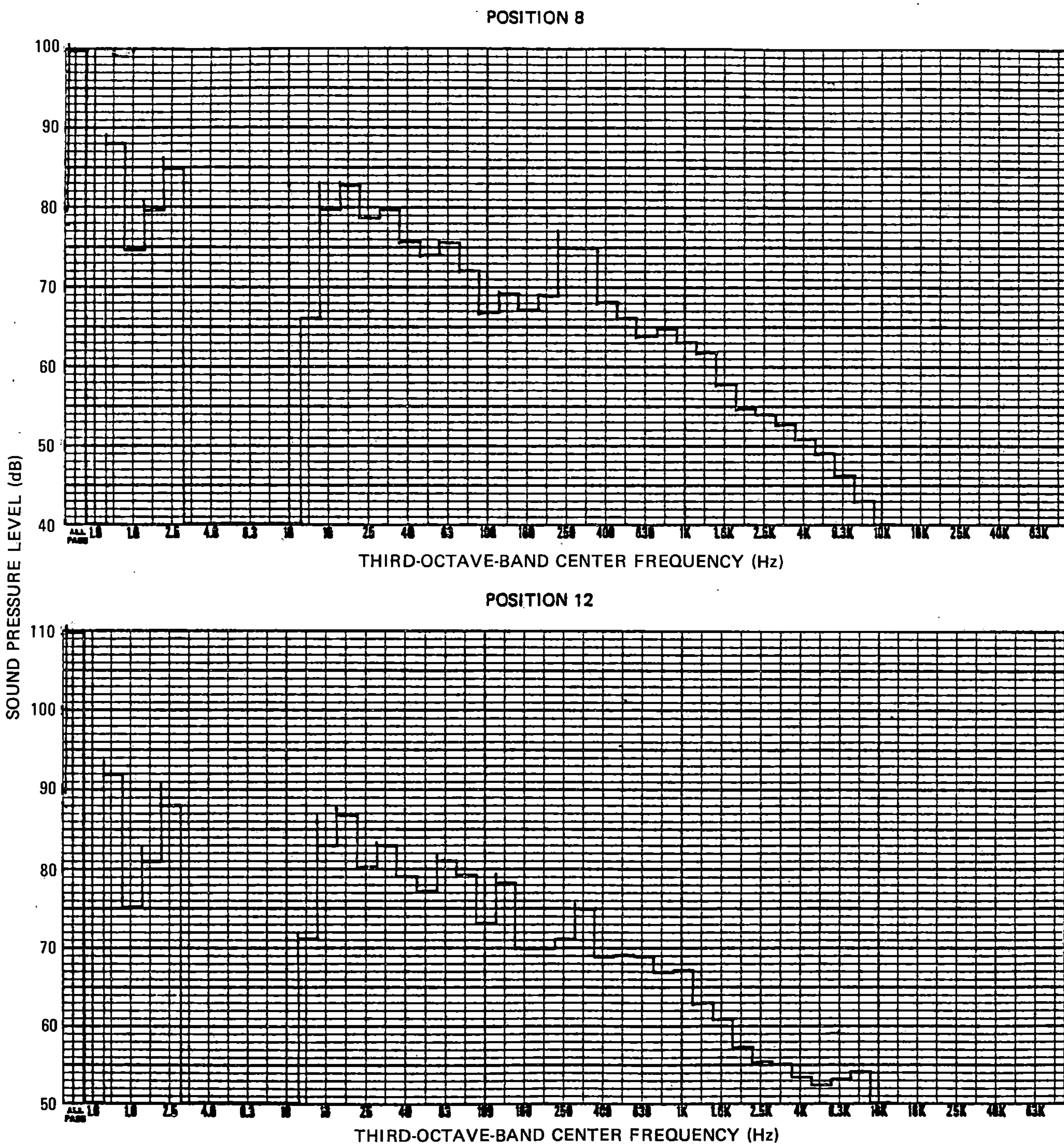


Figure 3–30. Third-Octave-Band Analysis of MBTA Interior Noise, AW0, 35 mph

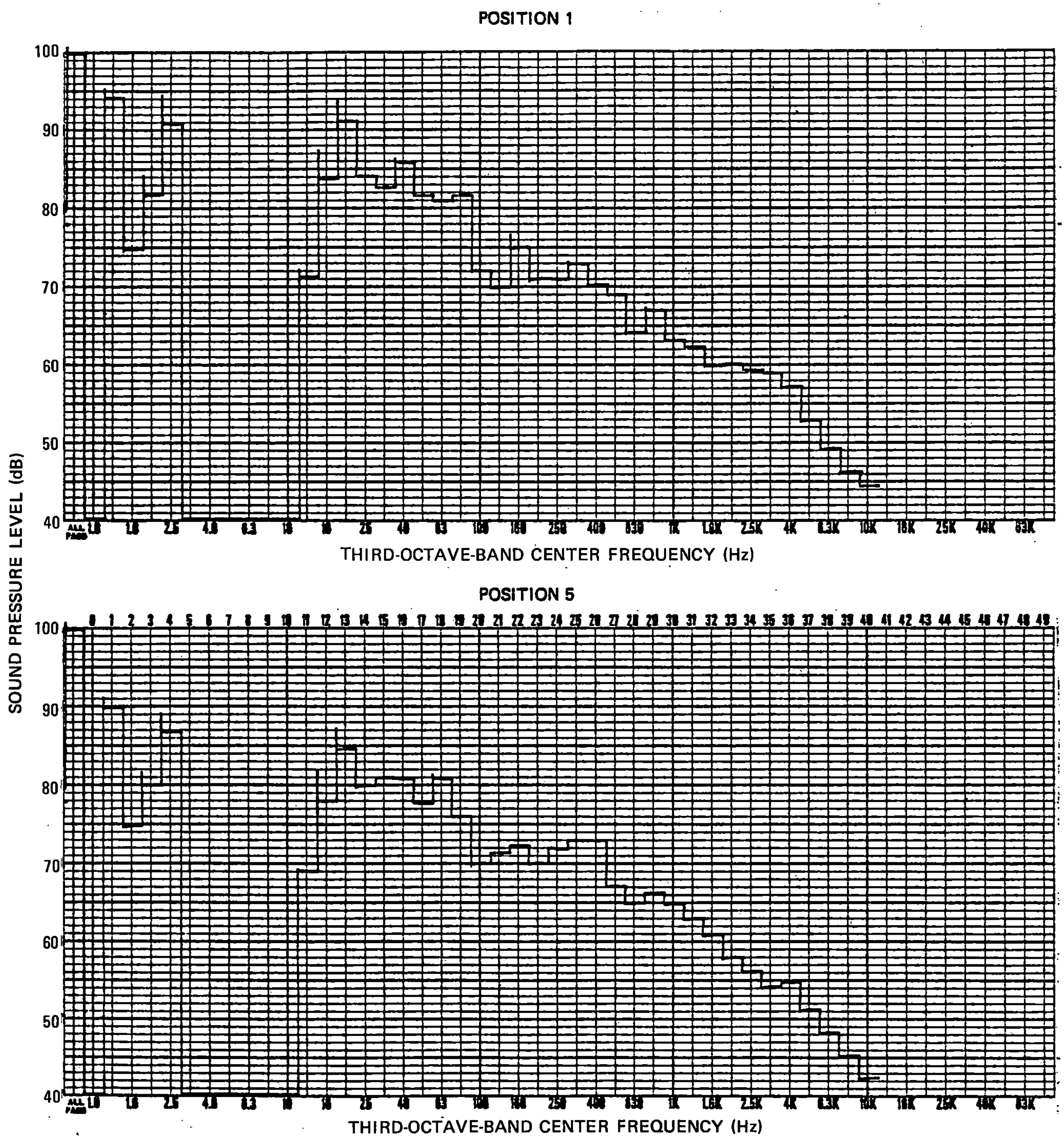


Figure 3–31. Third-Octave-Band Analysis of MBTA Interior Noise, AWO, 50 mph

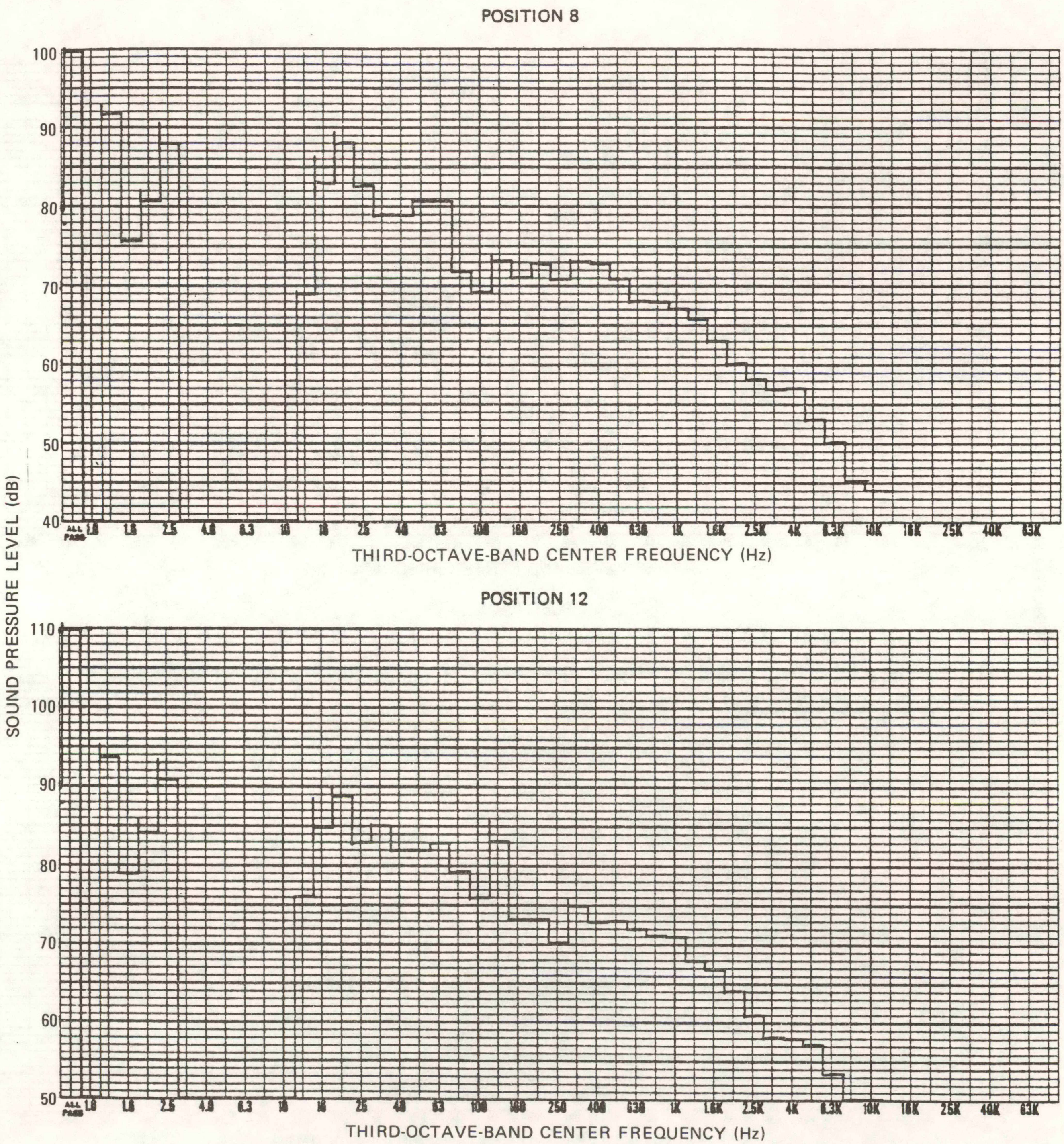


Figure 3–32. Third-Octave-Band Analysis of MBTA Interior Noise, AWO, 50 mph

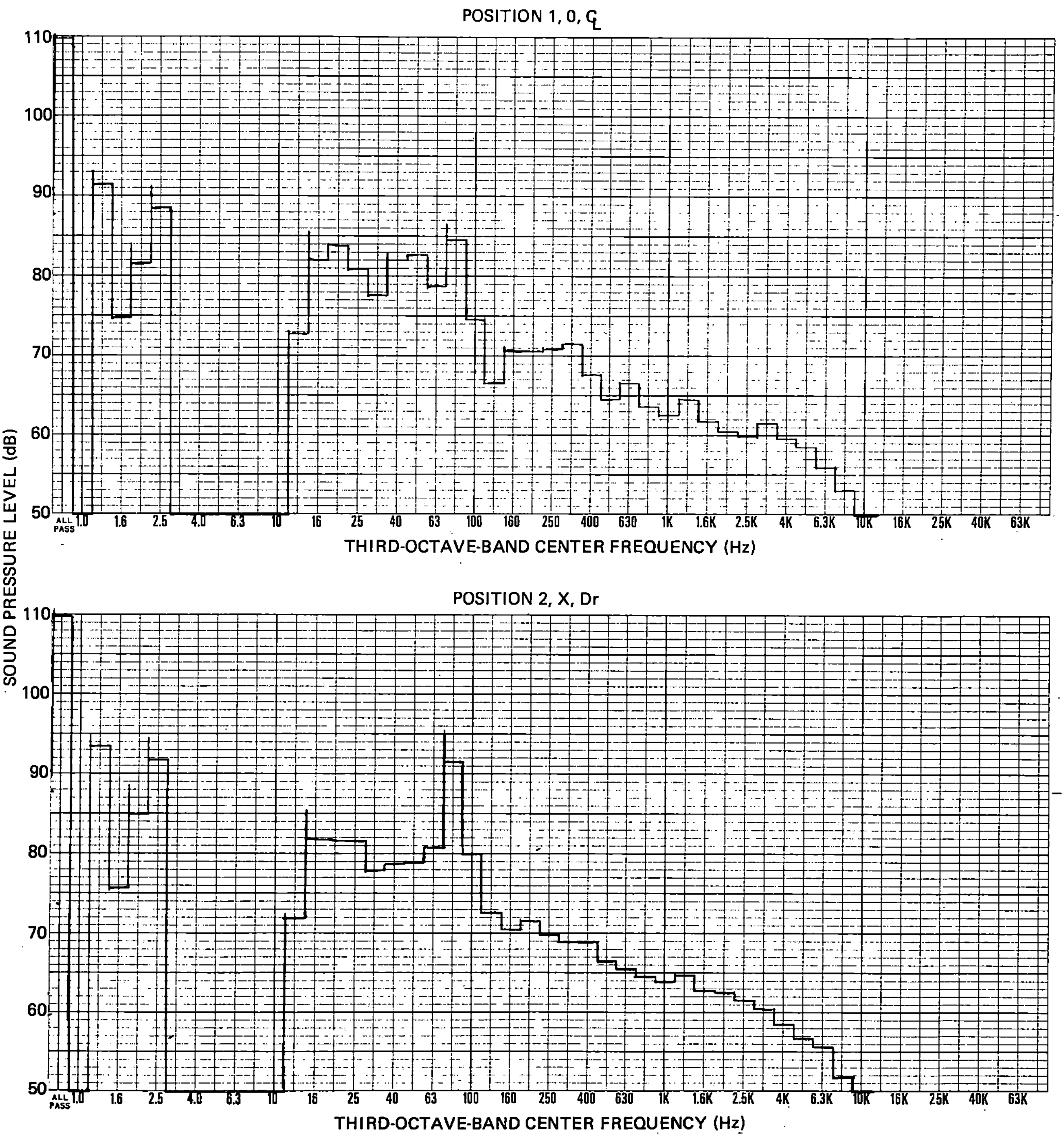


Figure 3–33. Third-Octave Band Analysis of SFMR Interior Noise, AWO, 40 mph.

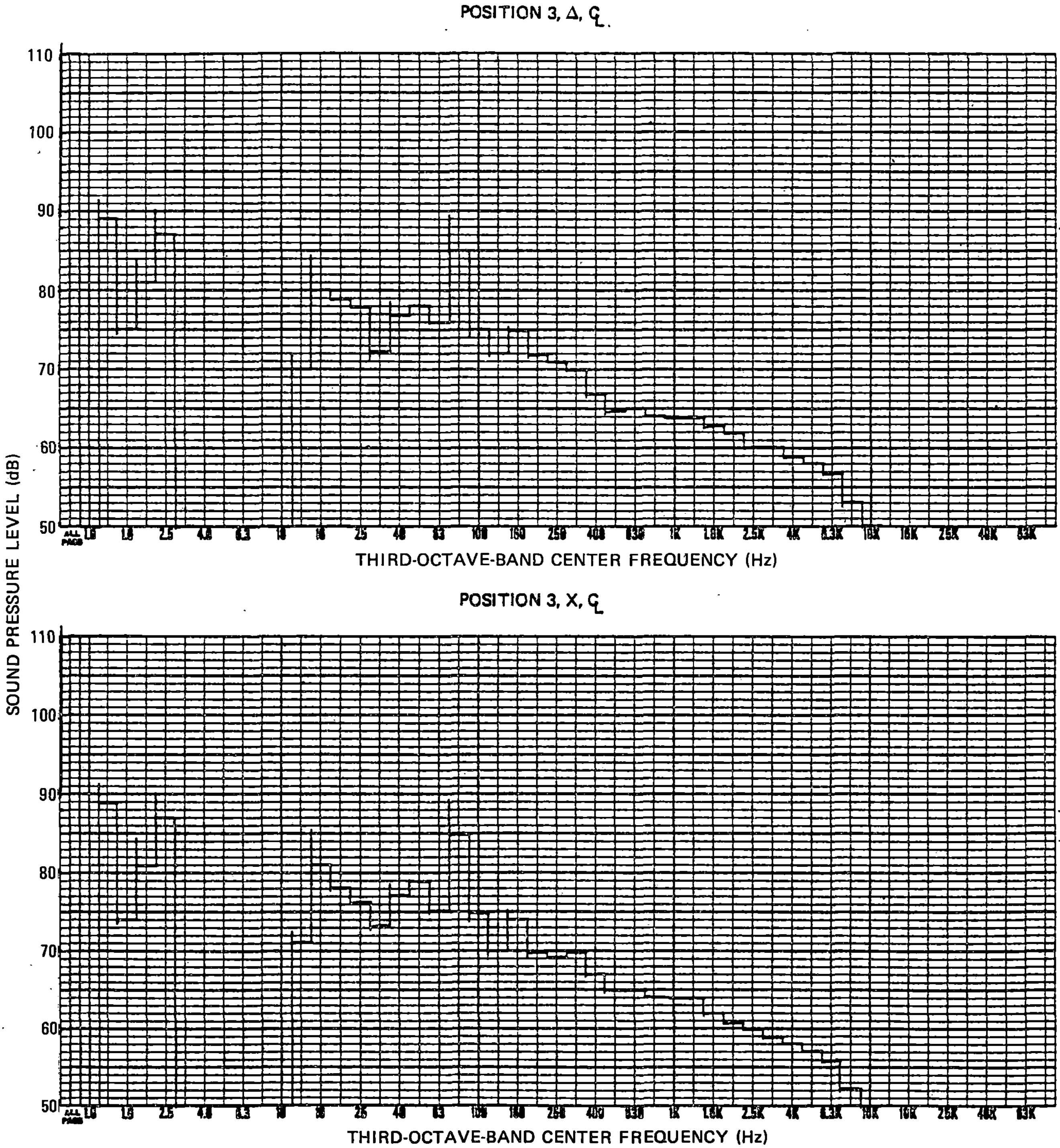


Figure 3–34. Third-Octave-Band Analysis of SFMR Interior Noise, AWO, 40 mph

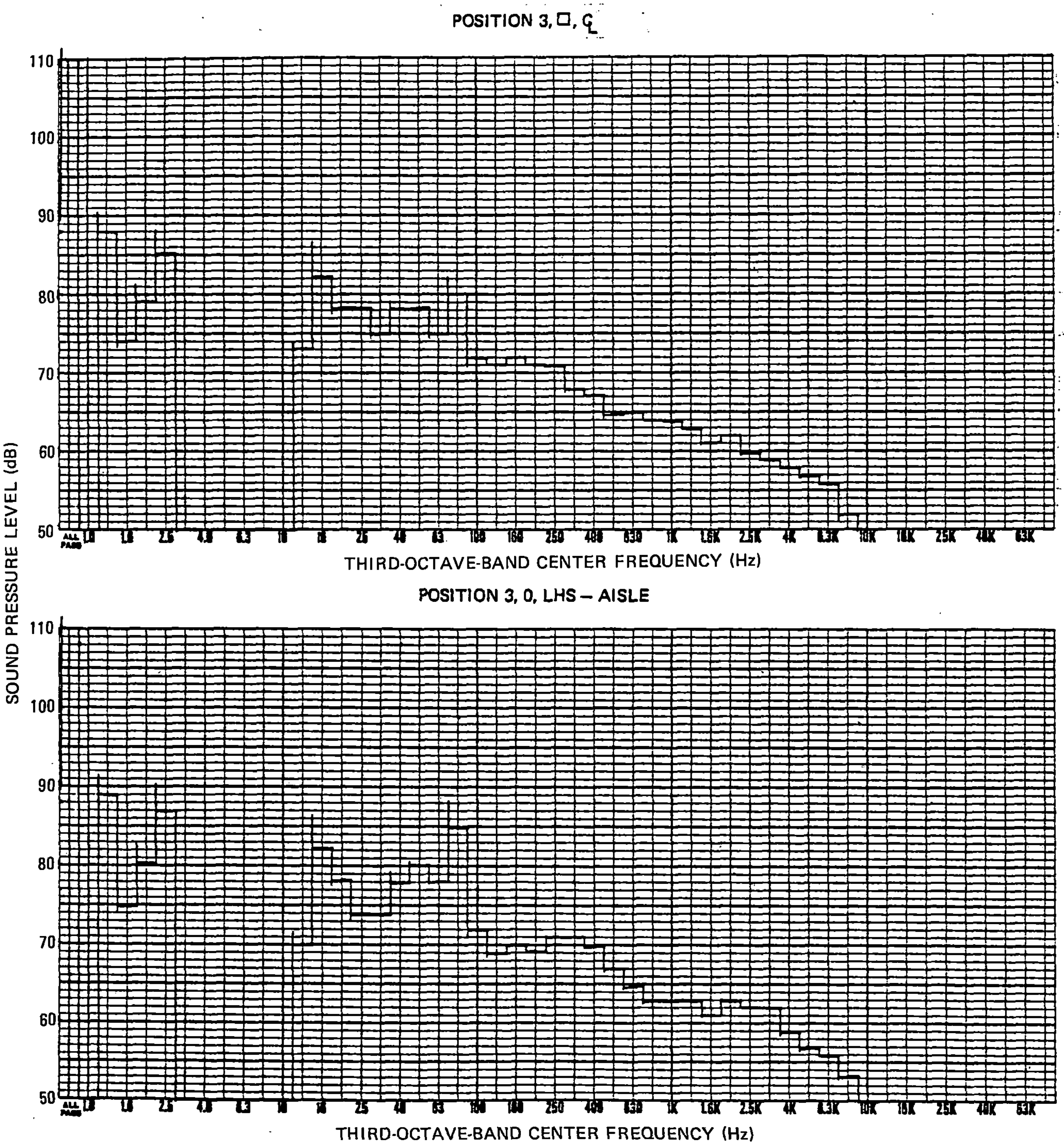
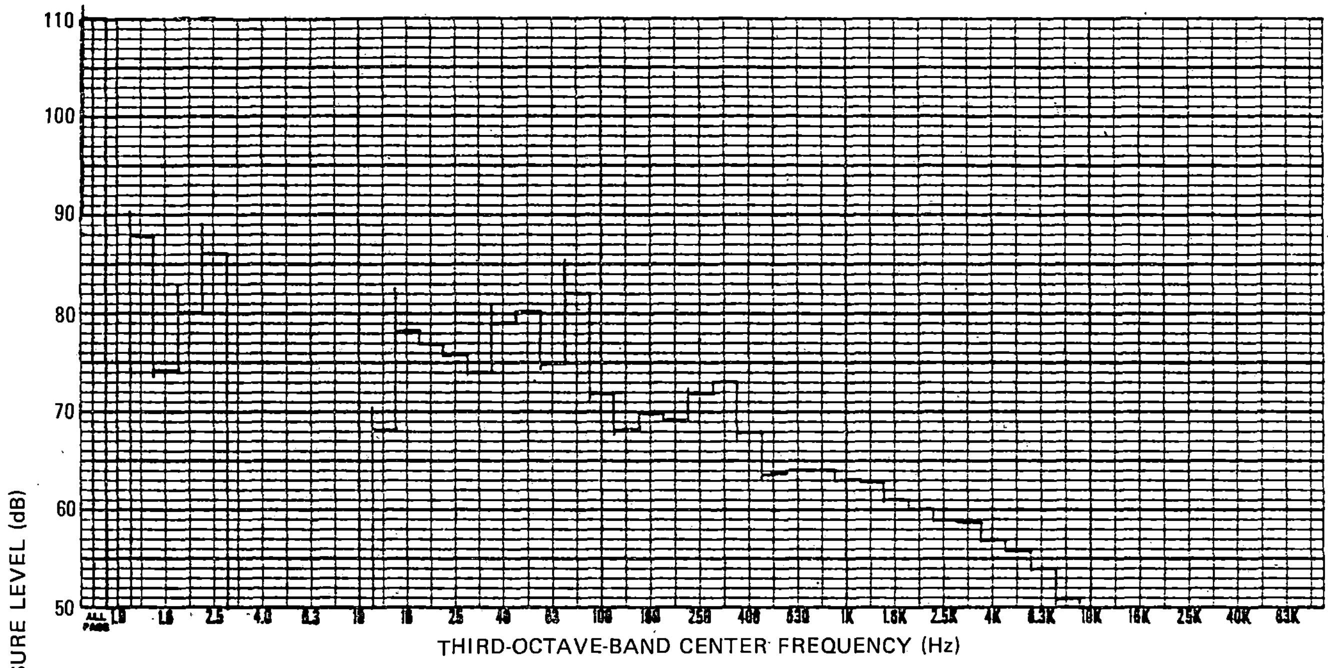


Figure 3–35. Third-Octave-Band Analysis of SFMR Interior Noise, AWO, 40 mph

POSITION 4, 0, LHS – AISLE



POSITION 5, 0, LHS – AISLE

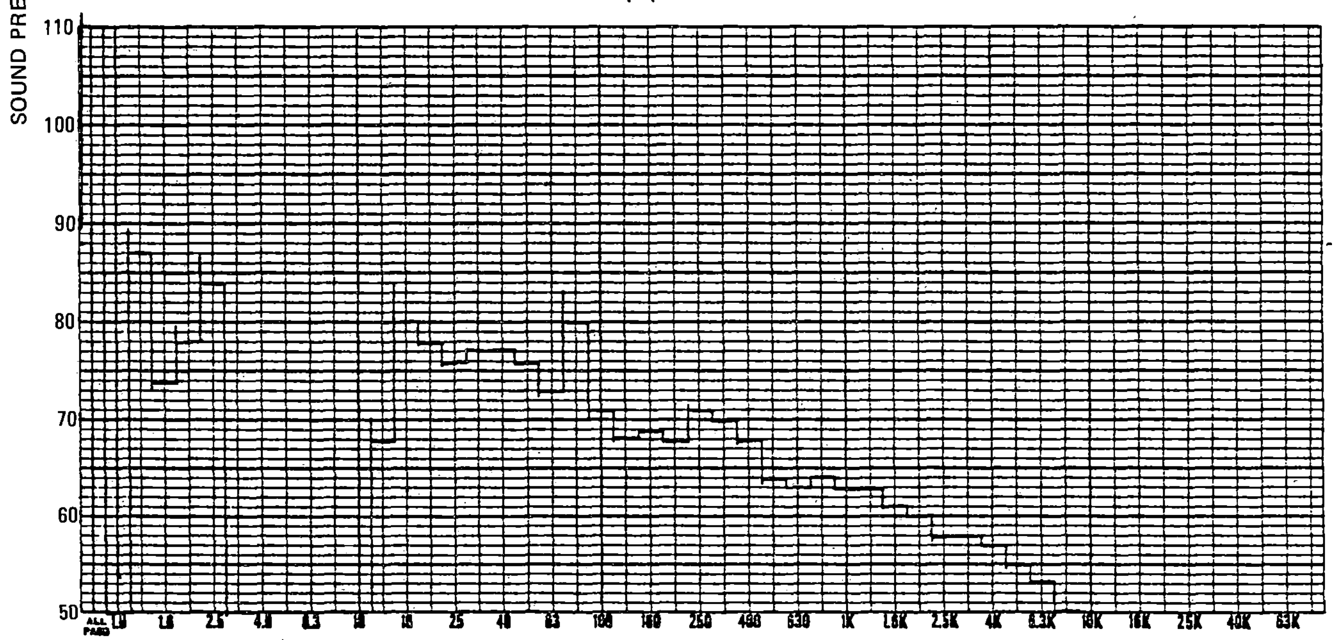


Figure 3–36. Third-Octave-Band Analysis of SFMR Interior Noise, AWO, 40 mph

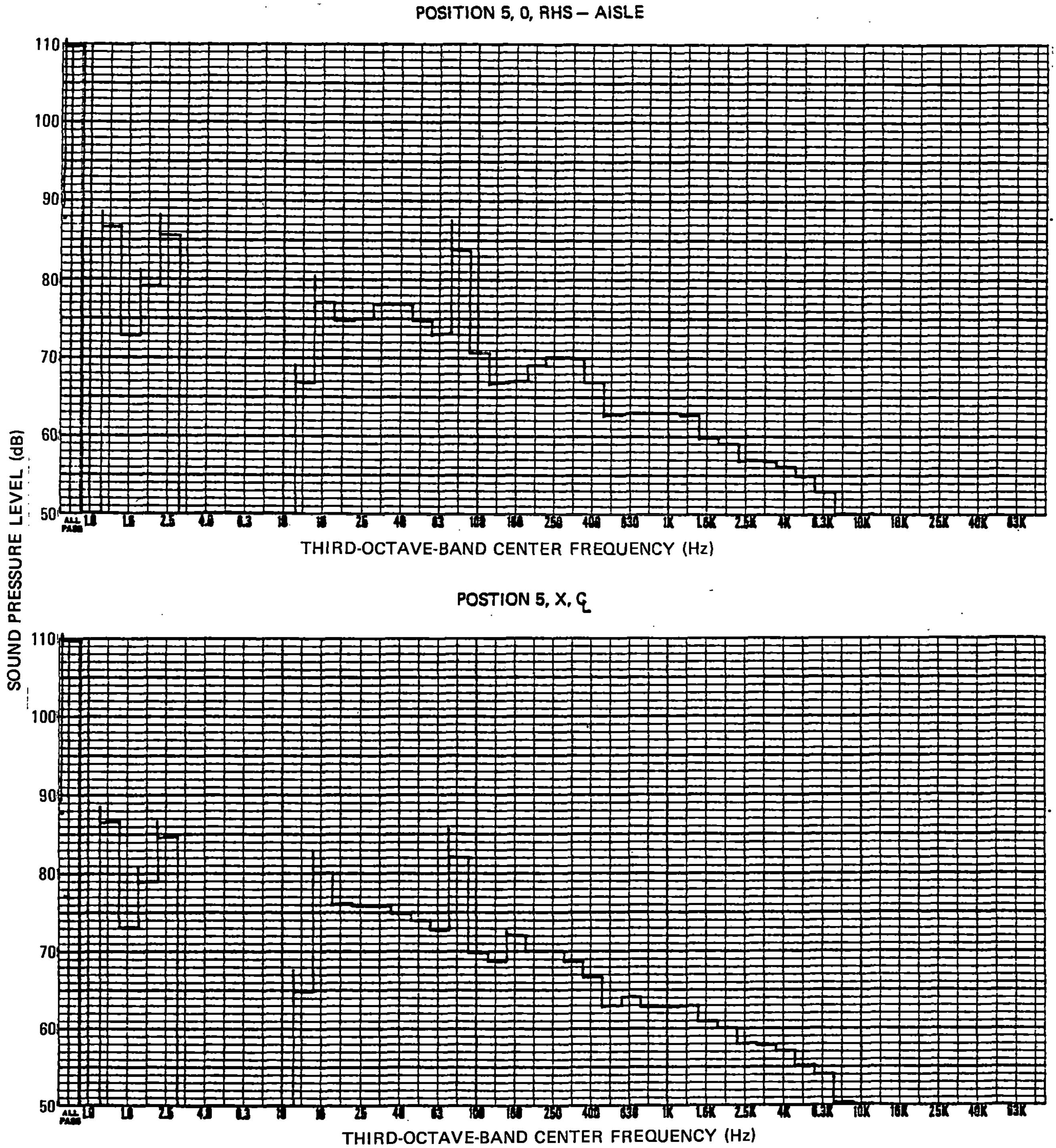
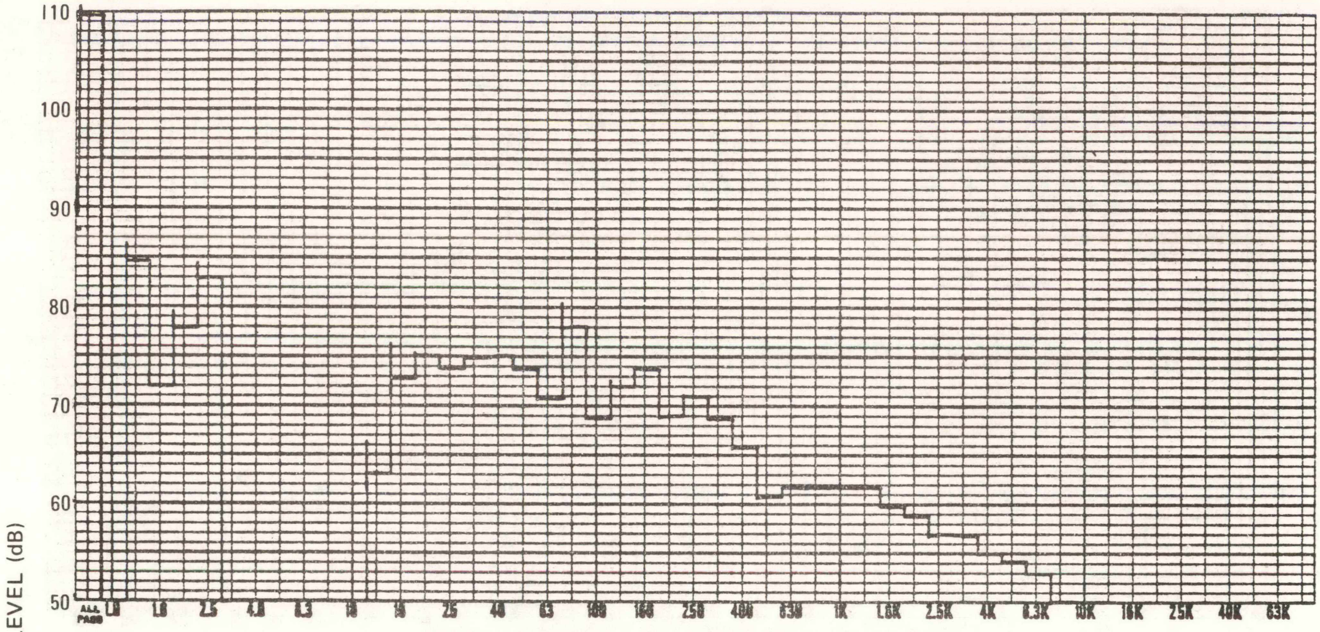


Figure 3–37. Third-Octave-Band Analysis of SFMR Interior Noise, AWO, 40 mph

POSITION 6, 0, LHS – WINDOW



POSITION 6, 0, LHS – AISLE

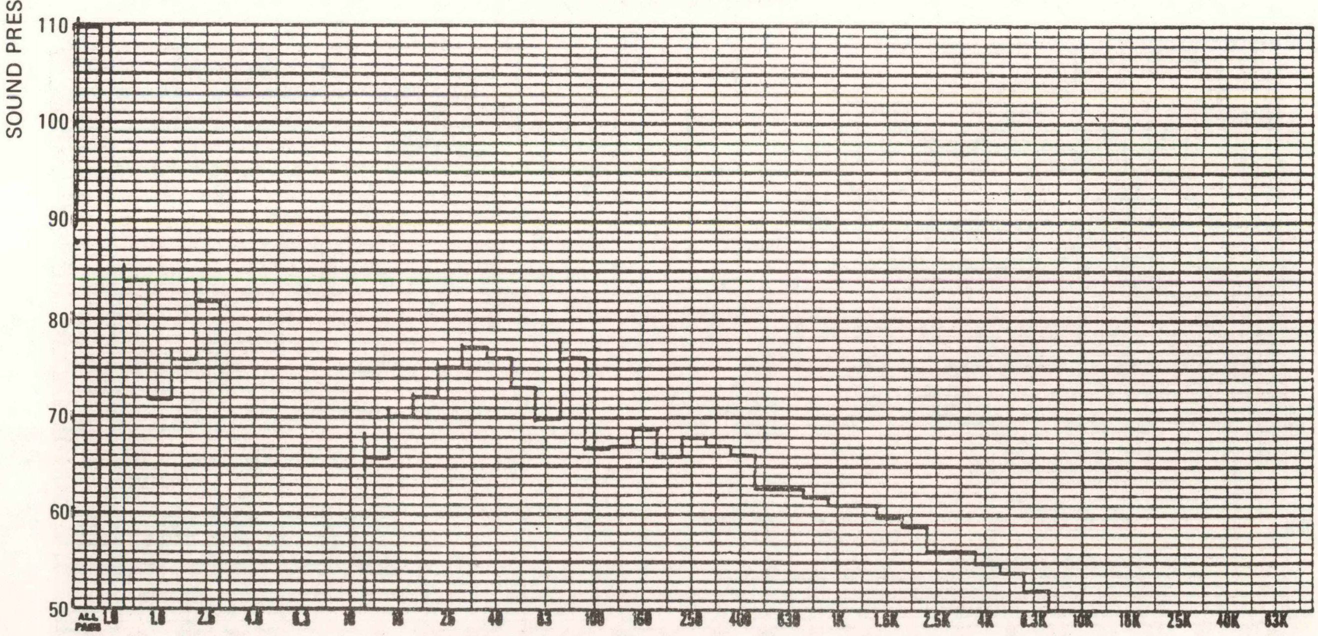


Figure 3–38. Third-Octave-Band Analysis of SFMR Interior Noise, AW0, 40 mph

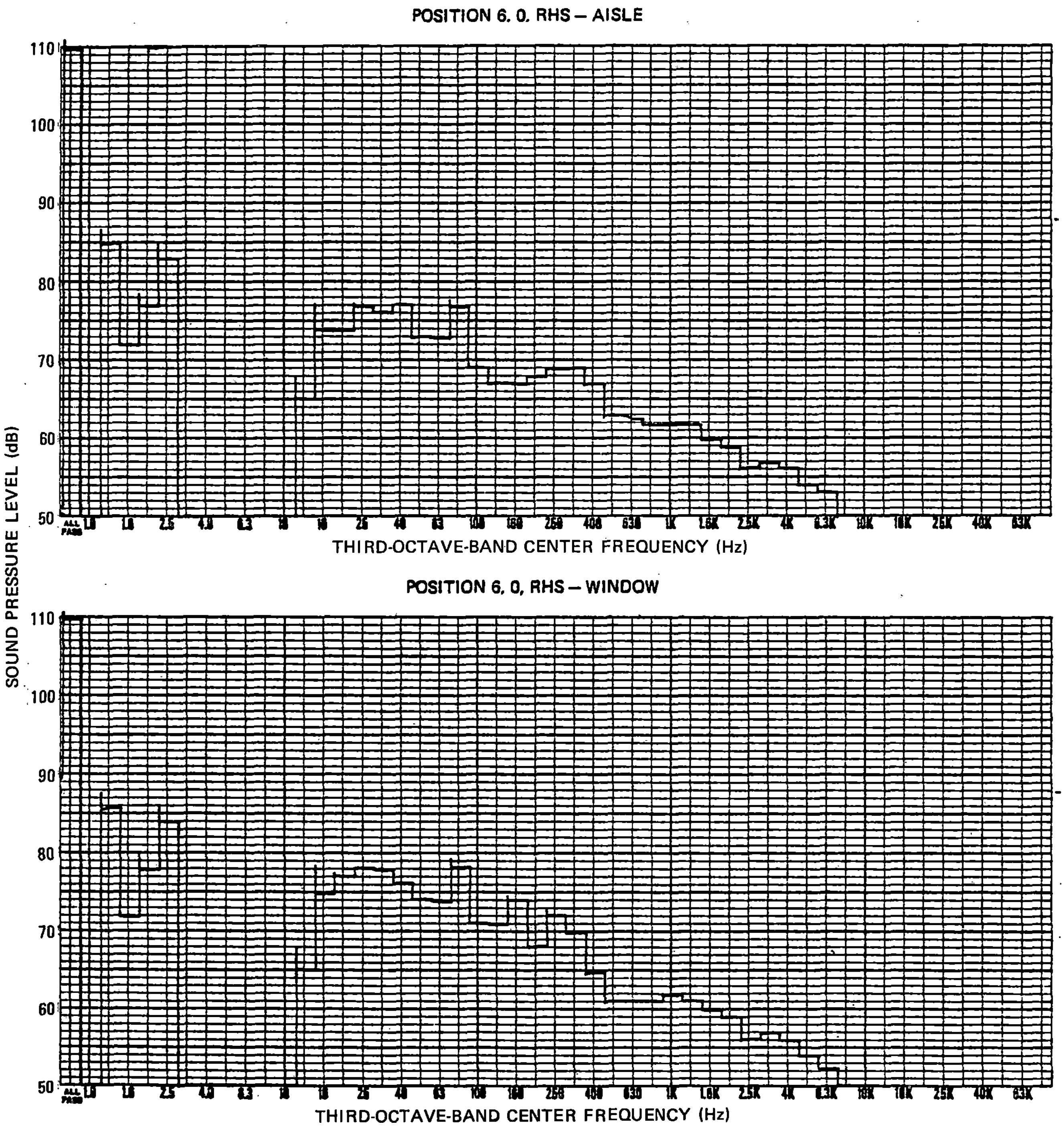
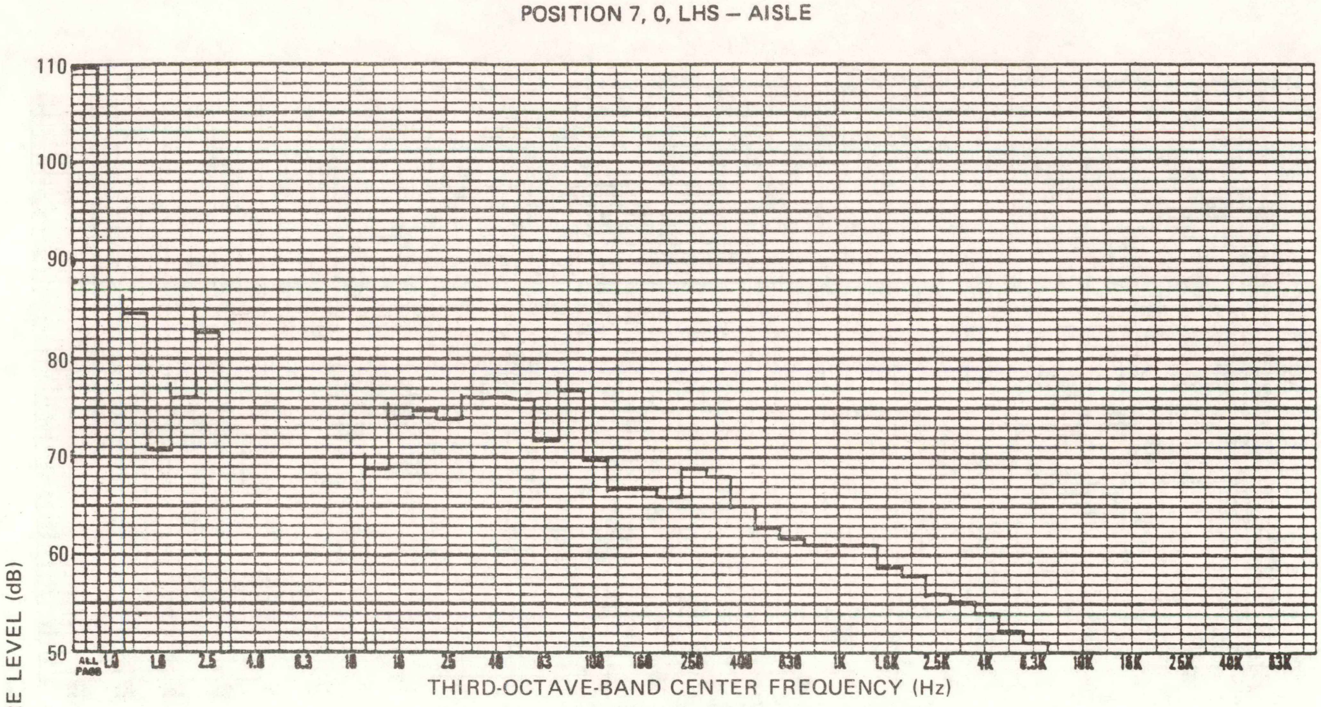


Figure 3–39. Third-Octave-Band Analysis of SFMR Interior Noise, AW0, 40 mph



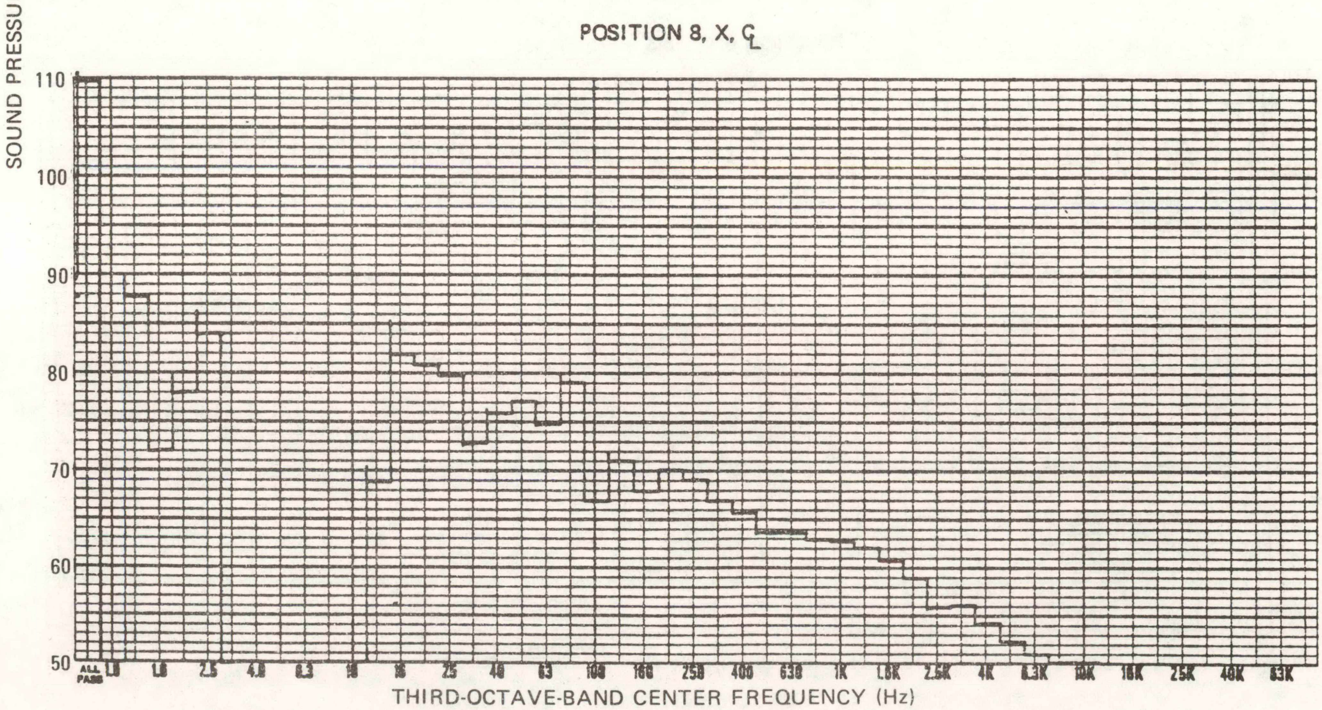


Figure 3–40. Third-Octave-Band Analysis of SFMR Interior Noise, AWO, 40 mph

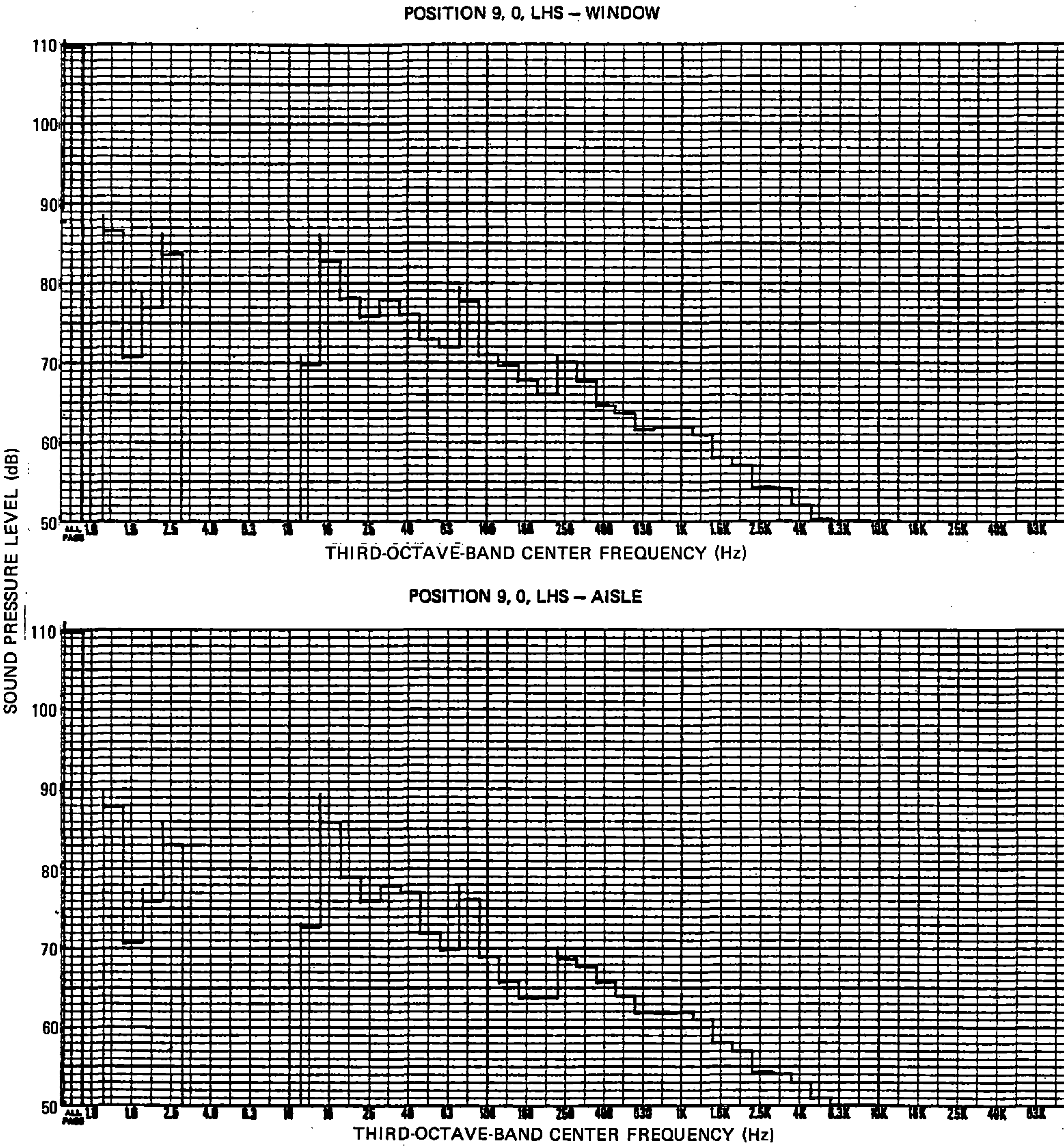


Figure 3–41. Third-Octave-Band Analysis of SFMR Interior Noise, AWO, 40 mph

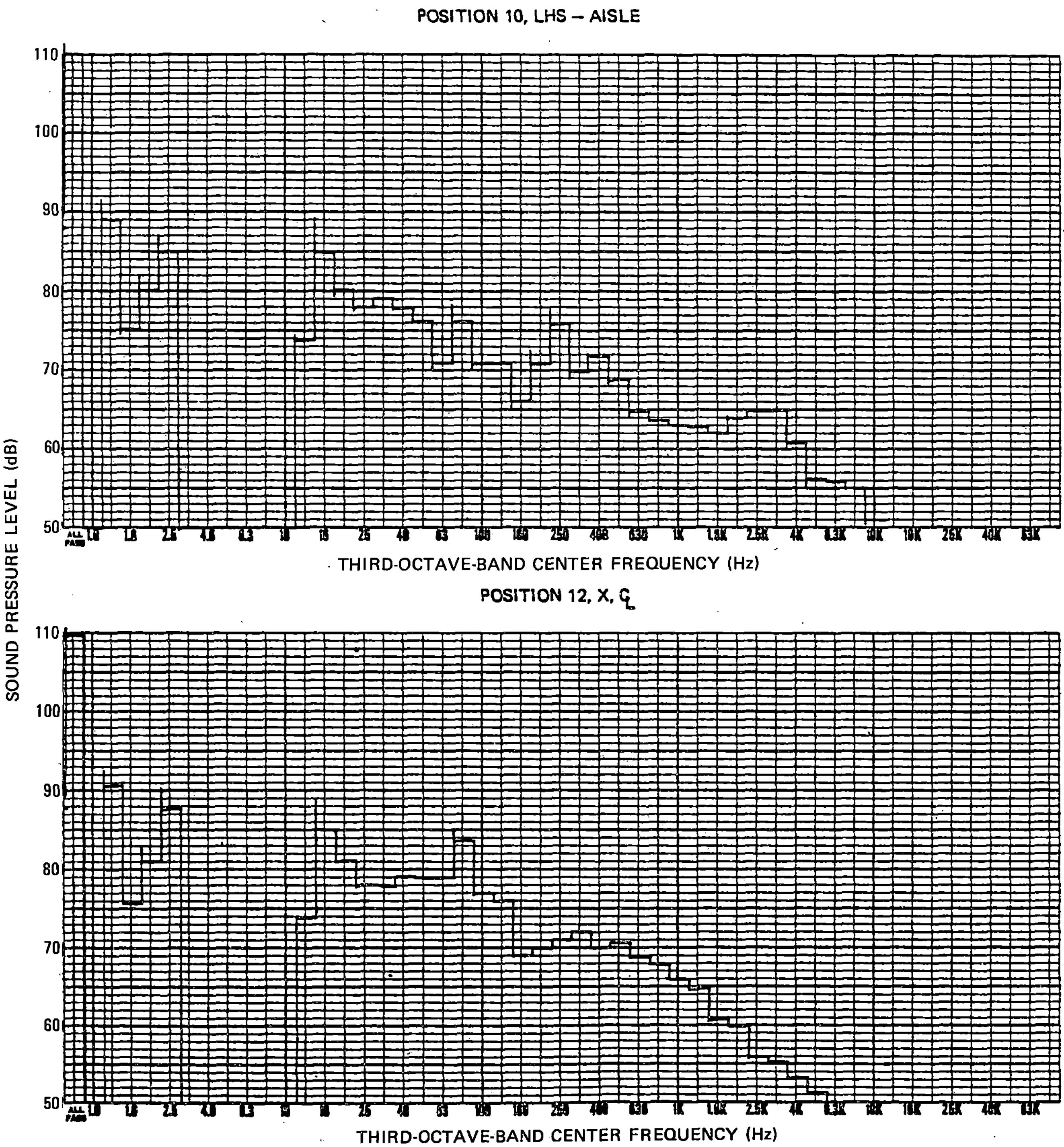


Figure 3–42. Third-Octave-Band Analysis of SFMR Interior Noise, AWO, 40 mph

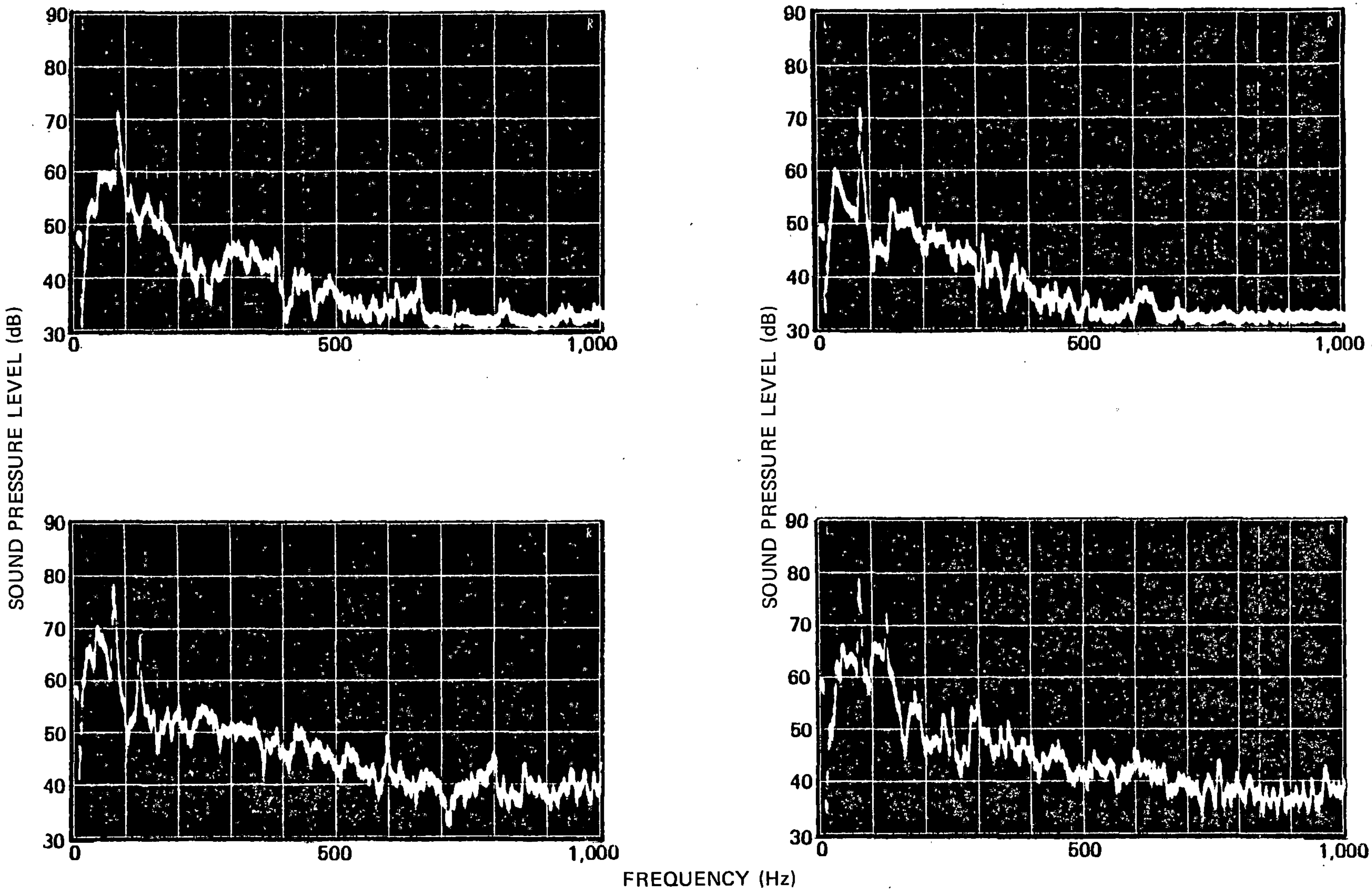


Figure 3–43. Narrowband Analysis of Interior Noise, SFMR, AW0, 0 mph

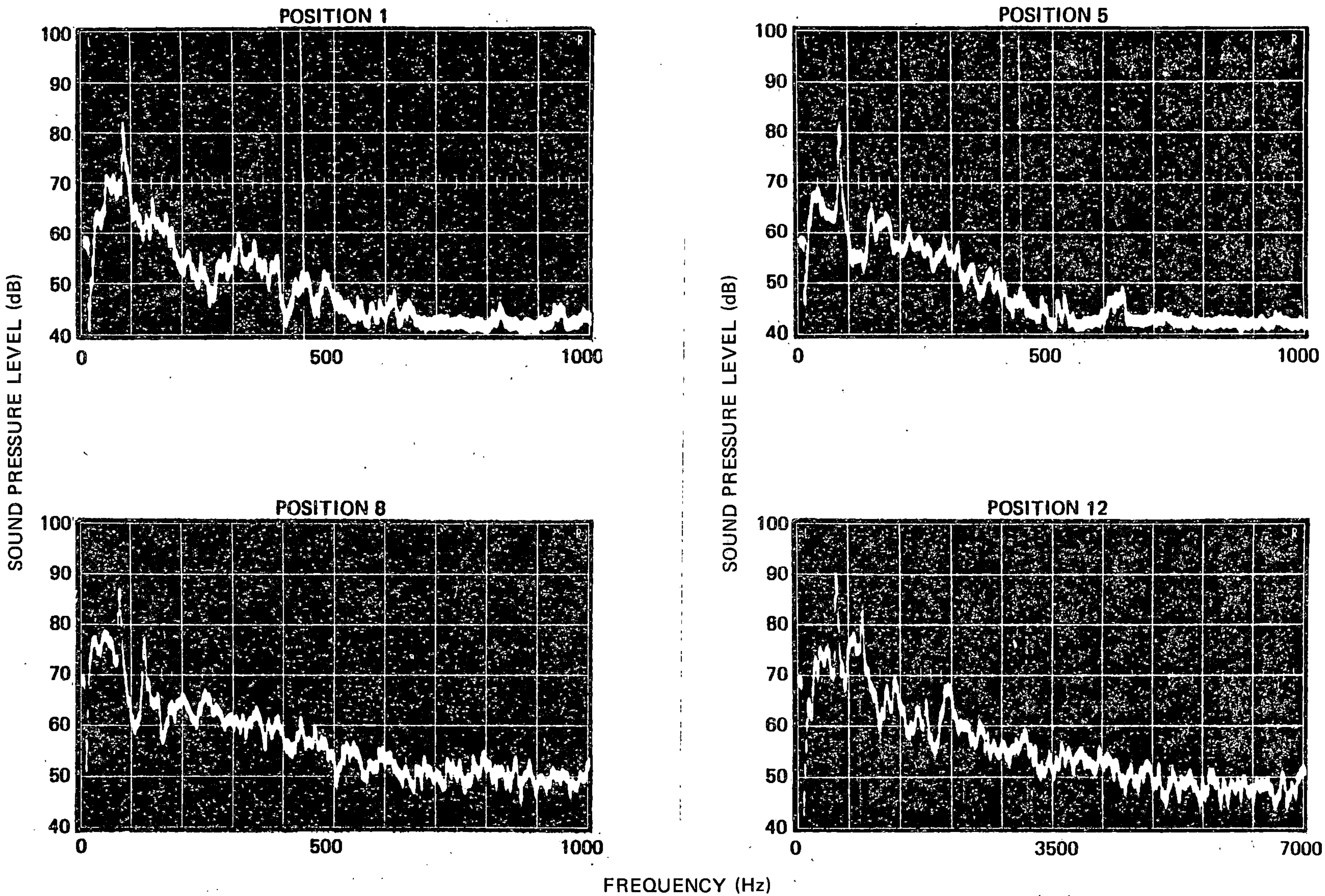


Figure 3–44. ***Narrowband Analysis of Interior Noise, SFMR, AWO, 15 mph***

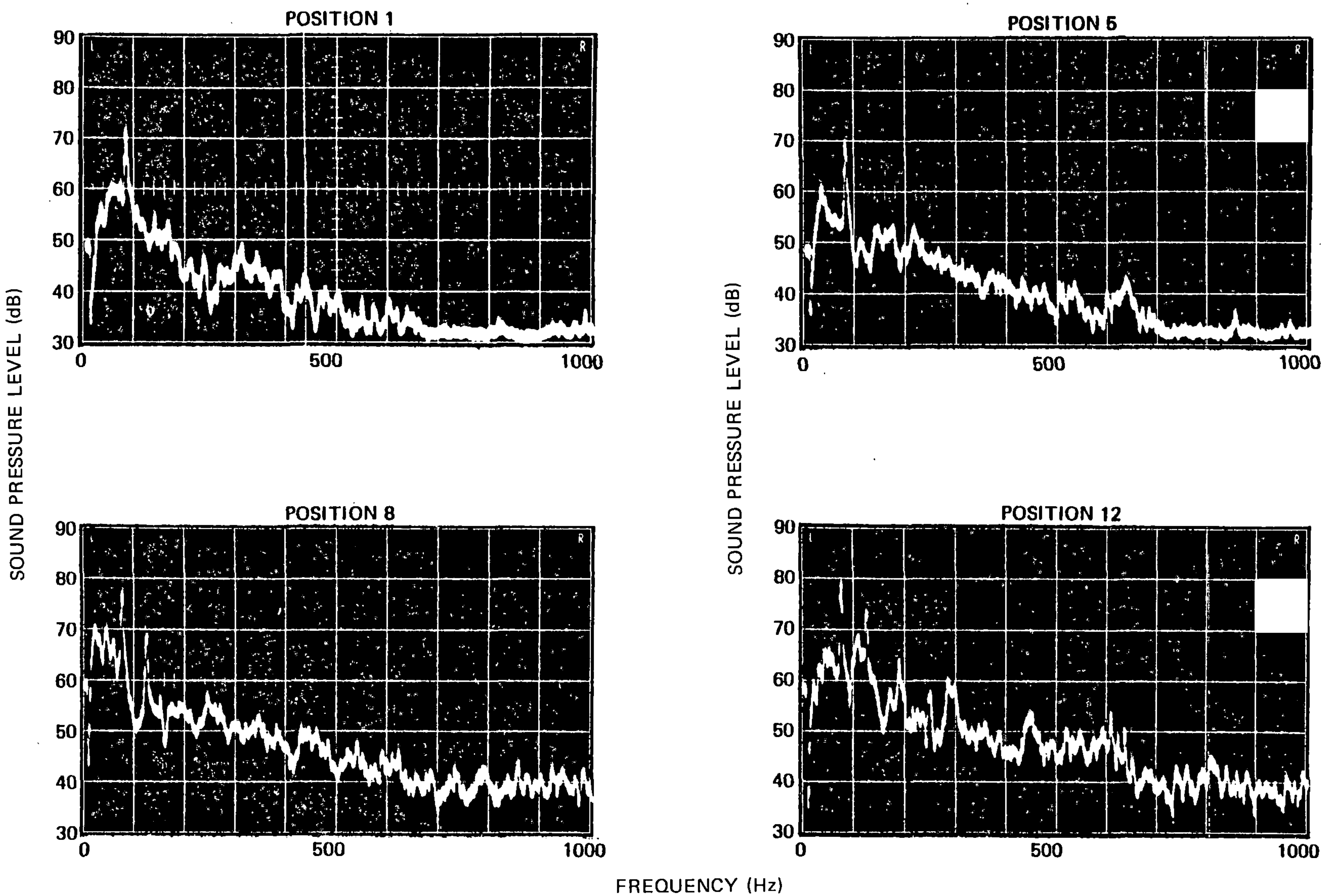


Figure 3–45. Narrowband Analysis of Interior Noise, SFMR, AWO, 25 mph

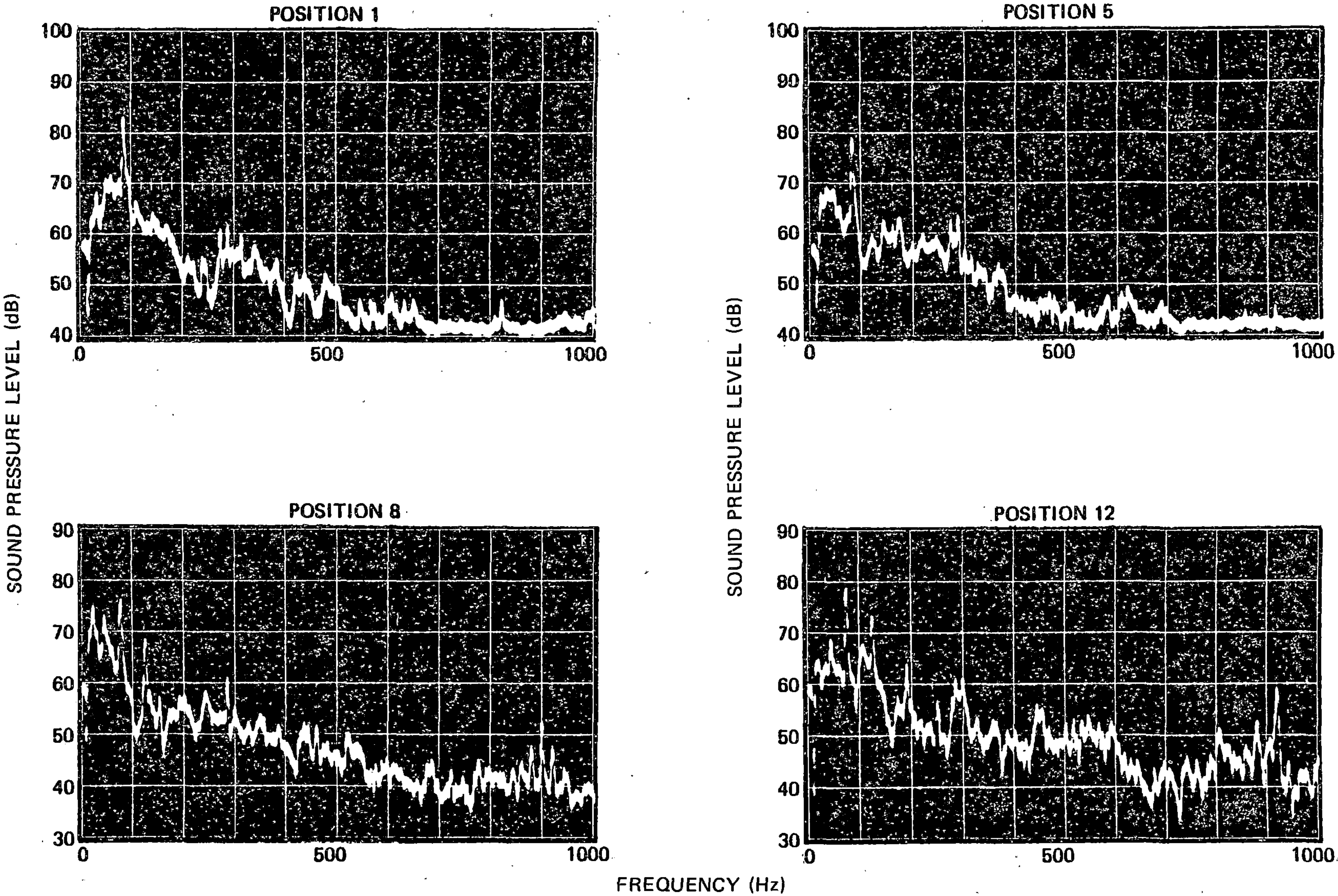


Figure 3–46. Narrowband Analysis of Interior Noise, SFMR, AWO, 35 mph

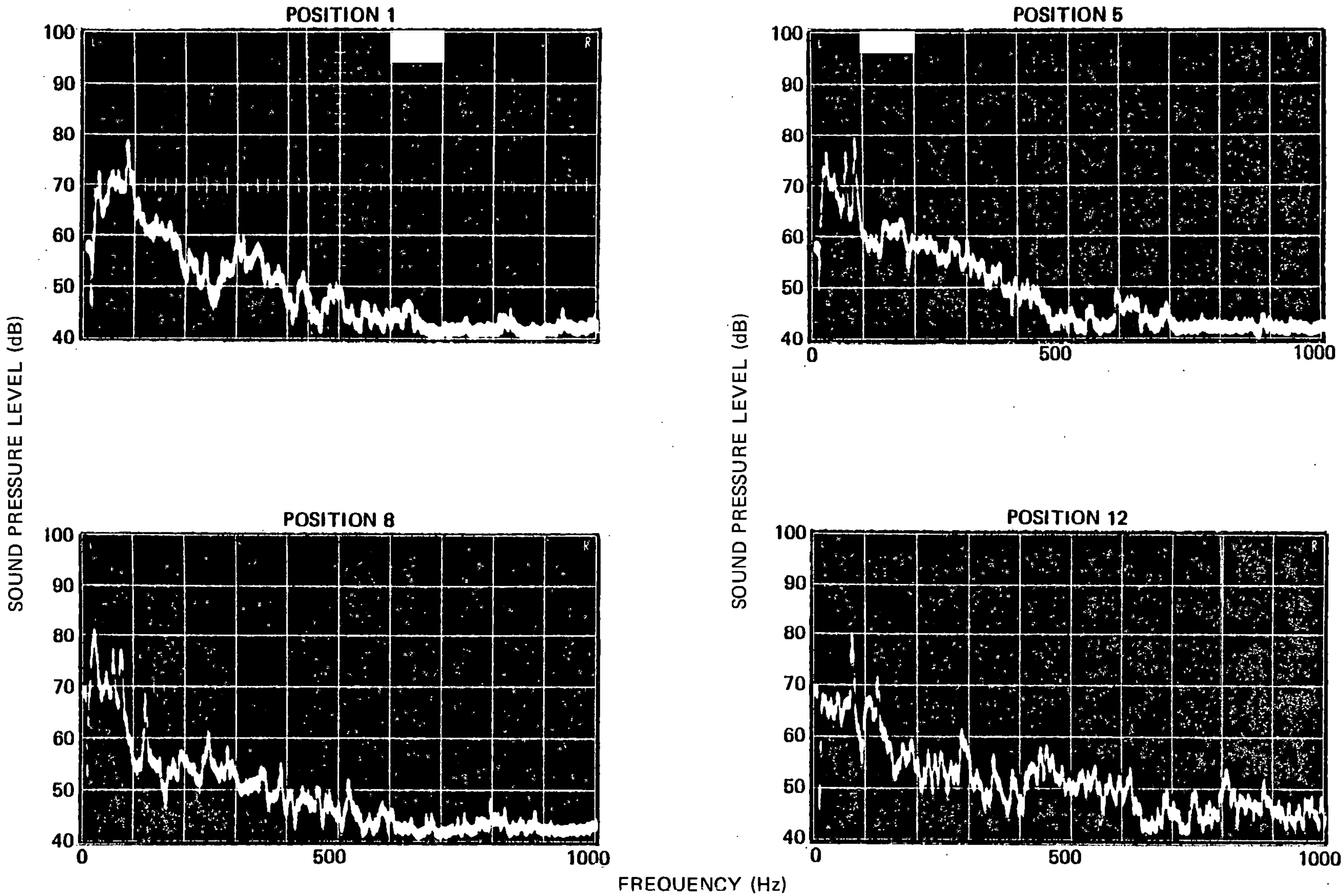


Figure 3–47. Narrowband Analysis of Interior Noise, SFMR, AWO, 50 mph

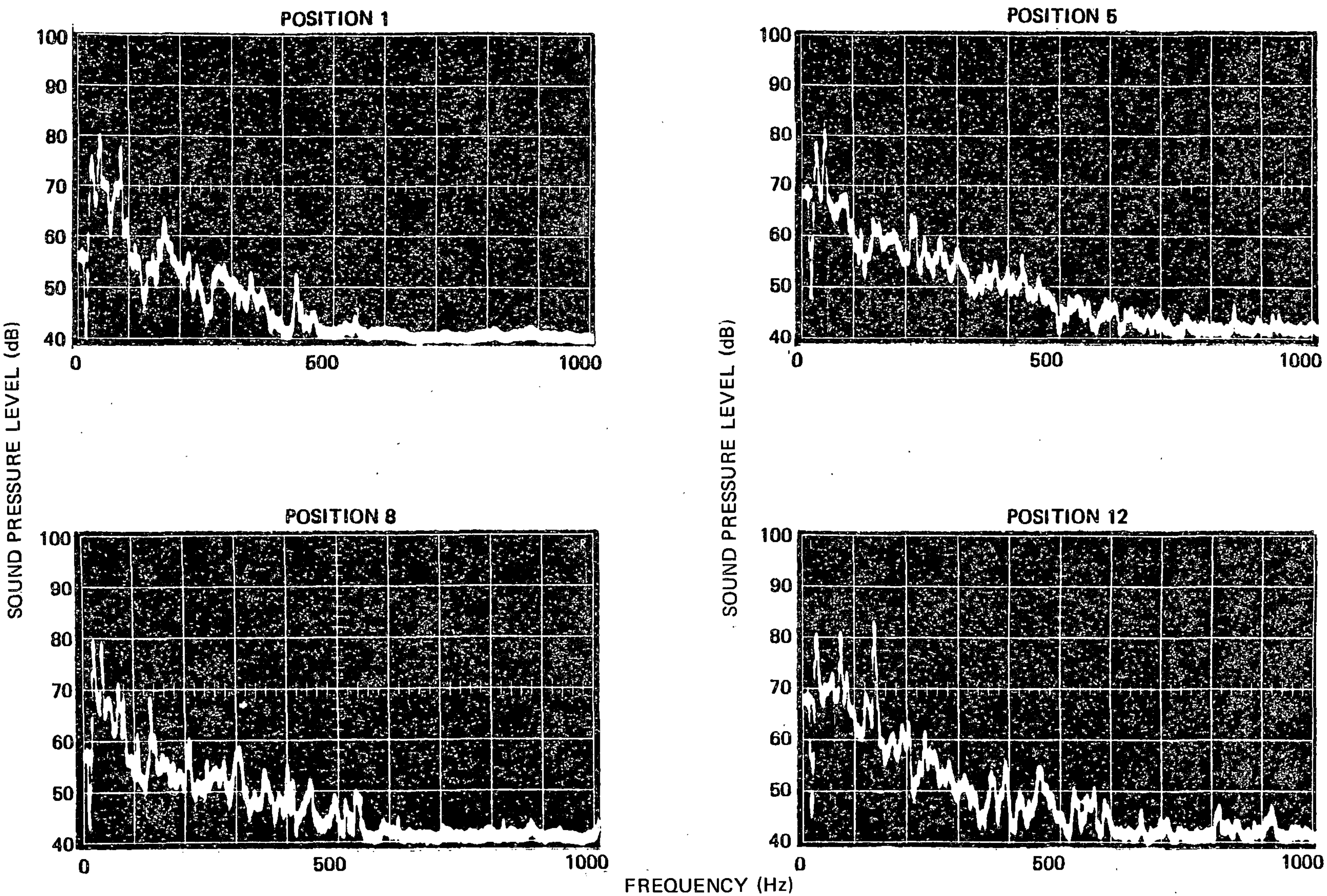


Figure 3—48. Narrowband Analysis of Interior Noise, MBTA, AW0, 15 mph

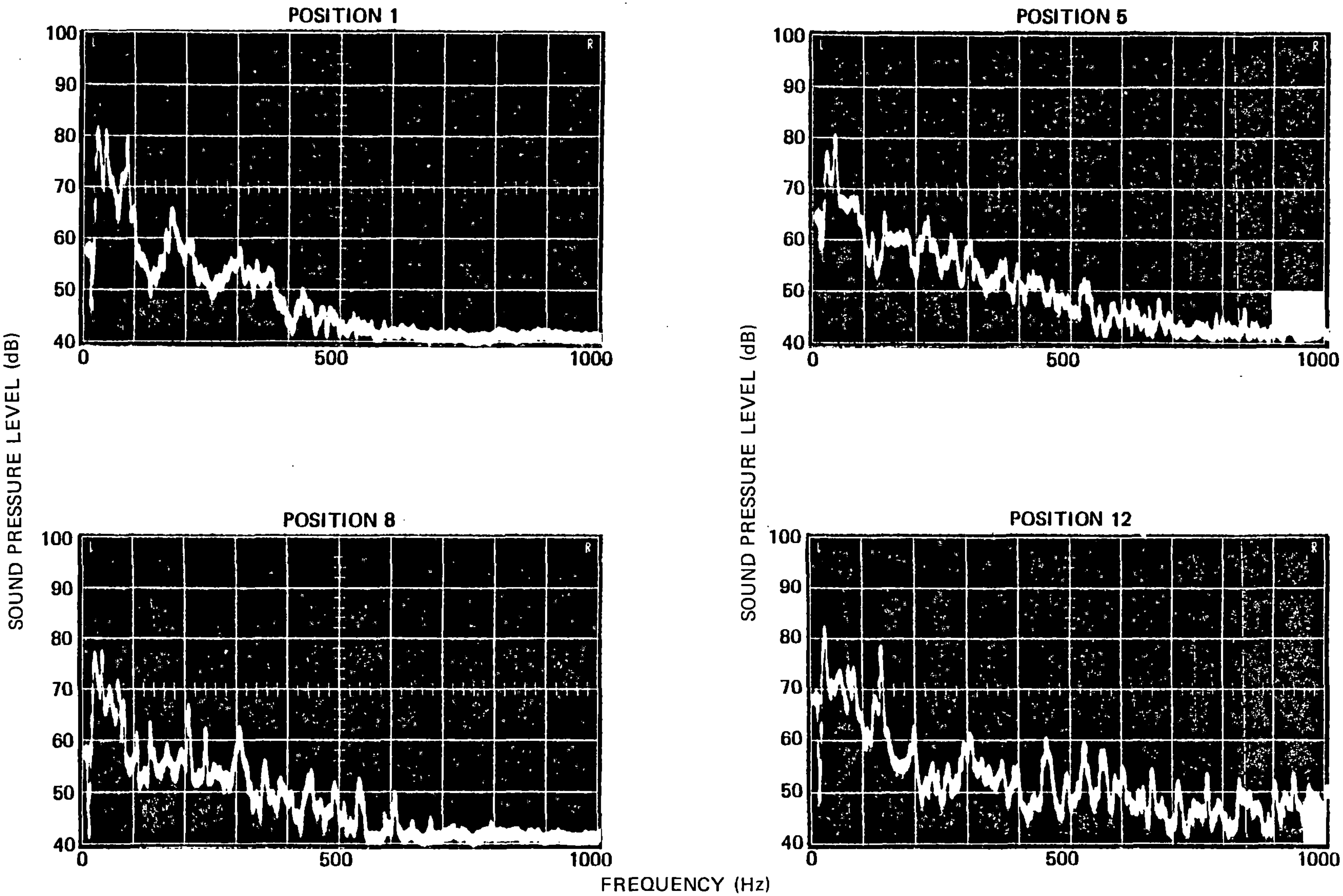


Figure 3–49. Narrowband Analysis of Interior Noise, MBTA, AW0, 25 mph

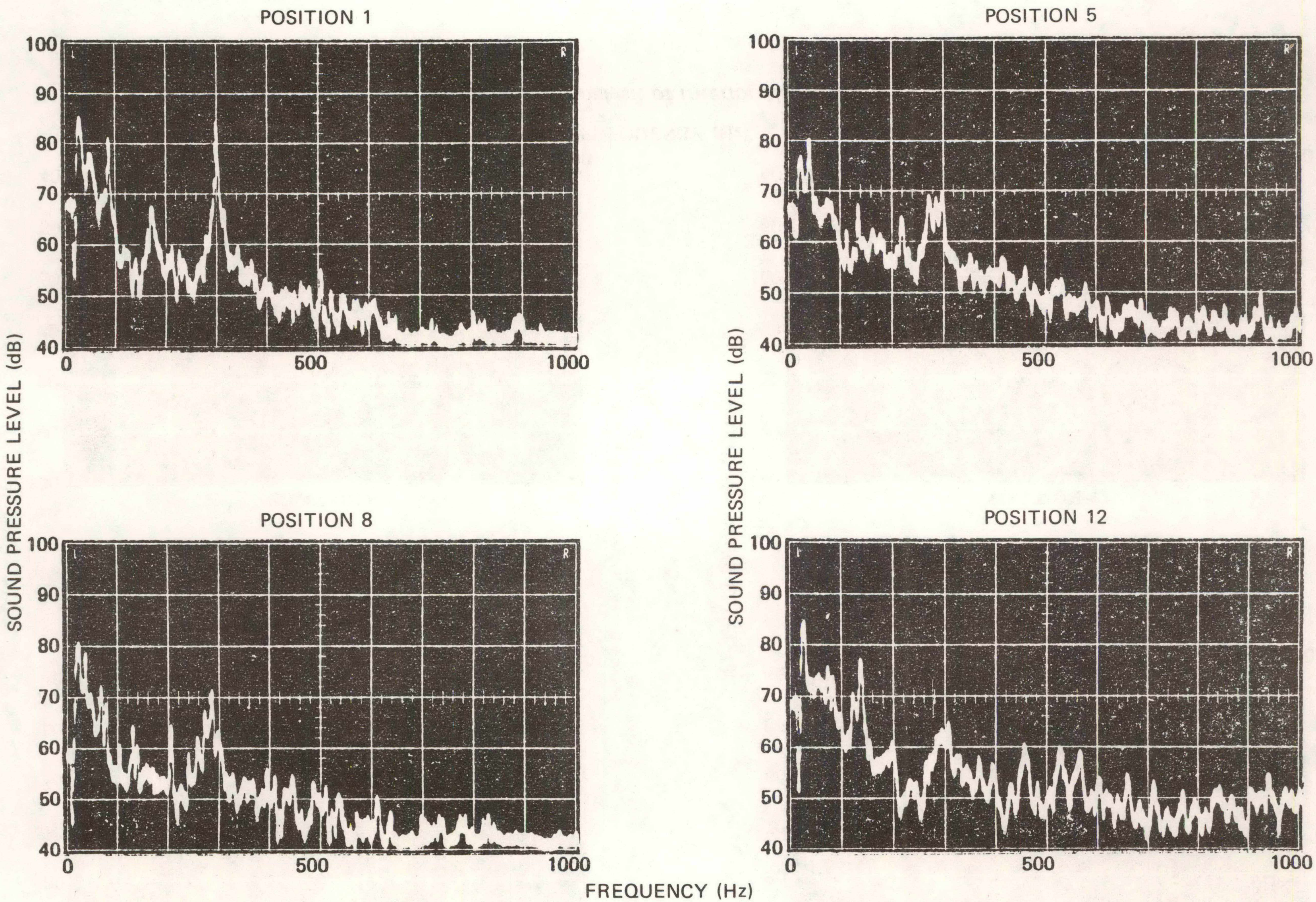


Figure 3–50. Narrowband Analysis of Interior Noise, MBTA, AWO, 35 mph

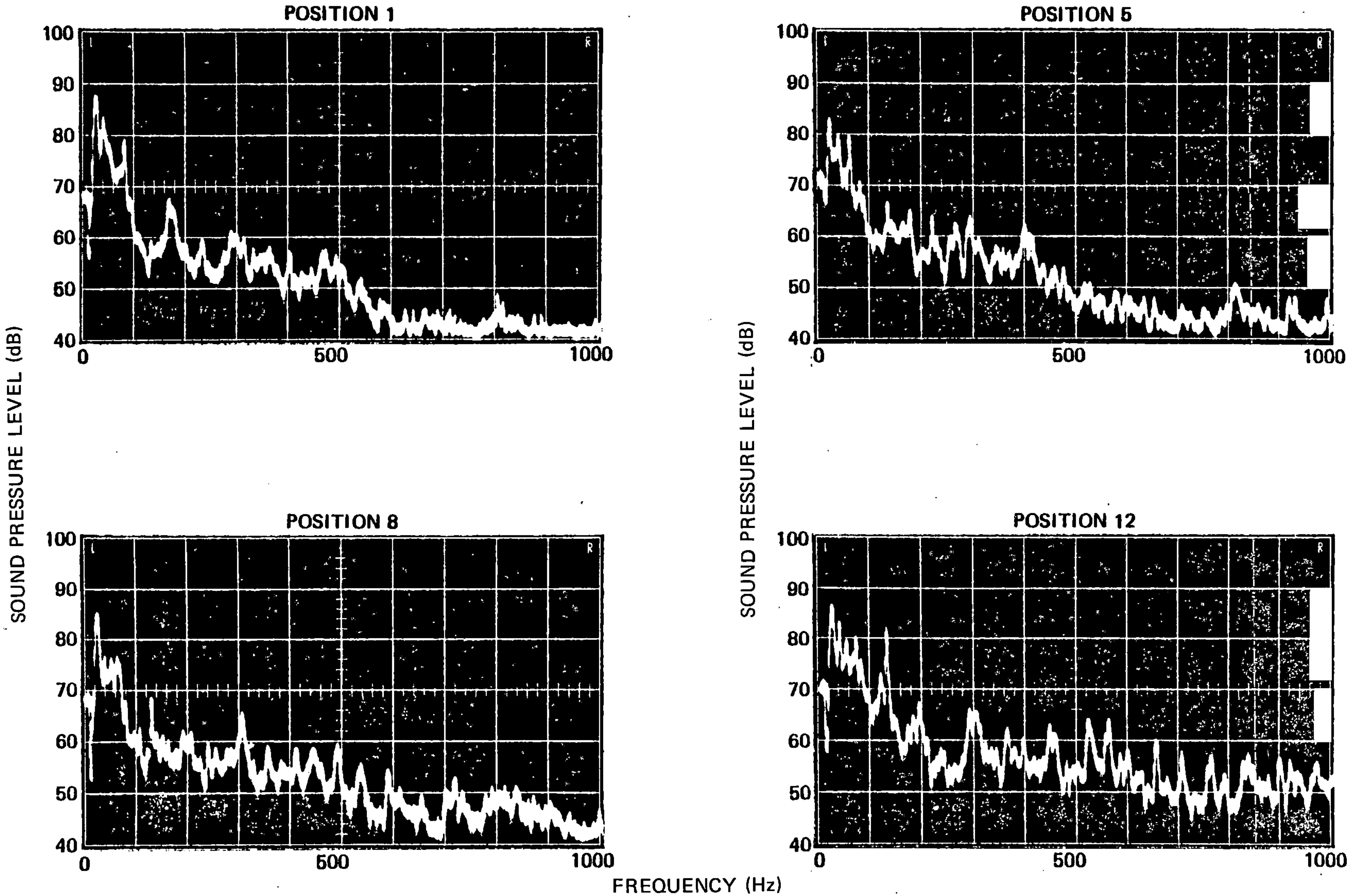


Figure 3–51. Narrowband Analysis of Interior Noise, MBTA, AW0, 50 mph

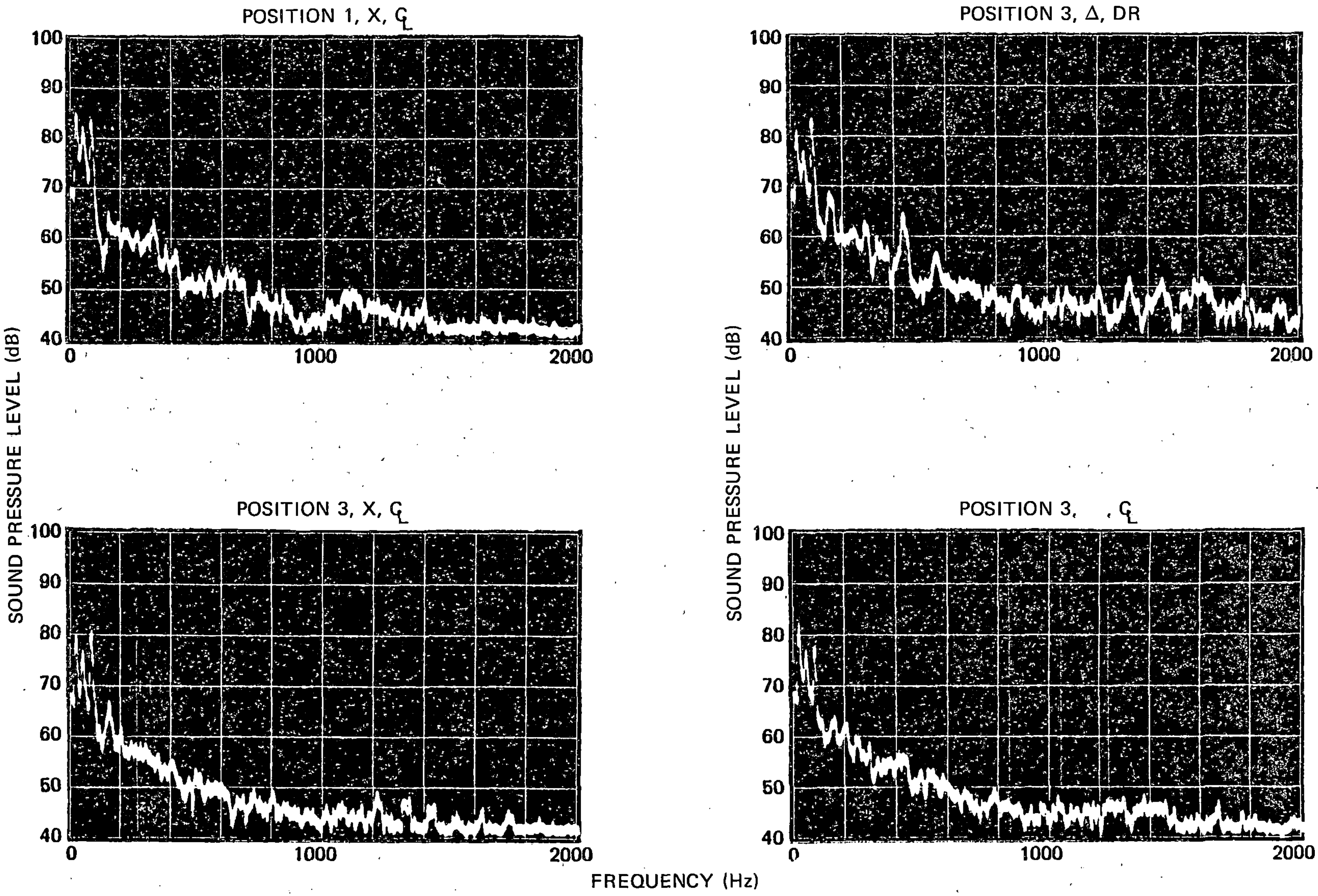


Figure 3–52. Narrowband Analysis of Interior Noise, SFMR, AWO, 40 mph

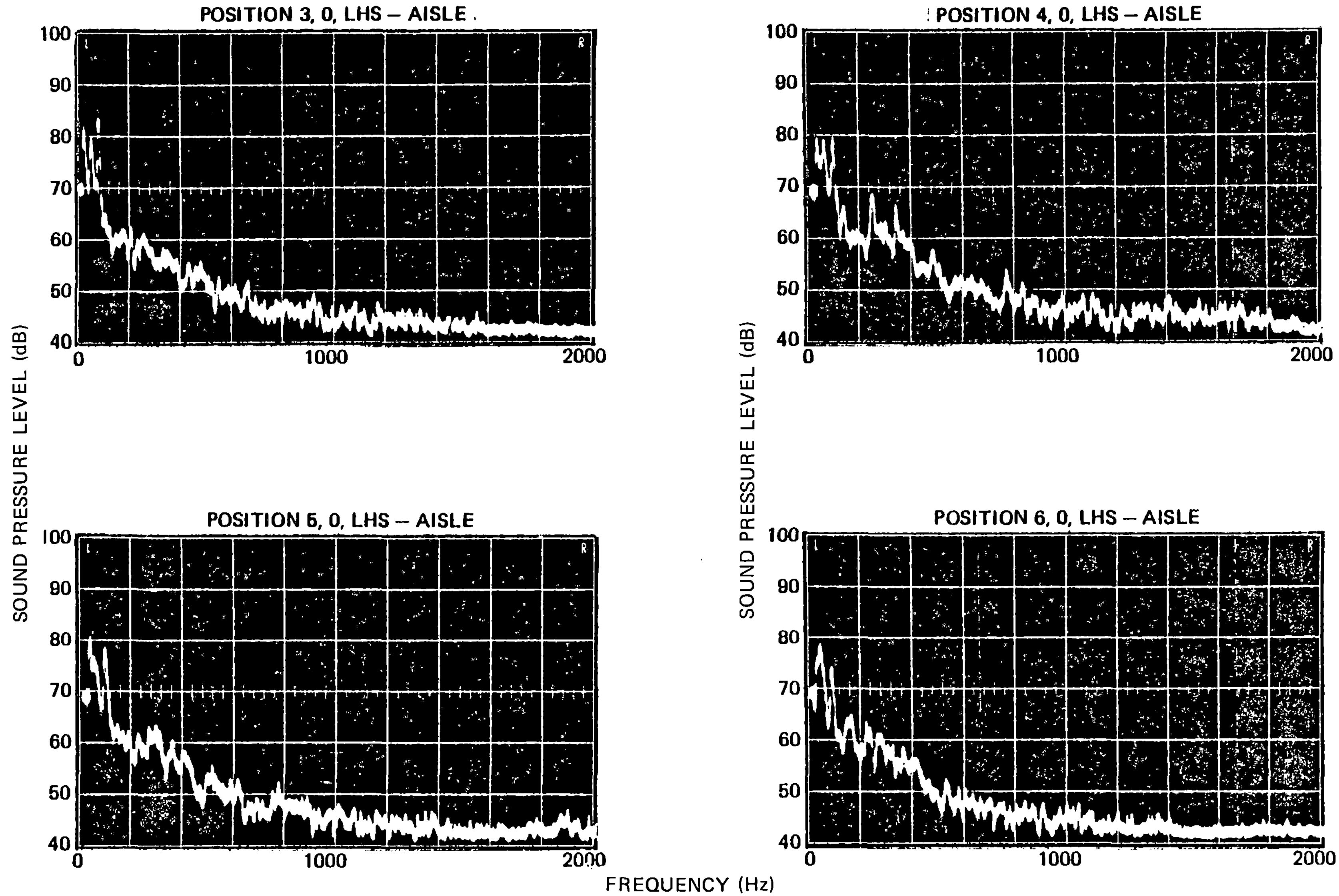


Figure 3–53. ***Narrowband Analysis of Interior Noise, SFMR, AW0, 40 mph***

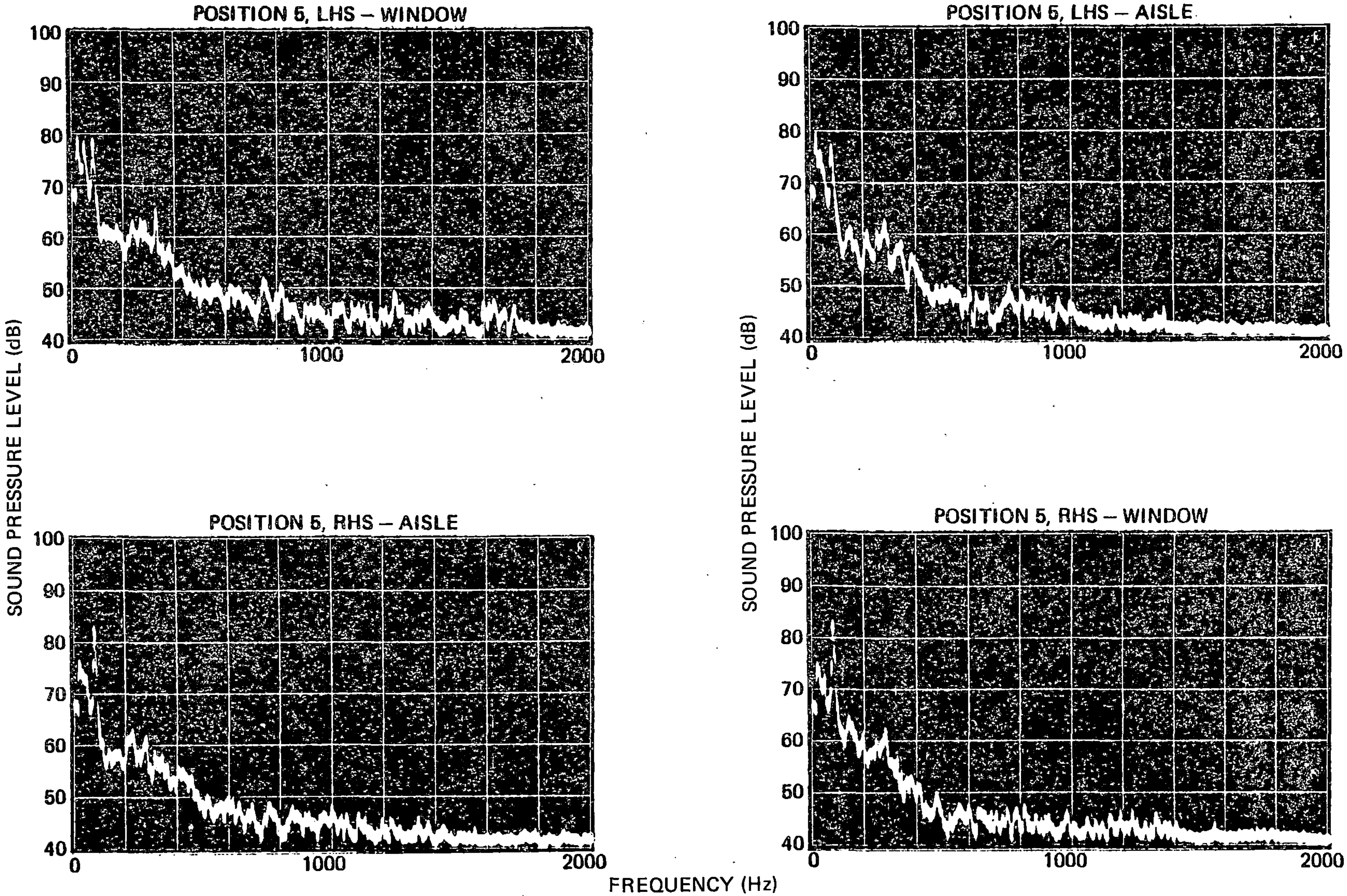


Figure 3–54. Narrowband Analysis of Interior Noise, SFMR, AW0, 40 mph

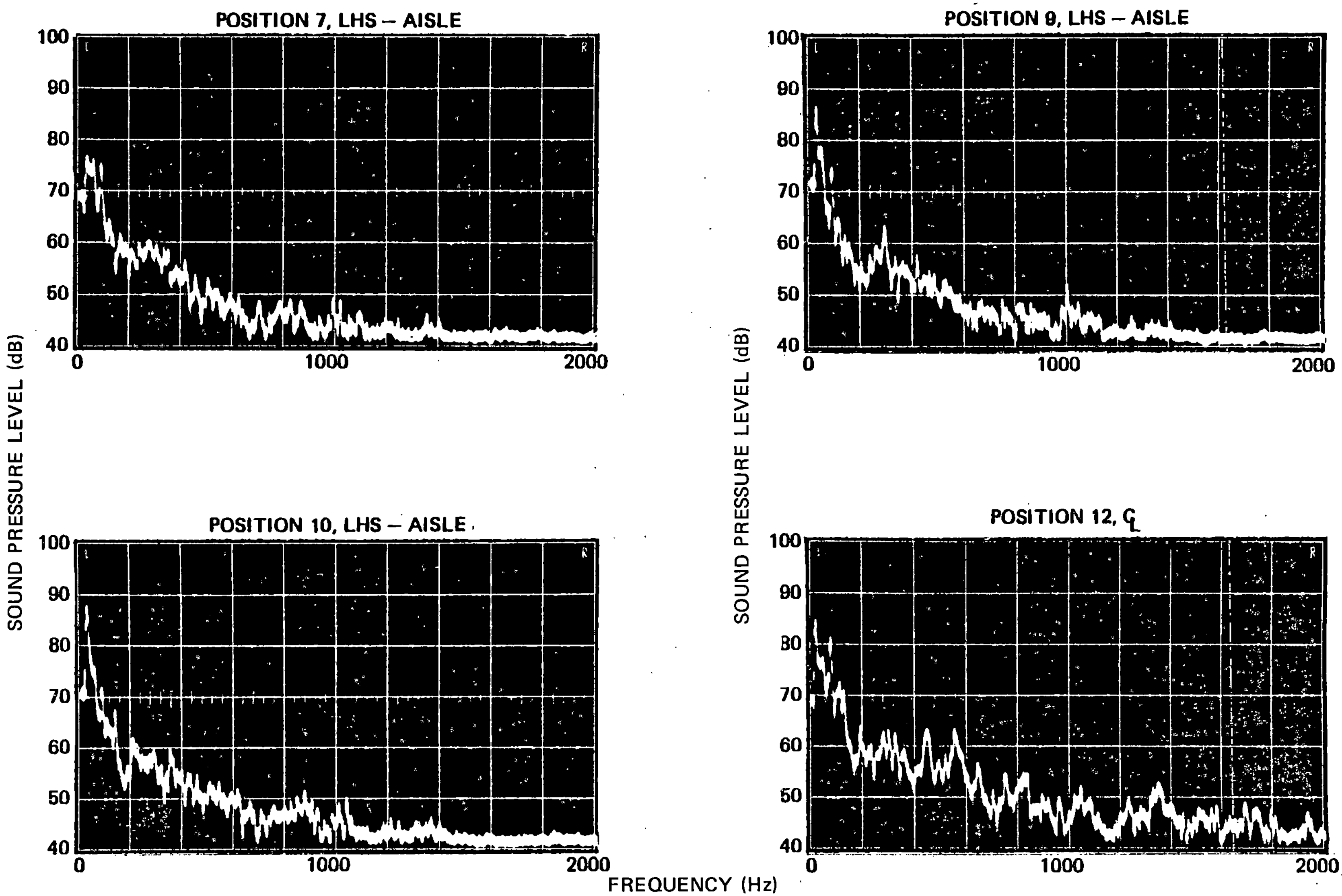


Figure 3–55. Narrowband Analysis of Interior Noise, SFMR, AW0, 40 mph

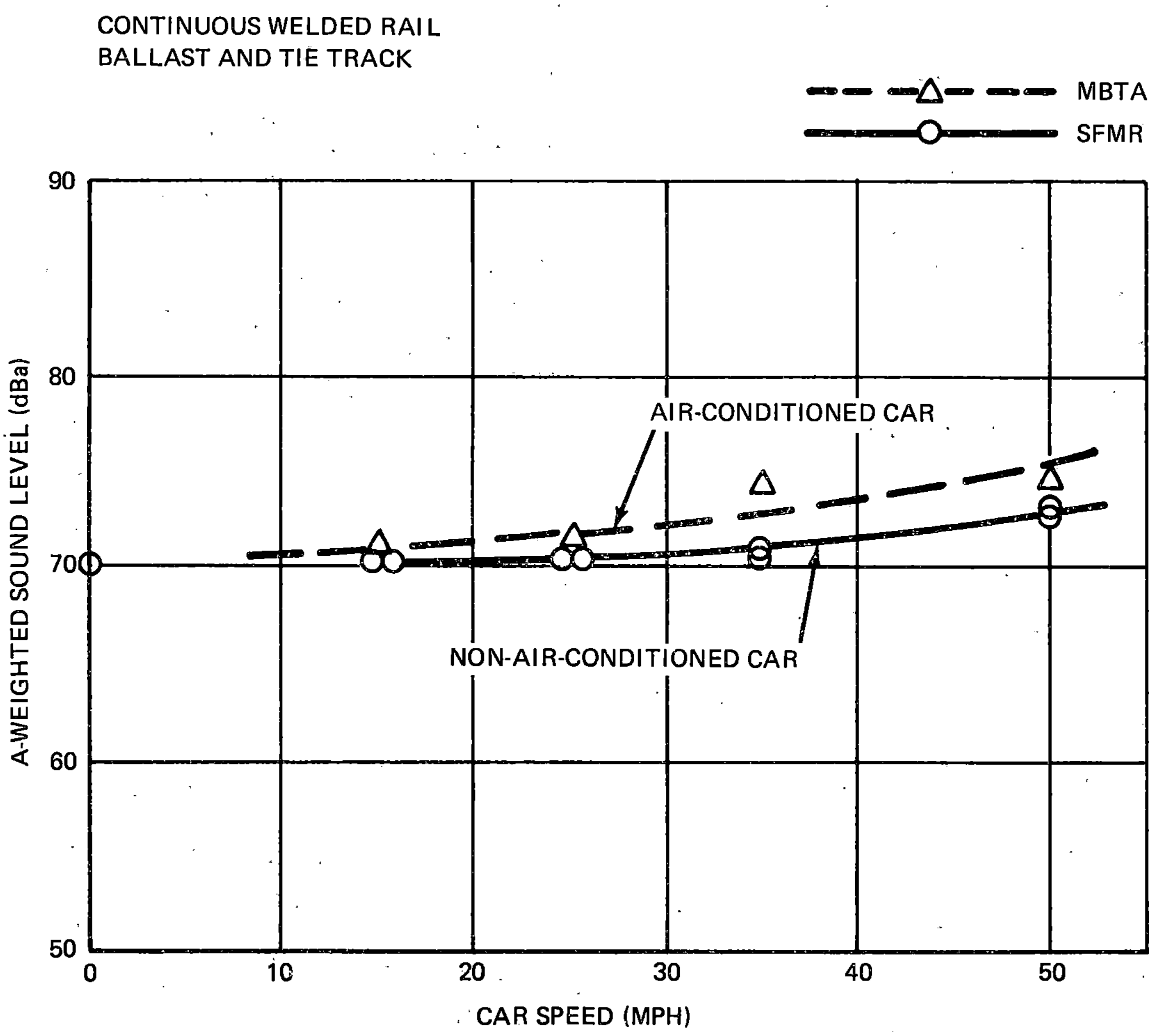


Figure 3–56. SLRV Interior Noise, Position 8, Centerline Between Doors

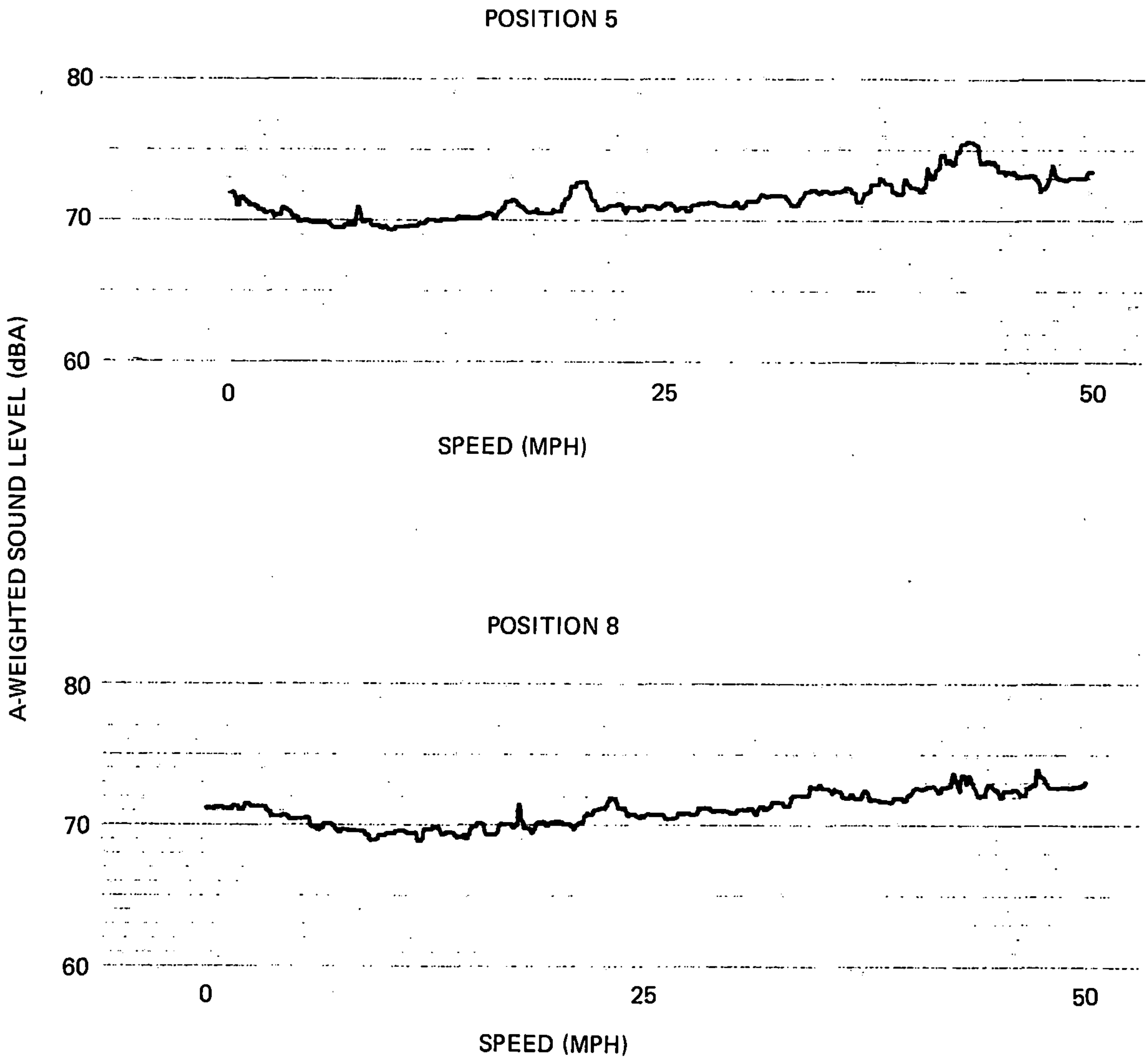


Figure 3–57. SLRV Acceleration Time Histories, SFMR, AW3.

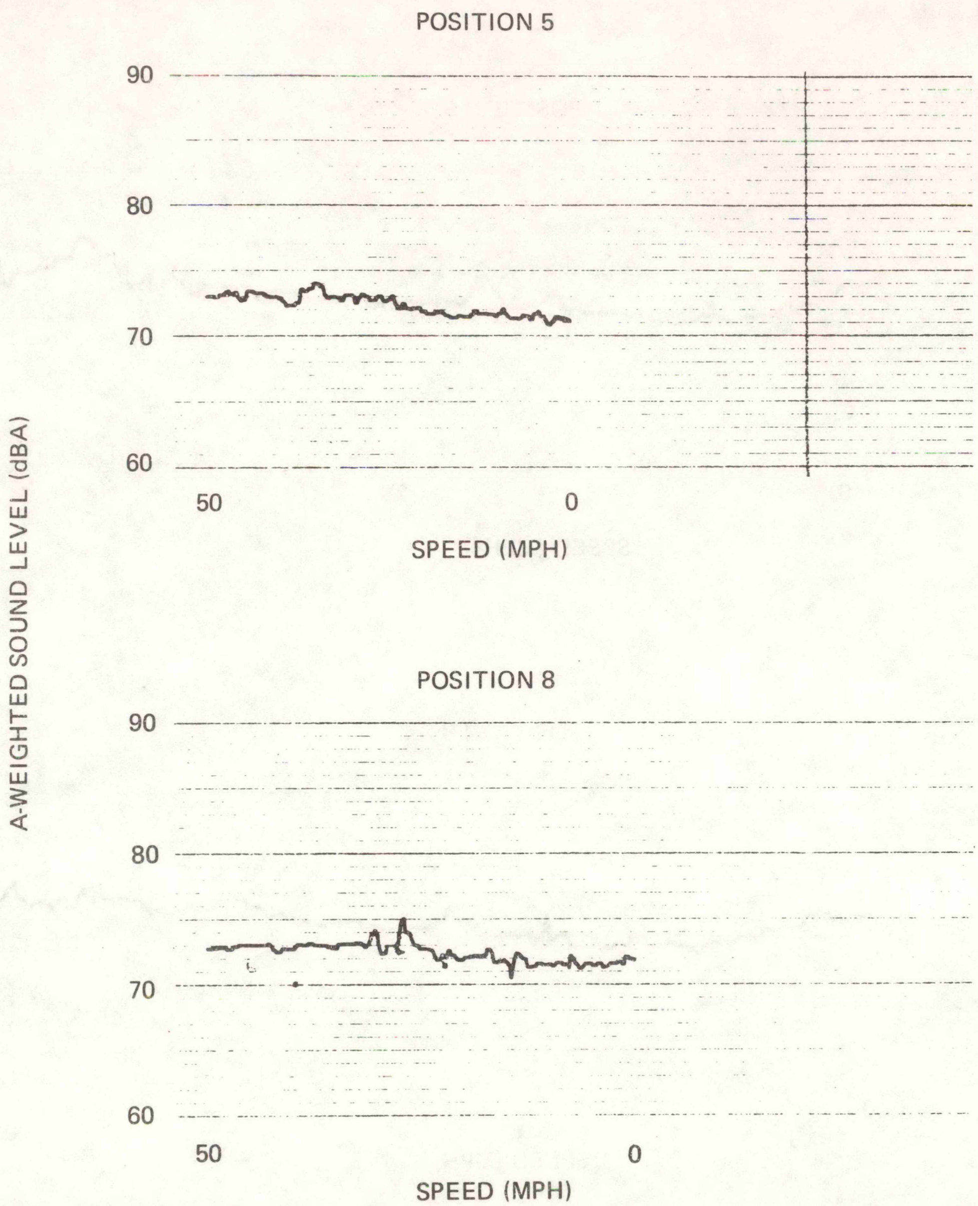


Figure 3–58. SLRV Deceleration Time Histories, SFMR, AW3

4. RADIO FREQUENCY INTERFERENCE

4.1 SUMMARY

Objective

The test objective was to measure the broadband radiated electromagnetic emissions from the MBTA and SFMR Standard Light Rail Vehicles. Fifty-foot and one-hundred foot wayside emission data were obtained for comparison with the radio frequency interference limits established for the SLRV.

Procedure

The test procedures for measurement of E-field radiated emissions were generally those established in Military Standards 461 and 462 for Method RE02 (14 kHz to 10 gHz), which encompass the procedures laid down in the GVTP sequence PSI-6001-TT.

Test Sequence

Fifty-foot wayside tests were run for MBTA Car Number 002 at each of the 13 car operating conditions with instrumentation set up to take measurements across a given frequency band. Each of the 10 frequency bands (described in Section 4.3) was sequenced through in this manner. The above procedure was then repeated with the measurement antenna(s) set up 100 feet from the track centerline. The whole series of runs was then duplicated for SFMR Car Number 003.

Status

The SLRV radio frequency interference tests were conducted during the period April 7 through May 6, 1976, at the DOT TTC facility in Pueblo, Colorado.

Wayside tests were performed under ambient conditions and for various operating states (i.e., maximum acceleration above and below base speed, constant speeds of 10, 20, 35, and 50 mph, and full service braking from 50, 35, 20 and 10 mph). The MBTA car was tested at AW0 weight and the SFMR car at AW3. More than 490 test cases were run.

There was no substantial difference in the results obtained with the two different car configurations. The electric field emissions at a wayside distance of 100 feet were within the limits established for the SLRV over the entire test frequency range from 14 kHz to 600 MHz. Figure 4-1 indicates the peak noise values measured at the various operating conditions for both the 50-foot and 100-foot wayside measurements.

4.2 TEST DESCRIPTION

Wayside E-field intensity measurements were obtained for the operating conditions listed in Table 4-1. The operating states are identified by the test condition numbers referred to in Figures 4-5 through 4-12.

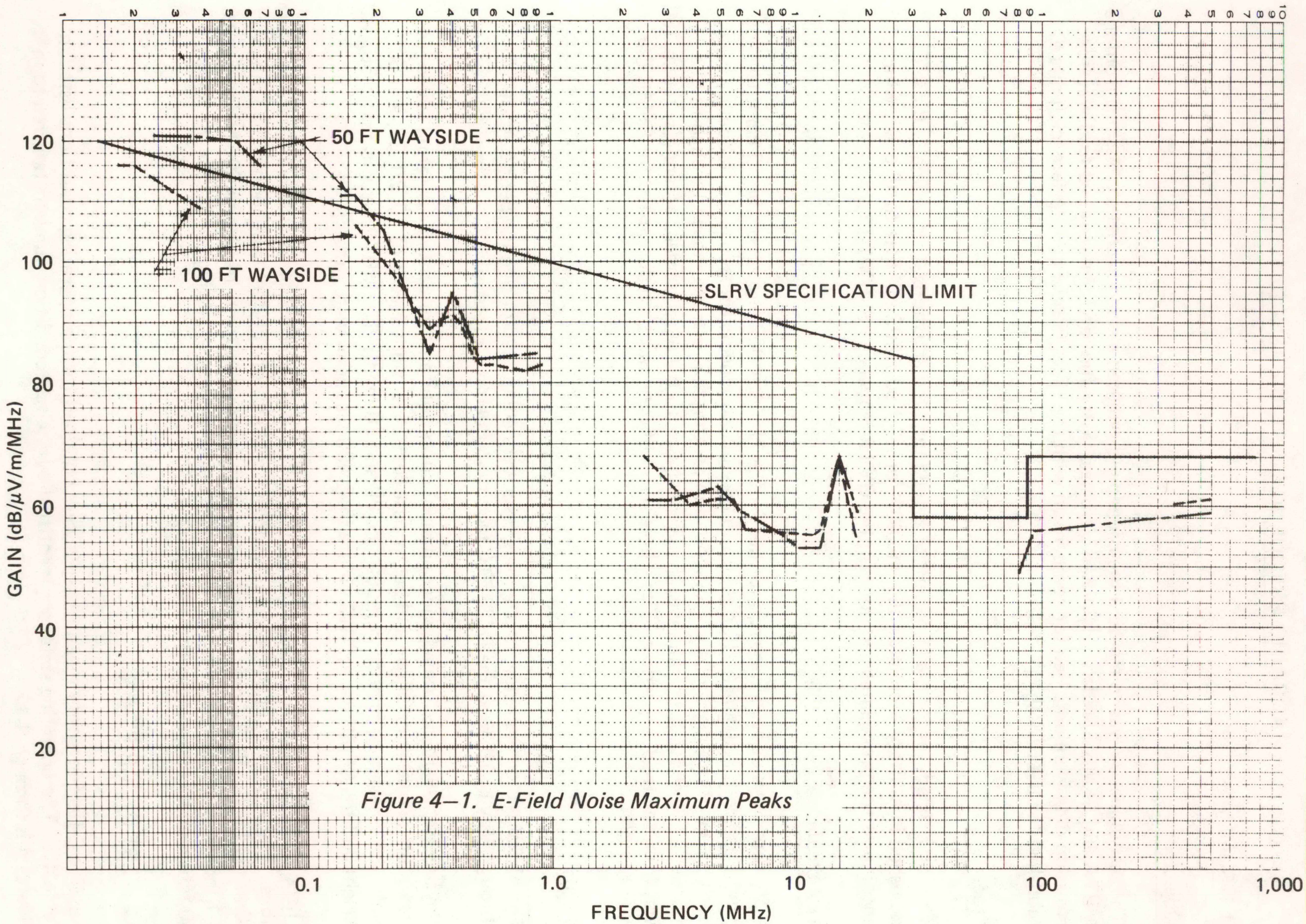


Figure 4—1. E-Field Noise Maximum Peaks

TABLE 4–1. RFI TEST CONDITIONS

Operating State	Identification Number 50-Ft Wayside	Identification Number 100-Ft Wayside
Ambient Check, All Systems Off	1	14
Ambient Check, Traction System On	2	15
Ambient Check, All Systems On	3	16
Constant Speed, 20 mph	4	17
Constant Speed, 35 mph	5	18
Constant Speed, 50 mph	6	19
Maximum Acceleration, Below Base Speed	7	20
Maximum Acceleration, Above Base Speed	8	21
Full Service Braking, Starting at 50 mph	9	22
Full Service Braking, Starting at 35 mph	10	23
Full Service Braking, Starting at 20 mph	11	24
Constant Speed, 10 mph	12	–
Full Service Braking, Starting at 10 mph	13	–

The type of spectrum analysis equipment used in these tests made it unnecessary to scan the frequency range and select specific frequencies for monitoring. Hewlett-Packard 8550 series equipment was used, which provided a continuous frequency scan CRT presentation across a defined frequency band. Thus, it was only necessary to configure the spectrum analyzer and set up the proper antenna to obtain an indication of all noise peaks existing in a particular frequency band.

A location just north of Station 290 on the TTC transit oval was selected for the wayside station. The antennas were situated on the inside of the loop, as shown in Figure 4-2. This location was chosen because the land was relatively flat and slightly above track grade at a 50- to 100-foot setback from the track.

4.3 TEST INSTRUMENTATION

The E-field measurement system comprised Hewlett-Packard spectrum analyzer equipment and a series of antennas appropriate to the frequency ranges involved. The spectrum analysis hardware included:

- Tuning section, Model 8553B (1.0 kHz to 110 MHz)
- Tuning section, Model 8554L (0.5 MHz to 1250 MHz)
- IF section, Model 8552B
- Display section, Model 141T

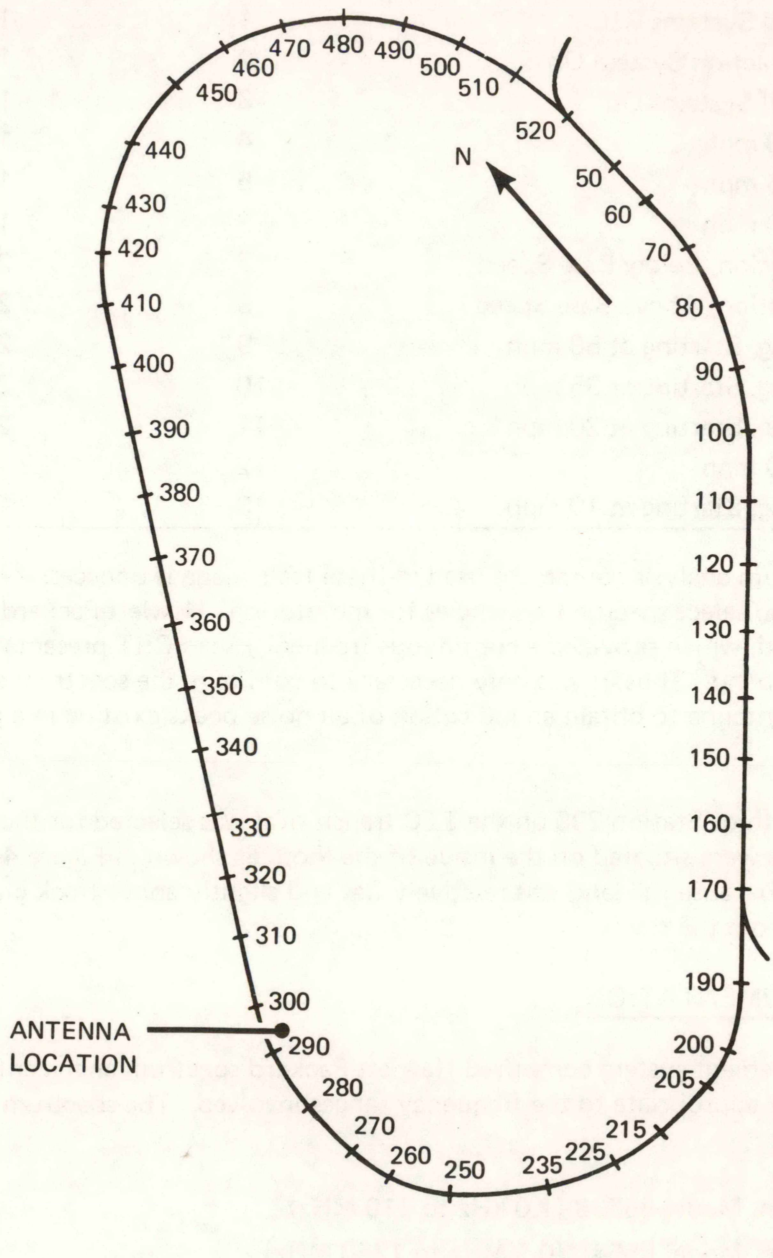


Figure 4–2. Location of RFI Wayside Station

The antennas and corresponding frequency ranges were:

Empire Devices Model VR-105 rod antenna (14 kHz to 30 MHz)

Electro-Mechanics Company Model 3104 biconical antenna (20 to 200 MHz)

Electro-Mechanics Company Model 3101, conical log spiral antenna (200 to 1000 MHz)

The frequency bands as defined in Hewlett-Packard application Note 142, EMI Measurement Procedure, are:

A	14	kHz	to	100	kHz
B	100	kHz	to	150	kHz
C	150	kHz	to	360	kHz
D	360	kHz	to	870	kHz
E	870	kHz	to	2.1	MHz
F	2.1	MHz	to	5.2	MHz
G	5.2	MHz	to	12.7	MHz
H	12.7	MHz	to	30	MHz
I	30	MHz	to	200	MHz
J	200	MHz	to	600	MHz

These are the bands for which the spectrum analyzer was set up and at which each of the test operating conditions was run.

For maximum coupling with vehicle emissions, the rod antennas were oriented vertically, the biconical antenna longitudinally, and the conical log spiral antenna laterally. A typical rod antenna installation is shown in Figure 4-3.

An oscilloscope camera, using Polaroid 107 film, was mounted on the spectrum analyzer display unit, and the display was recorded during each test condition. Thus, the raw data comprises photographs of the spectrum analyzer display, as shown in Figure 4-4.

4.4 TEST PROCEDURES

The data reduction procedures can be understood by considering how the data points in Figures 4-5 through 4-12 are derived from the spectrum analyzer display in Figure 4-4, which was recorded during maximum acceleration above base speed (condition 8) over the frequency range of 0 to 200 MHz. In this frequency range, the maximum emission peaks were recorded during condition 8. The peak shown at 30 MHz is an internal reference signal from the spectrum analyzer. The peaks shown between 100 and 130 MHz appeared on the record of condition 1 (reference ambient check) as well and are to be ignored (e.g., commercial broadcast frequencies). The peaks of −66 dB at 81 MHz and −62 dB at 94 MHz are significant data points.

The basic calibration of the display is given in the Hewlett-Packard application note, as shown in Figure 4-13. The basic broadband calibration shown in Figure 4-13 must be corrected twice. First, +26 dB must be added because no preamplifier was used. Second, the antenna factor must be added. The antenna factor represents the ratio of measured field intensity (in V/m) to potential at the antenna terminals (in V); it is expressed in dB/m. Adding the antenna factor (dB/m) to the basic broadband units shown in Figure 4-13 (dB/μV/MHz) yields the desired specification units of dB/μV/m/MHz.

In the frequency range of 20 to 200 MHz, the biconical antenna was used. Antenna factor data for the specific antenna used in this test are shown in Table 4-2. The antenna factor varies with frequency between 8.1 and 18.5 dB/m; at 40 MHz, it is 14. Thus, the broadband grid line marked 21 dB in Figure 4-13 becomes 61 dB (21 + 26 + 14) at 40 MHz. Other points on the 61 dB reference line are plotted in Figure 4-13. The two data points are also identified. At 81 MHz, −66 falls 11 dB below the 61 dB reference line; that is, 50 dB. Similarly, −62 at 94 MHz is determined to be 56 dB/μV/m/MHz.

4.5 TEST DATA

Since no substantial differences were noted between the raw data measurements taken for the MBTA and SFMR cars, rigorous data reduction was undertaken for the MBTA vehicle only.

The ability of the Hewlett-Packard spectrum analysis equipment to record E-field emissions across a given frequency band on a continuous basis made it more appropriate to present the noise peak data on log frequency plots rather than in a table format. This provides a more complete picture of the noise spectrum than is available by monitoring discrete frequencies only.

Corrected noise peak data has been plotted for each of the test operating conditions (13 conditions for the 50-foot wayside and 10 conditions for the 100-foot wayside). These plots are presented as Figures 4-5 through 4-8 for the 50-foot wayside and Figures 4-9 through 4-12 for the 100-foot wayside. The traces for each car operating state are identified by the test condition numbers. The specification limit established for the SLRV E-field emissions is included on each of the figures for reference purposes. Gaps which appear in the plots indicate ranges throughout which no significant noise peaks were recorded (i.e., no peaks greather than 76 dB as read on the spectrum analyzer CRT display).

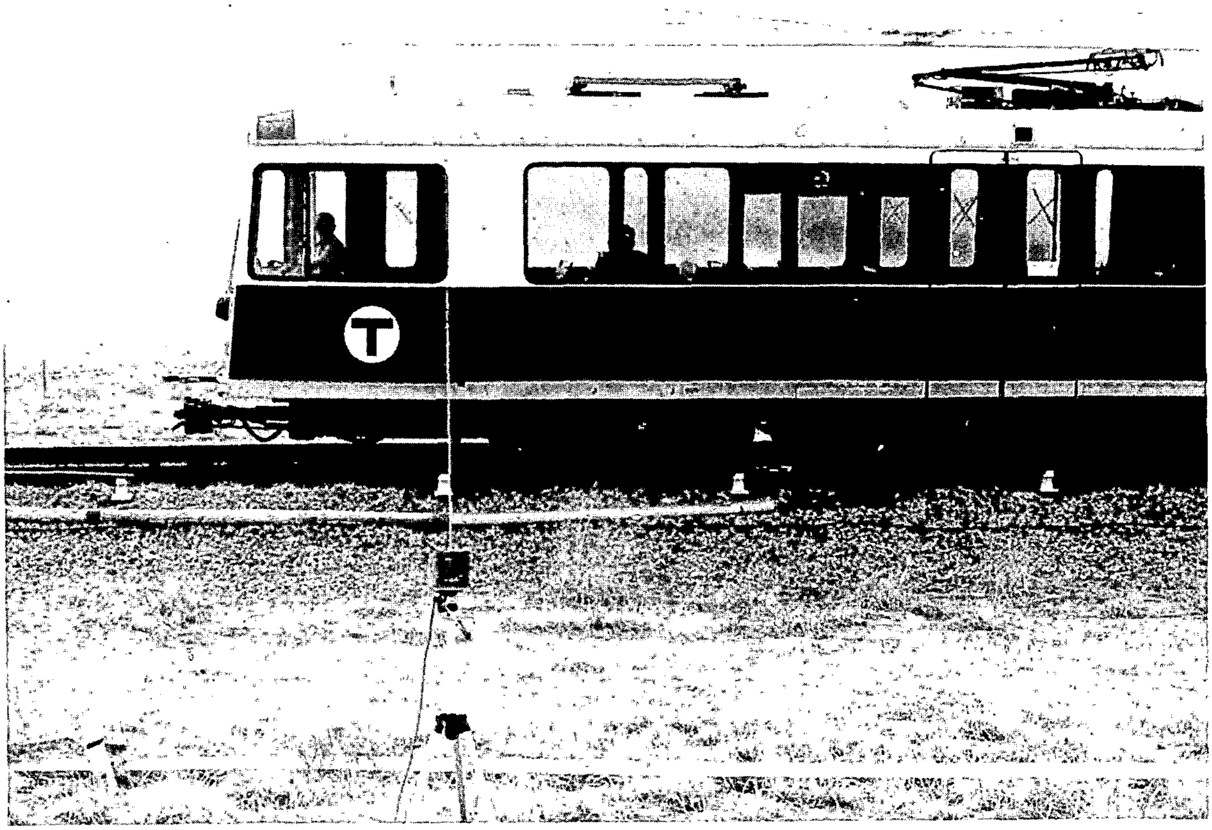


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Figure 4–3. Typical Wayside Antenna Installation

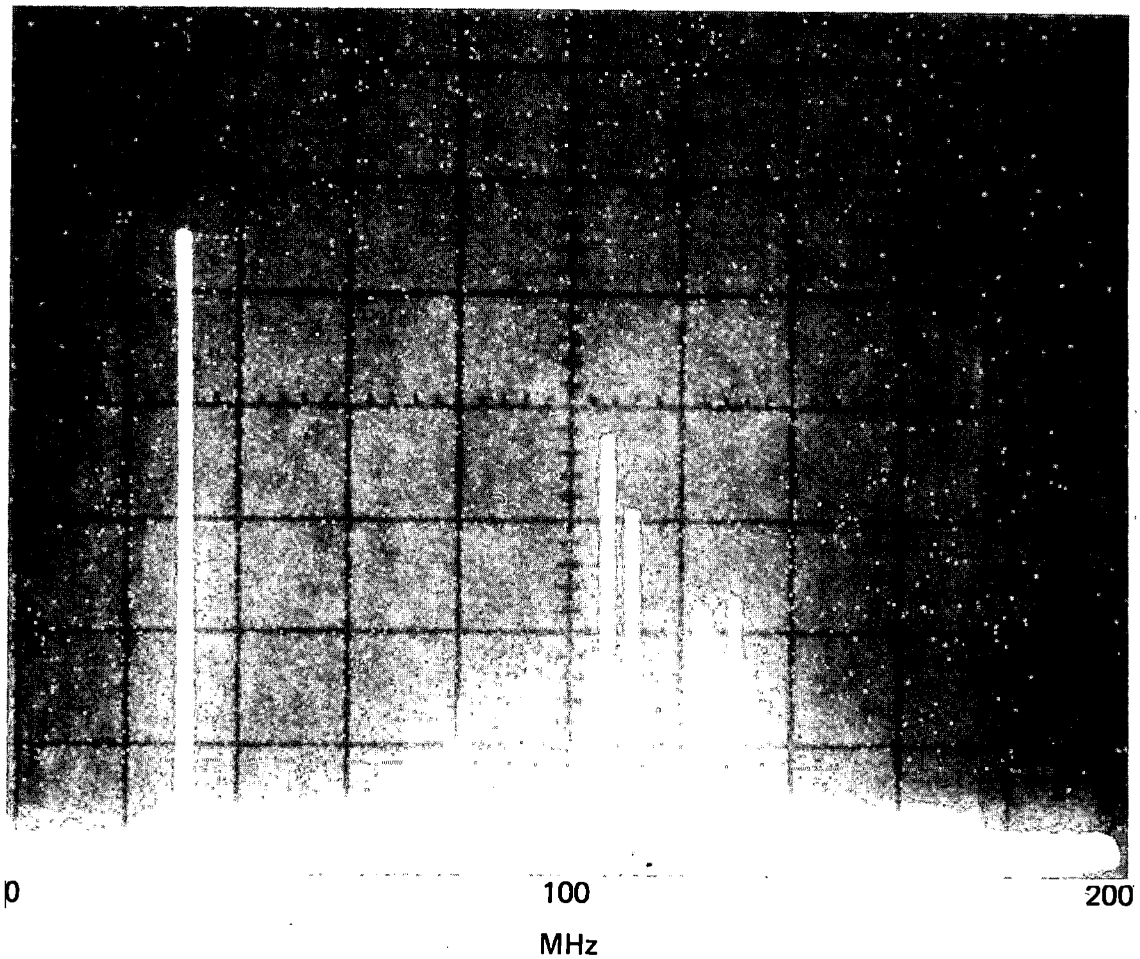


Figure 4—4. Spectrum Analyzer Display

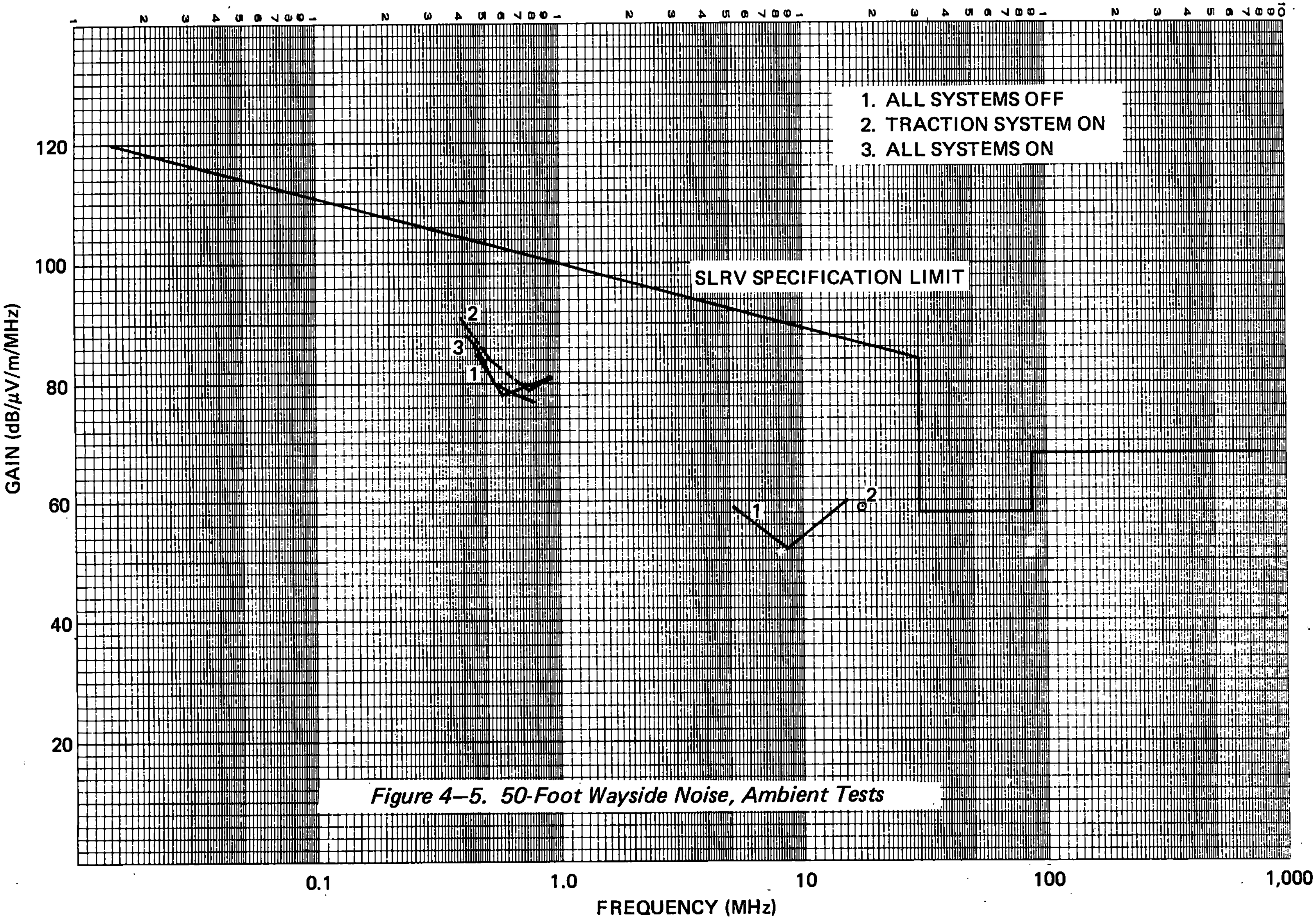


Figure 4–5. 50-Foot Wayside Noise, Ambient Tests

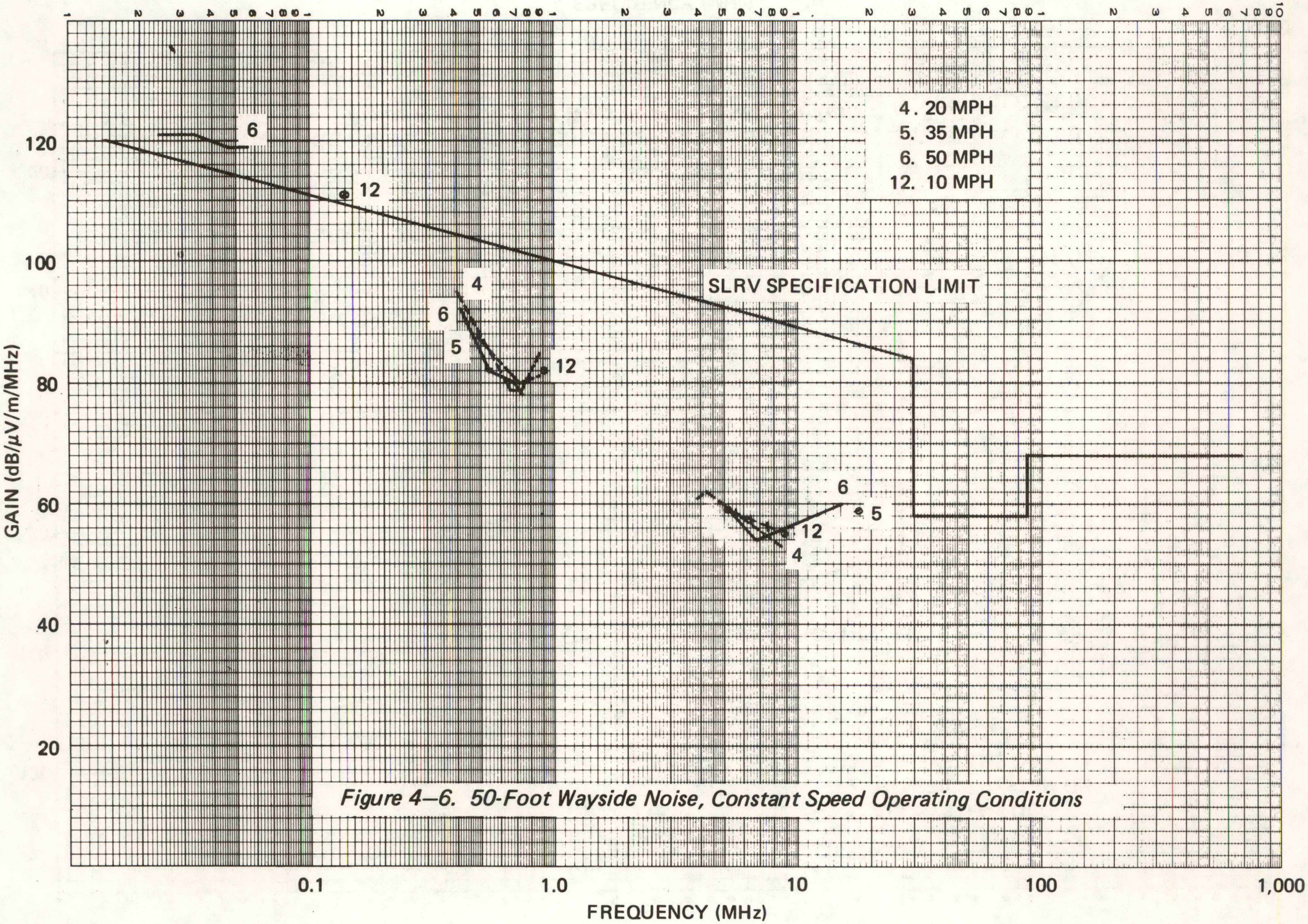


Figure 4–6. 50-Foot Wayside Noise, Constant Speed Operating Conditions

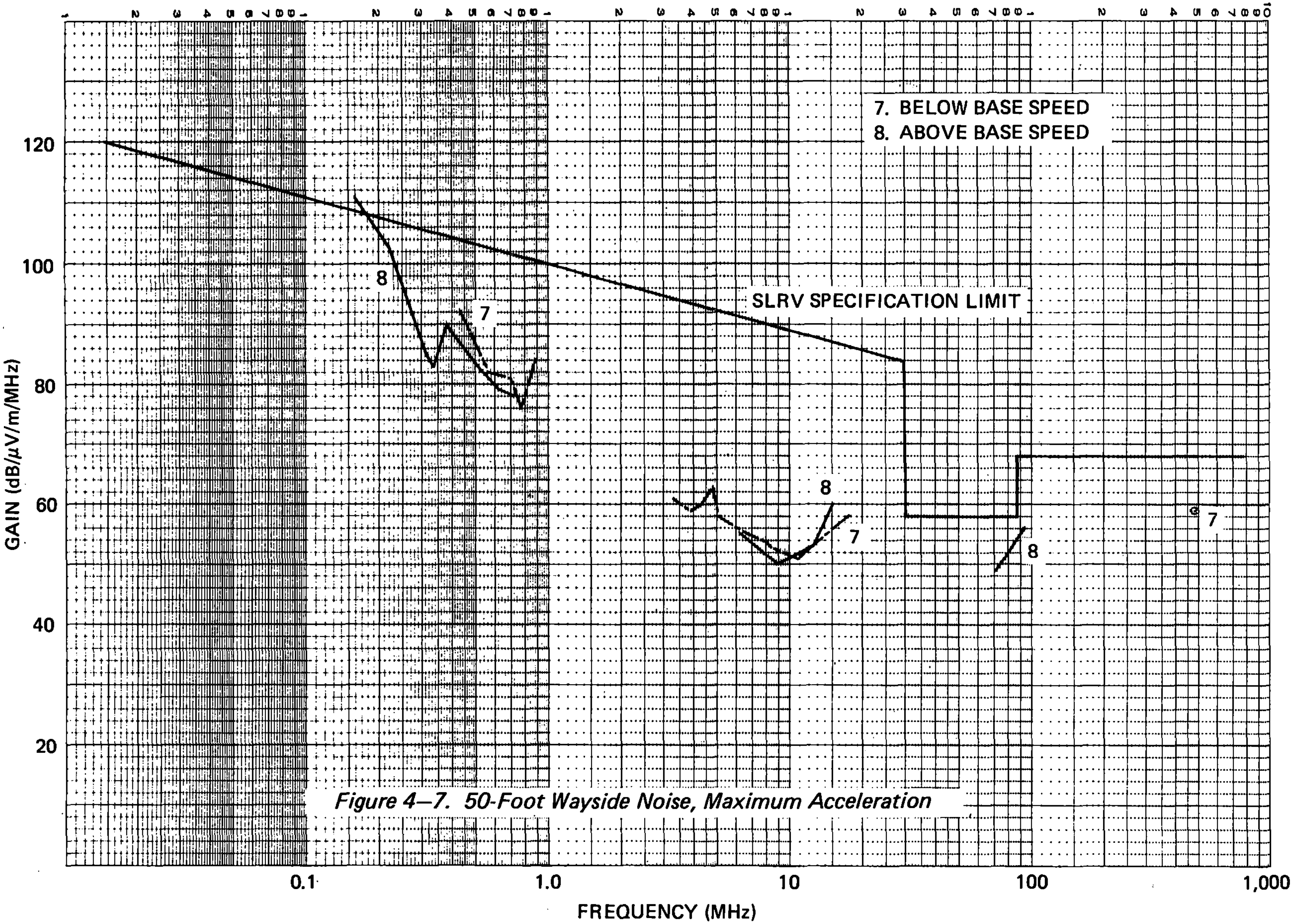


Figure 4—7. 50-Foot Wayside Noise, Maximum Acceleration

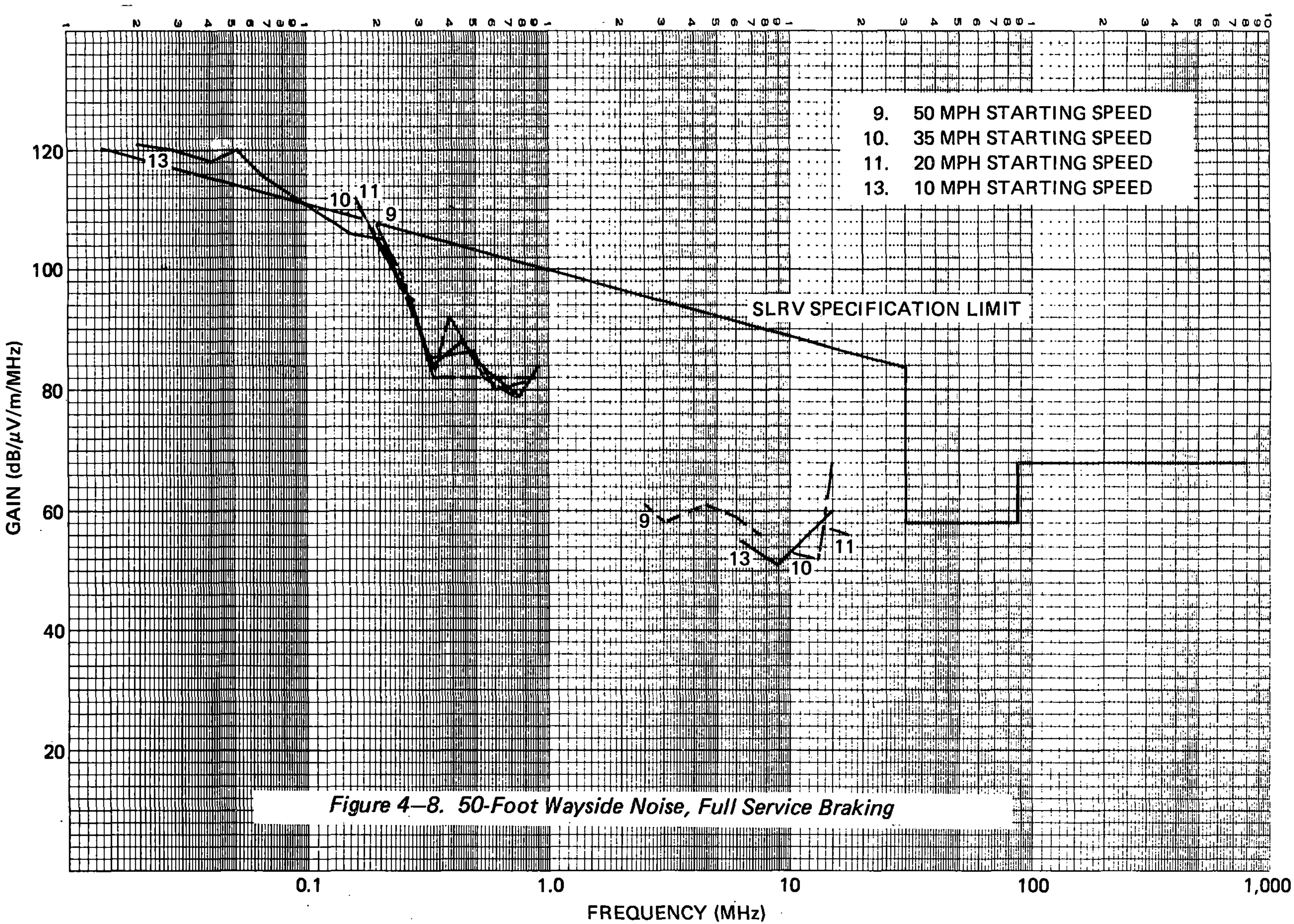


Figure 4–8. 50-Foot Wayside Noise, Full Service Braking

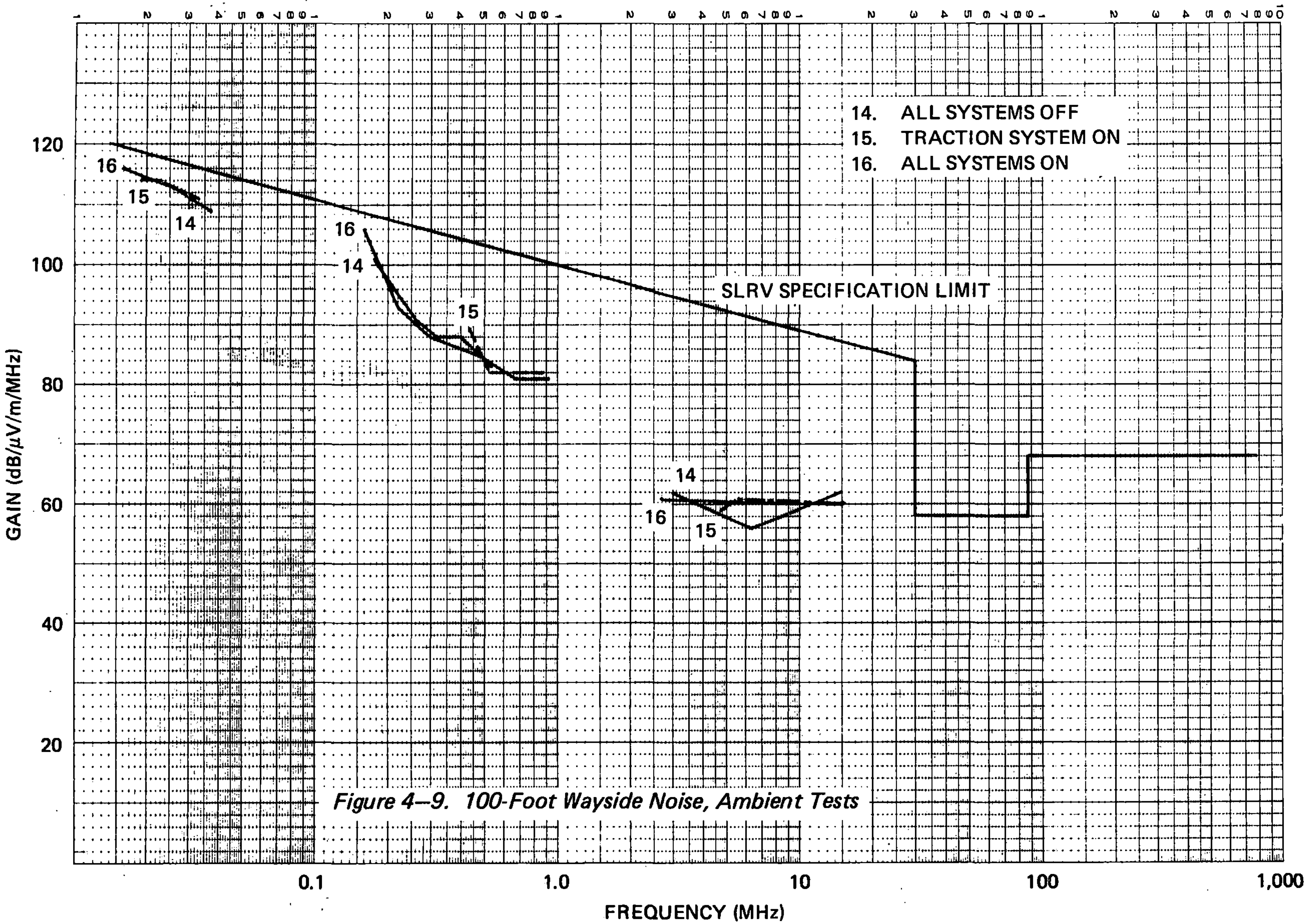


Figure 4–9. 100-Foot Wayside Noise, Ambient Tests

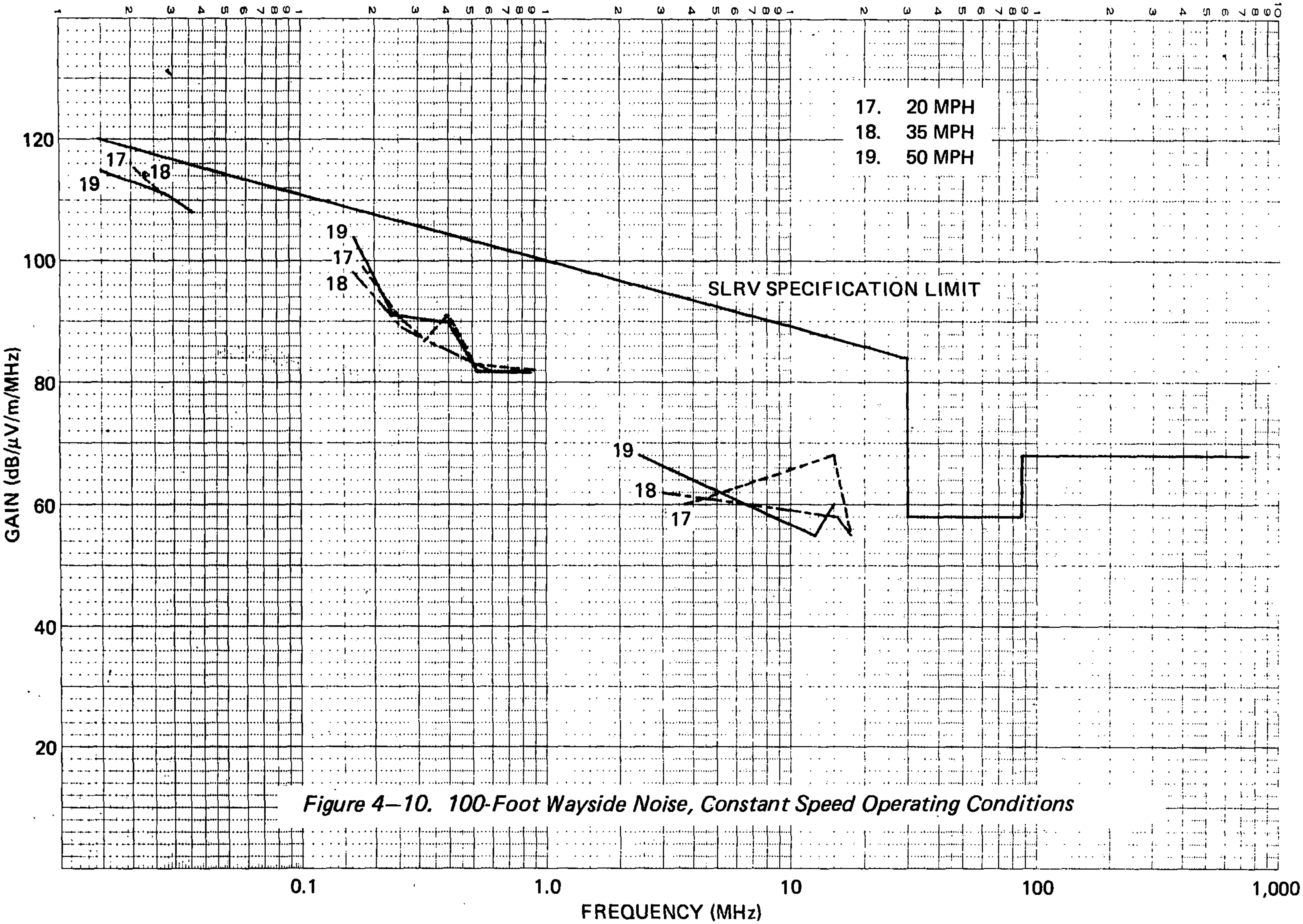


Figure 4—10. 100-Foot Wayside Noise, Constant Speed Operating Conditions

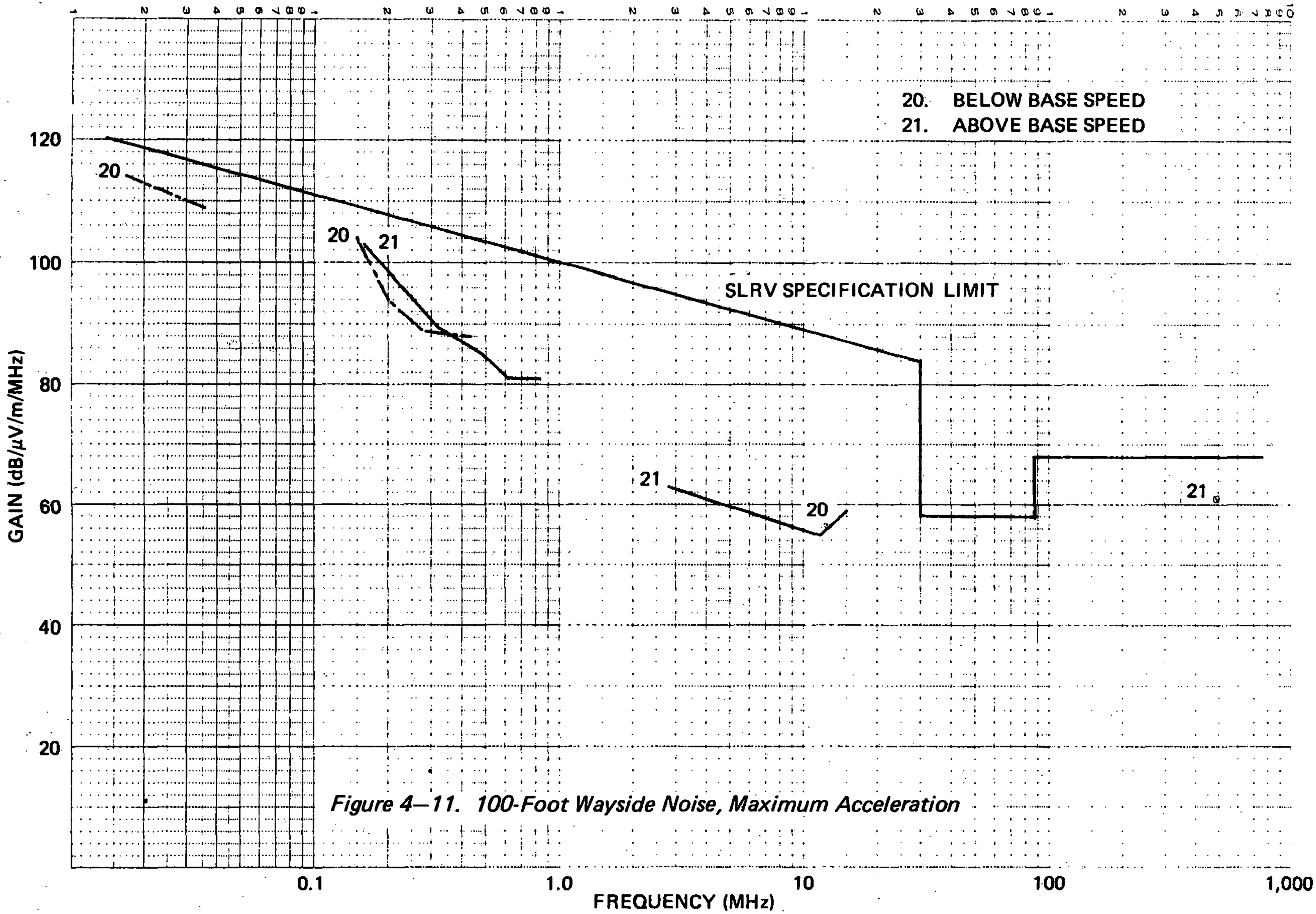


Figure 4—11. 100-Foot Wayside Noise, Maximum Acceleration

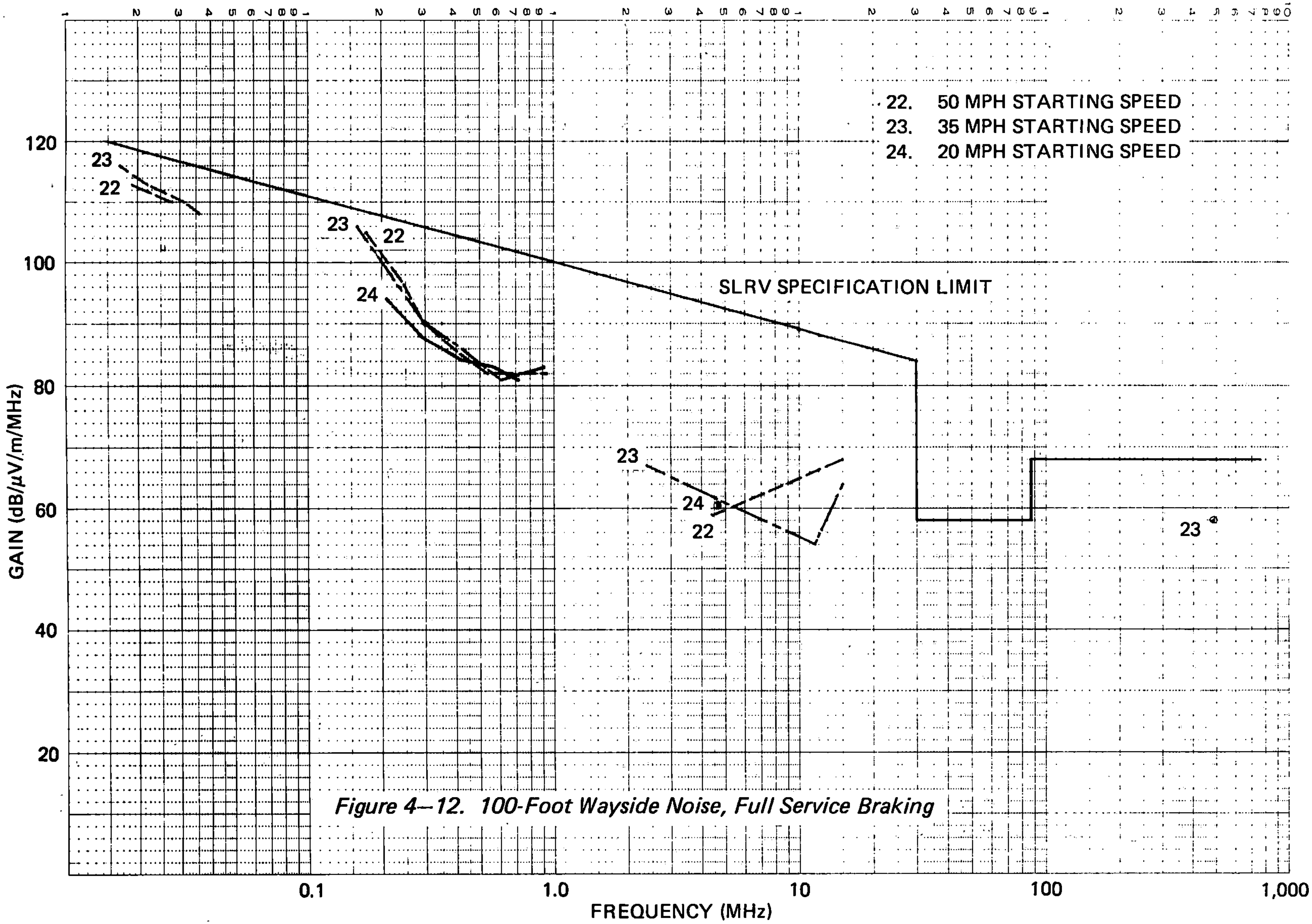
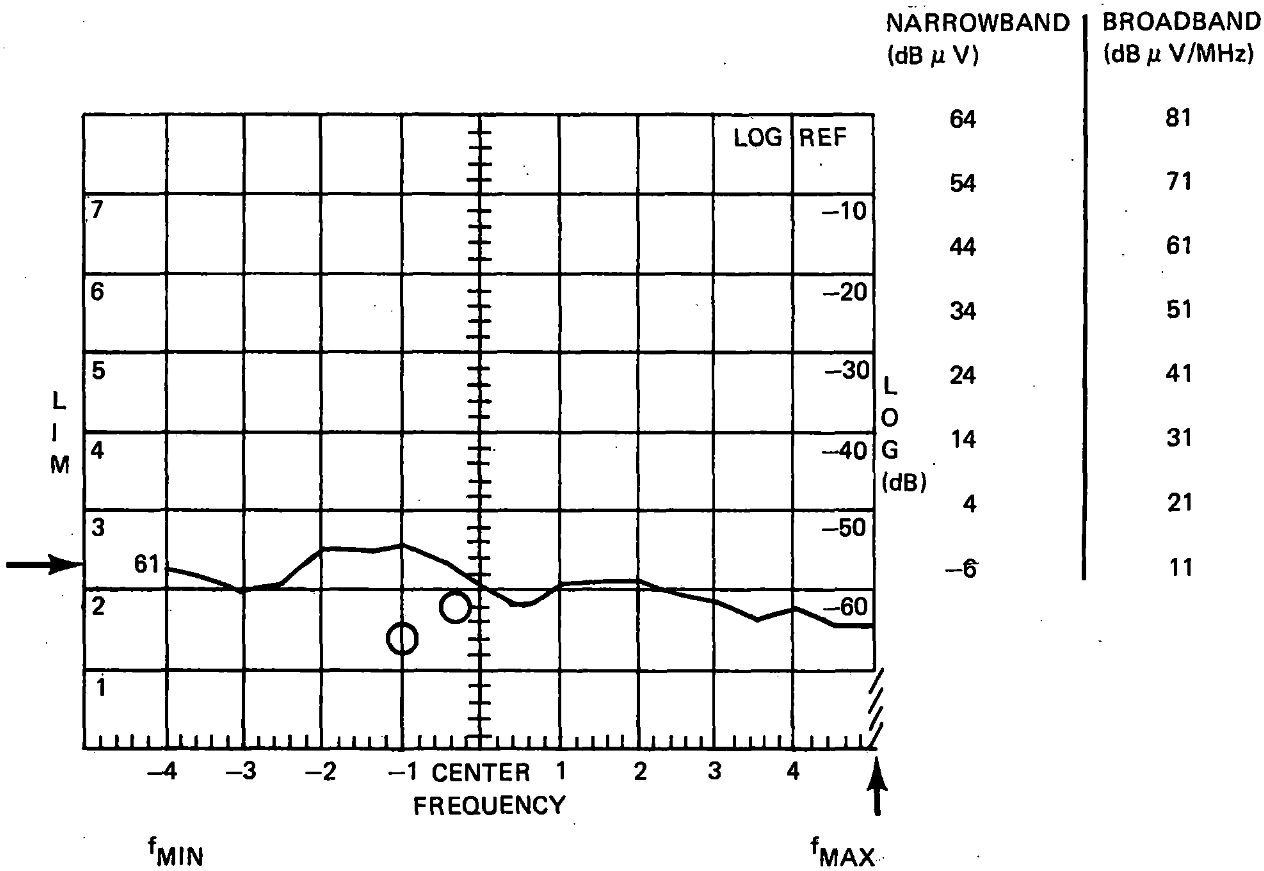


Figure 4–12. 100-Foot Wayside Noise, Full Service Braking

Band	Frequency Range		Bandwidth	Scan Width	Center Frequency	Log Ref Level
	f_{min}	f_{max}				
0.01–2.05	20 MHz	200 MHz	100 kHz	20 MHz/Div	100 MHz	90 dBμV



NOTES: SCALES SHOWN TAKE INTO ACCOUNT THE 28 dB GAIN OF THE PREAMPLIFIER.

Figure 4–13. Calibration of Spectrum Analyzer Display Per H-P Application Note 142

TABLE 4–2. BICONICAL ANTENNA DATA

Frequency (MHz)	Gain	Antenna Factor * (dB)
20	0.03	11.0
30	0.06	11.8
40	0.07	14.0
50	0.15	12.5
60	0.56	8.3
70	0.74	8.5
80	1.06	8.1
90	0.95	9.6
100	0.47	13.5
110	0.33	15.9
120	0.71	13.3
130	0.97	12.7
140	0.93	13.5
150	0.79	14[illegible]
160	0.84	15.1
170	0.57	17.3
180	0.85	16.1
190	0.56	18.3
200	0.59	18.5

* Specification Compliance Testing Factor (1.0 meter spacing) to be added to receiver meter reading in dBμv to convert to field intensity in dBμv/meter.

APPENDIX A

RIDE QUALITY

NARROW-BAND SPECTRUM ANALYSES

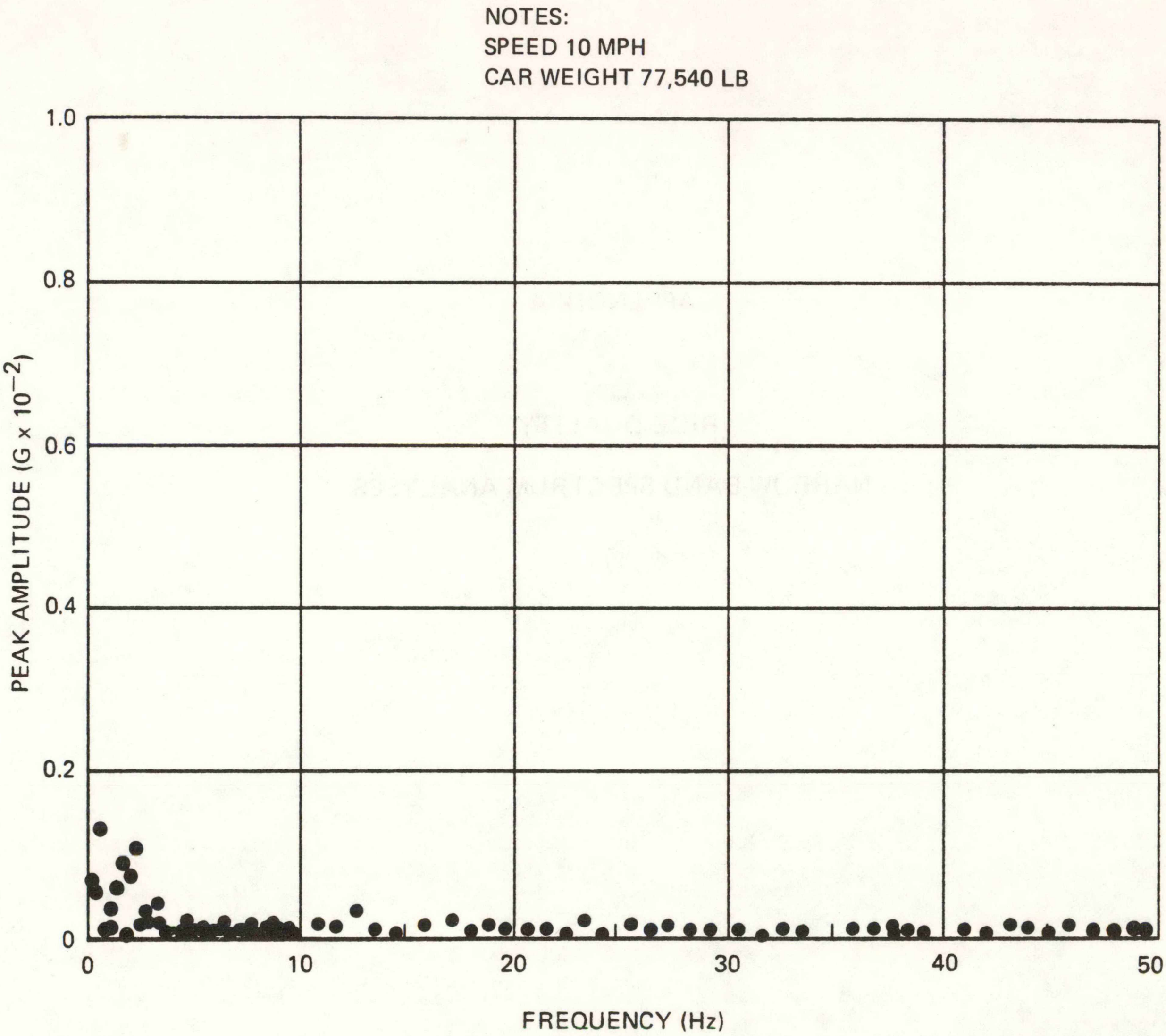


Figure A–1. Narrow-Band Spectrum Analysis – End Car, Vertical

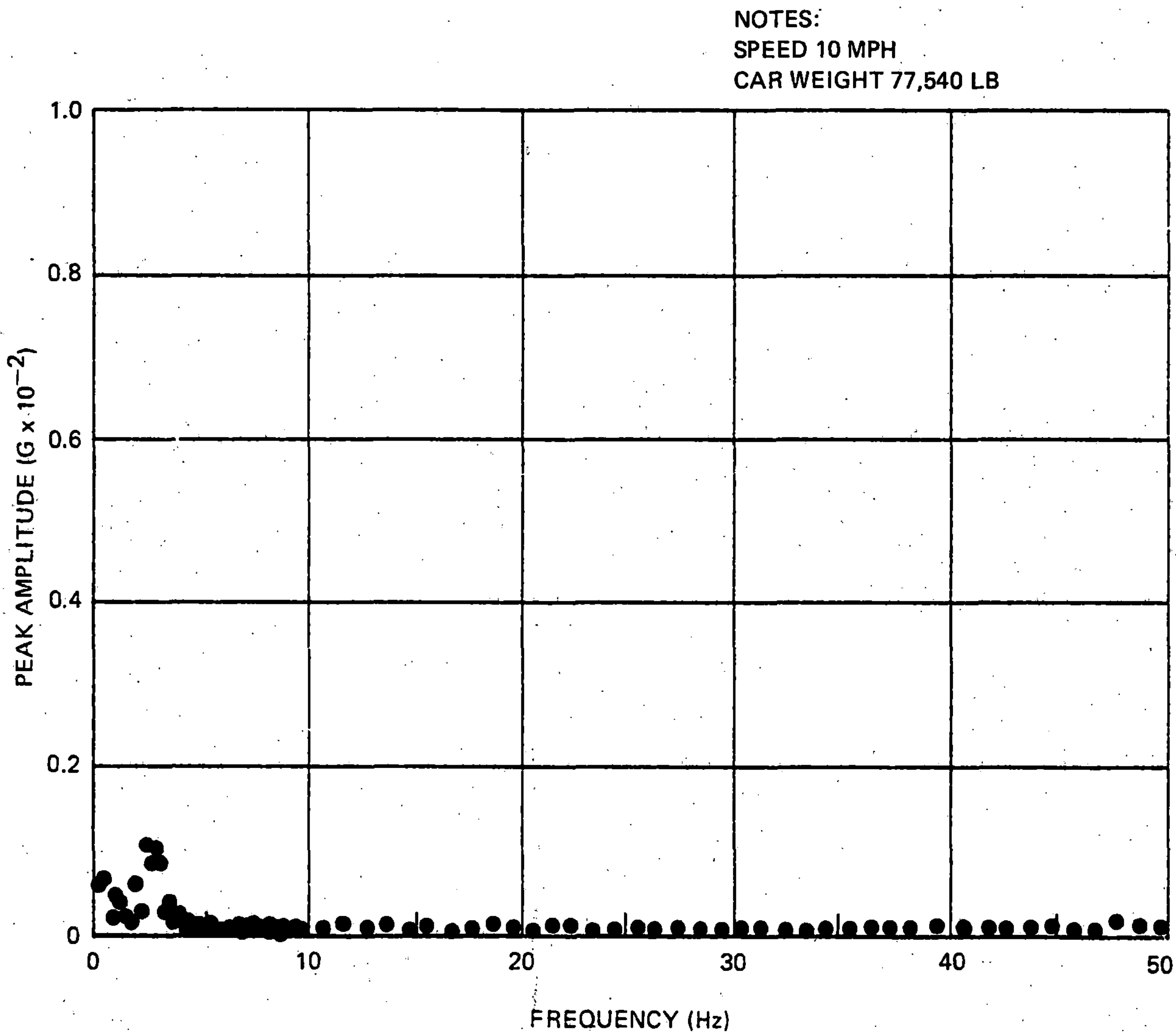


Figure A–2. Narrow-Band Spectrum Analysis – End Car, Lateral

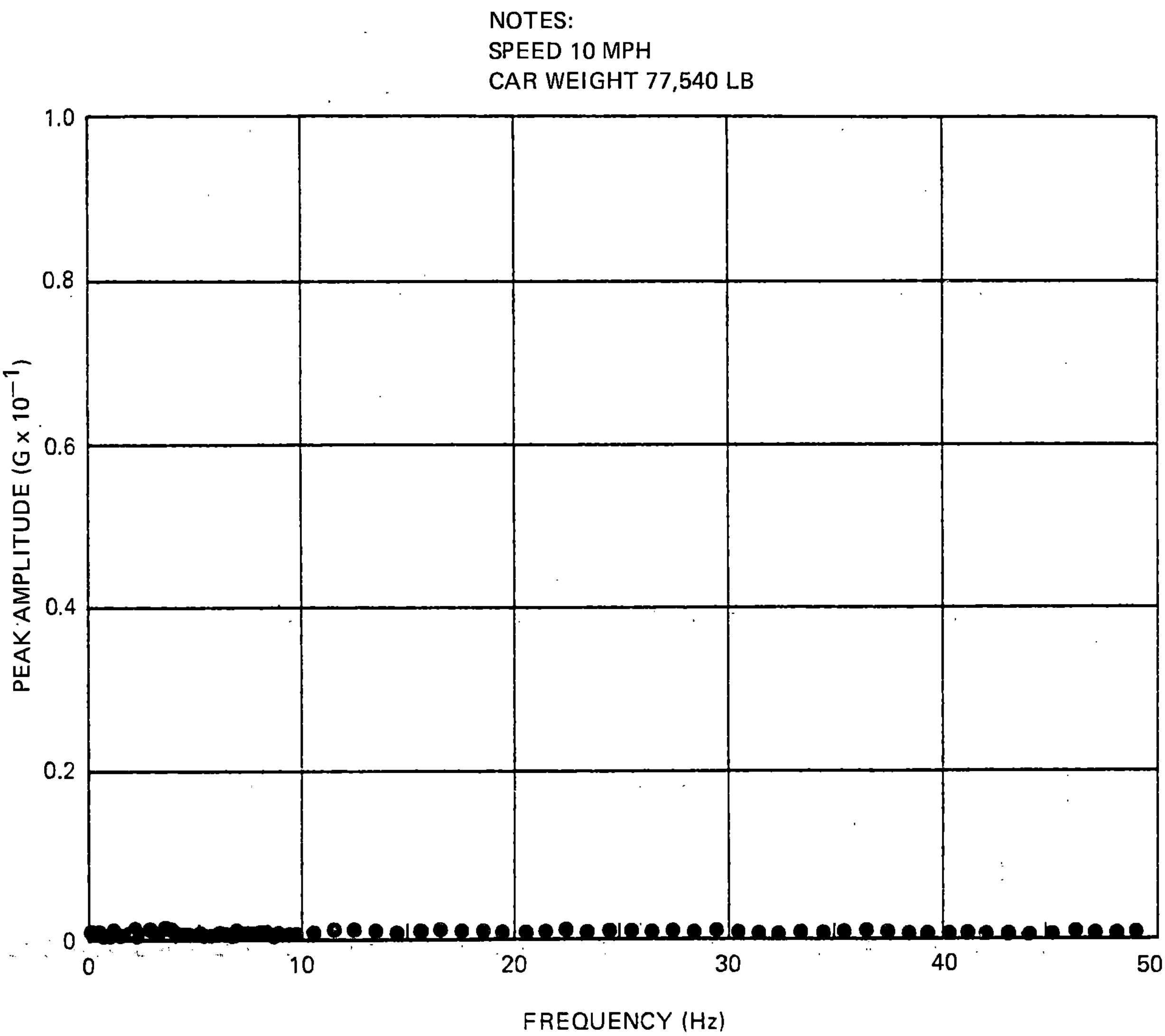


Figure A–3. Narrow-Band Spectrum Analysis – End Car, Longitudinal

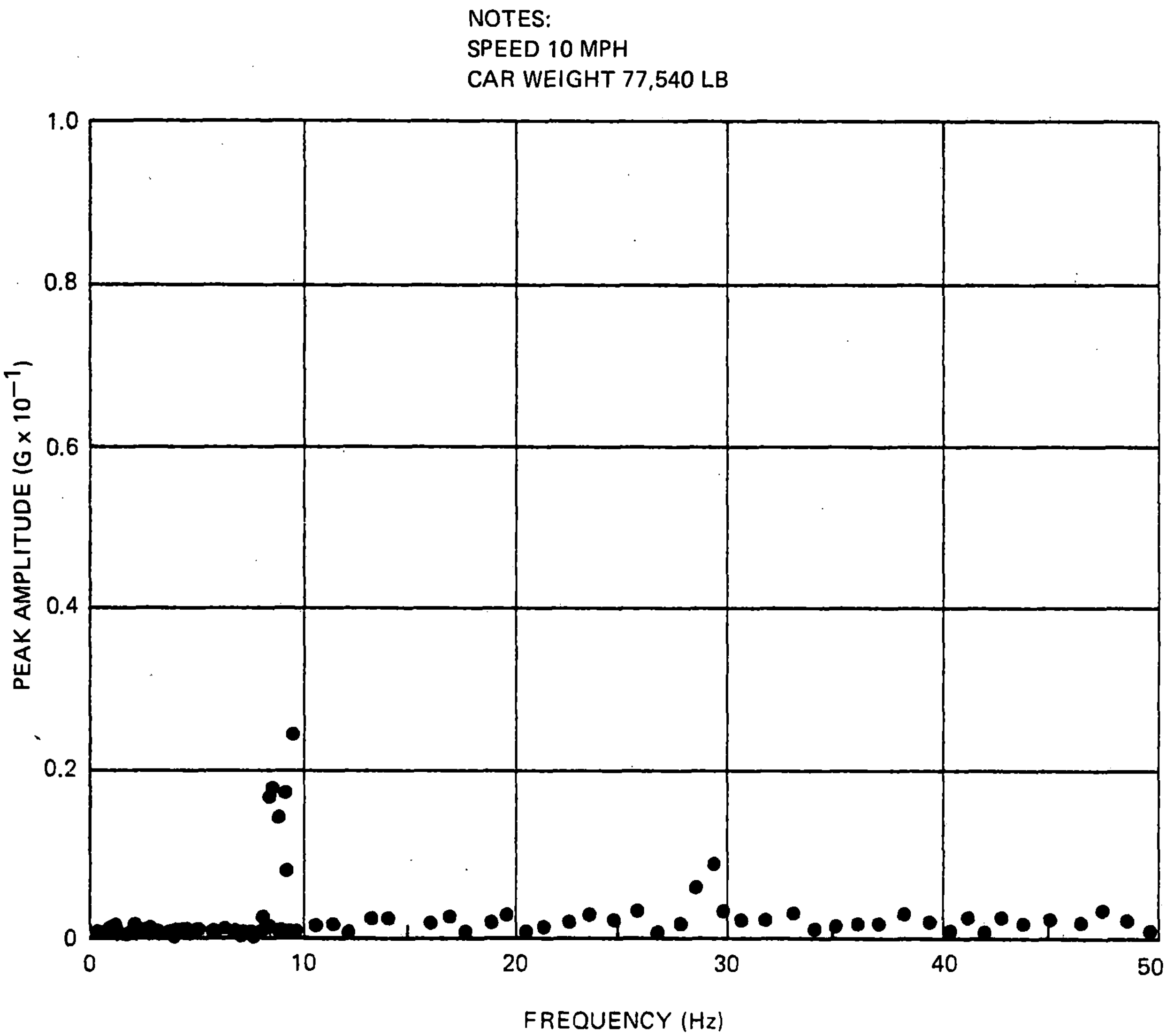


Figure A–4. Narrow-Band Spectrum Analysis – Mid Car, Vertical

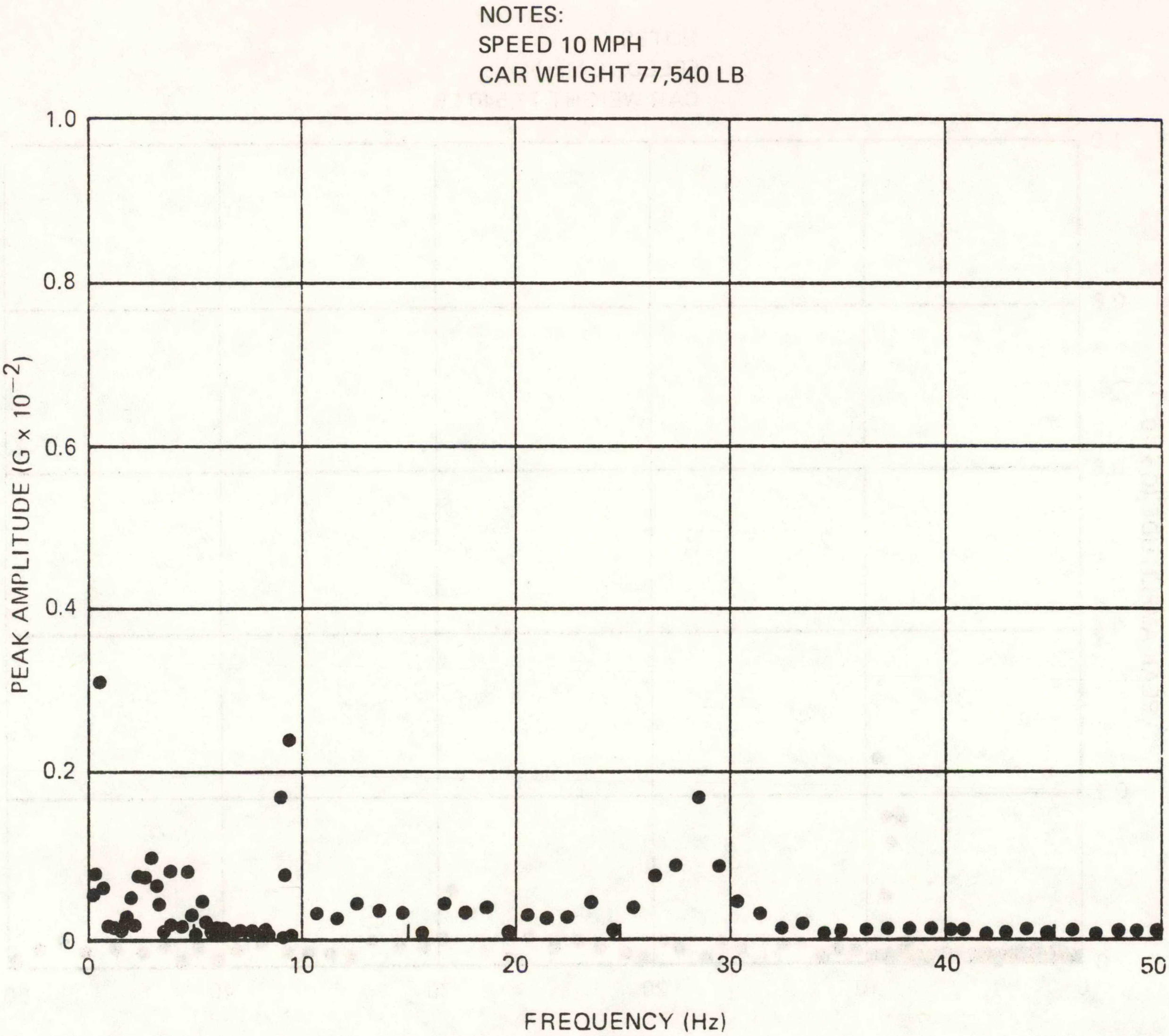


Figure A–5. Narrow-Band Spectrum Analysis – Mid Car, Lateral

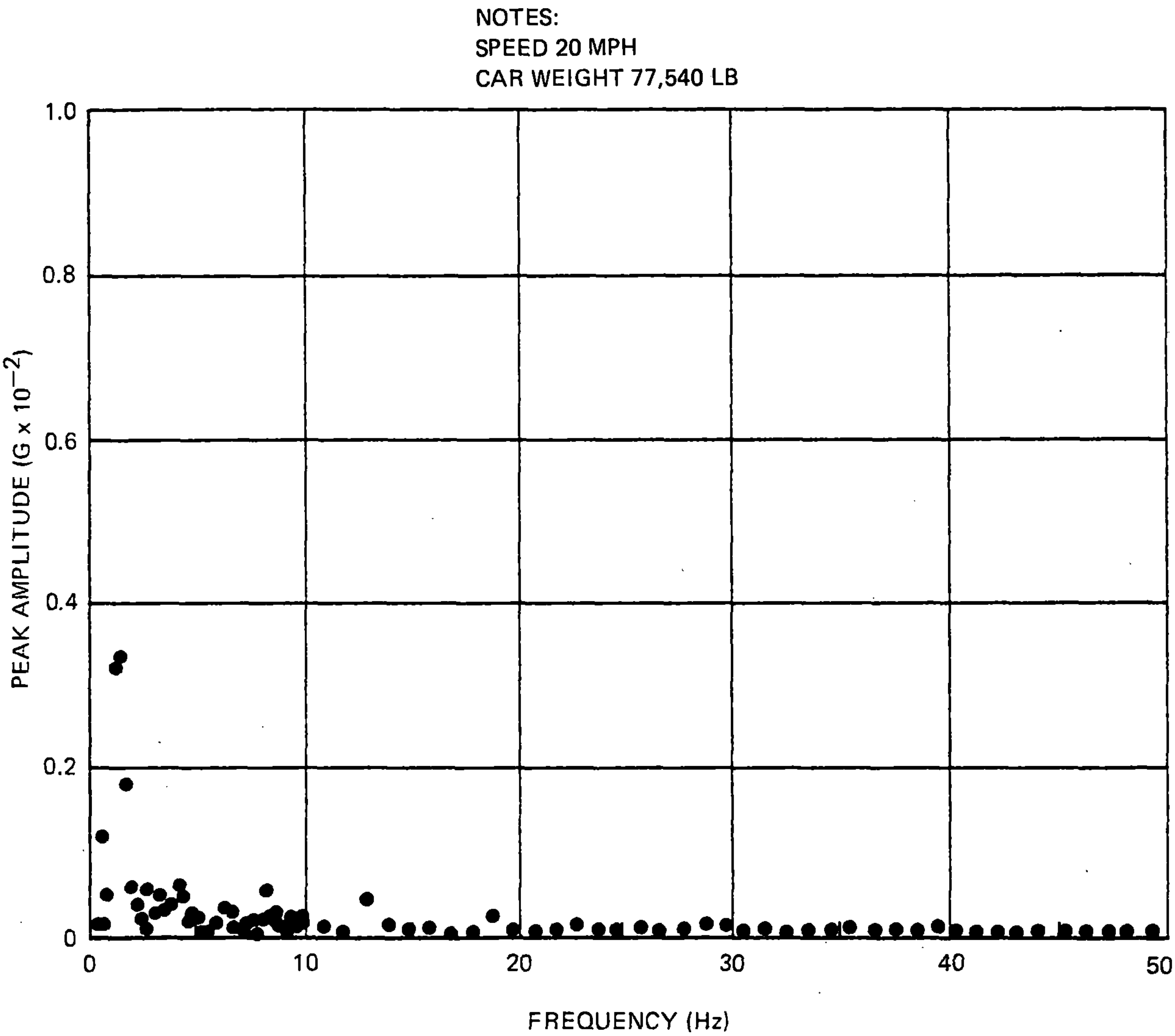


Figure A–6. Narrow-Band Spectrum Analysis – End Car, Vertical

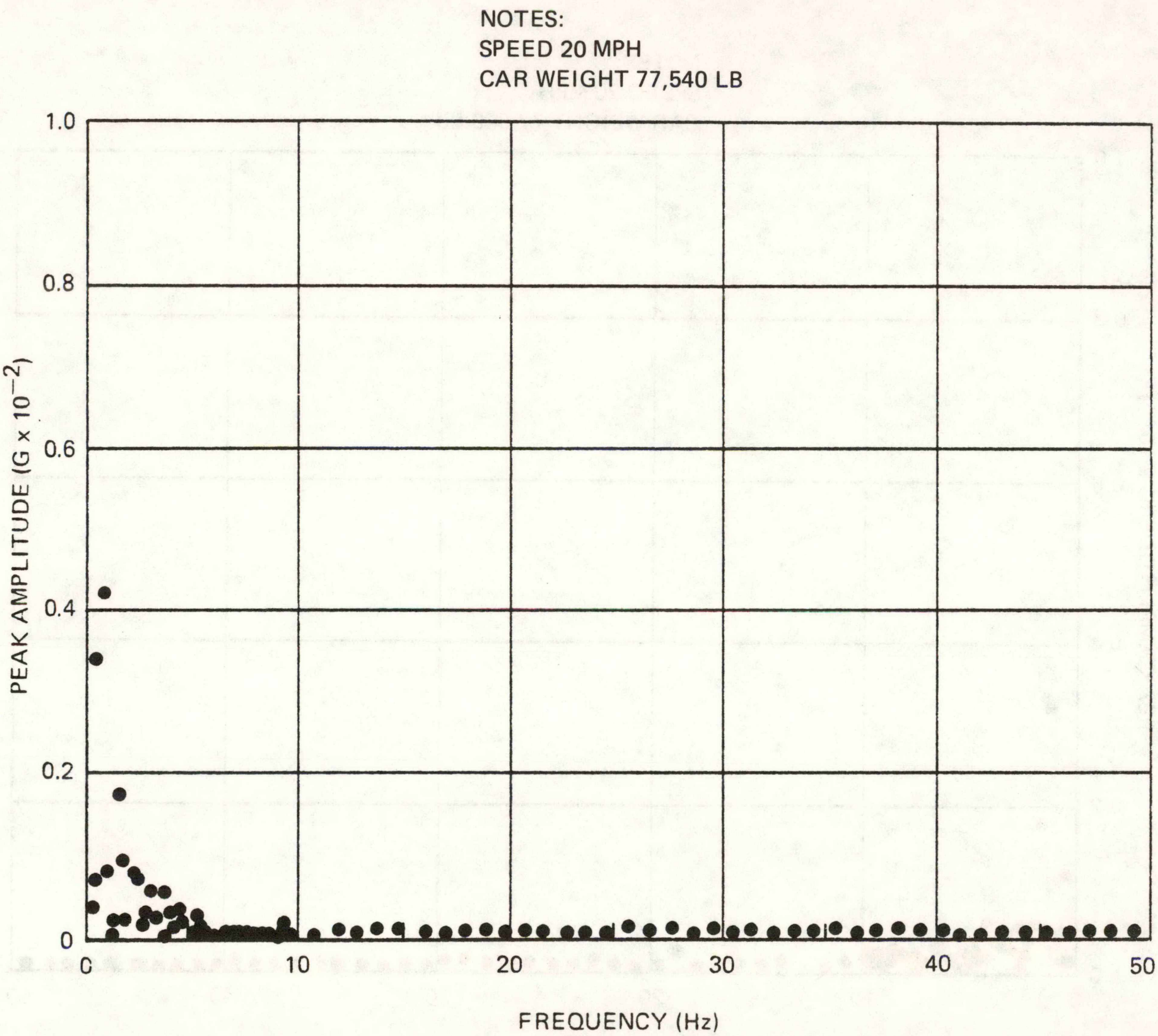


Figure A–7. Narrow-Band Spectrum Analysis – End Car, Lateral

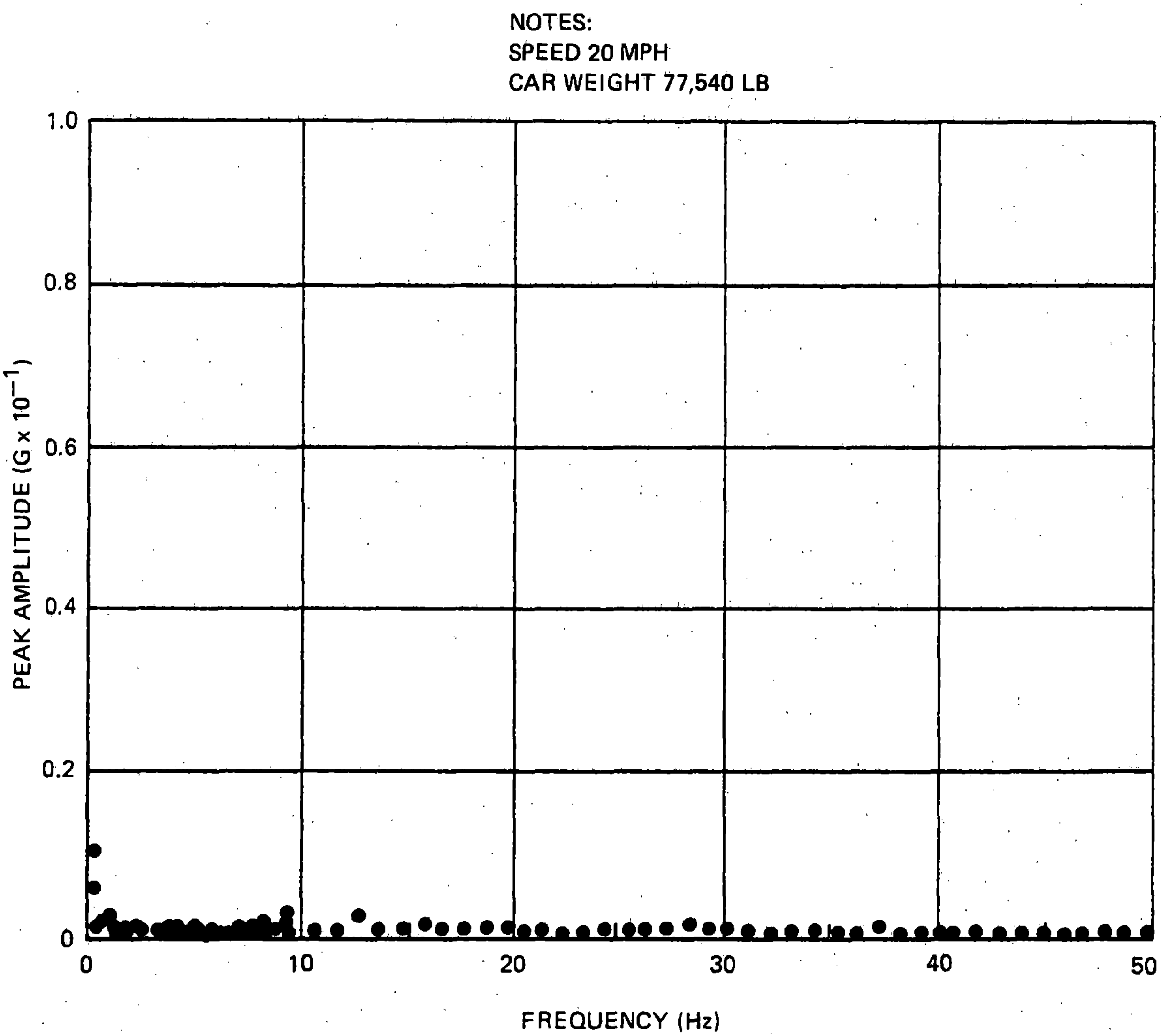


Figure A–8. Narrow-Band Spectrum Analysis — End Car, Longitudinal

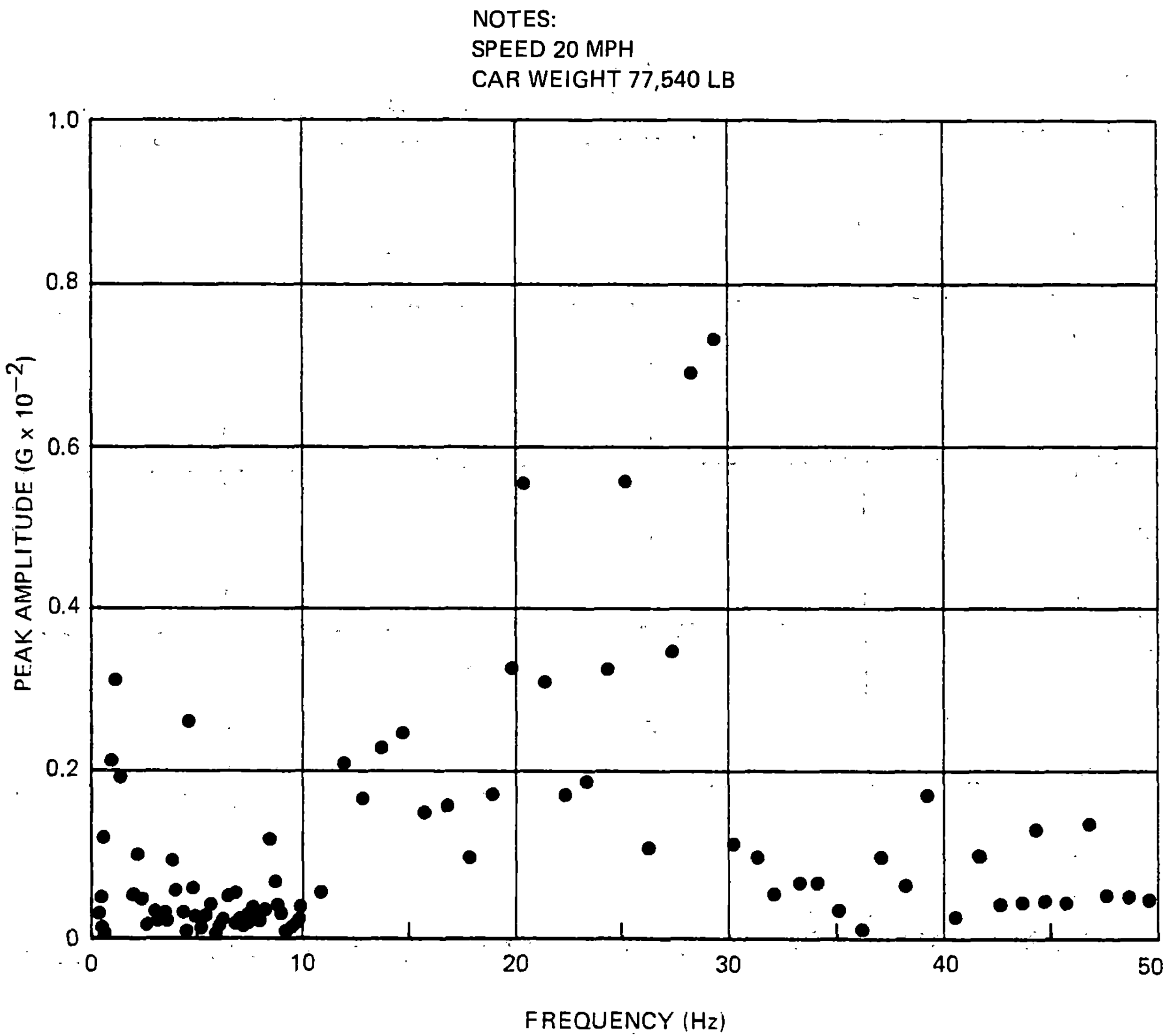


Figure A–9. Narrow-Band Spectrum Analysis – Mid Car, Vertical

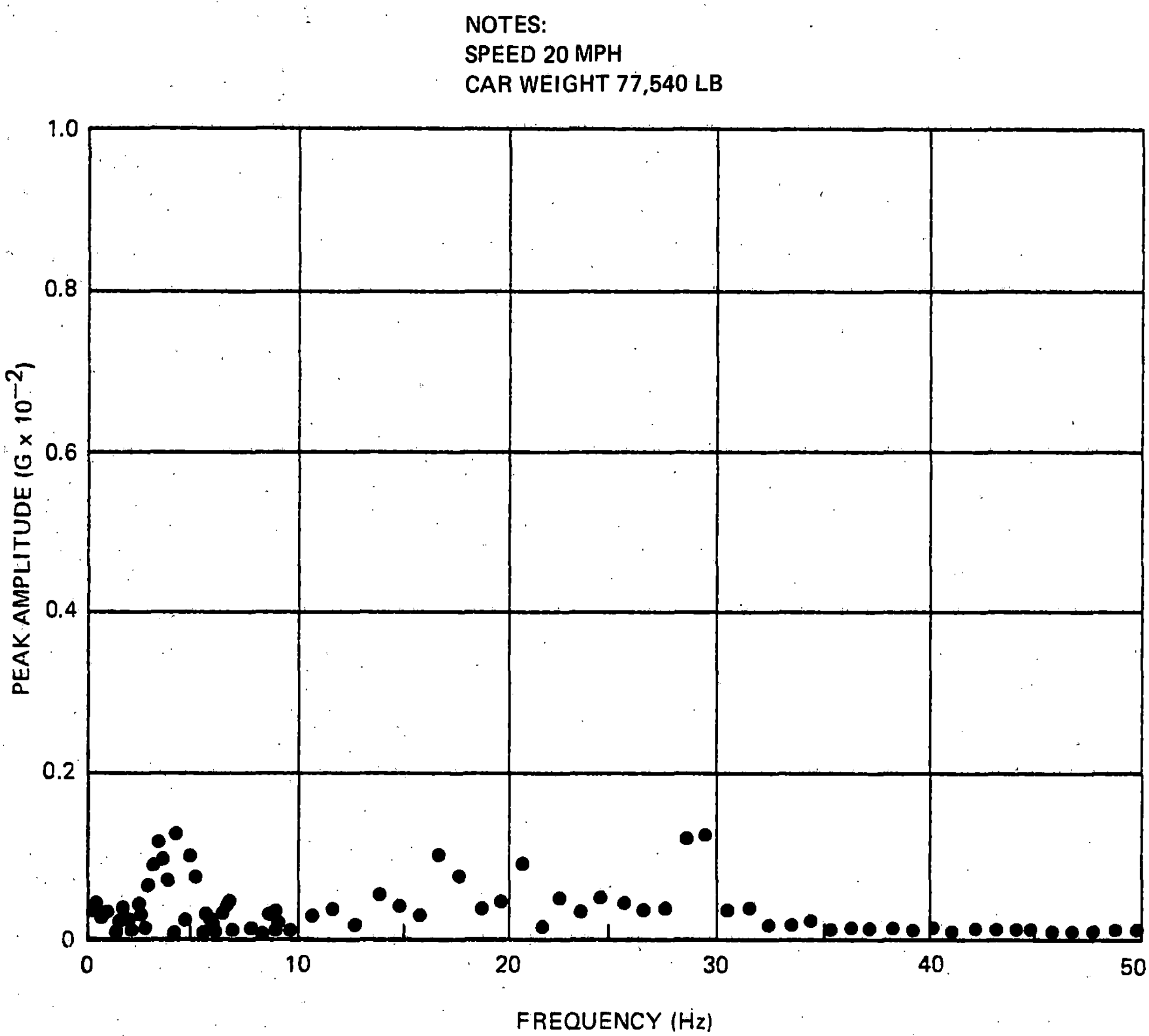


Figure A–10. Narrow-Band Spectrum Analysis – Mid Car, Lateral

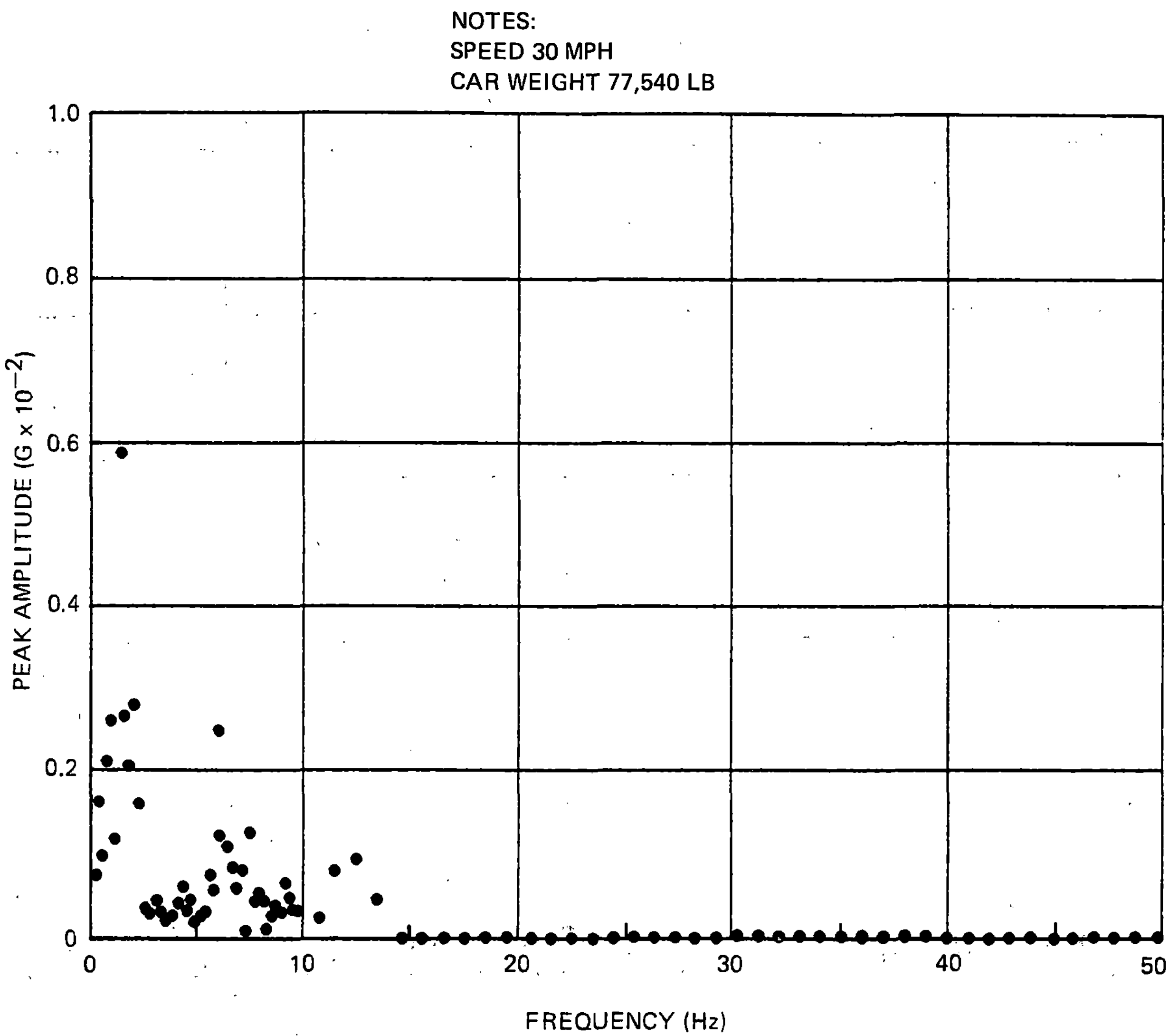


Figure A–11. Narrow-Band Spectrum Analysis – End Car, Vertical

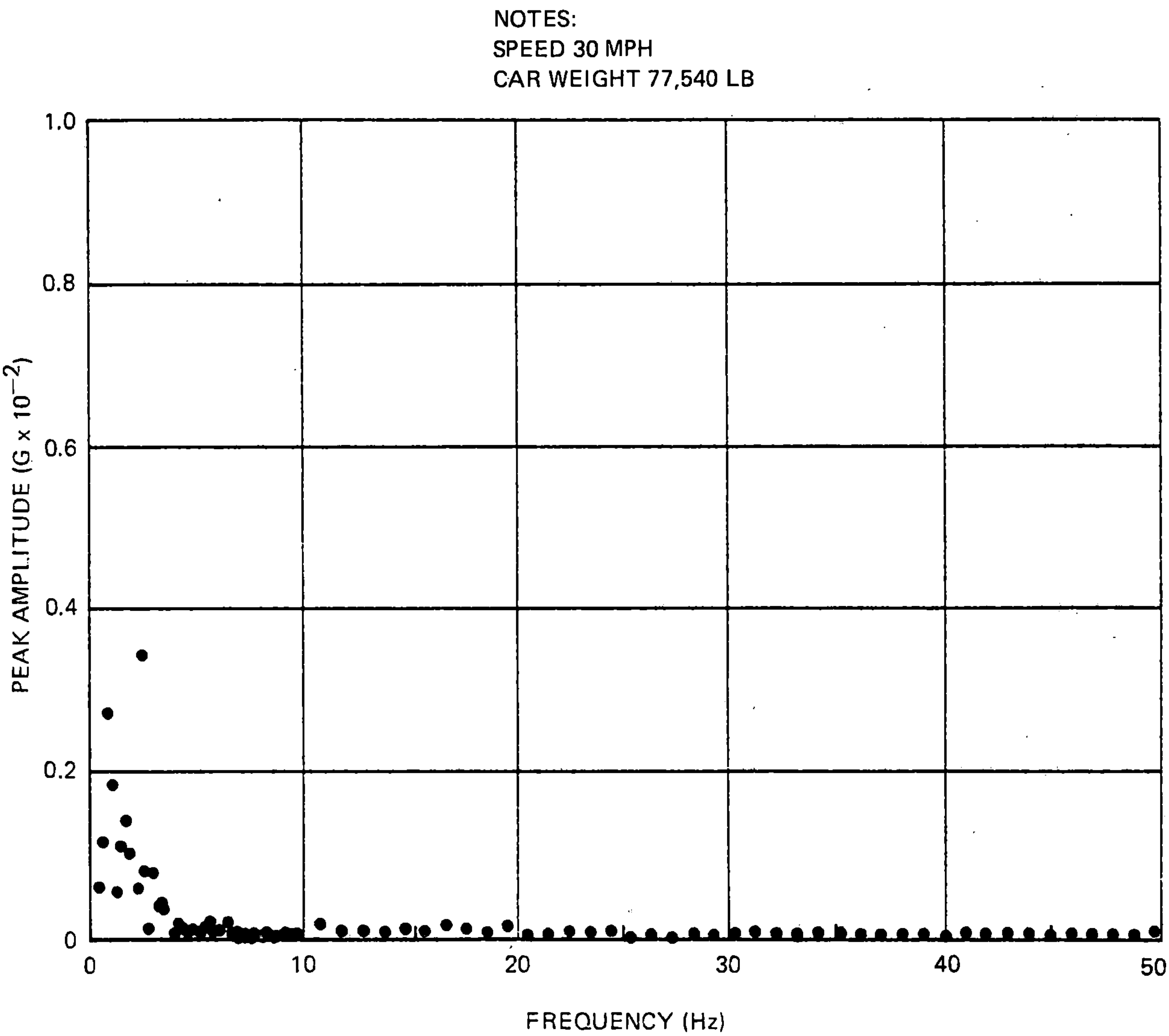


Figure A—12. Narrow-Band Spectrum Analysis — End Car, Lateral

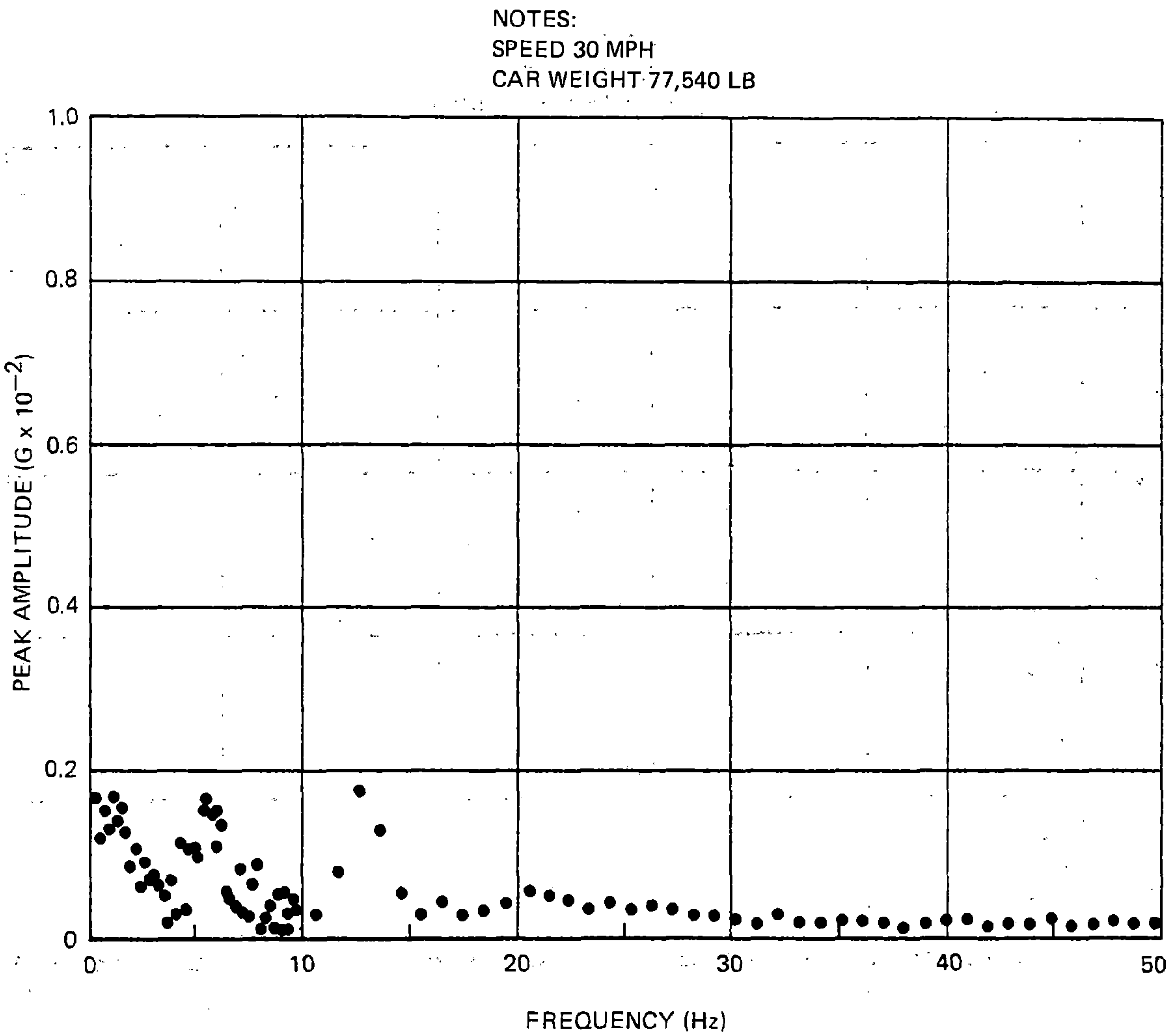


Figure A–13. Narrow-Band Spectrum Analysis – End Car, Longitudinal

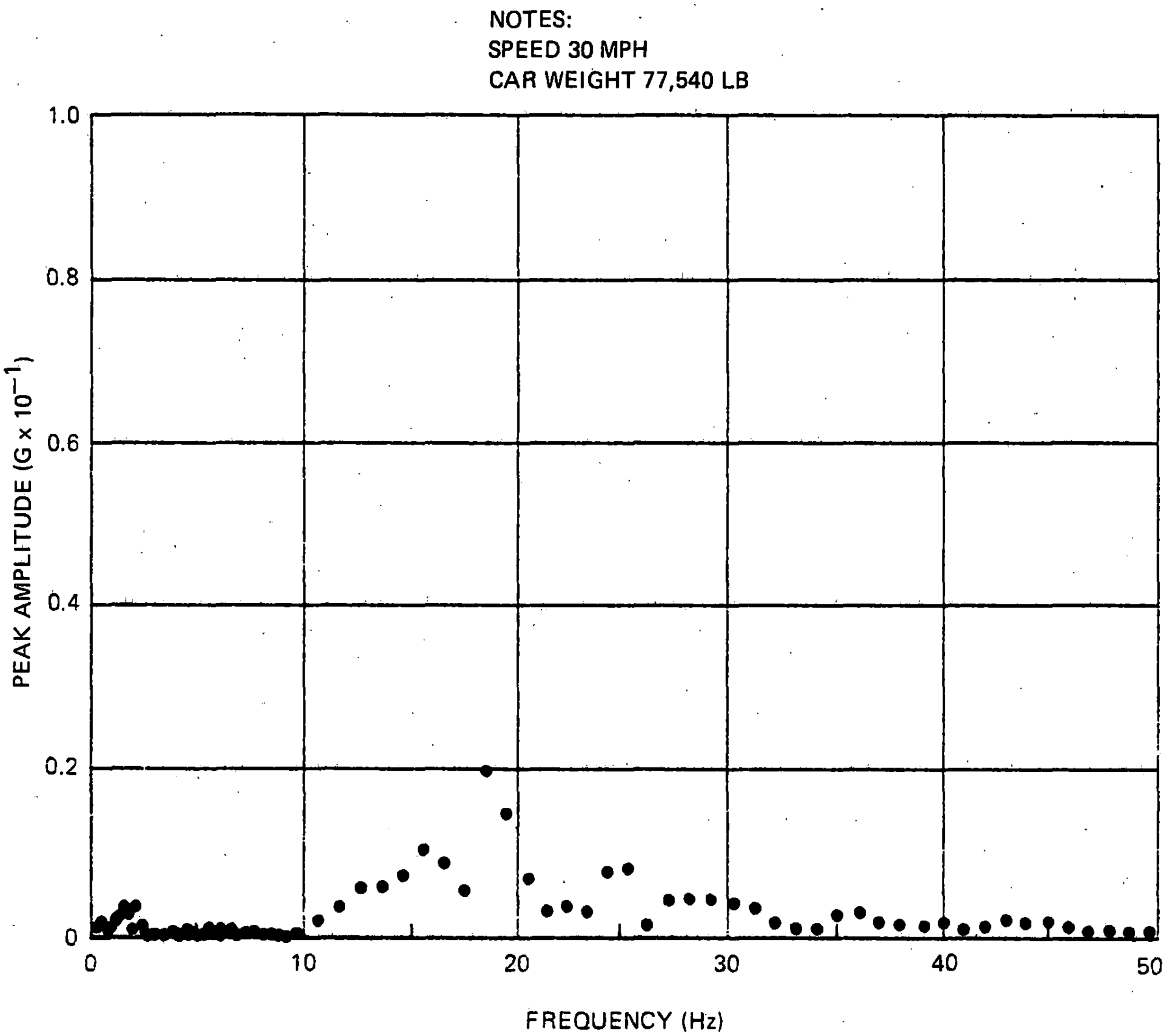


Figure A–14. Narrow-Band Spectrum Analysis – Mid Car, Vertical

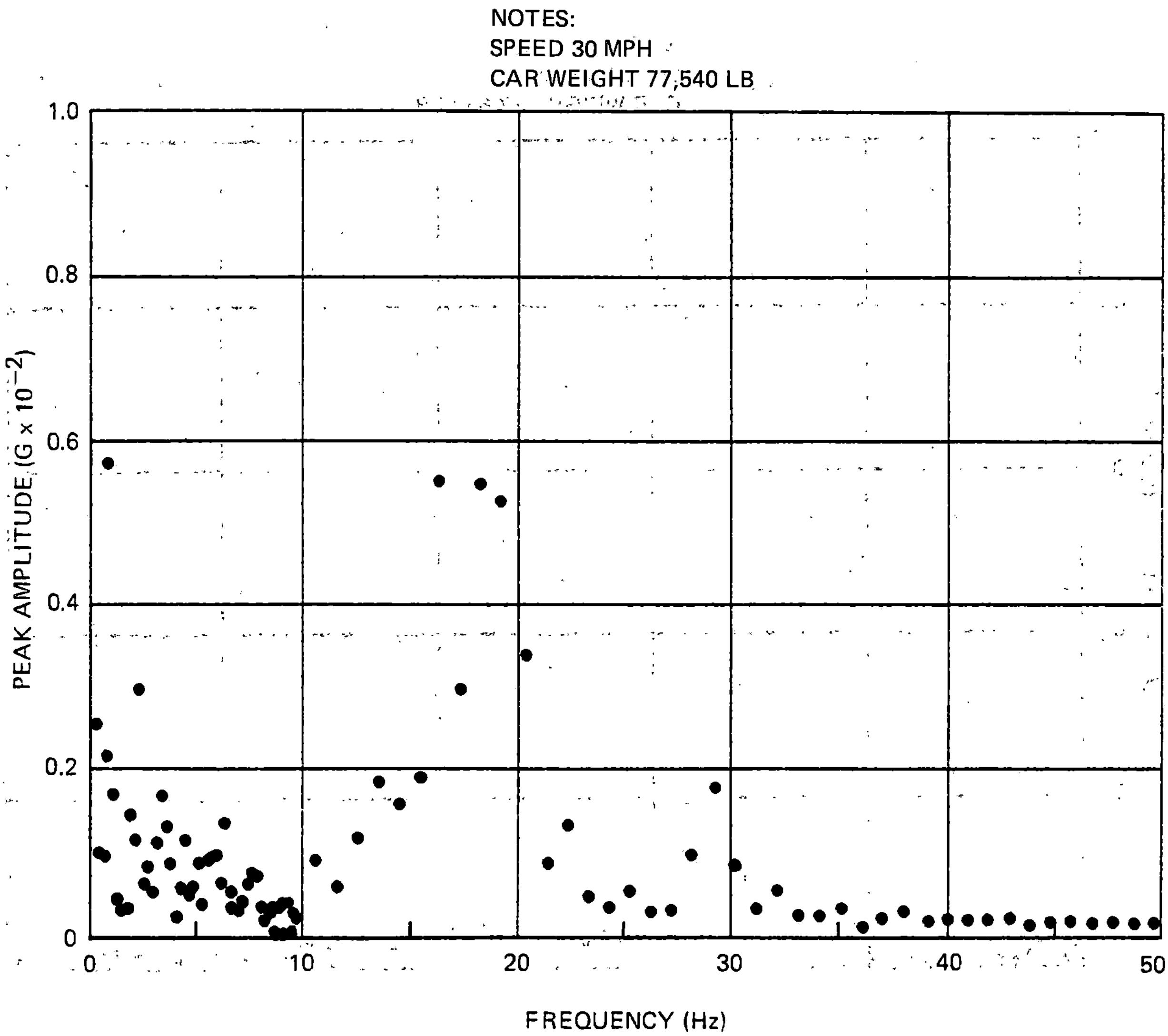


Figure A—15. Narrow-Band Spectrum Analysis — Mid Car, Lateral

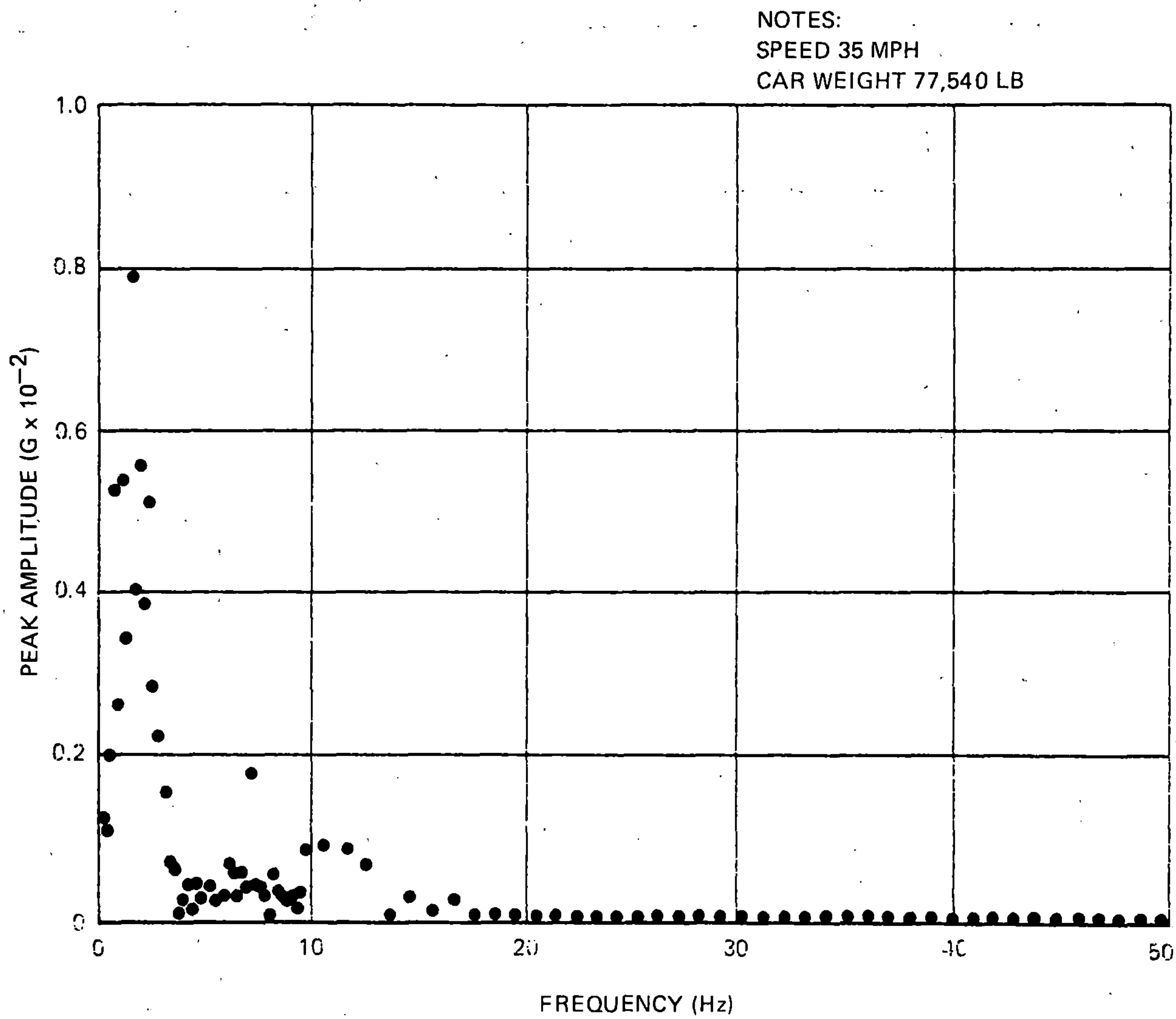


Figure A–16. Narrow-Band Spectrum Analysis – End Car, Vertical

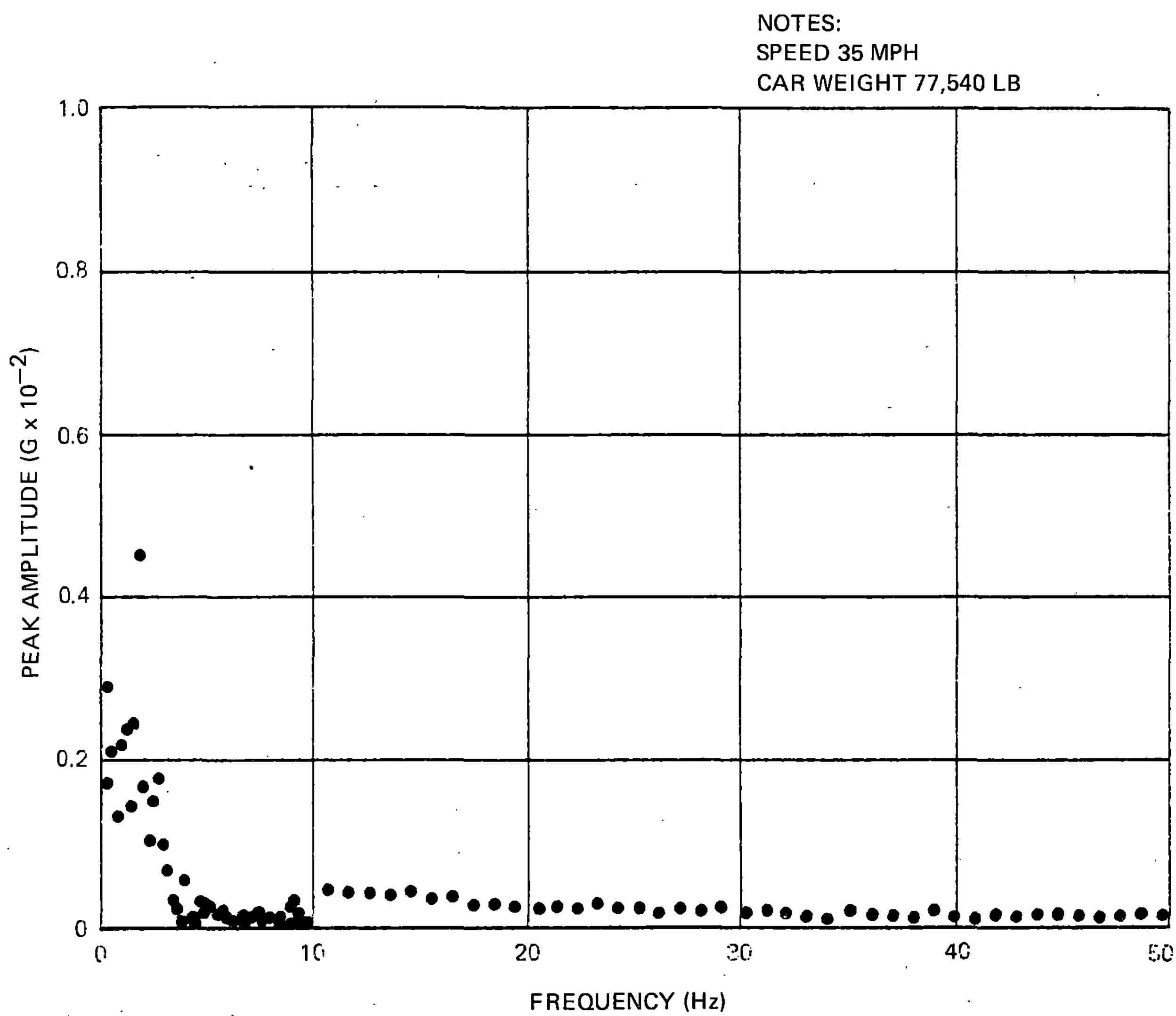


Figure A—17. Narrow-Band Spectrum Analysis — End Car, Lateral

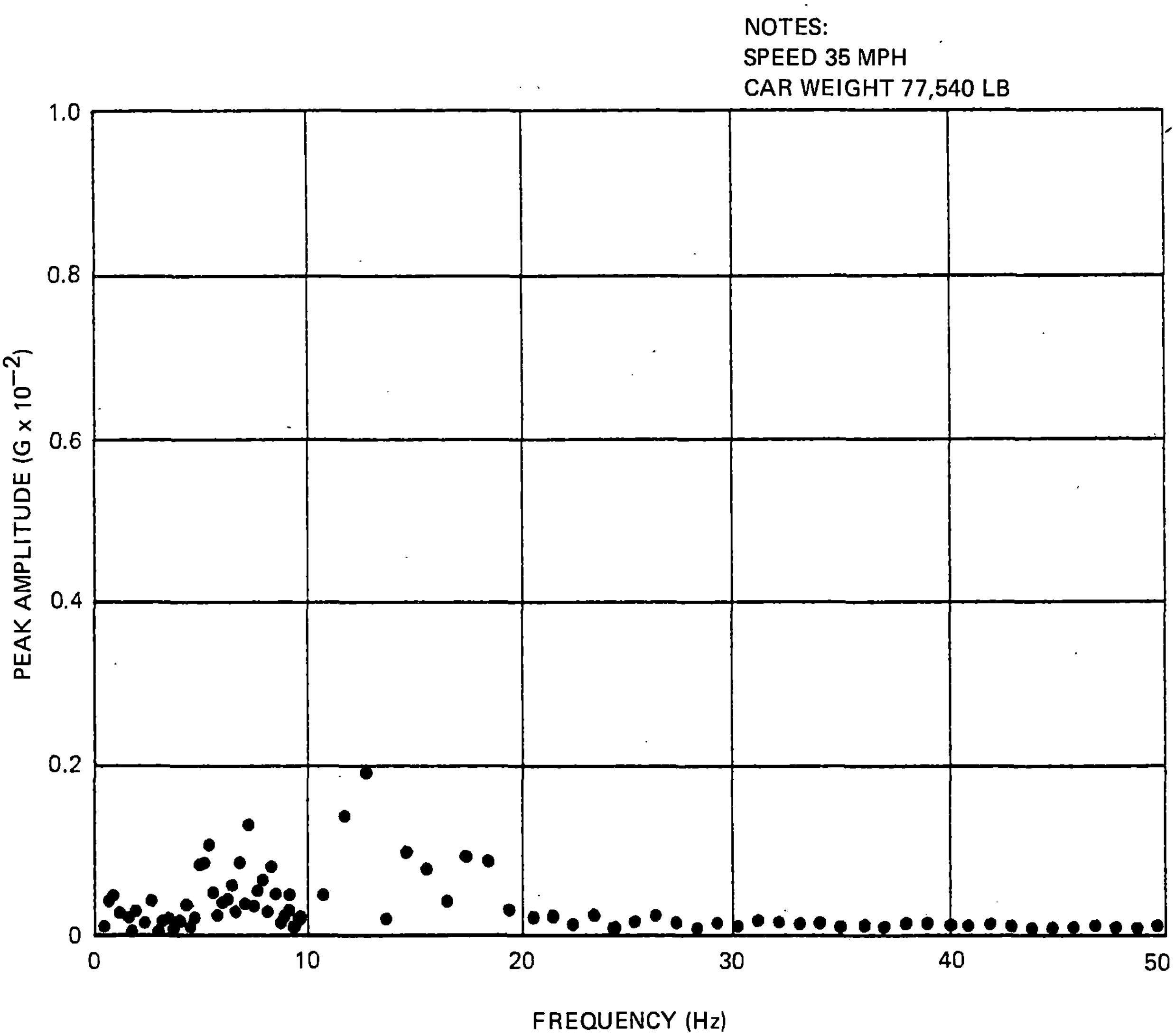


Figure A–18. Narrow-Band Spectrum Analysis – End Car, Longitudinal

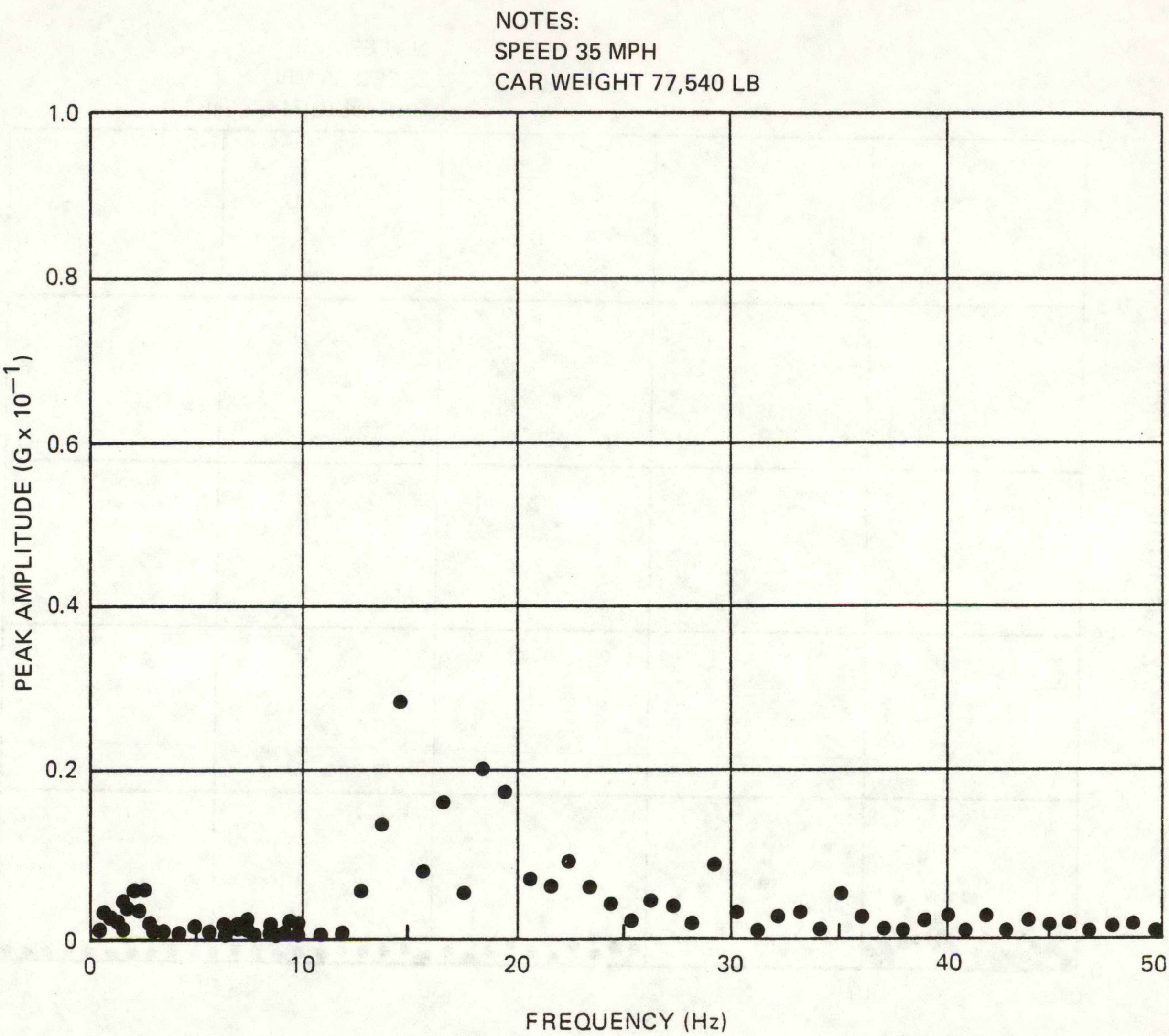


Figure A–19. Narrow-Band Spectrum Analysis – Mid Car, Vertical

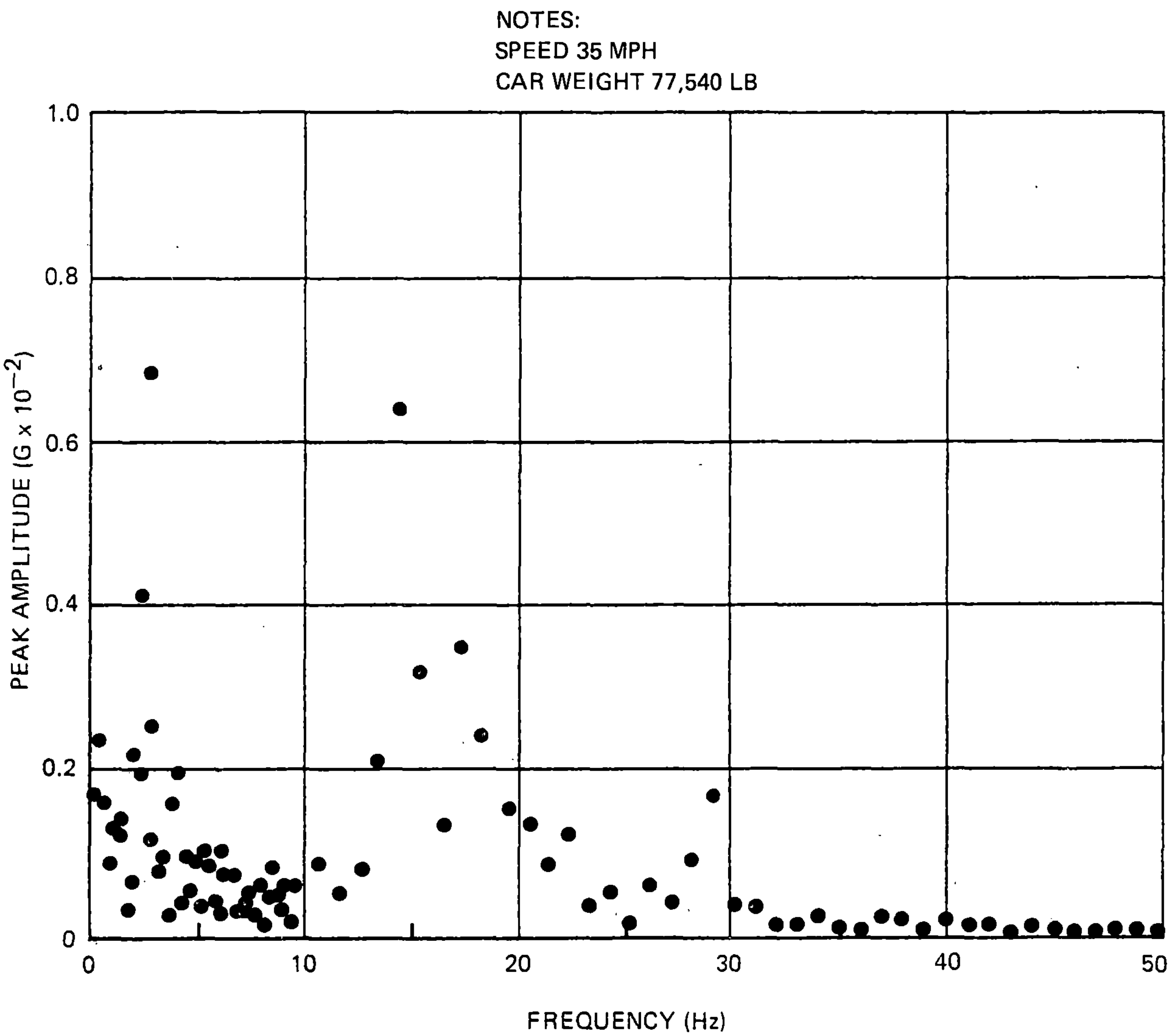


Figure A–20. Narrow-Band Spectrum Analysis – Mid Car, Lateral

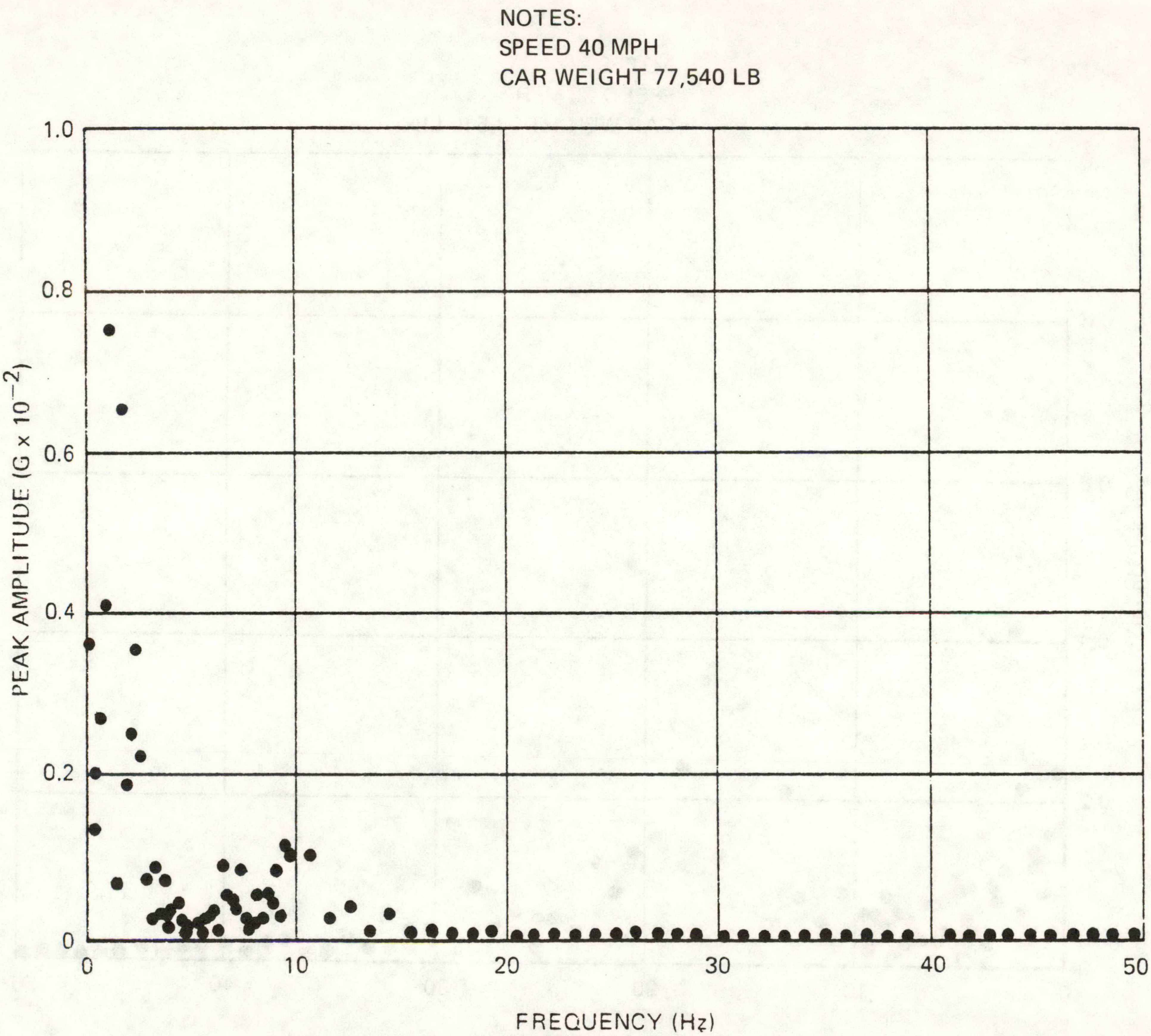


Figure A–21. Narrow-Band Spectrum Analysis – End Car, Vertical

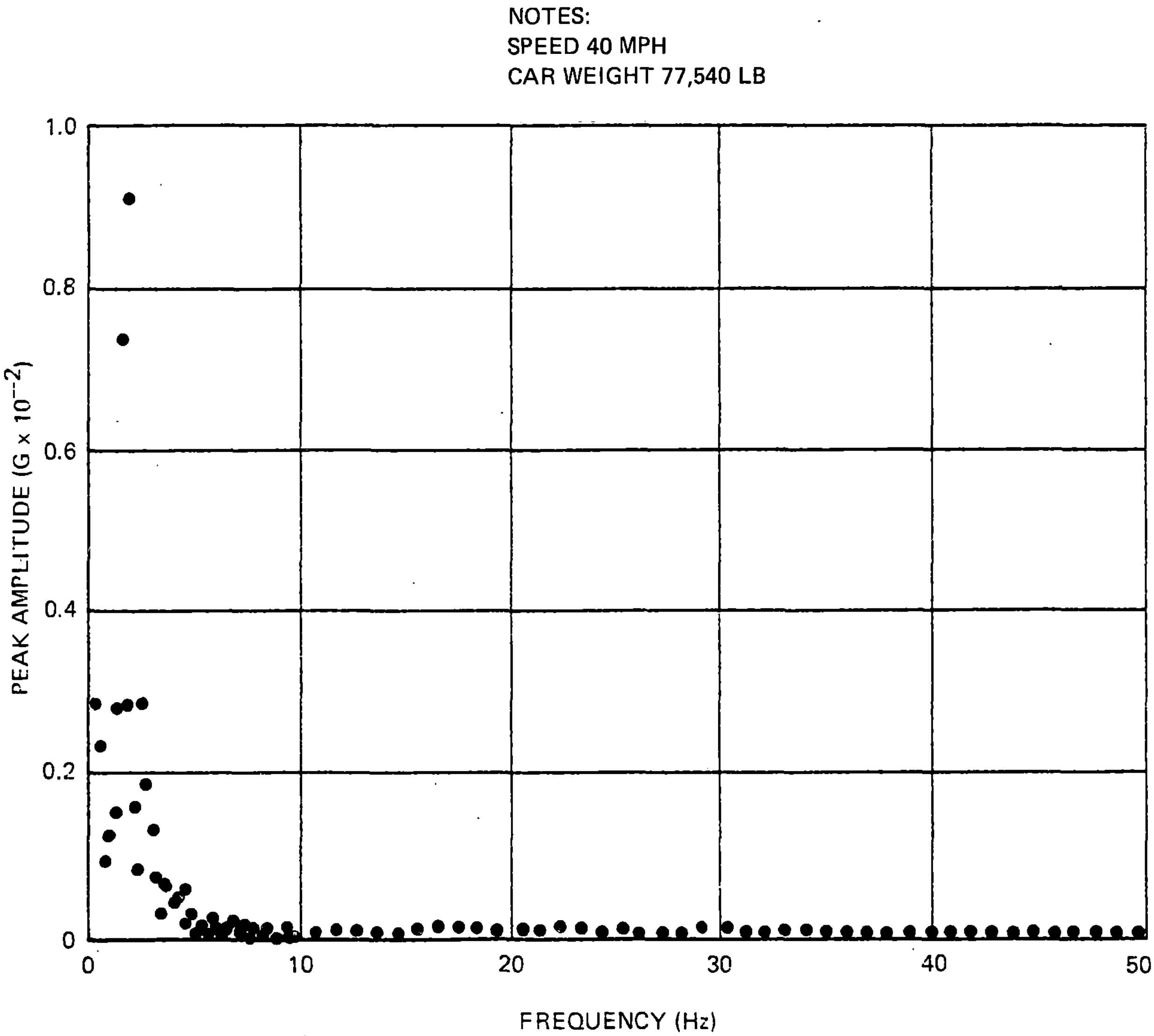


Figure A—22. Narrow-Band Spectrum Analysis — End Car, Lateral

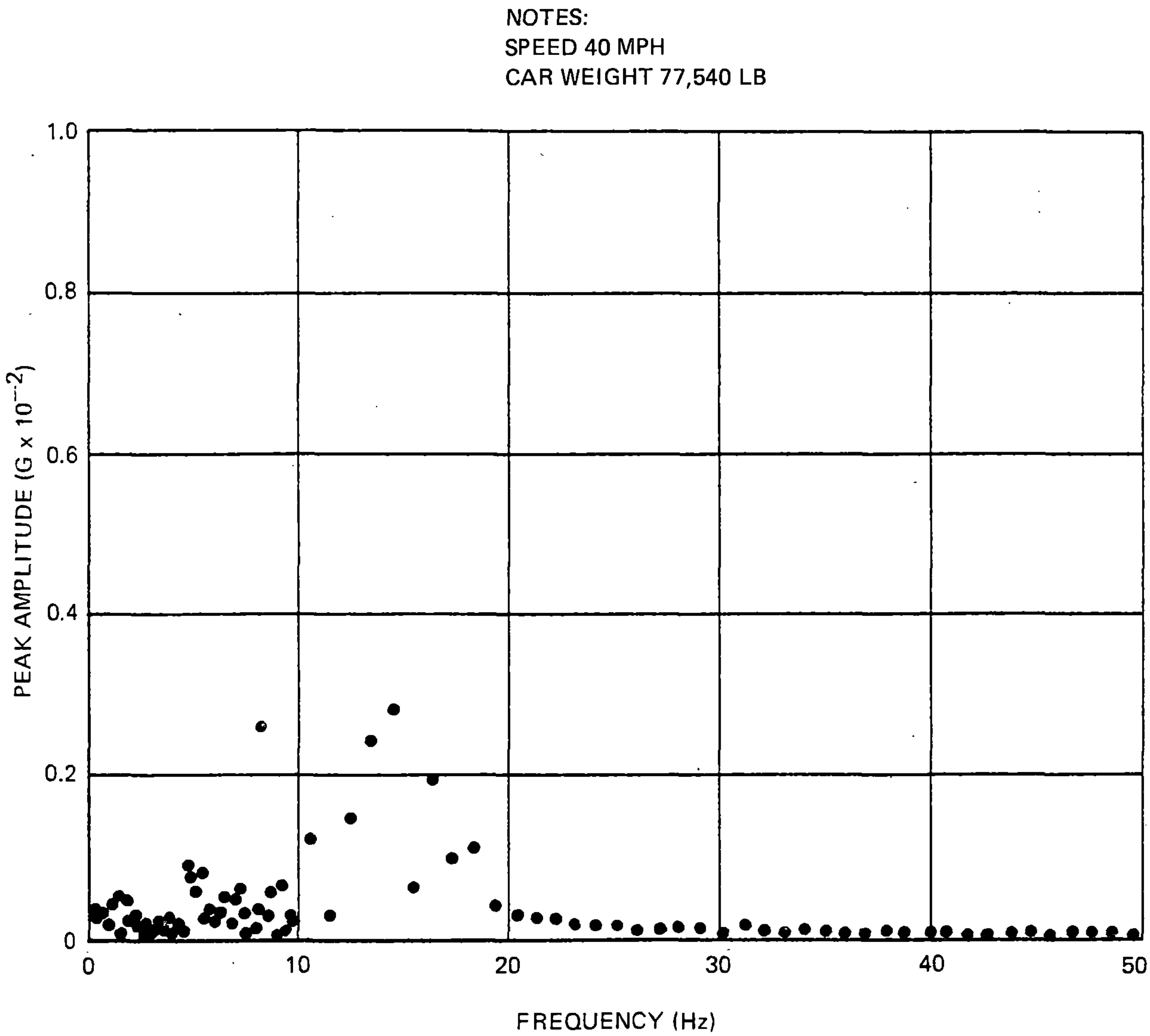


Figure A—23. Narrow-Band Spectrum Analysis — End Car, Longitudinal

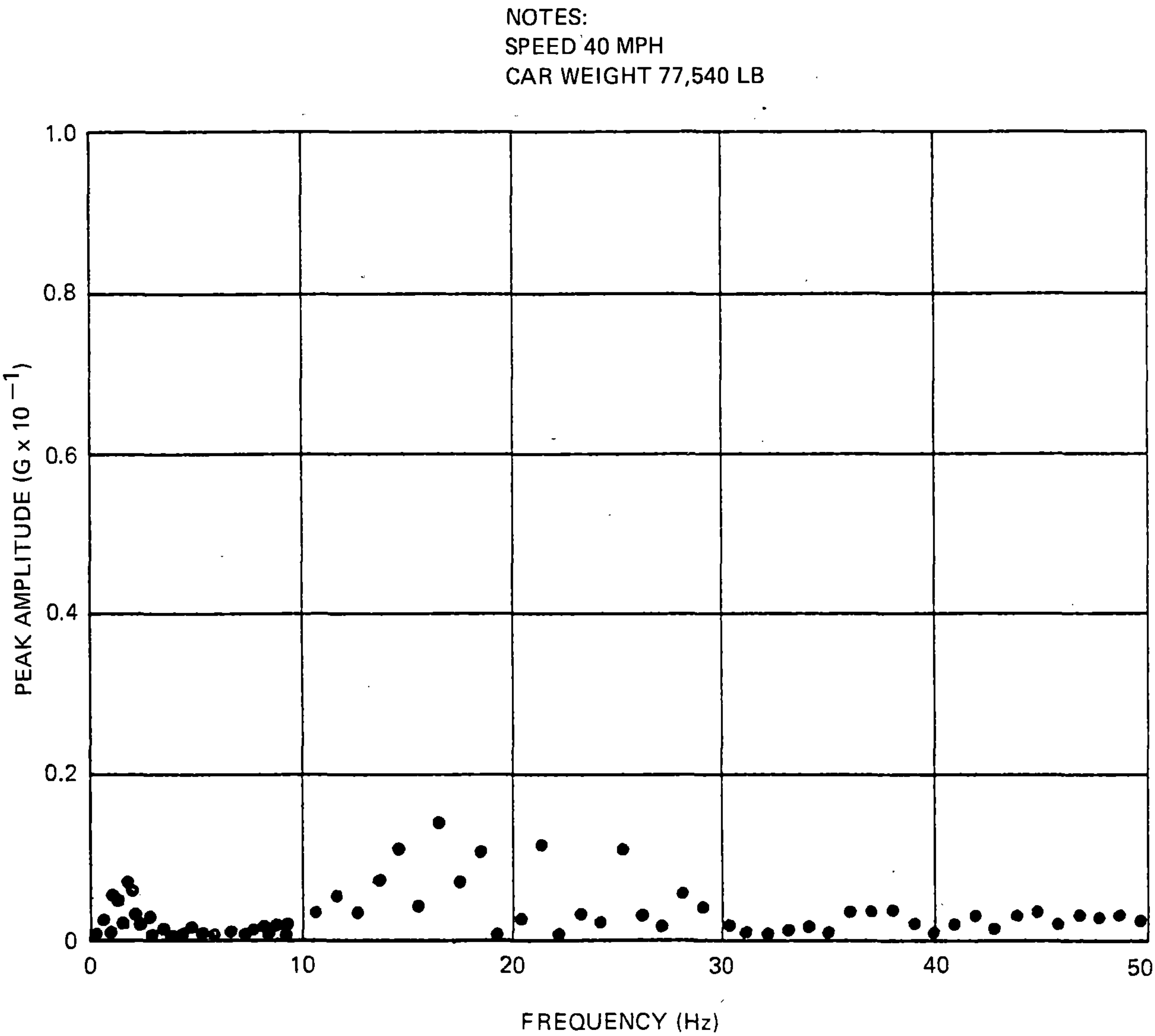


Figure A–24. Narrow-Band Spectrum Analysis – Mid Car, Vertical

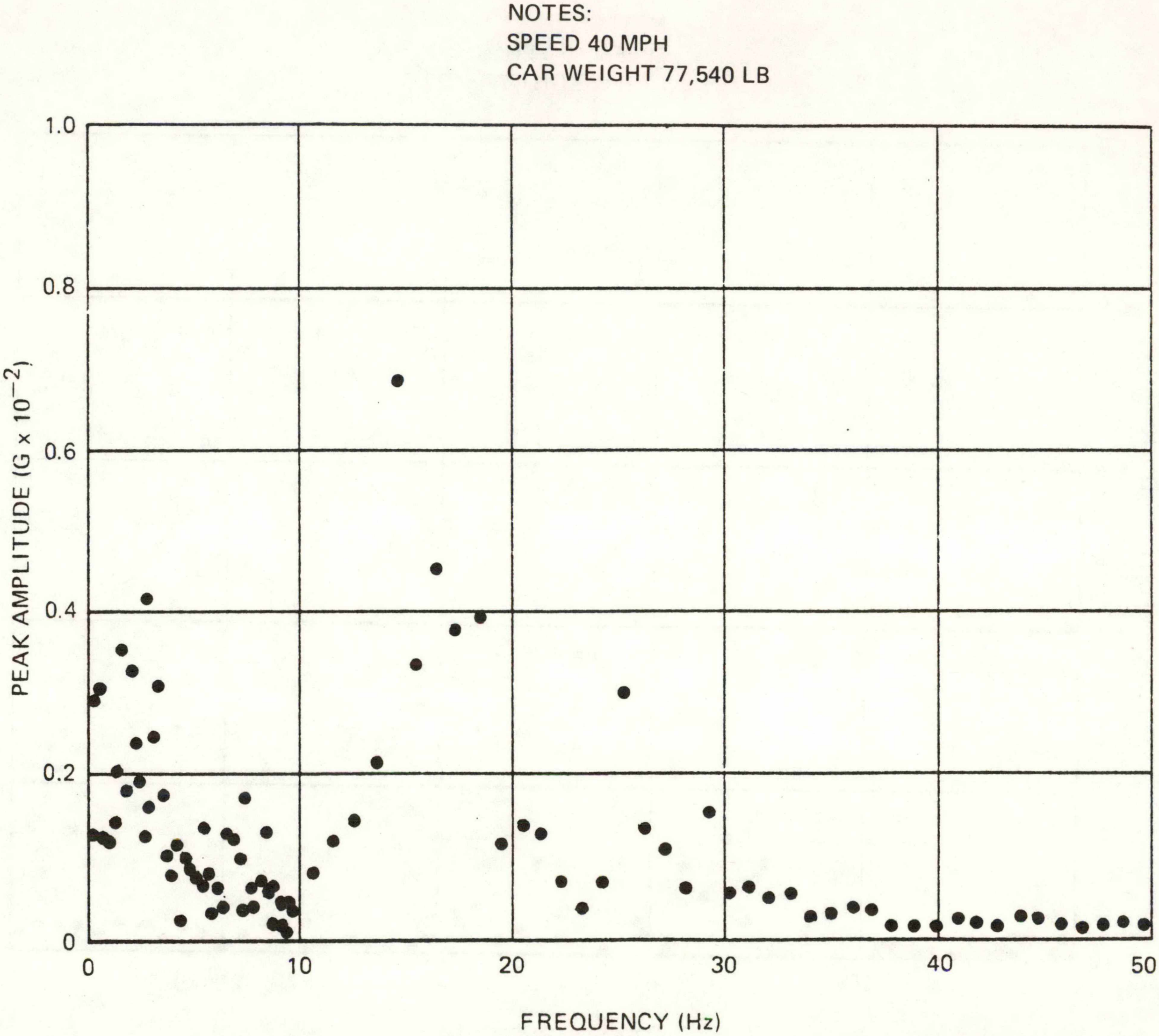


Figure A–25. Narrow-Band Spectrum Analysis – Mid Car, Lateral

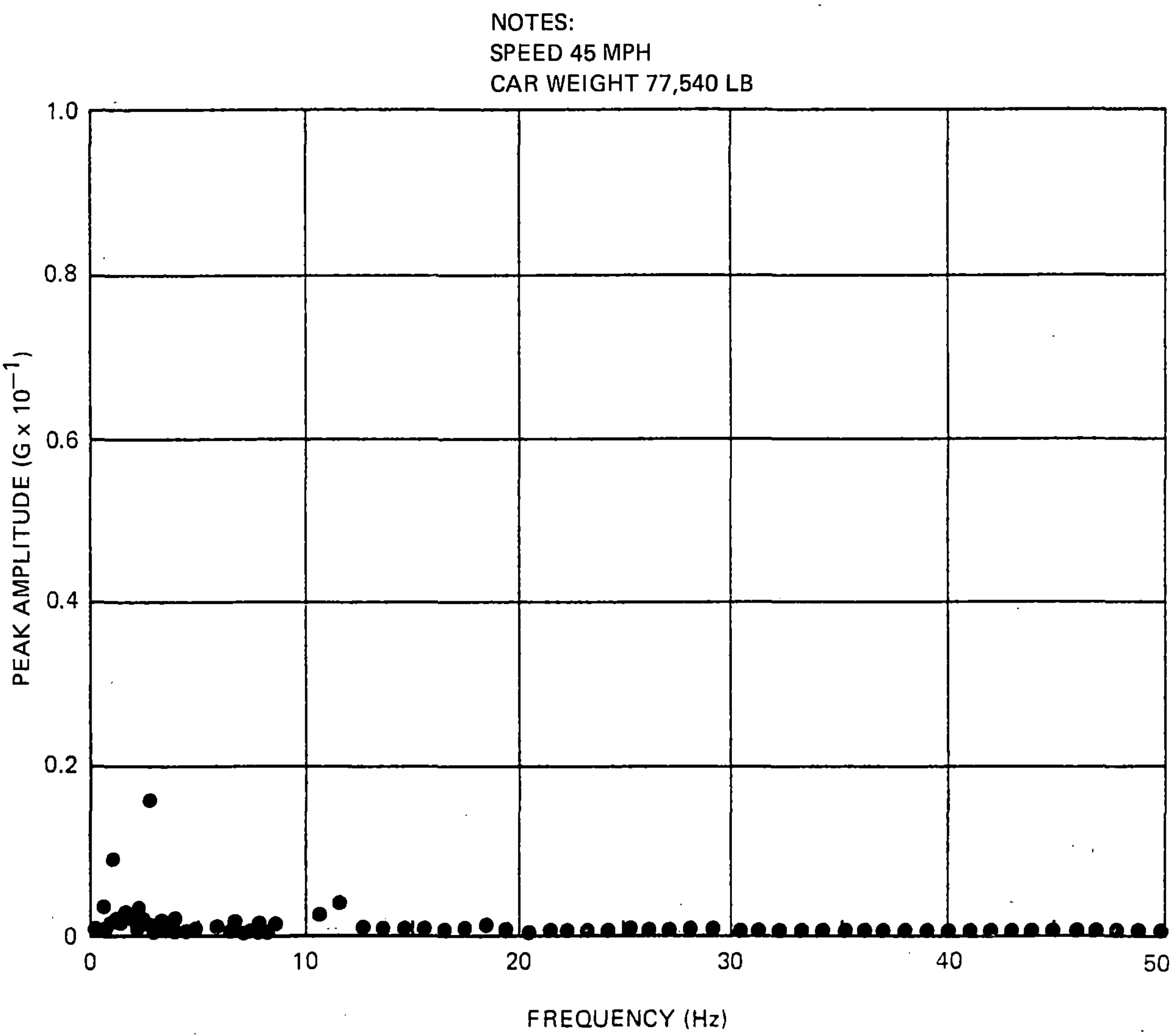


Figure A–26. Narrow-Band Spectrum Analysis – End Car, Vertical

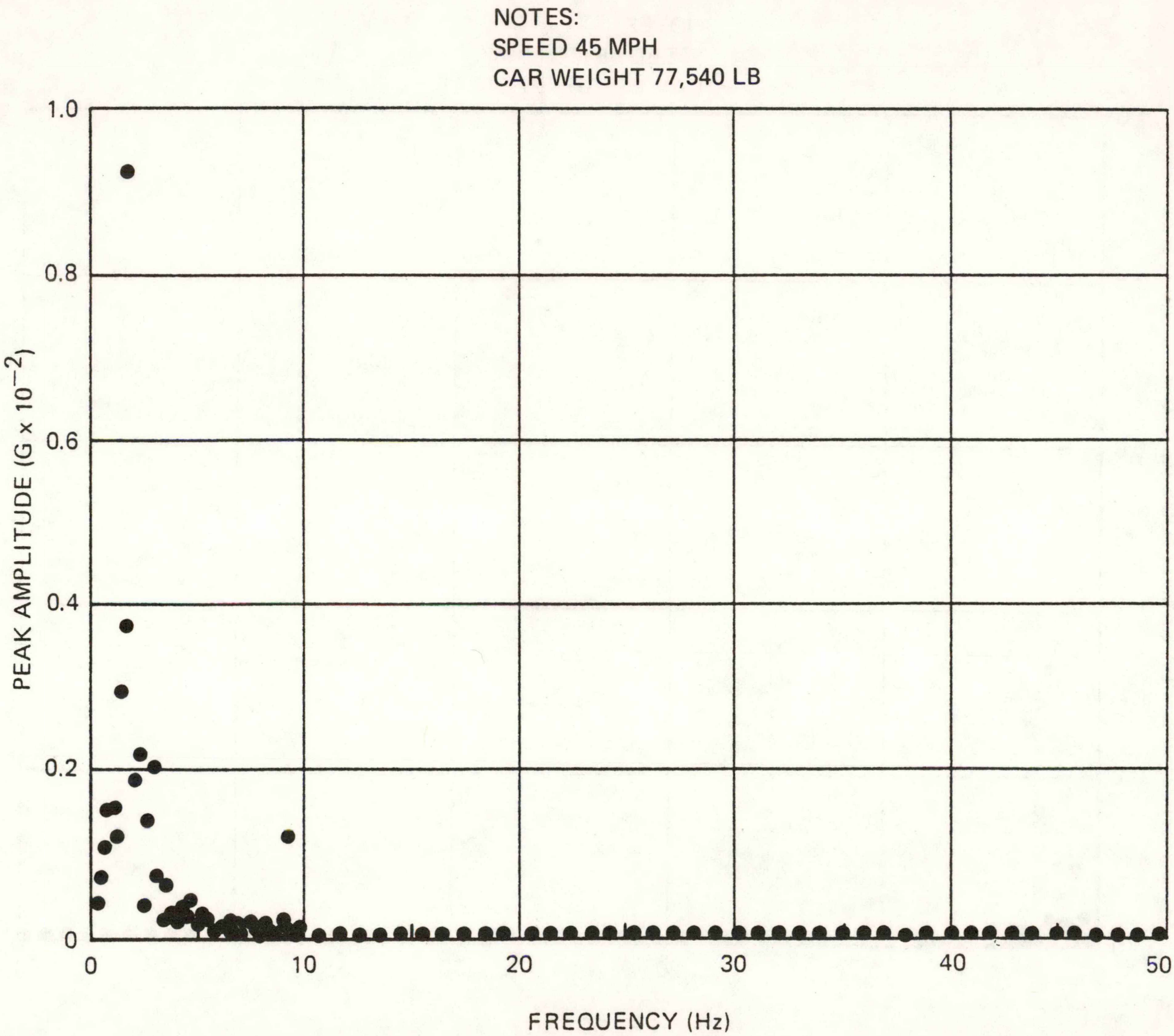


Figure A–27. Narrow-Band Spectrum Analysis – End Car, Lateral

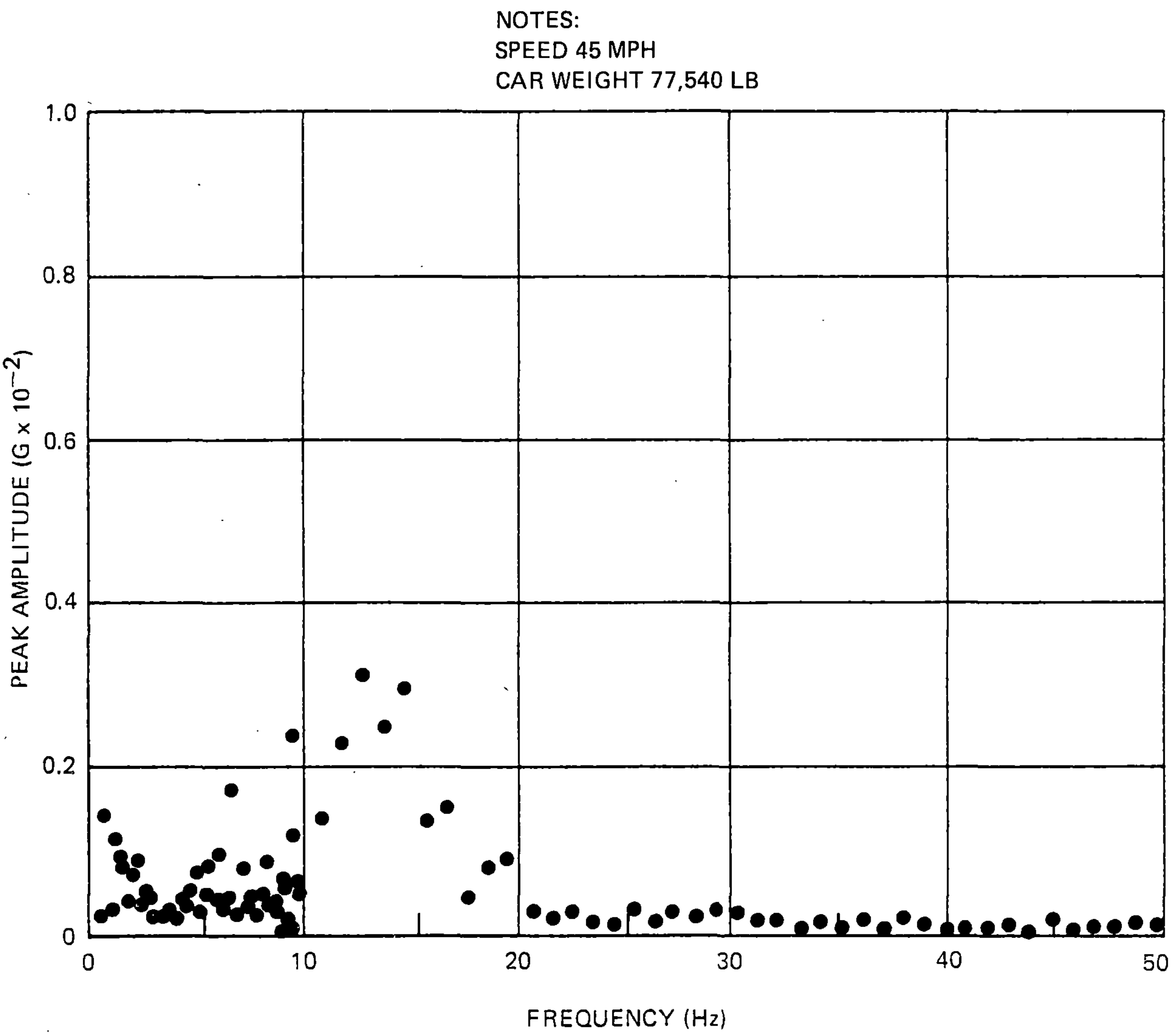


Figure A–28. Narrow-Band Spectrum Analysis – End Car, Longitudinal

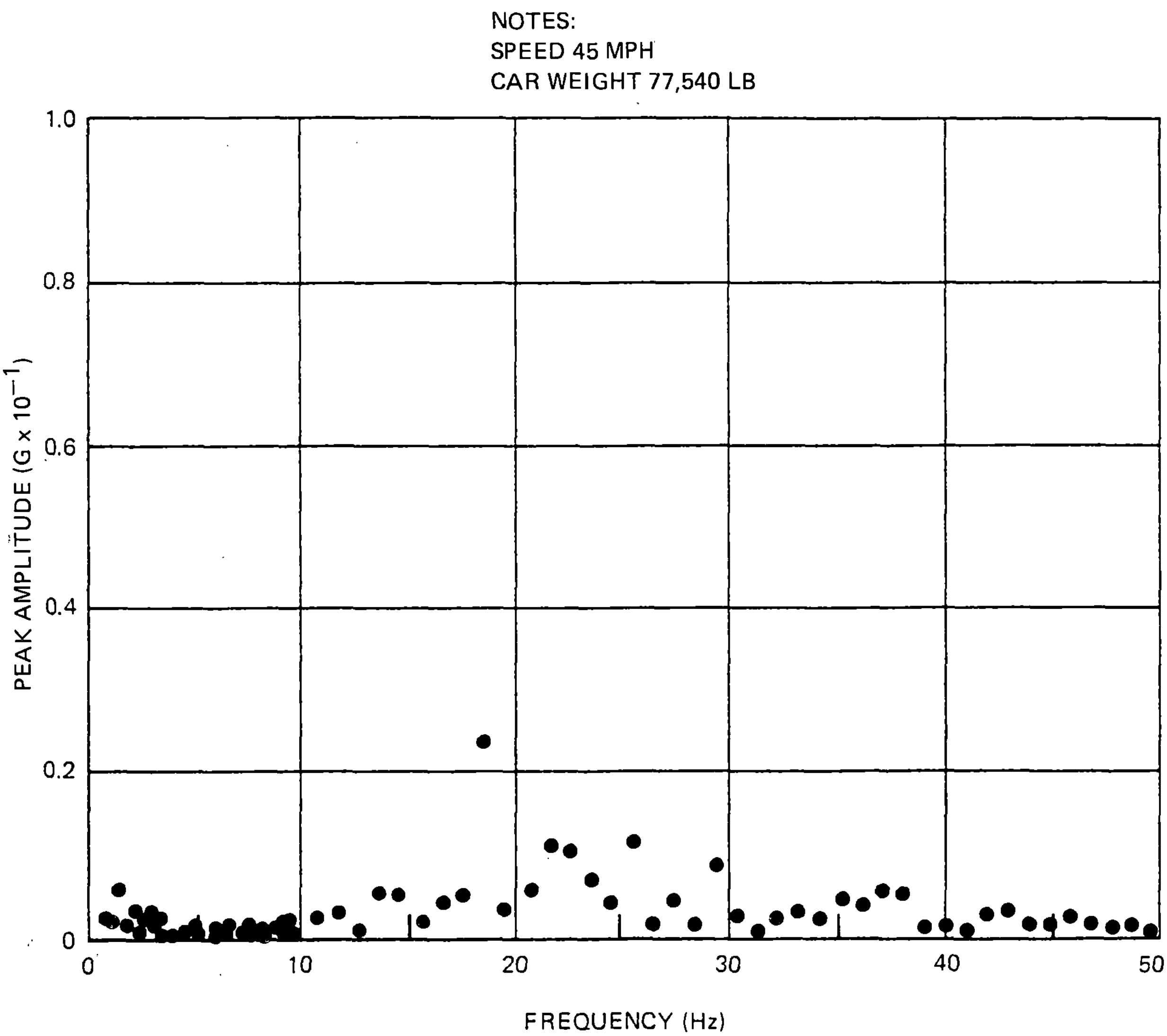


Figure A–29. Narrow-Band Spectrum Analysis – Mid Car, Vertical

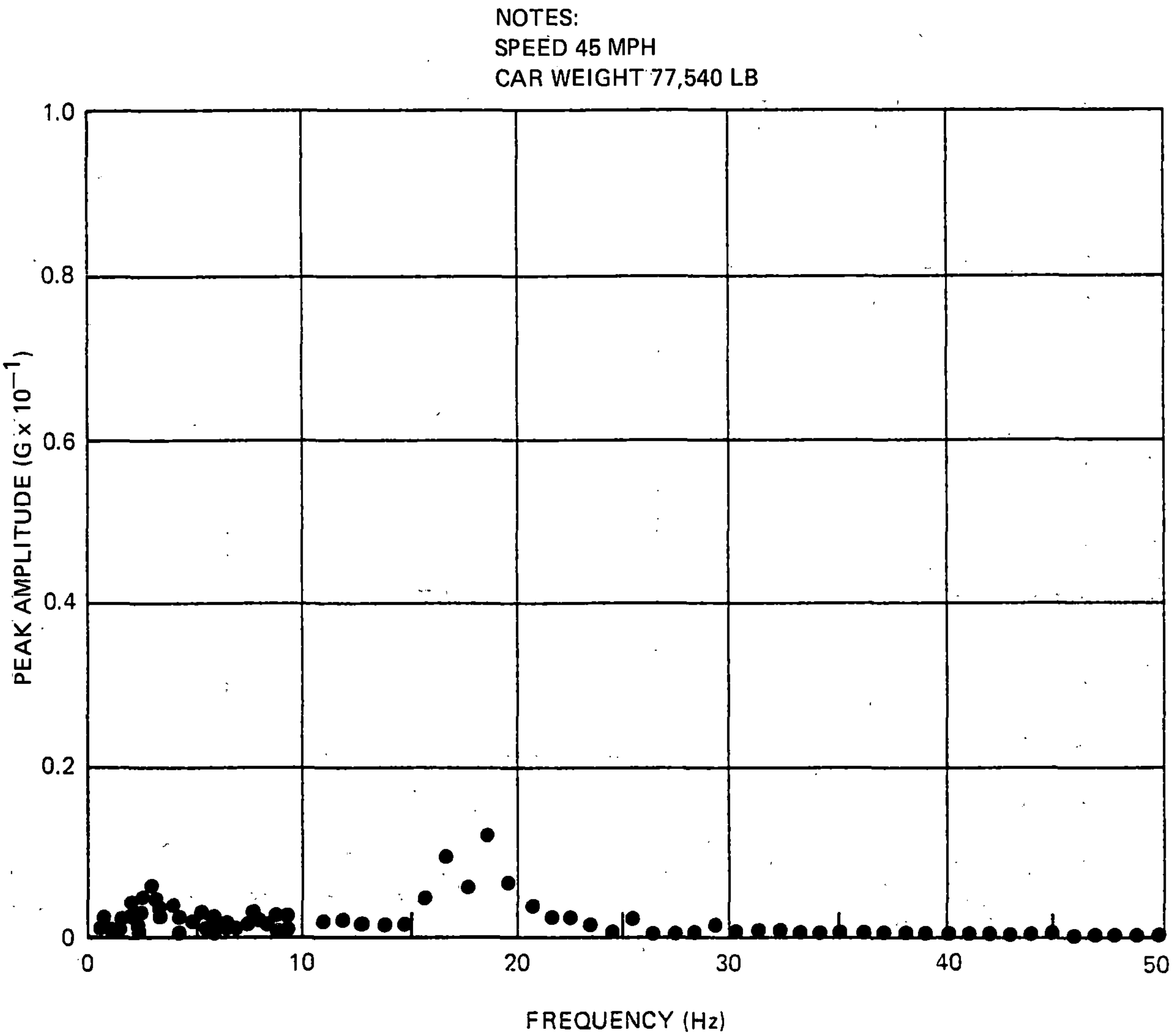


Figure A–30. Narrow-Band Spectrum Analysis – Mid Car, Lateral

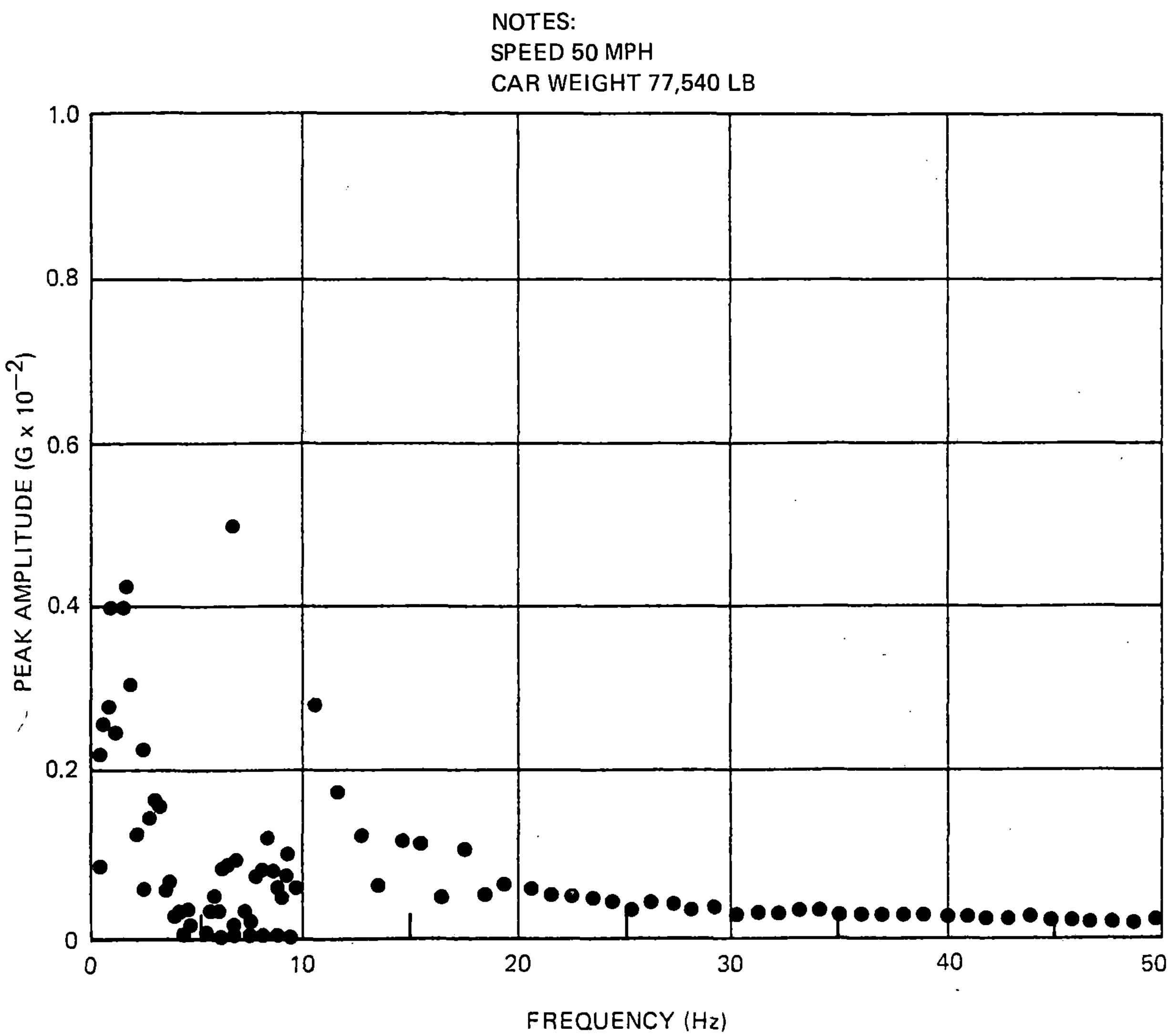


Figure A–31. Narrow-Band Spectrum Analysis – End Car, Vertical

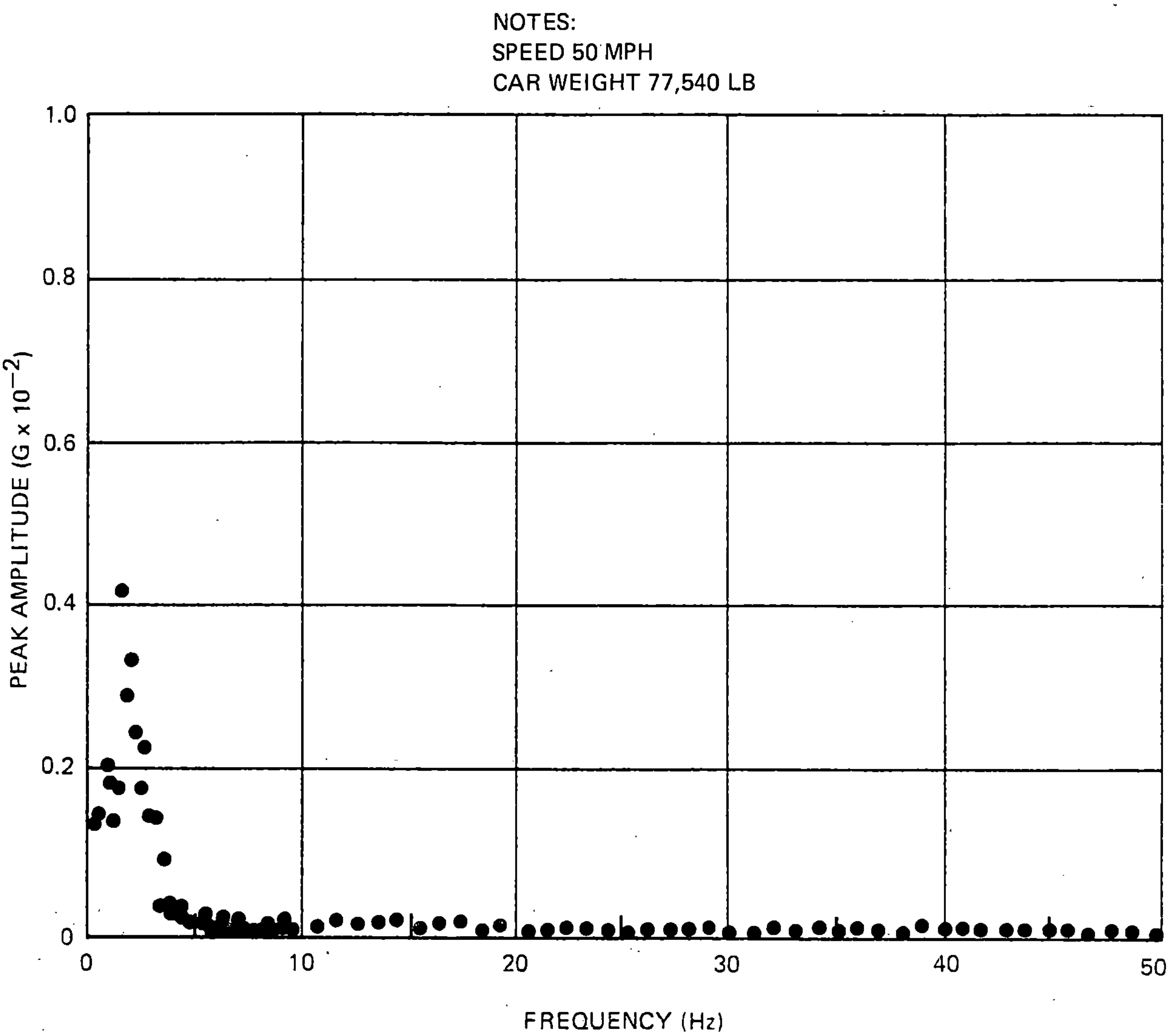


Figure A—32. Narrow-Band Spectrum Analysis — End Car, Lateral

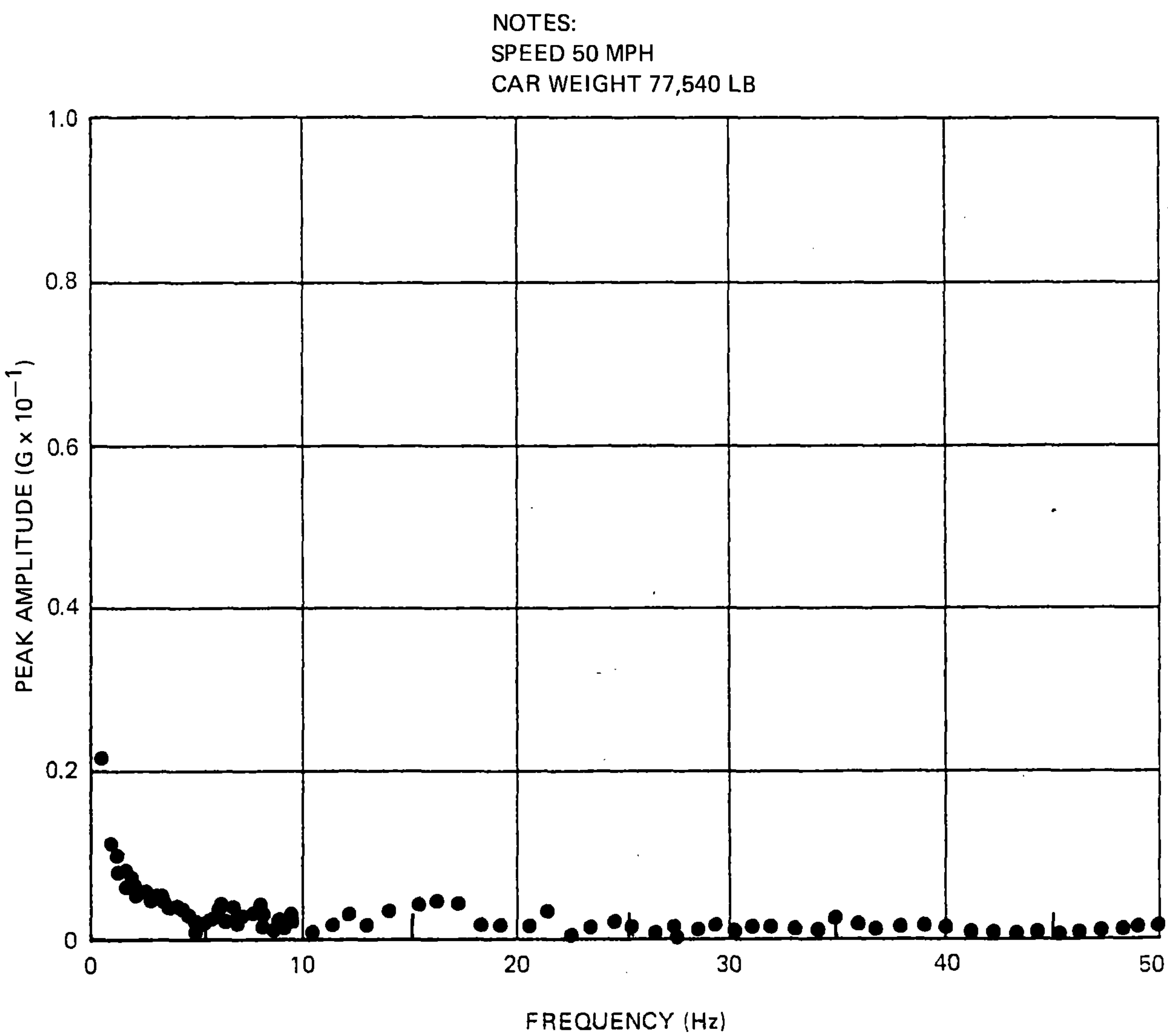


Figure A–33. Narrow-Band Spectrum Analysis – End Car, Longitudinal

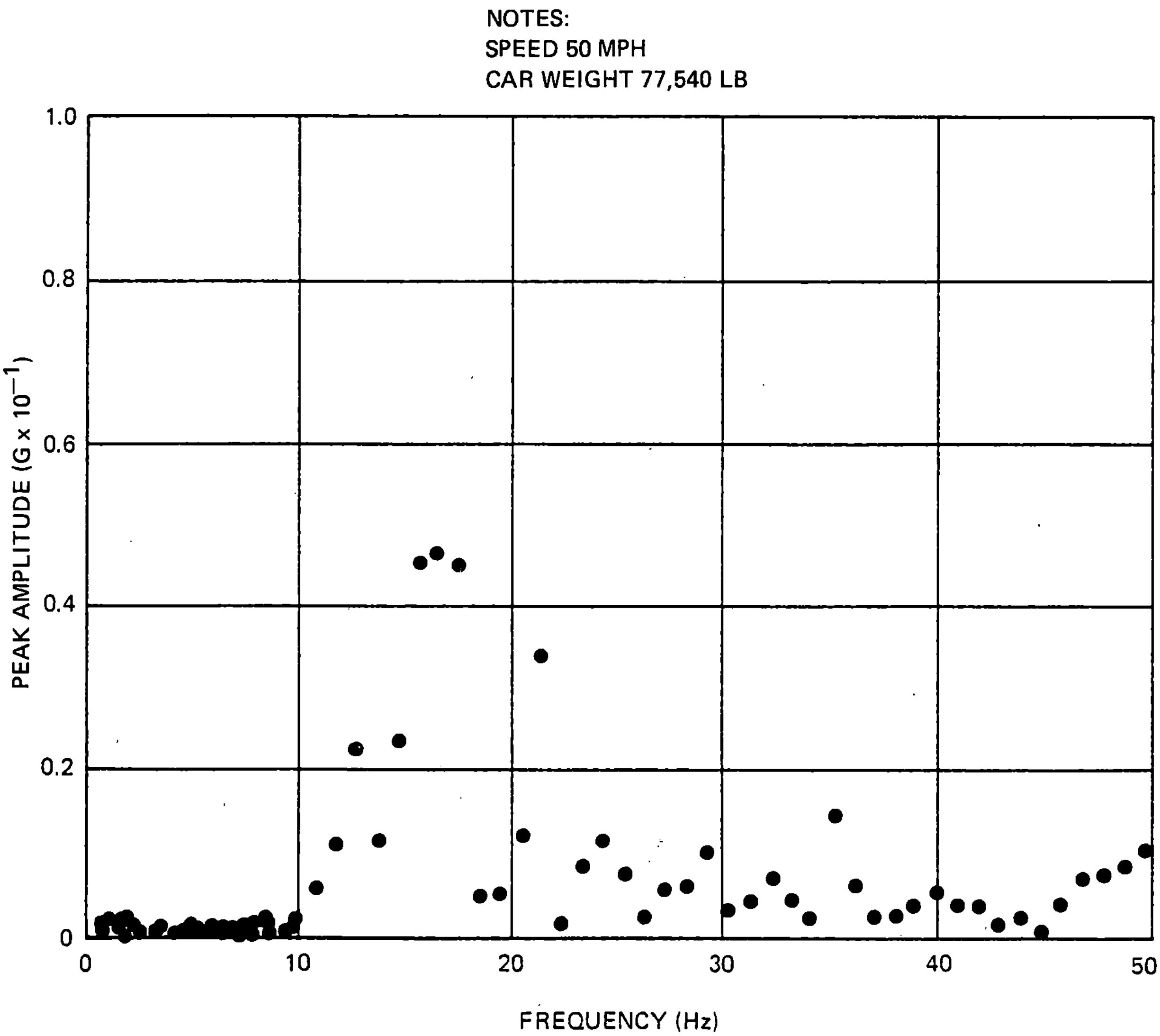


Figure A–34. Narrow-Band Spectrum Analysis – Mid Car, Vertical

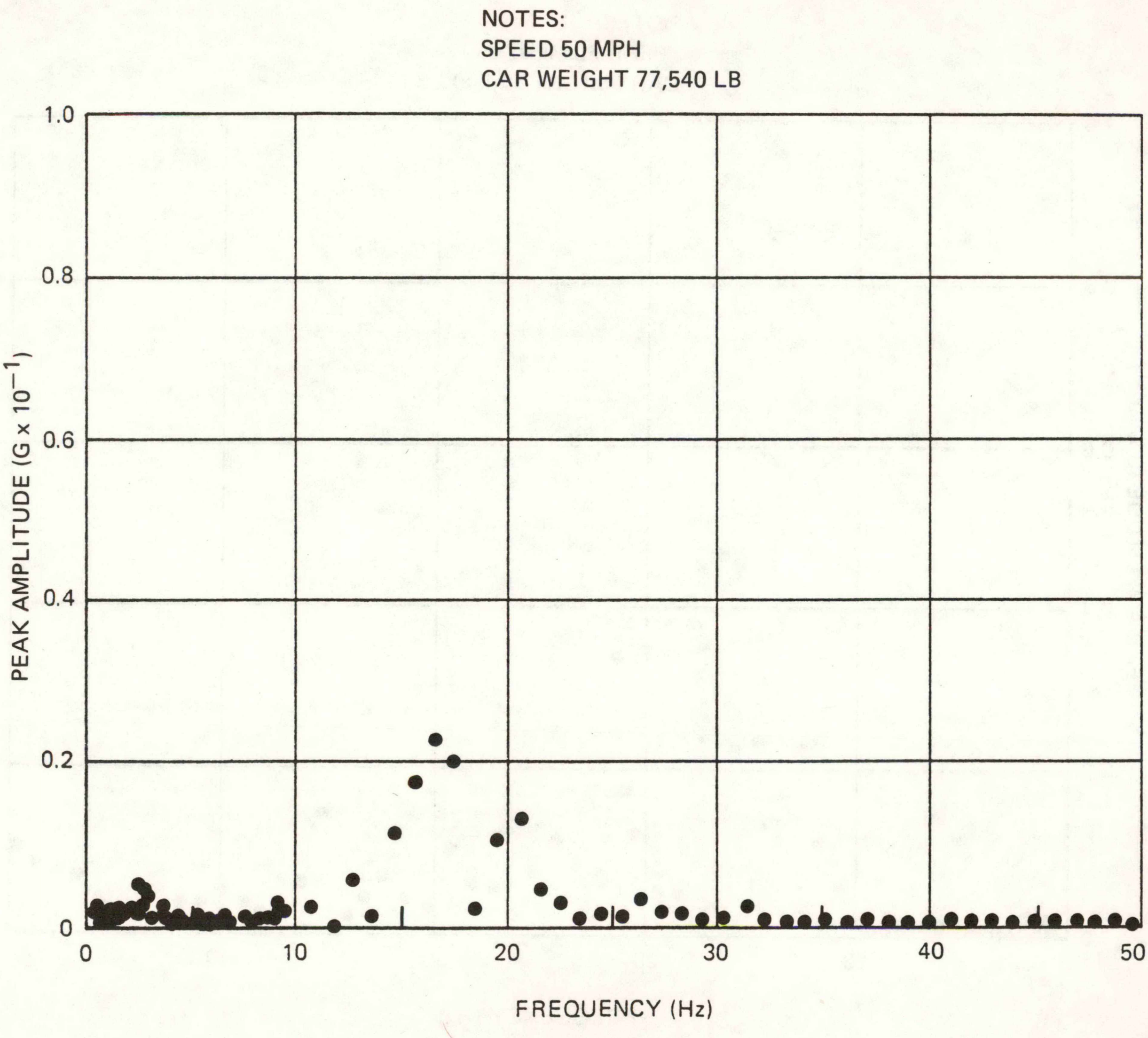


Figure A–35. Narrow-Band Spectrum Analysis – Mid Car, Lateral

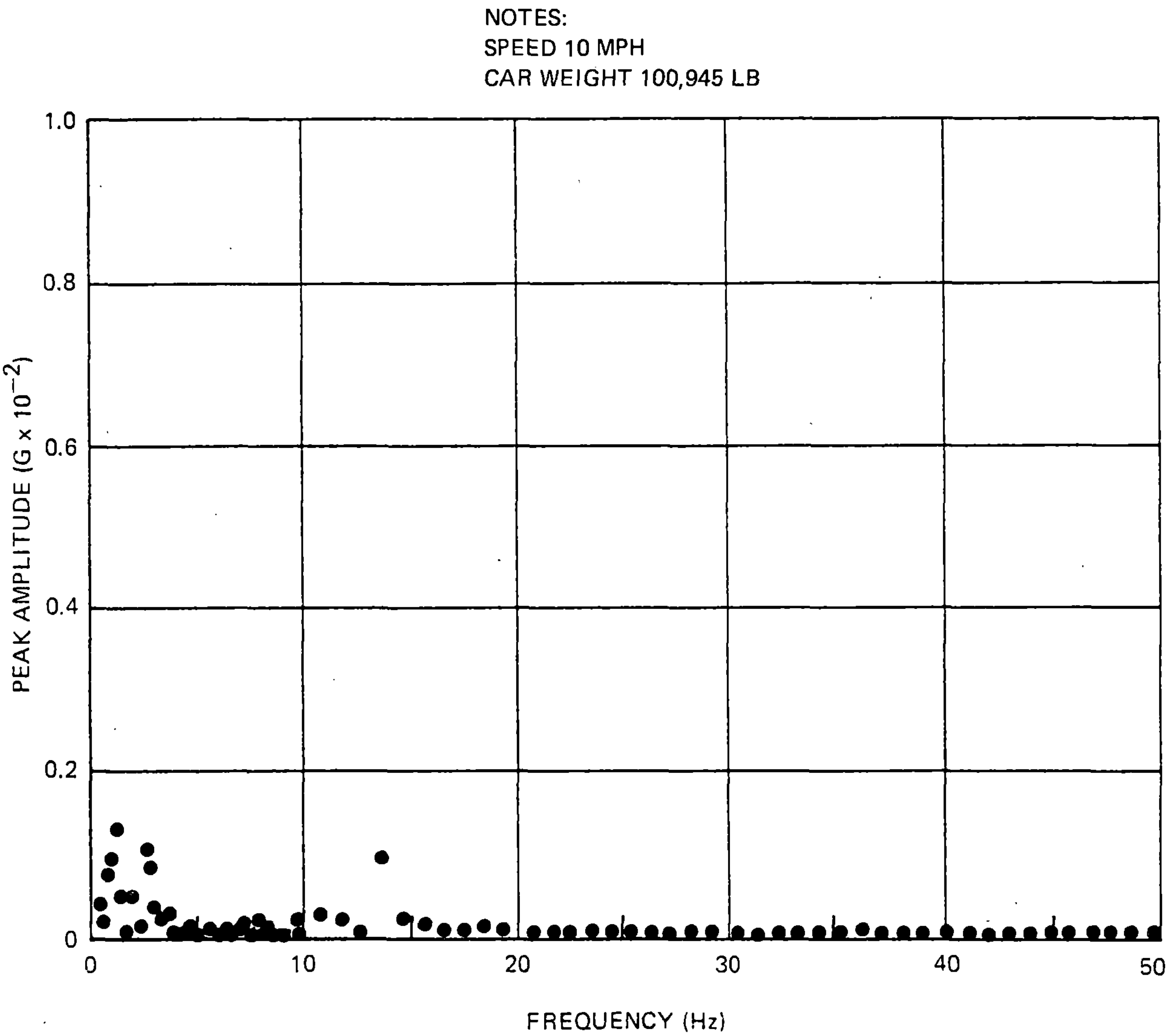


Figure A–36. Narrow-Band Spectrum Analysis – End Car, Vertical

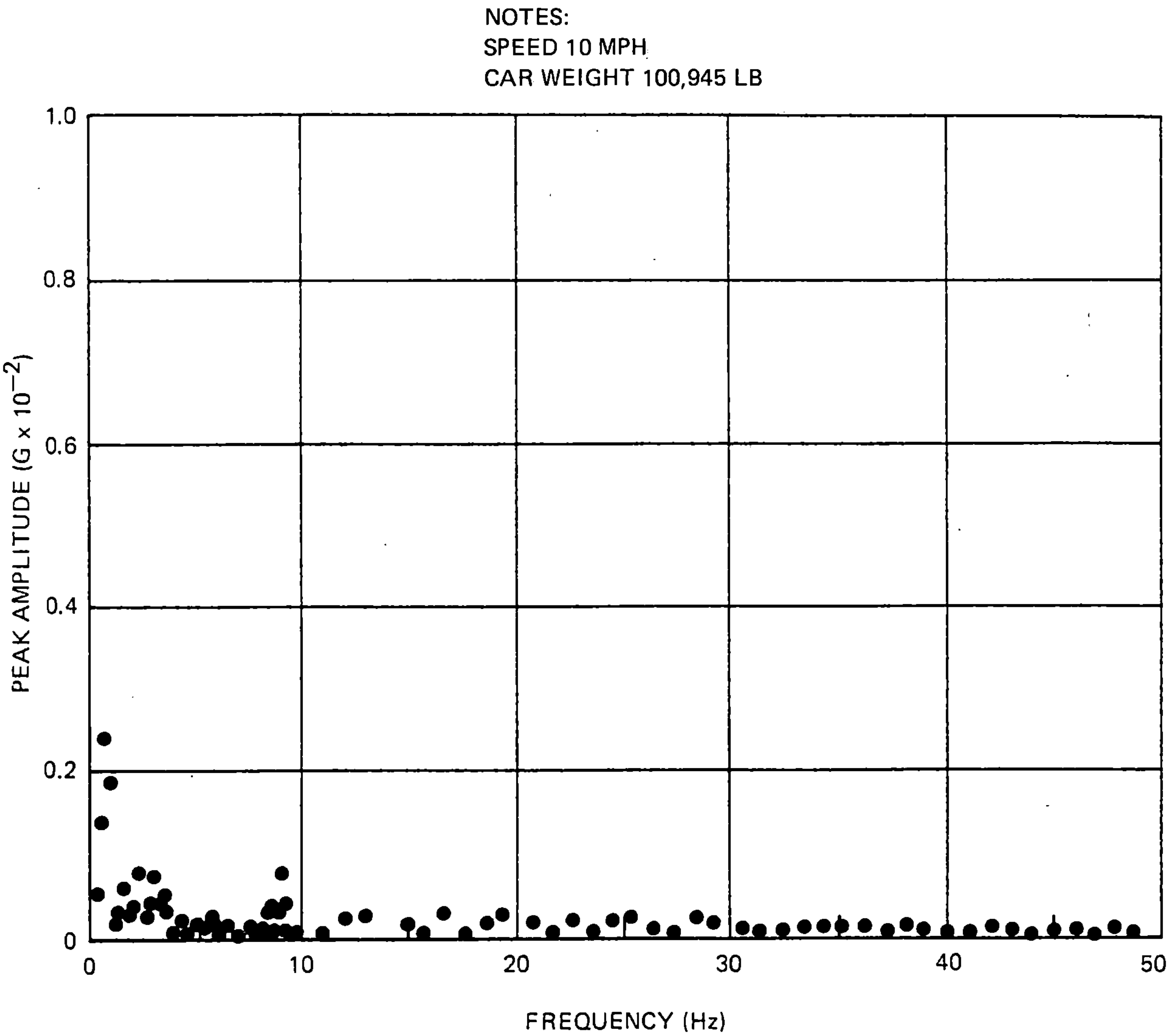


Figure A–37. Narrow-Band Spectrum Analysis – End Car, Lateral

NOTES:
SPEED 10 MPH
CAR WEIGHT 100,945 LB

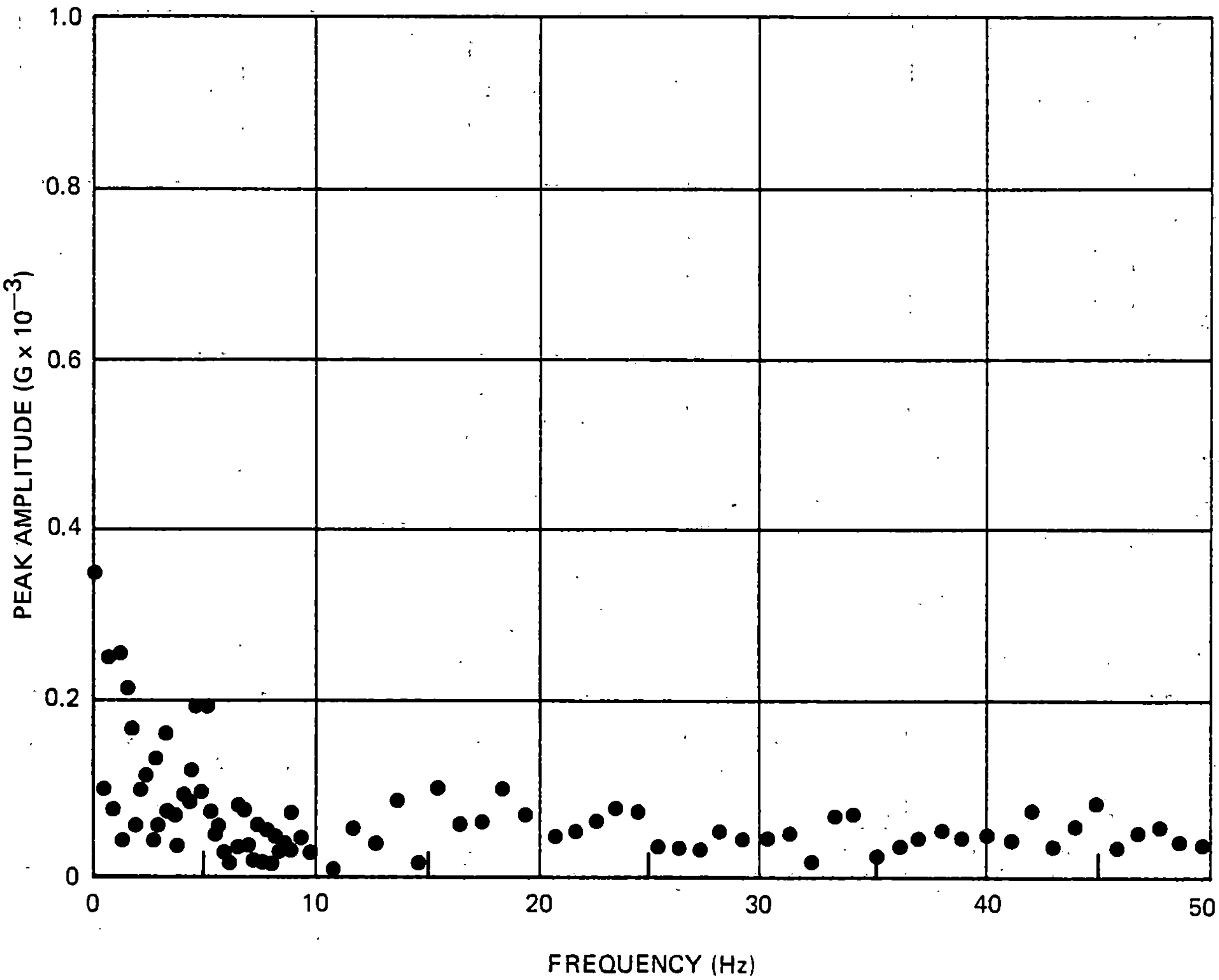


Figure A–38. Narrow-Band Spectrum Analysis – End Car, Longitudinal

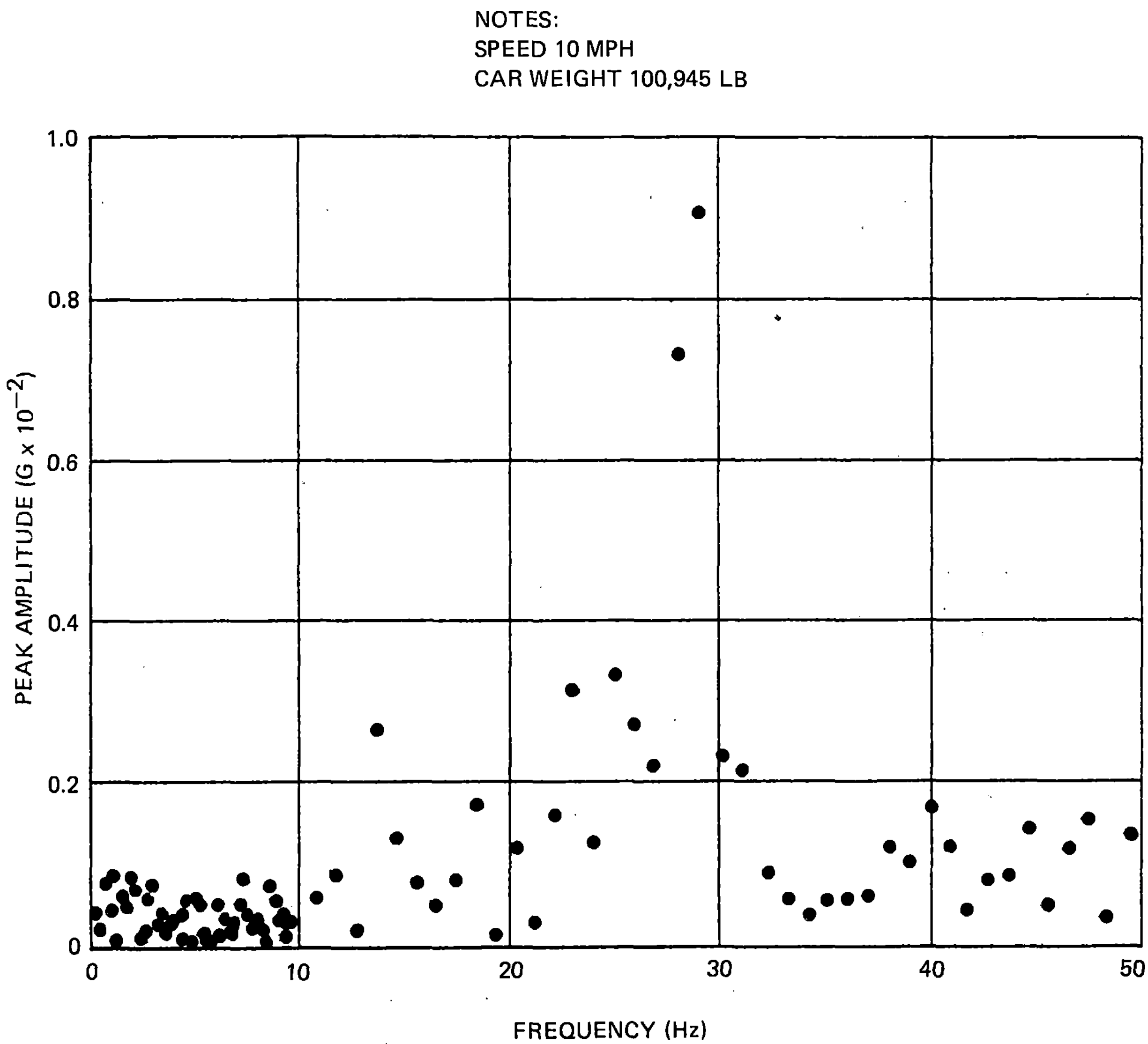


Figure A–39. Narrow-Band Spectrum Analysis – Mid Car, Vertical

NOTES:
SPEED 10 MPH
CAR WEIGHT 100,945 LB

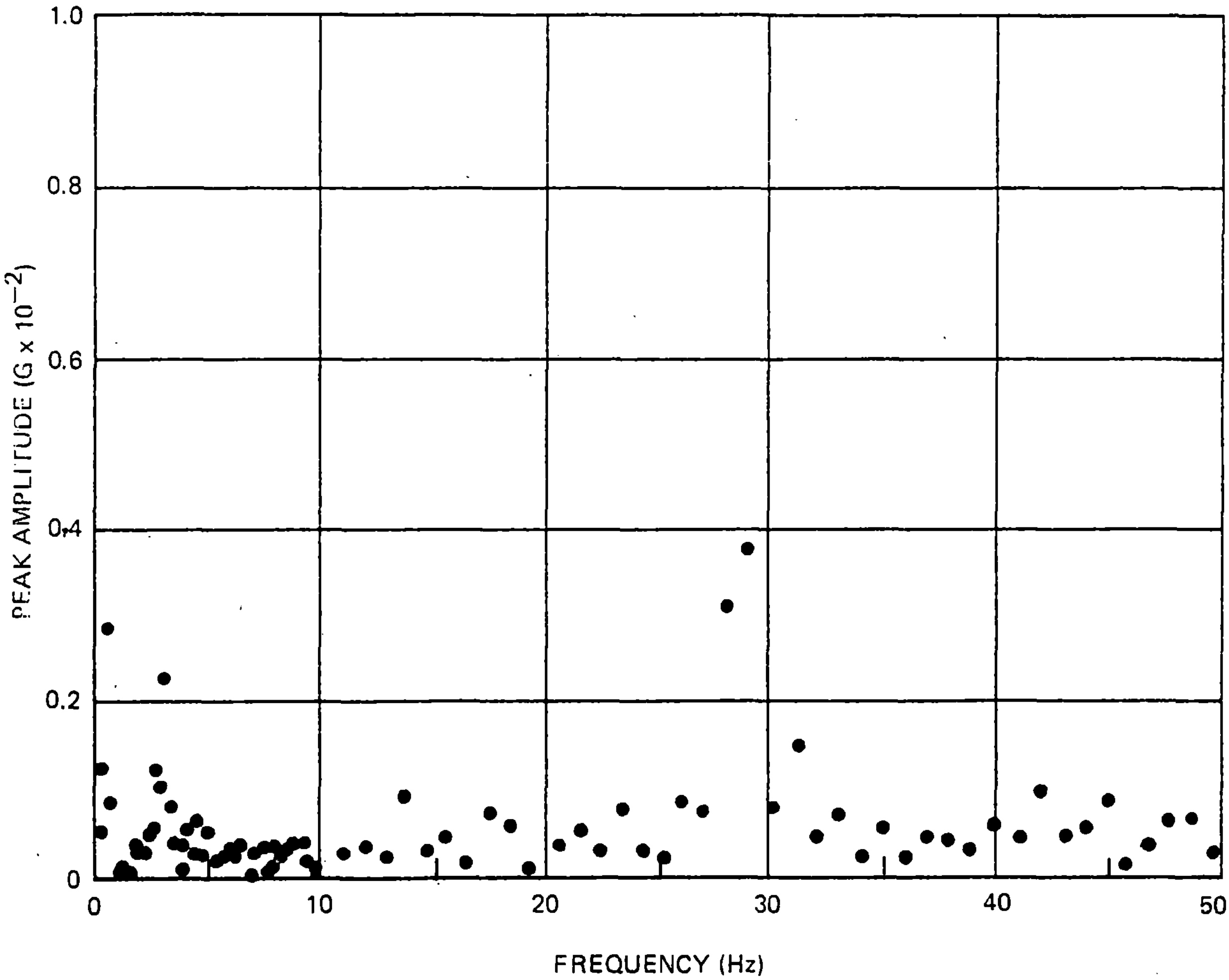


Figure A–40. Narrow-Band Spectrum Analysis – Mid Car, Lateral

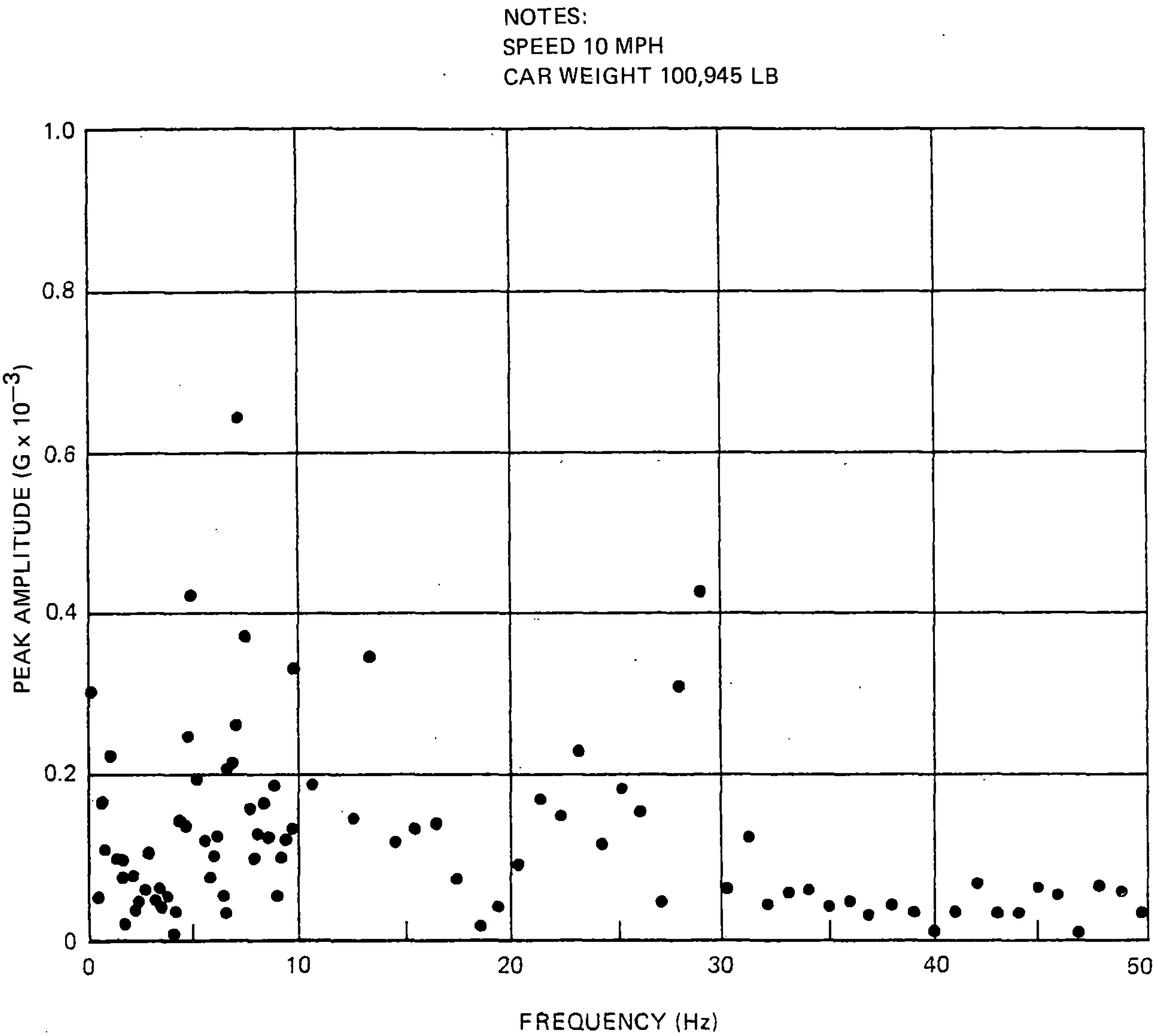


Figure A–41. Narrow-Band Spectrum Analysis – Mid Car, Longitudinal

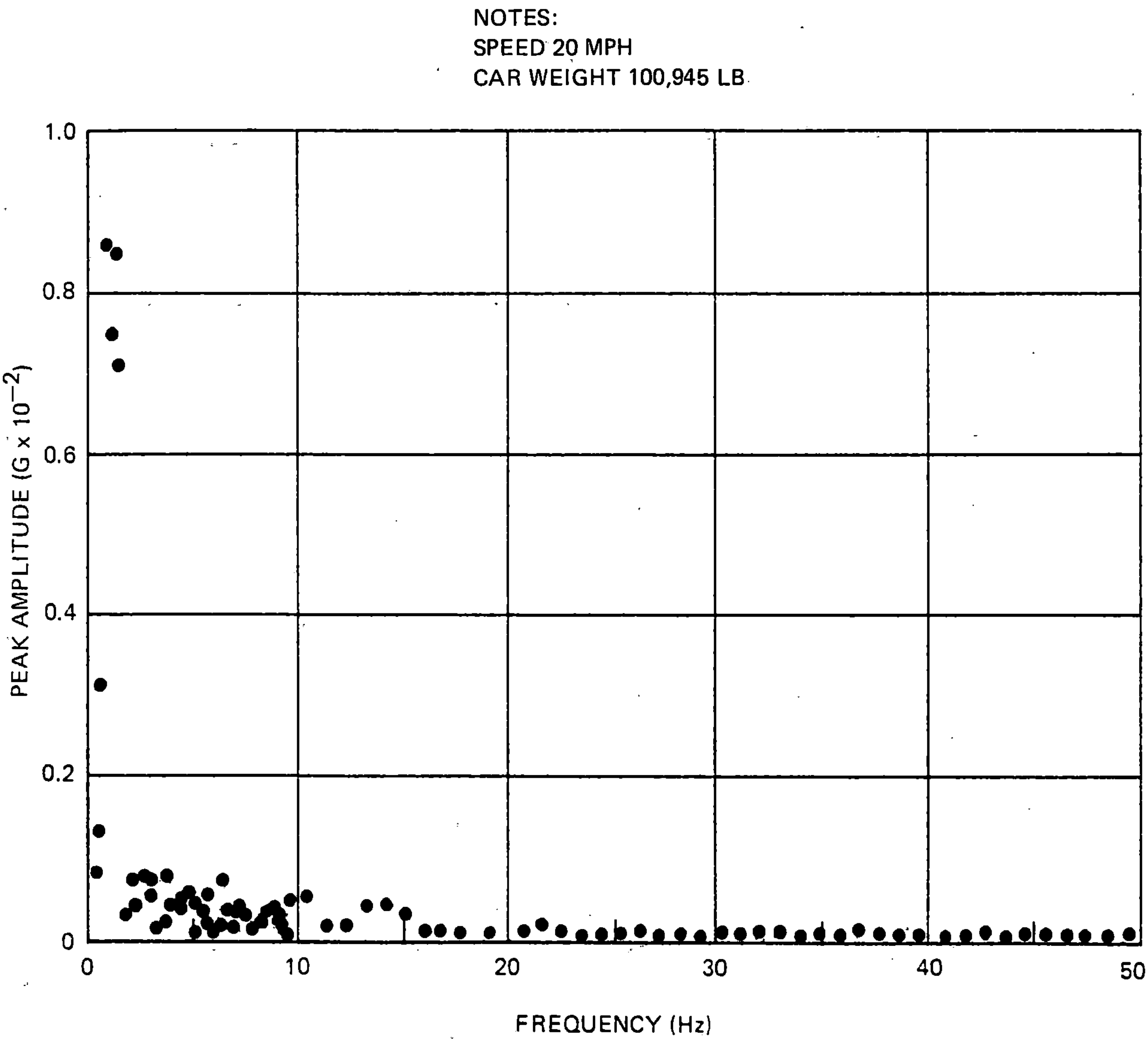


Figure A–42. Narrow-Band Spectrum Analysis – End Car, Vertical

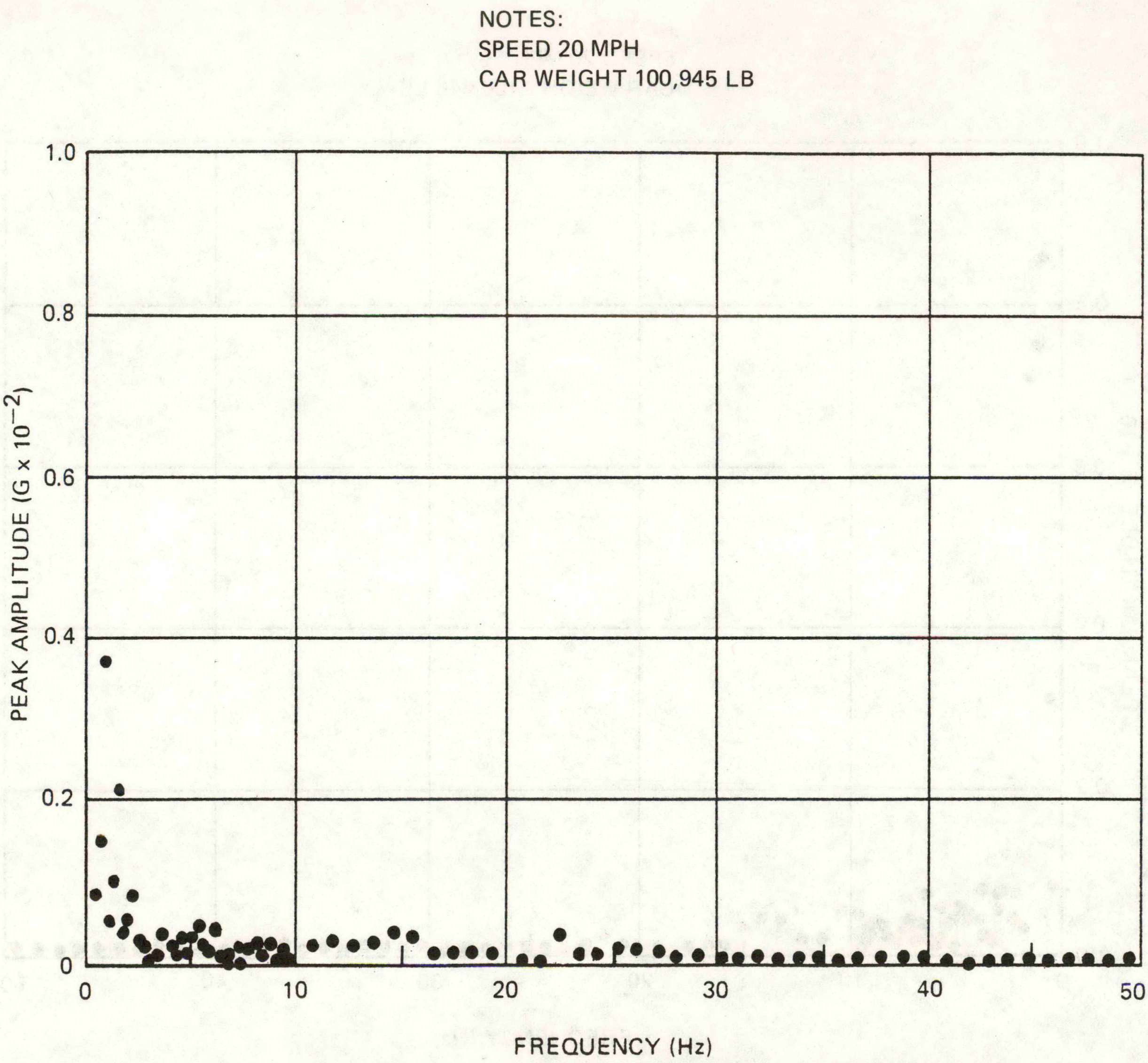


Figure A–43. Narrow-Band Spectrum Analysis – End Car, Lateral

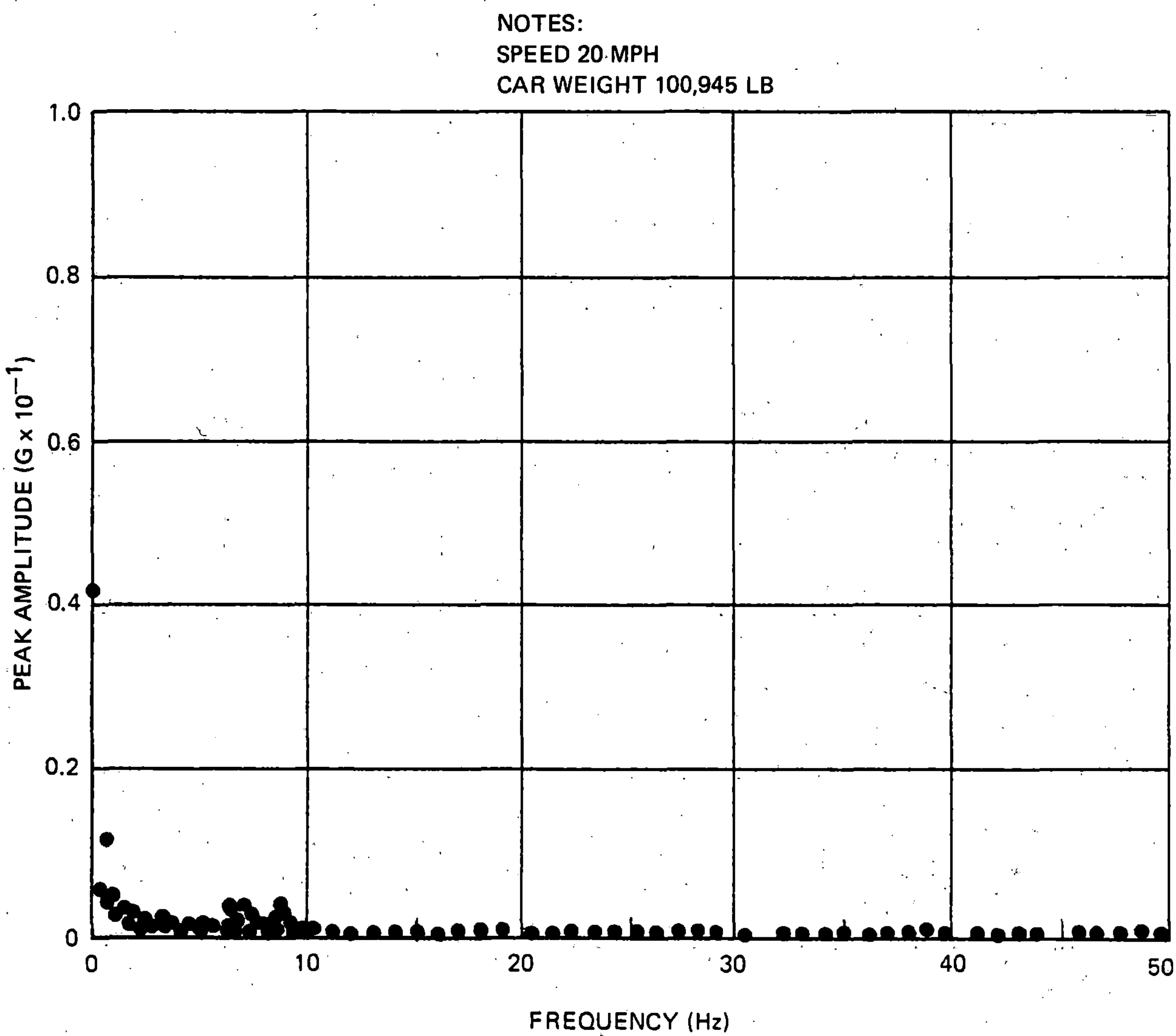


Figure A–44. Narrow-Band Spectrum Analysis – End Car, Longitudinal

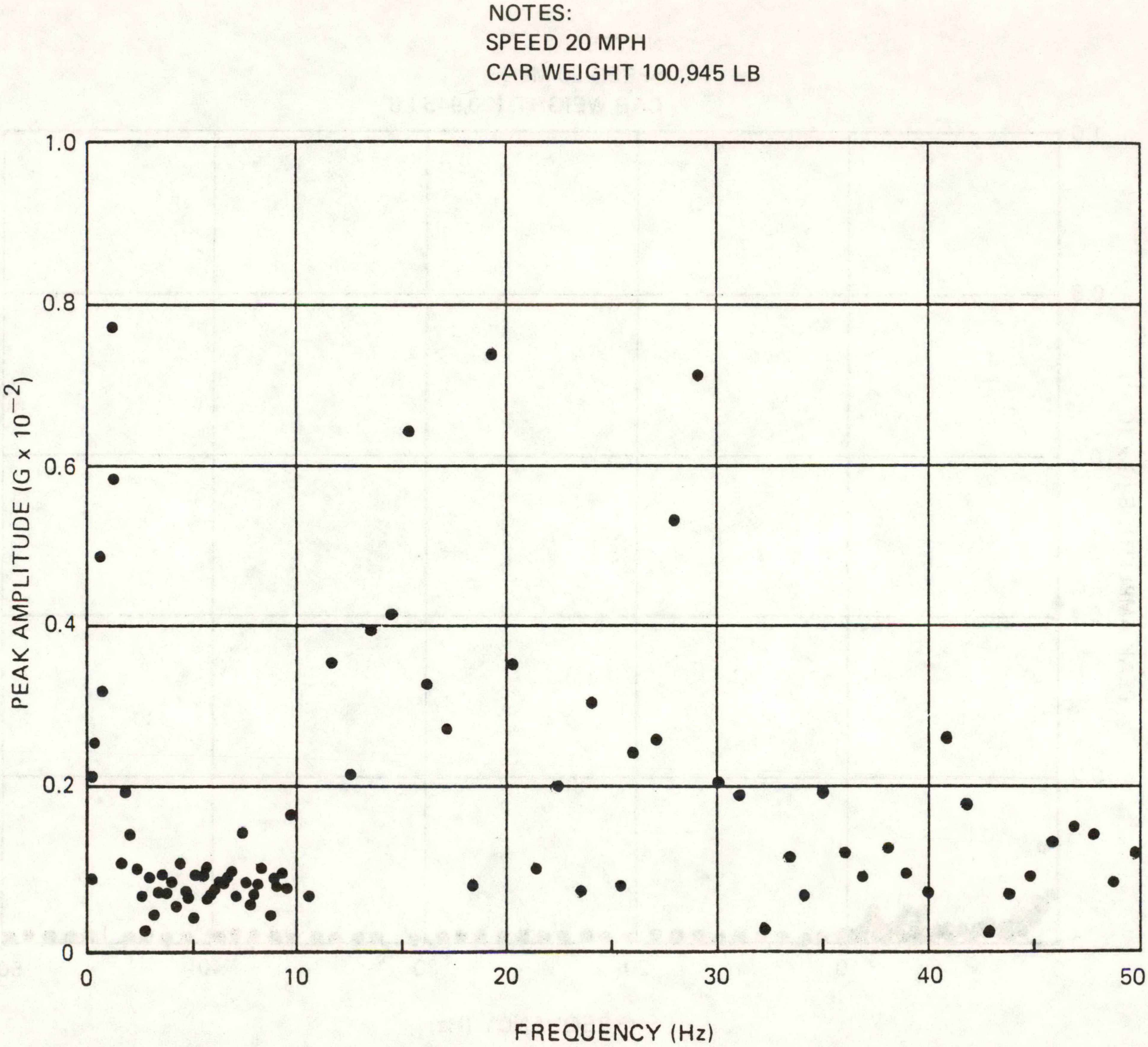


Figure A–45. Narrow-Band Spectrum Analysis – Mid Car, Vertical

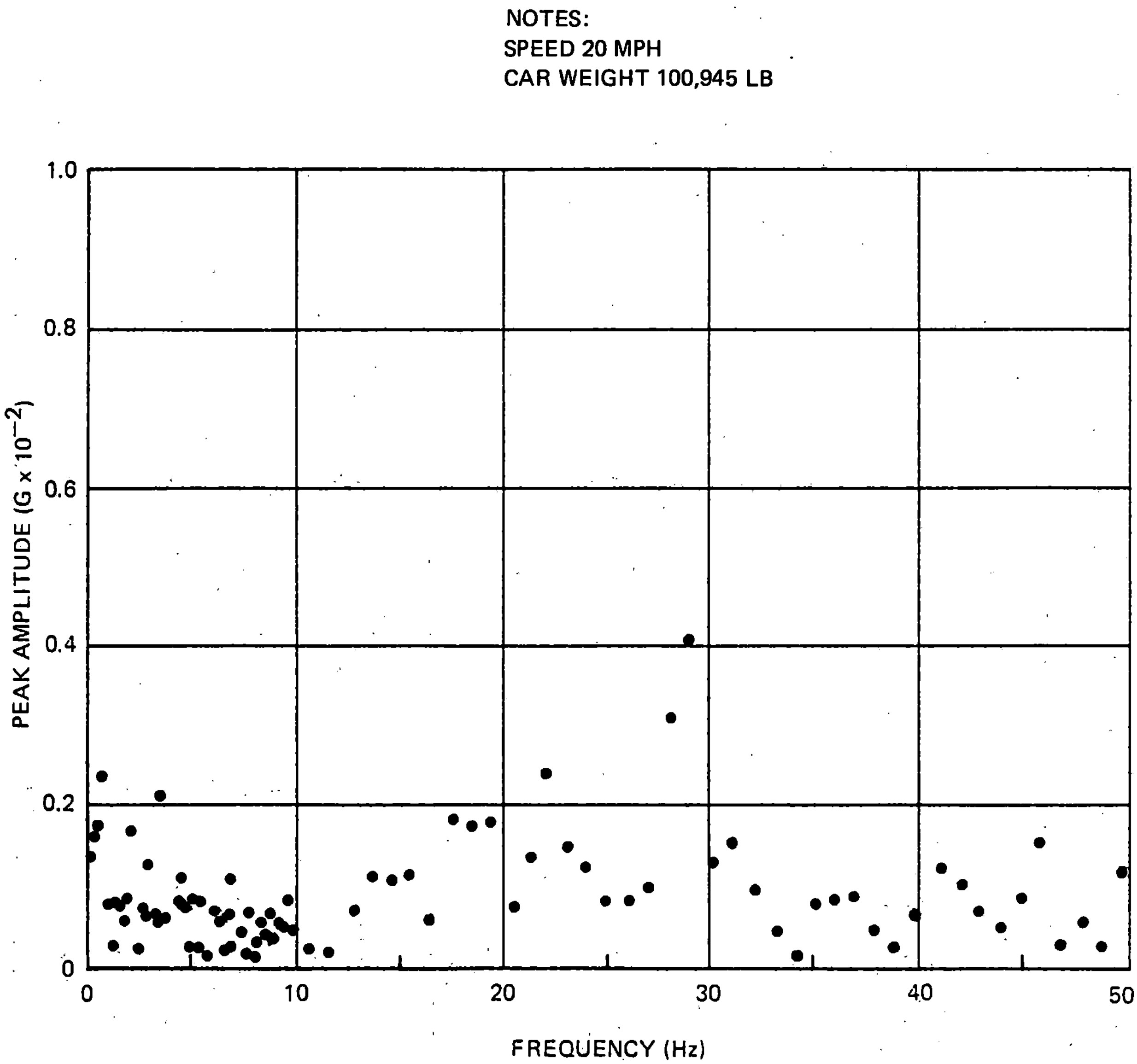


Figure A–46. Narrow-Band Spectrum Analysis – Mid Car, Lateral

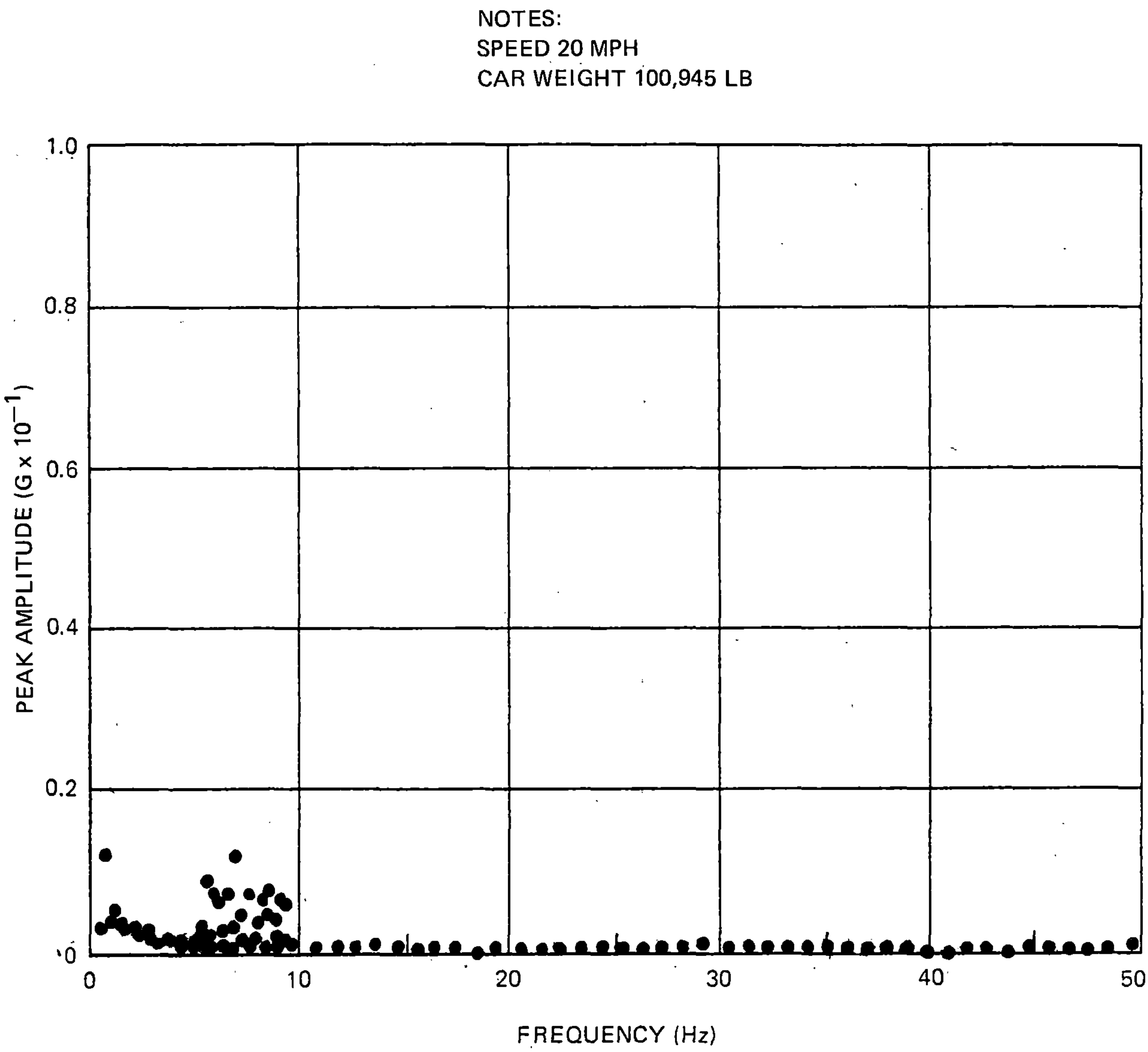


Figure A–47. Narrow-Band Spectrum Analysis – Mid Car, Longitudinal

NOTES:
SPEED 30 MPH
CAR WEIGHT 100,945 LB

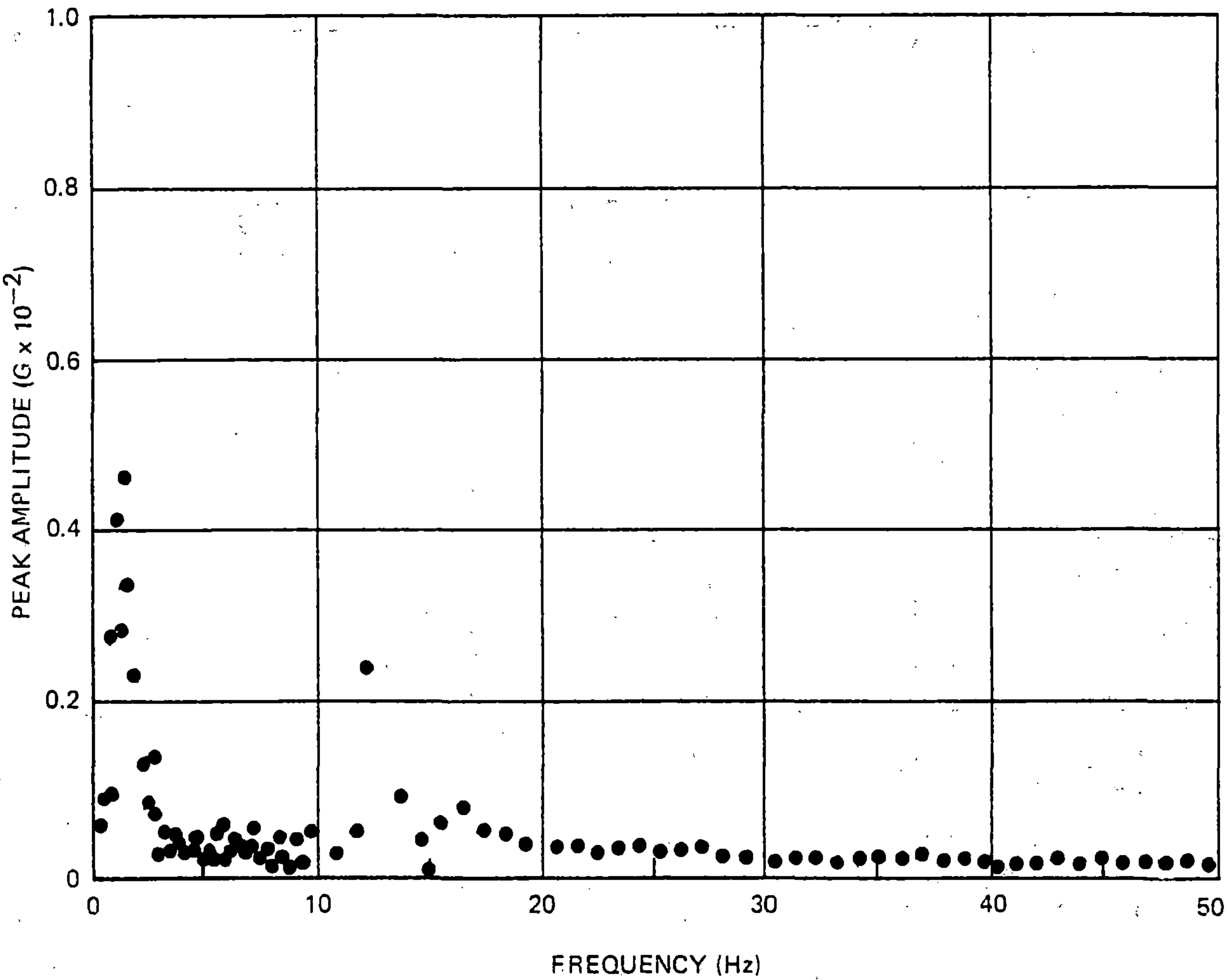


Figure A—48. Narrow-Band Spectrum Analysis — End Car, Vertical

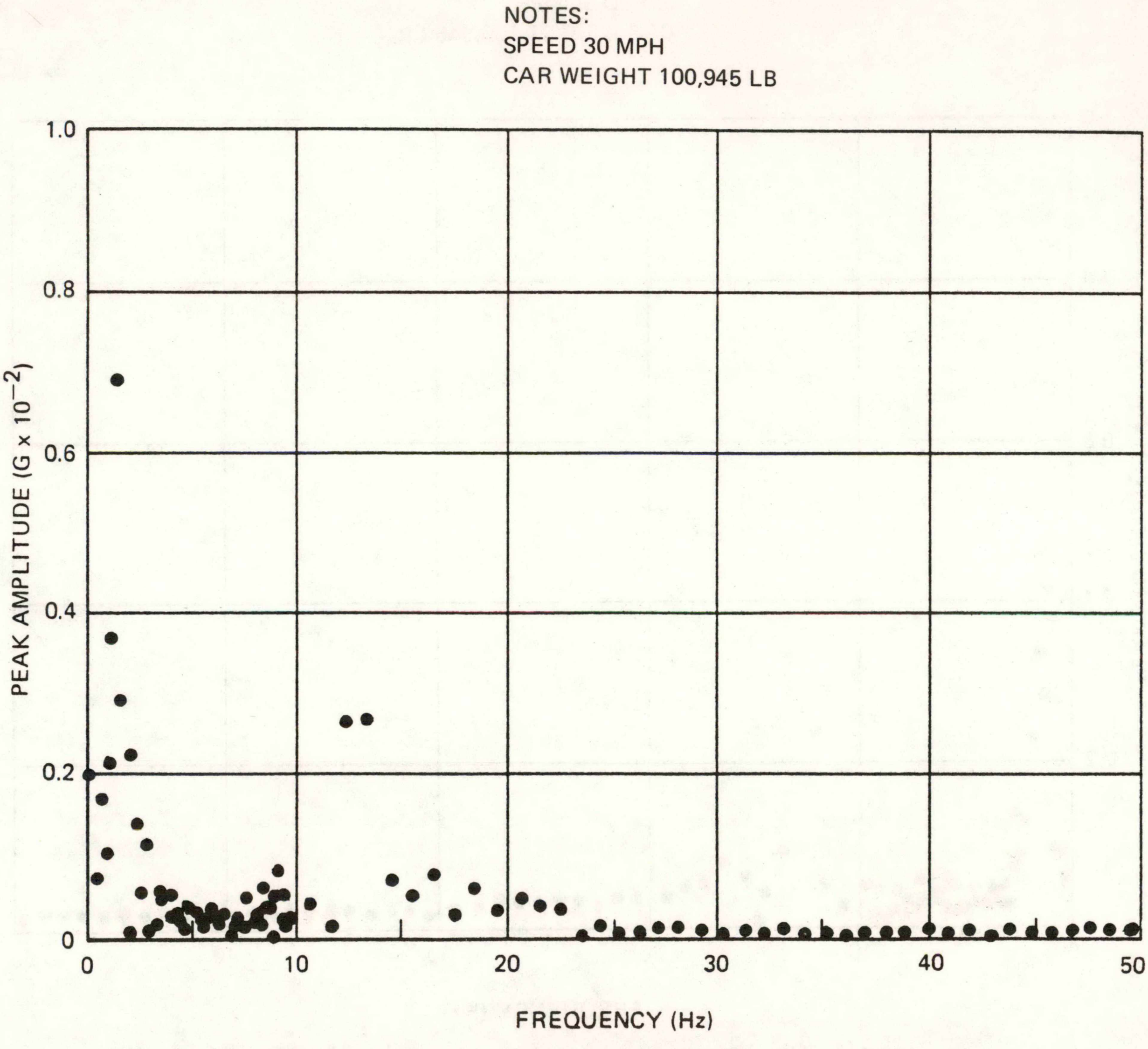


Figure A–49. Narrow-Band Spectrum Analysis – End Car, Lateral

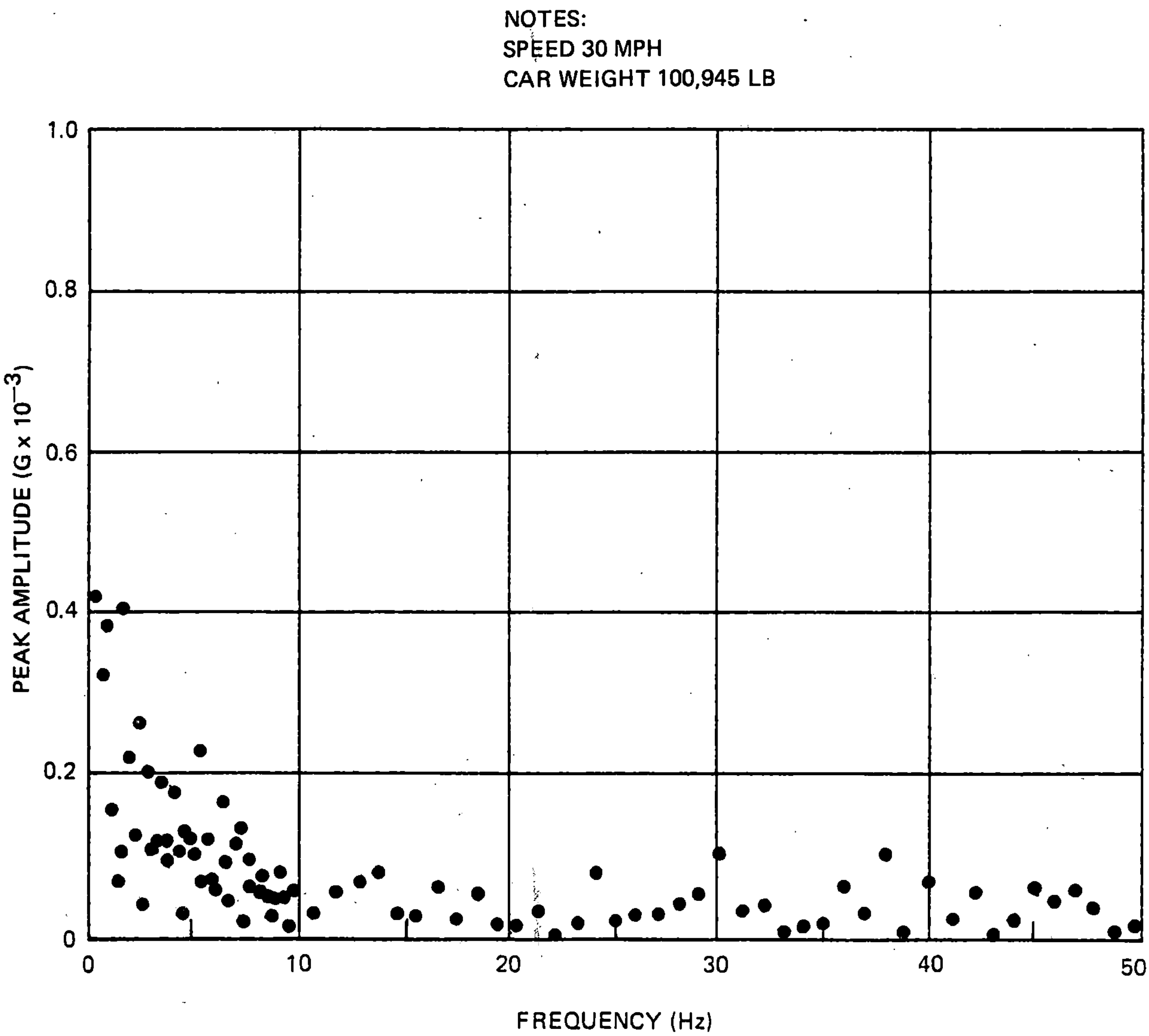


Figure A—50. Narrow-Band Spectrum Analysis — End Car, Longitudinal

NOTES:
SPEED 30 MPH
CAR WEIGHT 100,945 LB

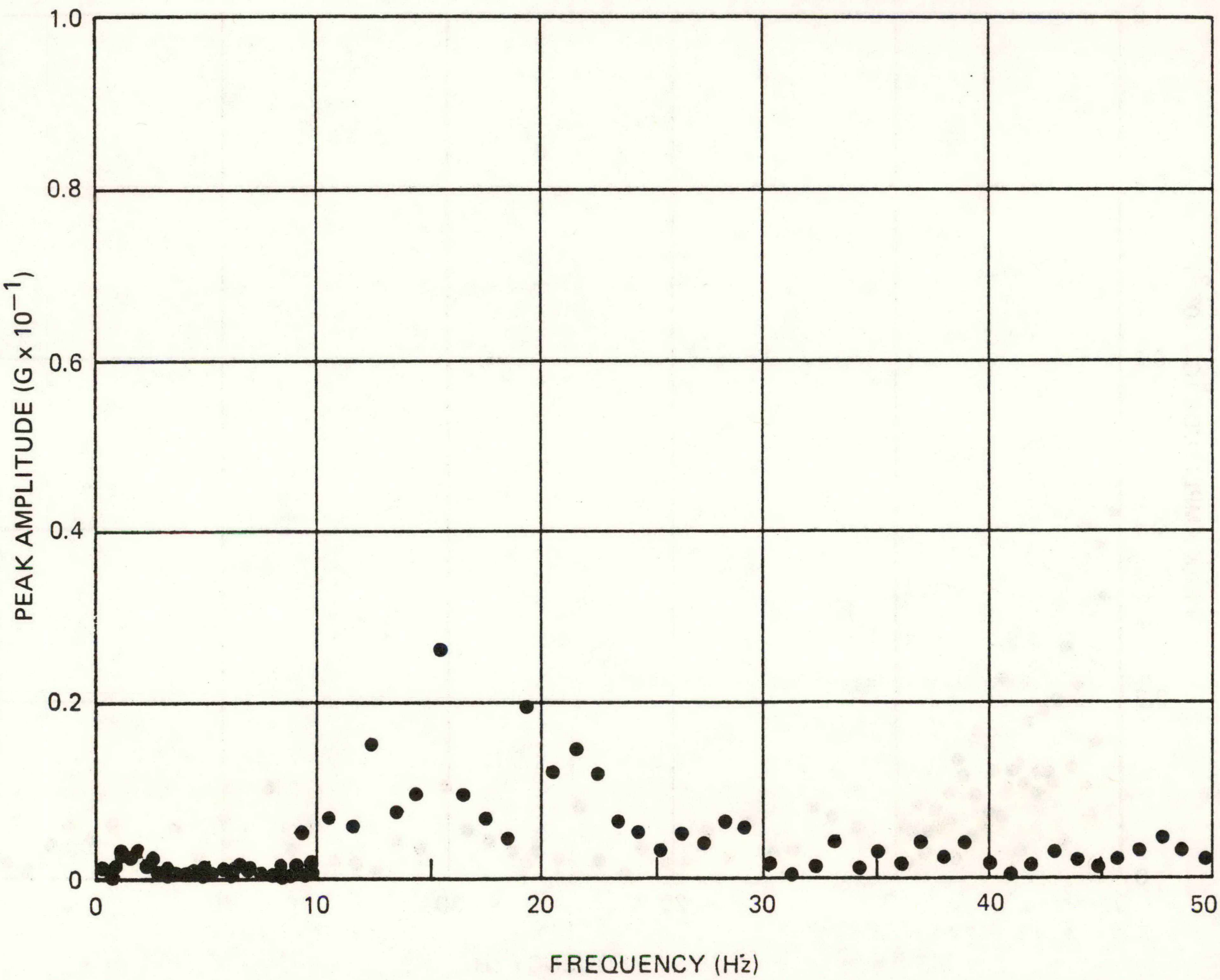


Figure A–51. Narrow-Band Spectrum Analysis – Mid Car, Vertical

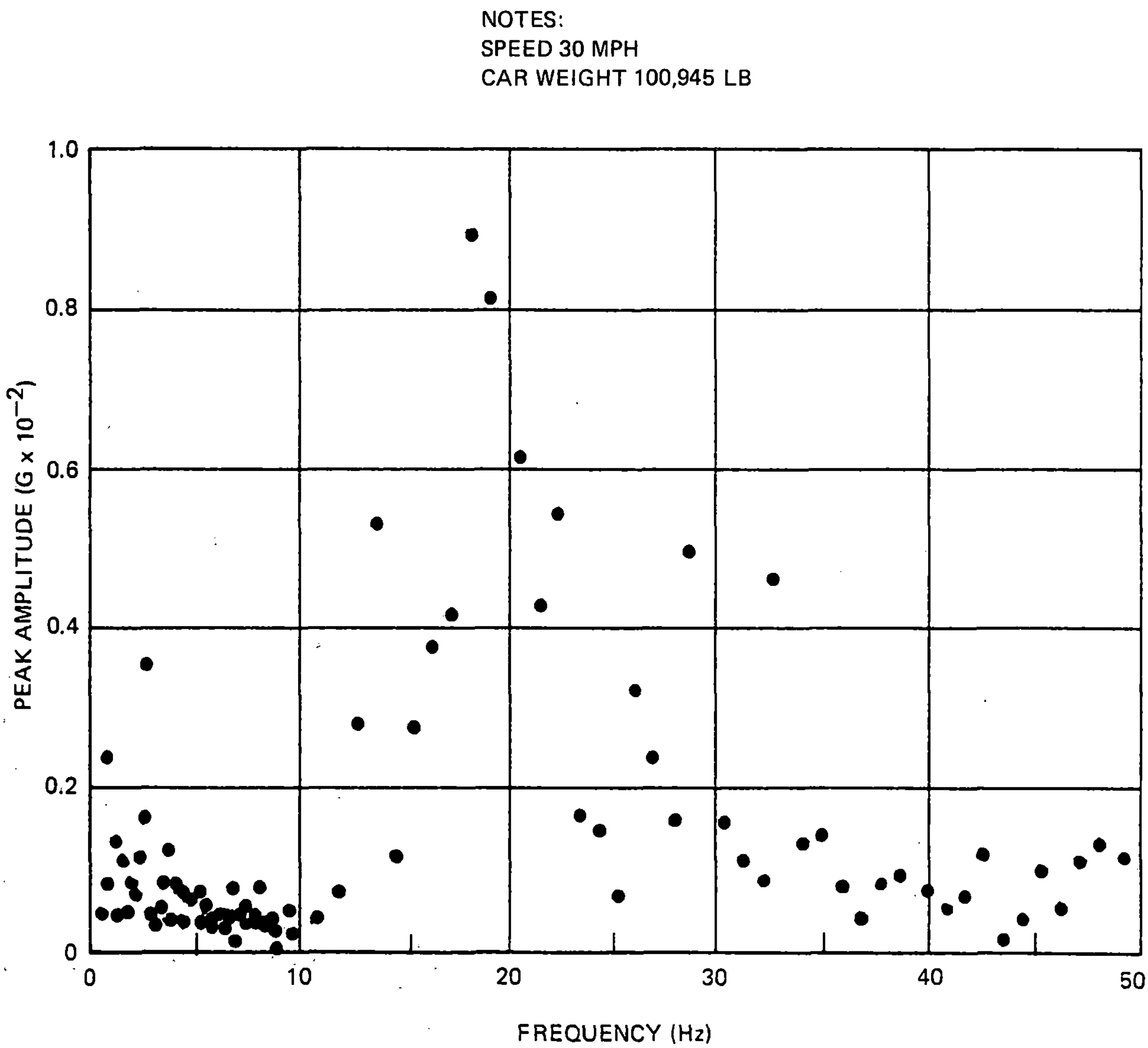


Figure A—52. Narrow-Band Spectrum Analysis — Mid Car, Lateral

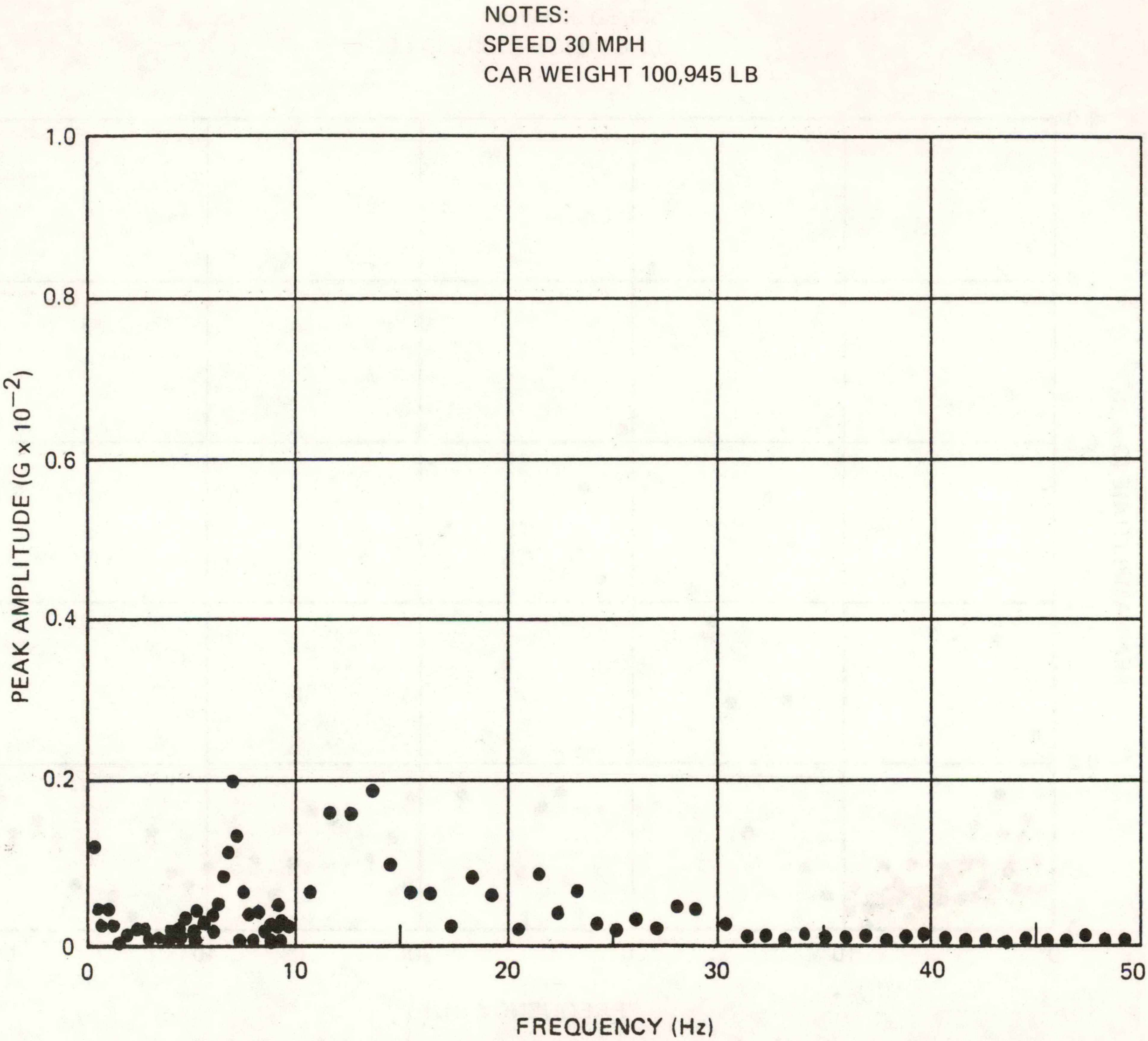


Figure A–53. Narrow-Band Spectrum Analysis – Mid Car, Longitudinal

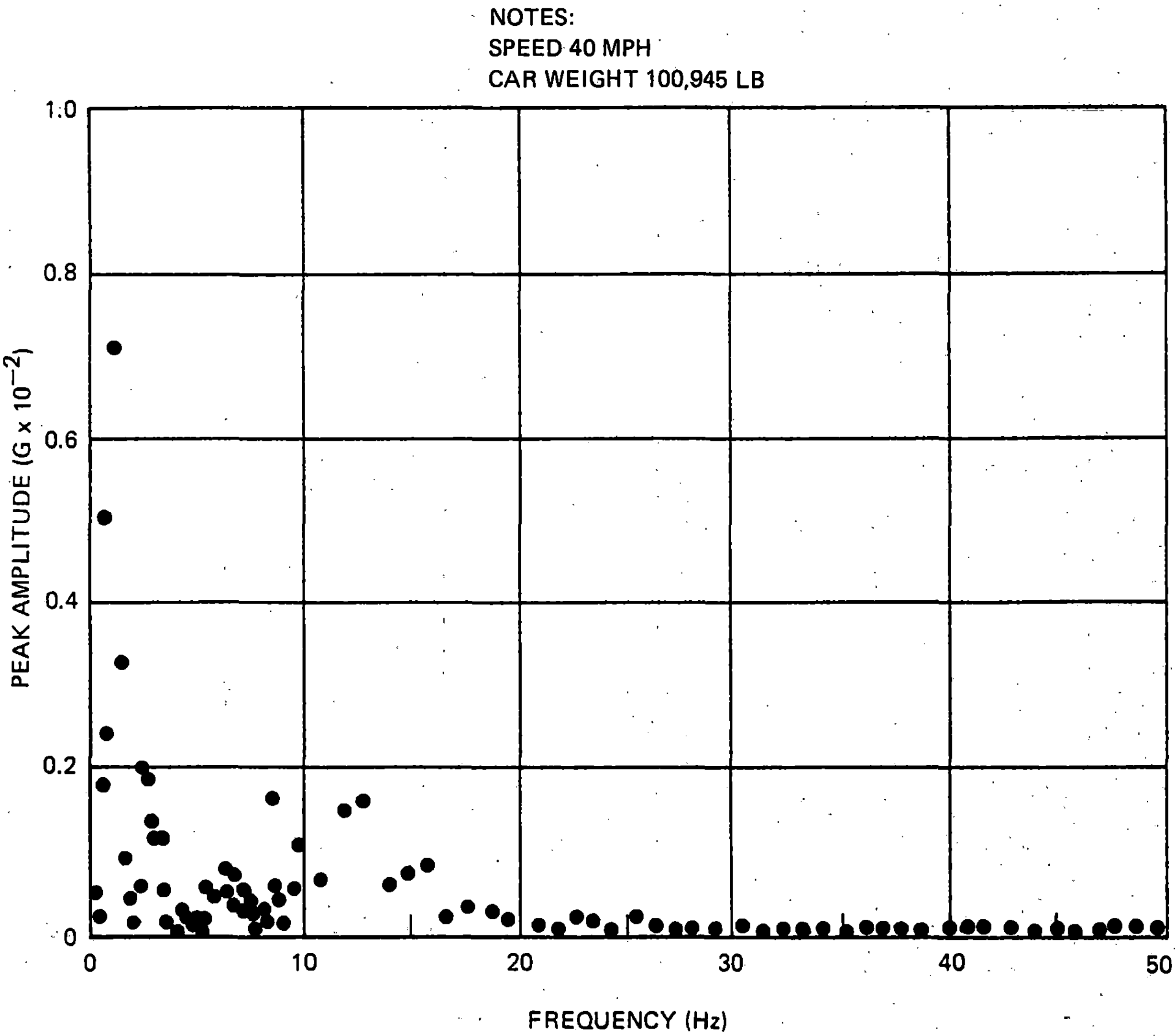


Figure A—54. Narrow-Band Spectrum Analysis — End Car, Vertical

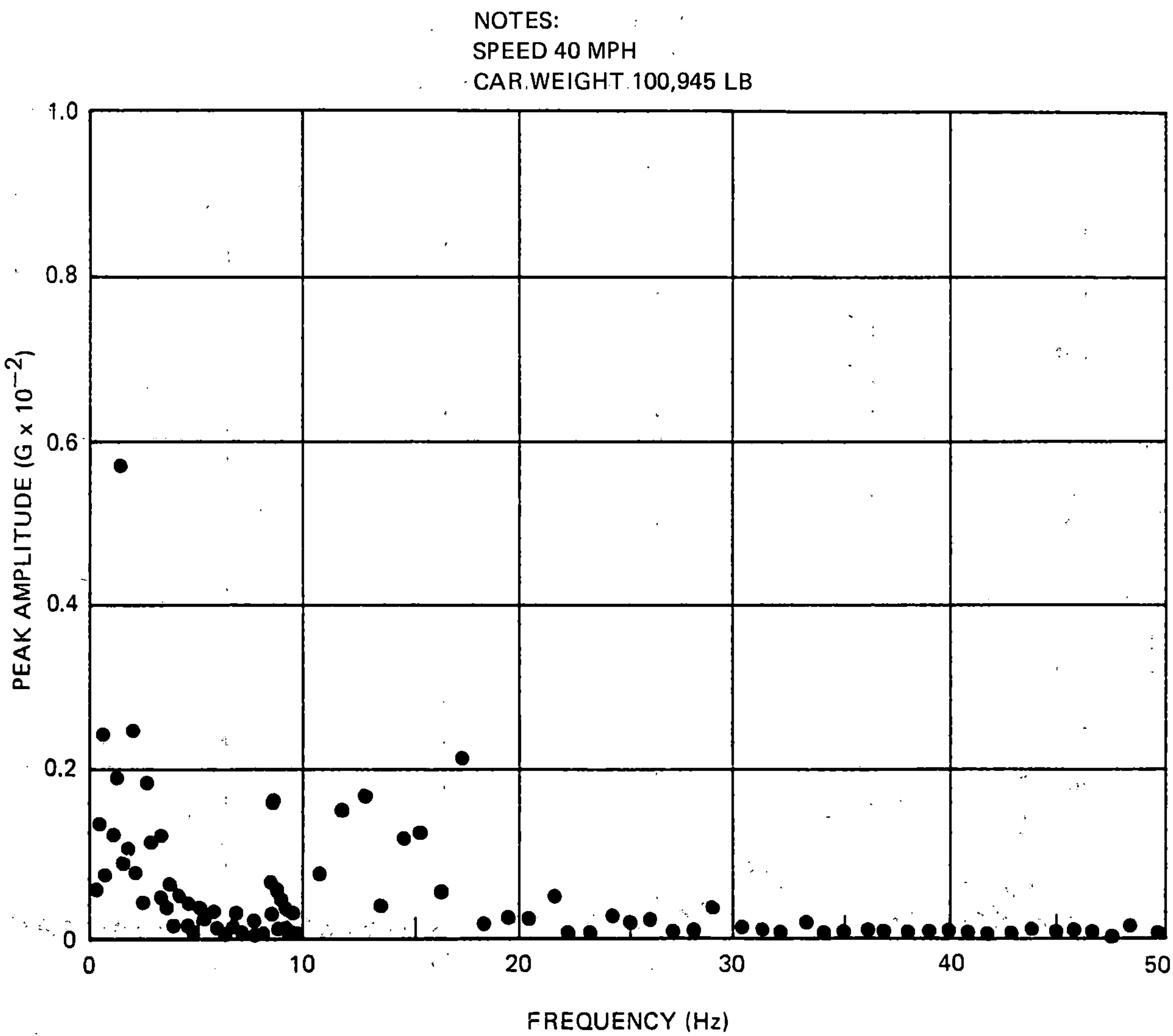


Figure A–55. Narrow-Band Spectrum Analysis — End Car, Lateral

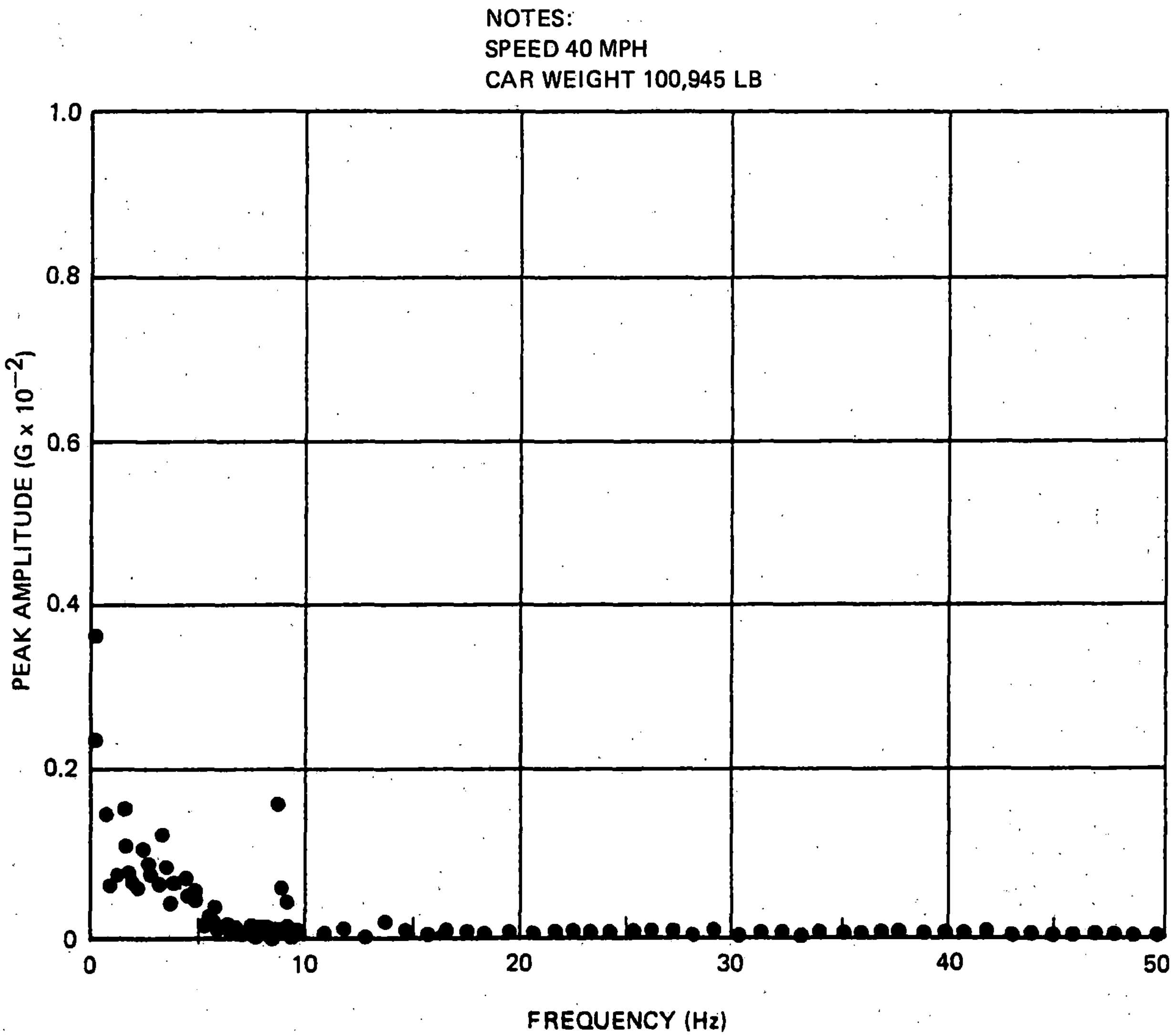


Figure A–56. Narrow-Band Spectrum Analysis – End Car, Longitudinal

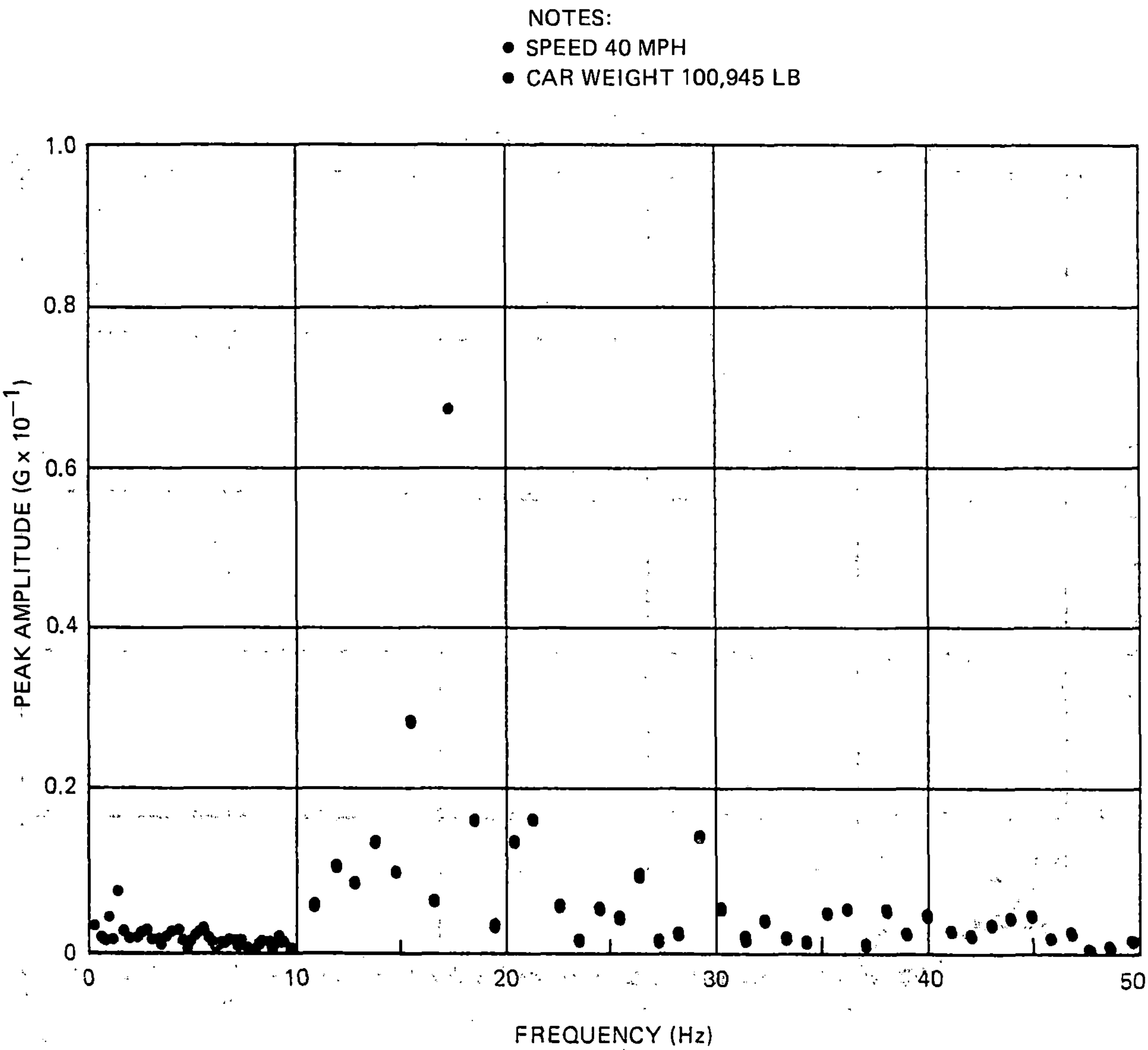


Figure A–57. Narrow-Band Spectrum Analysis – Mid Car, Vertical

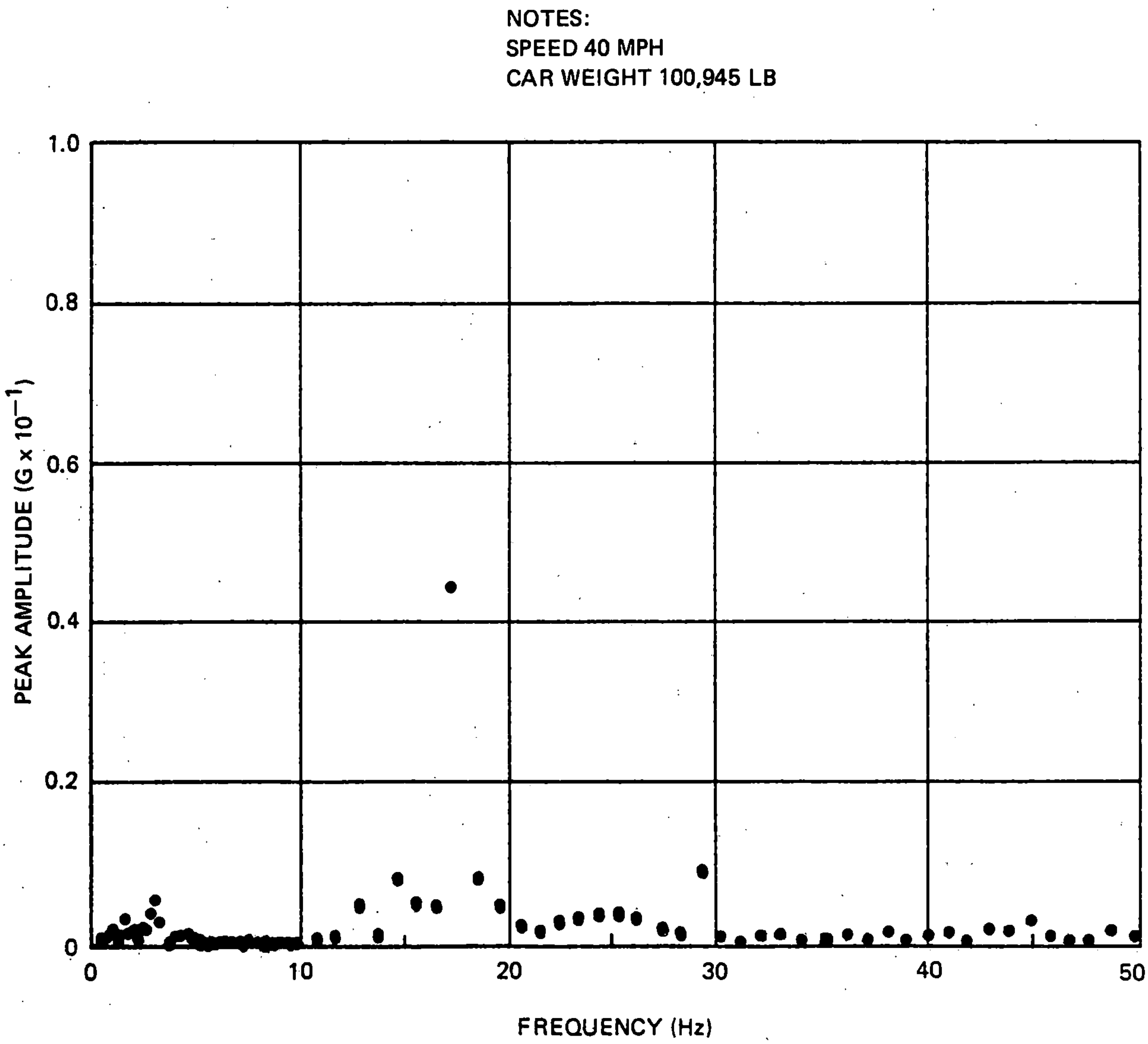


Figure A–58. Narrow-Band Spectrum Analysis – Mid Car, Lateral

NOTES:
SPEED 40 MPH
CAR WEIGHT 100,945 LB

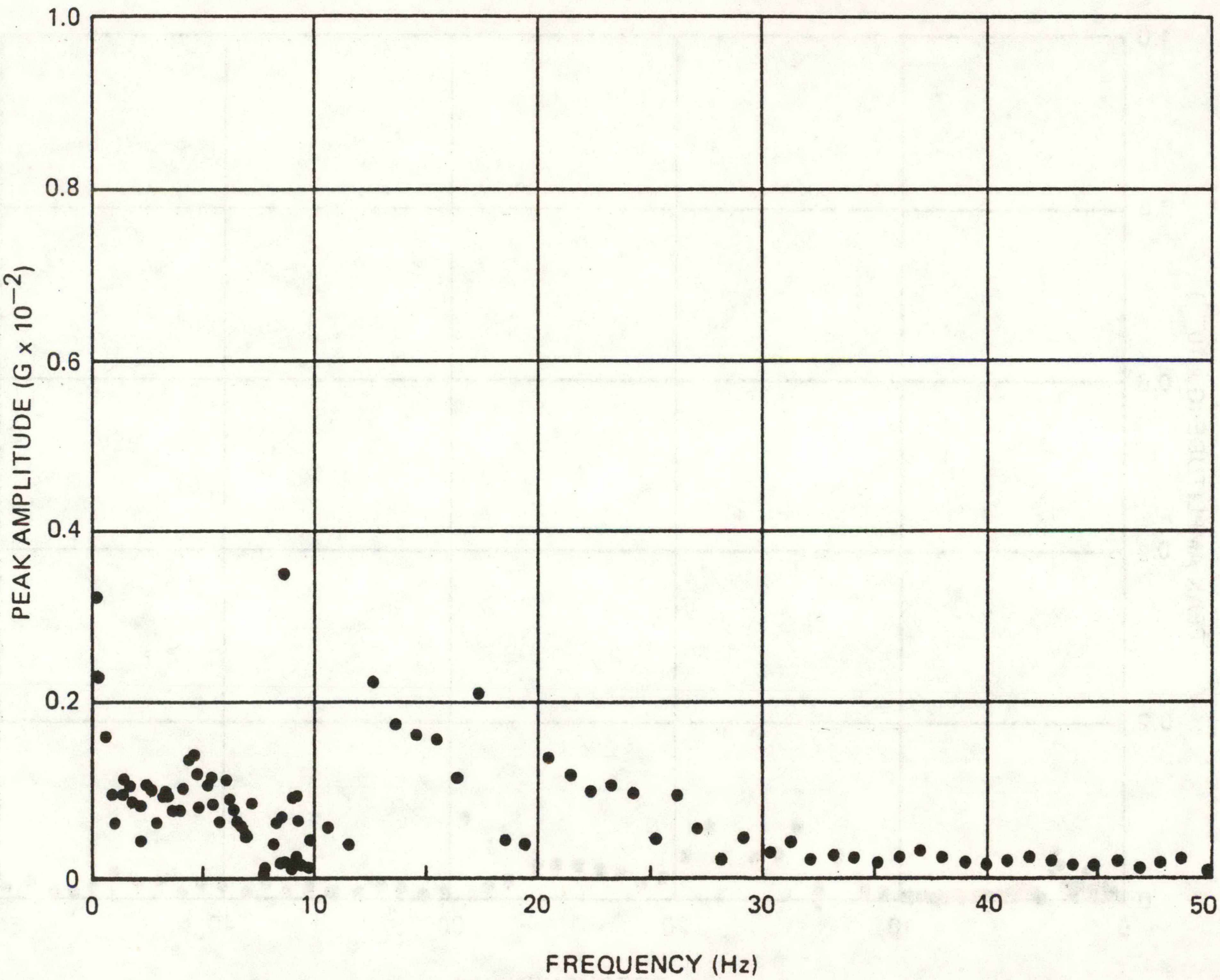


Figure A–59. Narrow-Band Spectrum Analysis – Mid Car, Longitudinal

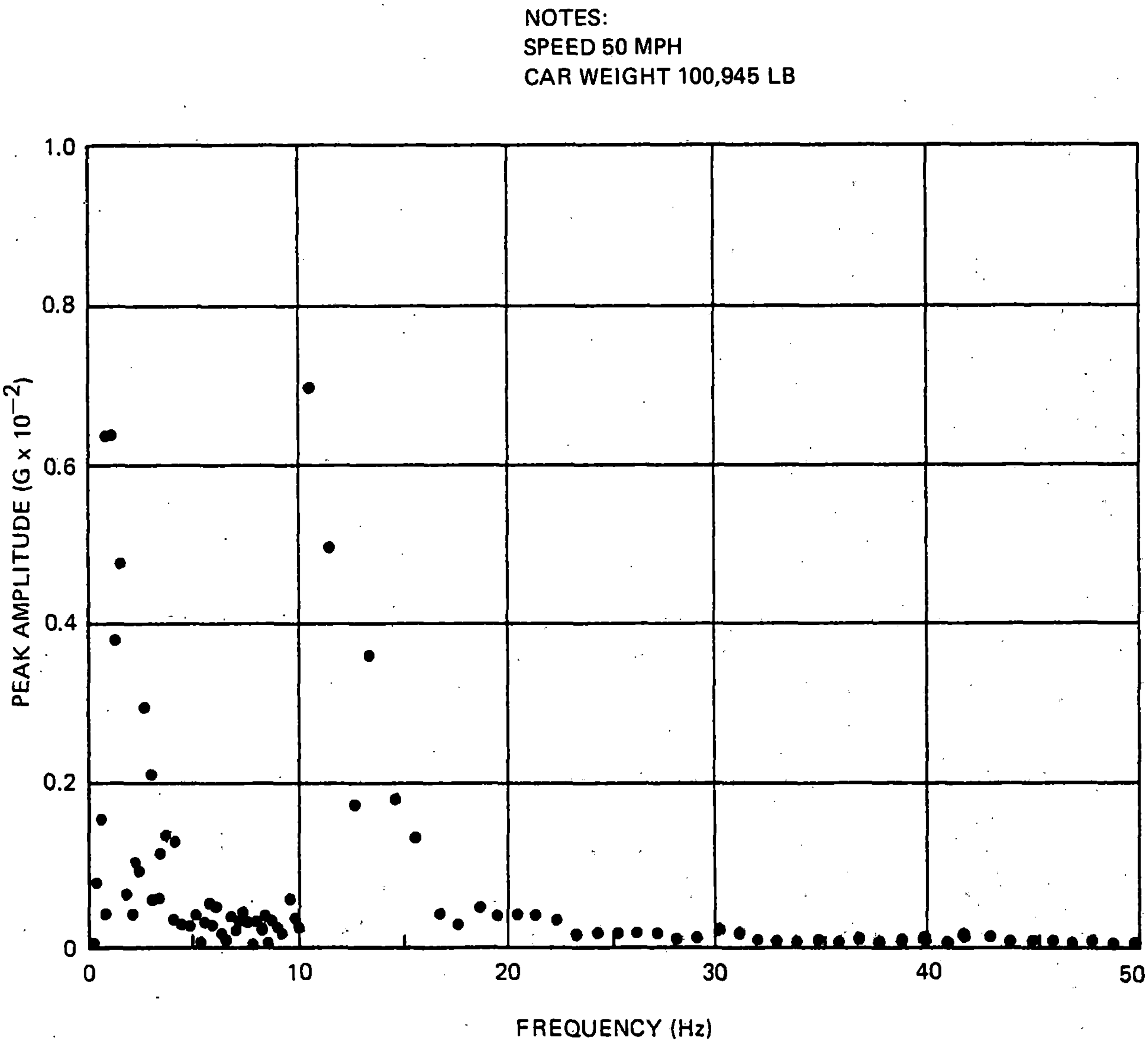


Figure A–60. Narrow-Band Spectrum Analysis – End Car, Vertical

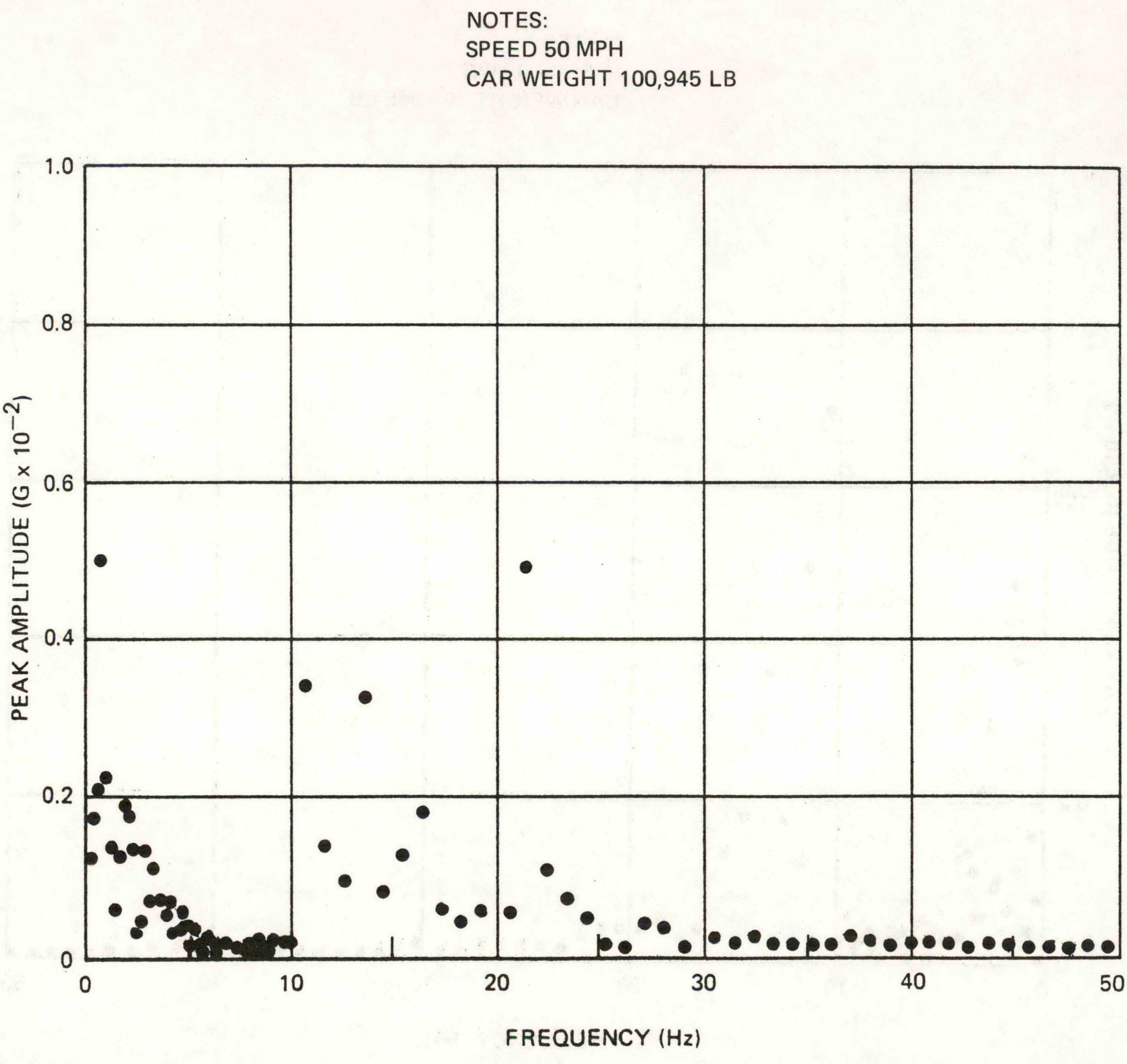


Figure A–61. Narrow-Band Spectrum Analysis – End Car, Lateral

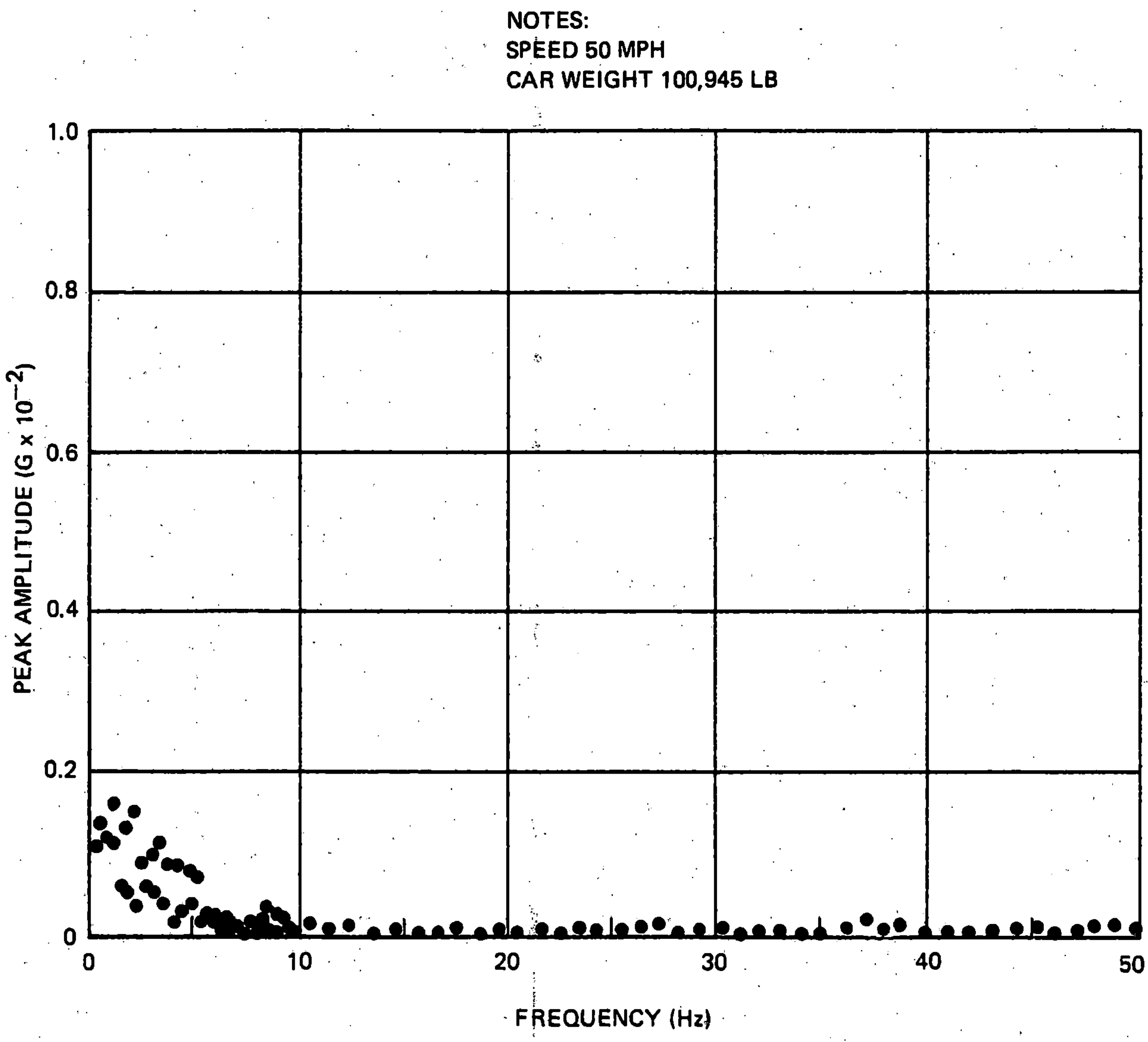


Figure A–62. Narrow-Band Spectrum Analysis – End Car, Longitudinal

NOTES:
SPEED 50 MPH
CAR WEIGHT 100,945 LB

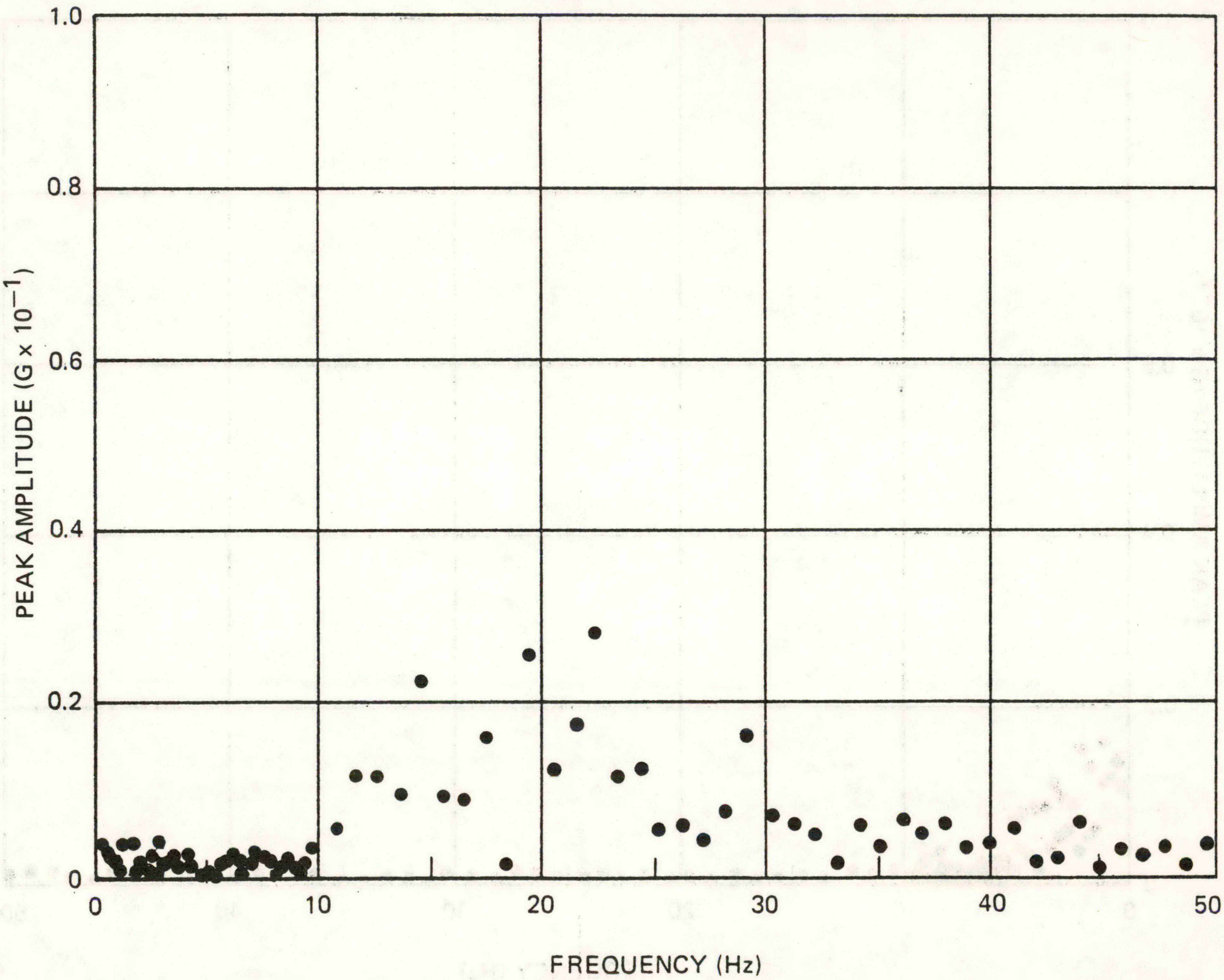


Figure A–63. Narrow-Band Spectrum Analysis – Mid Car, Vertical

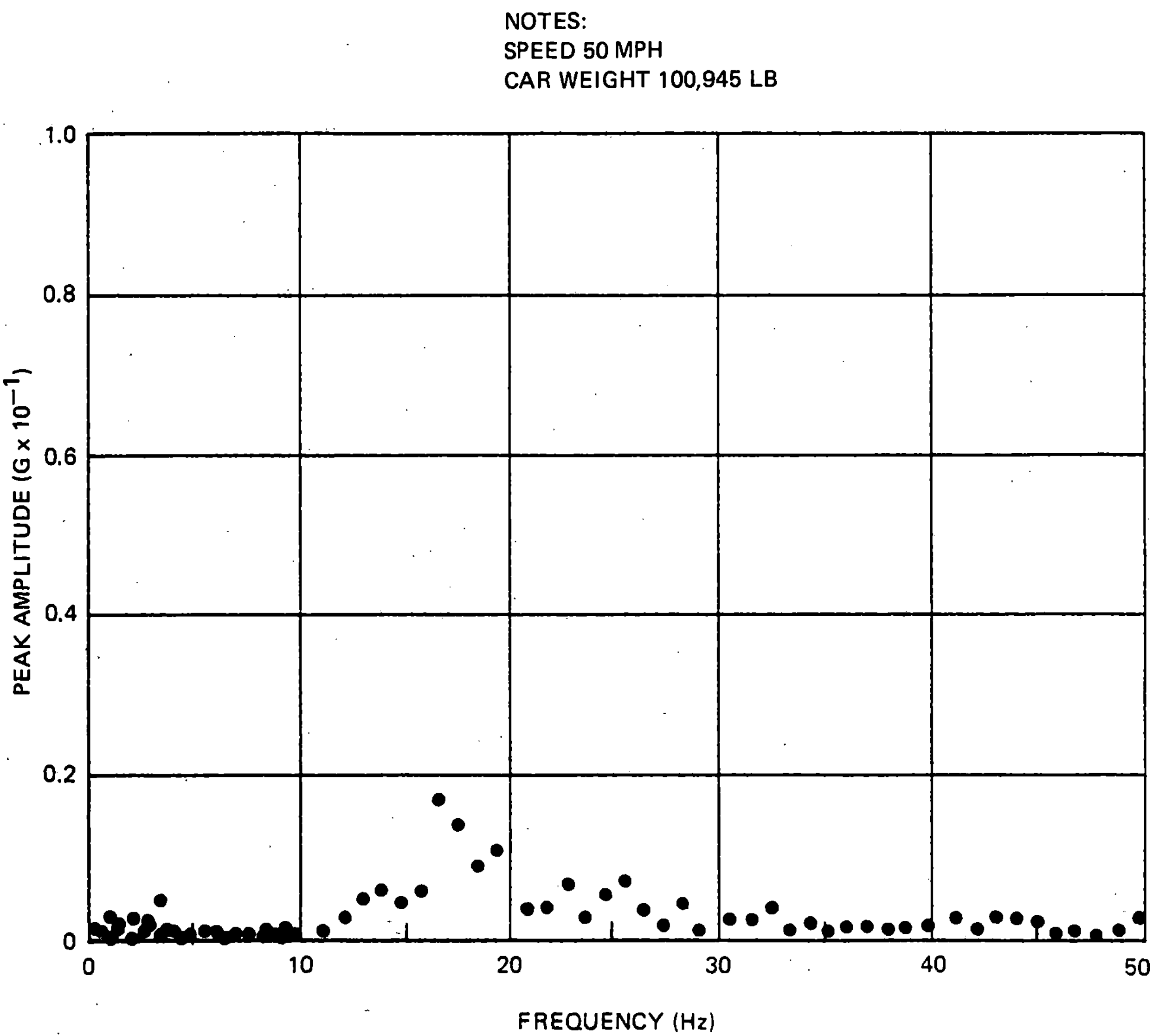


Figure A–64. Narrow-Band Spectrum Analysis – Mid Car, Lateral

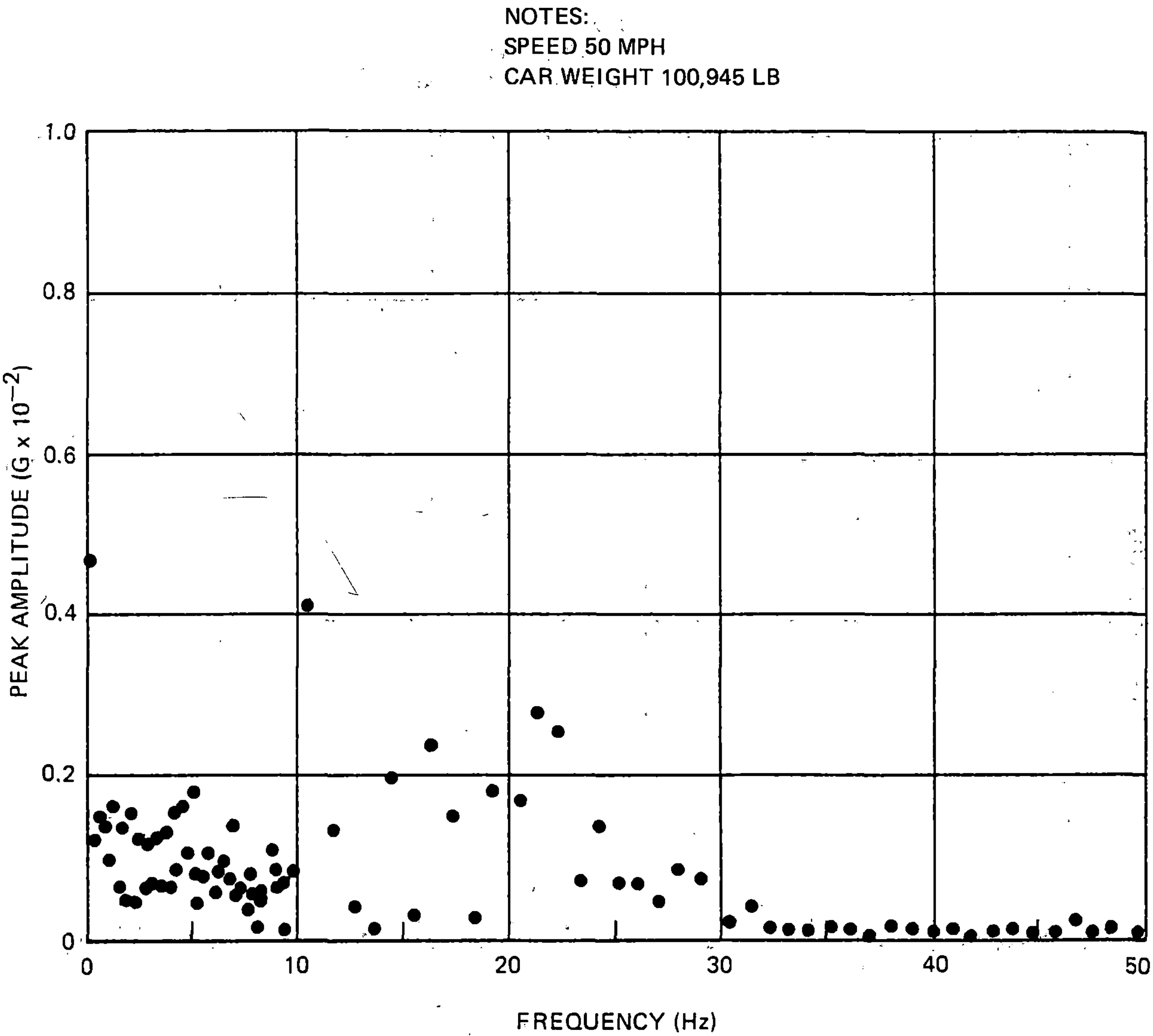


Figure A–65. Narrow-Band Spectrum Analysis – Mid Car, Longitudinal

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