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MBTA GREEN LINE TESTS
RIVERSIDE LINE
DECEMBER 1972

VOLUME I
TEST DESCRIPTION

George W. Neat, Editor

SEPTEMBER 1973
FINAL REPORT

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16. Abstract

The UMTA sponsored Urban Rail Supporting Technology Program emphasizes three major task areas; facilities development, technology development, and test program development. The test program development is composed of three sub-areas; vehicle testing, ways and structures testing, and track geometry measurement. This report presents the technical methodology, data samples, and results of tests conducted on the Massachusetts Bay Transit Authority (MBTA) Green Line in December, 1972 prior to initiation of the Green Line refurbishment effort.

An instrumented revenue type car was used for the measurement of track geometry, ride roughness, and interior noise. Actual car speed was approximately the same as normal revenue speed. The objectives of the tests were to identify critical track sections for improvement to quantify the benefits produced by the track rehabilitation program, and to provide data for TSC's development of an advanced track geometry measurement system.

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PREFACE

The Rail Programs Branch of the Urban Mass Transportation Administration (UMTA) Office of Research, Development and Demonstrations is conducting programs directed toward the improvement of urban rail transportation systems. These research, development and demonstration programs will result in improved prototype vehicle and component designs, improved ways and structures, and improved structural components.

The Transportation Systems Center (TSC) has been designated by UMTA as System Manager for the necessary technical support in these developmental areas. The UMTA sponsored "Urban Rail Supporting Technology Program" at TSC has emphasized three major, but closely related areas of development to date. These are facilities development, technology development and test program development. A nine mile urban rapid rail test track has been completed at DOT's High Speed Ground Test Center (HSGTC) in Pueblo, Colorado. The technology effort is being concentrated on Noise, Tunneling and Safety. The test program has emphasized vehicle testing and track geometry measurement. Tests were conducted on the New York City Transit Authority "Sea Beach" line in May, 1971 using R42 cars. Two R42 cars were borrowed from New York for testing at Pueblo. Four different test series have been conducted on the R42 vehicles at HSGTC.

The track geometry measurement effort at TSC has been based on proven techniques with gage and midchord profile measurements made at HSGTC in November, 1971. These measurements compared favorably with similar data collected by the Federal Railroad Administration Rail Research Cars. The midchord and gage system utilized capacitance probes and analog data collection.

The midchord scheme, while satisfying the objectives of these tests by providing reliable, repeatable data, independent of vehicle speed, does have limitations. The data cannot be readily converted to actual profile, or to midchord data for a different length beam. This limits comparison of data and prevents classification of track according to IRT standards which are based on a 62 foot chord. This has prompted the development of an alternate scheme using accelerometers for direct measurement of profile. This system has been tested by TSC and specifications were written to procure two prototype measurement systems using this approach. These systems will be delivered in early 1974 and integrated with the TSC digital data acquisition system being built under a separate contract with Sperry Univac, Inc. The test data collected at HSGTC has been utilized in the development of software for processing track geometry data.

The track geometry measurement system can be utilized to supplement the maintenance programs of the operating properties. For routine mainteneance, out-of-tolerance track can be precisely located.

For track rehabilitation programs, the sections of track requiring priority treatment can be established quantitatively. From a safety standpoint, track can be classified according to IRT Safety Guidelines* While this system cannot replace the track walker, it will provide concise information to urban rail system managers regarding the track geometry parameters of the entire system. This uniformly collected data, along with other information available to the managers, should enhance the decision making process. Since the data can be collected at revenue speeds, frequent measurements can be made in order to detect changes in track condition.

The Massachusetts Bay Transportation Authority (MBTA) Green Line refurbishment program provided a timely opportunity for demonstrating the track geometry capability developed at TSC. The purpose of this report is to present the results from the first of a series of tests conducted on the MBTA Green Line. This data can be utilized to establish priorities for the money available to improve the track. Subsequent tests will provide data to evaluate the benefits obtained from the rehabilitation effort.

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* Institute for Rapid Transit, Moving People Safely, May 1972.

In addition to the benefits that will be derived by the MBTA, the data collected will be valuable to the TSC effort to develop the advanced track geometry system. Journal box acceleration data, in particular, will be used for checking out the software being prepared for the track geometry system presently being procured for use on rapid transit vehicles.

Although the long range track geometry effort is directed toward the direct measurement approach, the midchord data which is presented in this report will provide the information required to go ahead with the refurbishment program.

The vehicle testing capability which has been developed by TSC has also contributed to these tests. The General Vehicle Test Plan** defines procedures for testing urban rail vehicles. The ride roughness and noise procedures from the referenced document were used in these tests to evaluate vehicle/track characteristics.

The Green Line tests were coordinated with the Boston MBTA by Fredrick J. Rutyna in conjunction with his responsibility for the Applications Engineering Task of the Rail Technology Program.

Conduct, data processing, and documentation support for the tests were performed by TSC personnel as part of the Rail Program. Test instrumentation installation and test conduct were carried out by Robert Wilmarth, John Nickles, Lowell Babb, William Wade, Gunars Spons, Robert Stone and Philip Silvia. Data Processing support was provided by Richard Robichaud, Paul Poirier, David Brownell, Peter Mengert, John Cadigan and Edward Rickley.

The cooperation of Boston MBTA personnel, Harry D. Tietjen, James Burns, and Charles England, is gratefully acknowledged.

** Lotz, Robert and Robert Kasameyer, General Vehicle Test Plans for Urban Rapid Transit Cars, DOT/Transportation Systems Center, April, 1972.

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1. INTRODUCTION

The Massachusetts Bay Transportation Authority (MBTA) has undertaken an UMTA funded refurbishment and expansion program which is being implemented over a ten year period. Included in this overall program is a three year effort to improve the "Green Line" light rail system by replacing track structure, power system equipment and vehicles.

Subsequent to Pueblo testing, the Transportation Systems Center (TSC) conducted tests of a prototype measurement system on the Riverside Branch of the MBTA Green Line. The tests were designed to meet the following overall objectives:

1) Identify critical track sections for improvement

2) Quantify the benefits afforded by the rehabilitation program [Additional test data will be required after refurbishment to accomplish this objective]

3) Provide data for development of an advanced track geometry measurement system.

This report covers tests which were conducted on a President's Conference Committee (PCC) light rail car in December, 1972. These initial tests have provided data to define track-dependent characteristics on the line prior to refurbishment of the track. Data have also been obtained for the vehicle/track characteristics for the existing rolling stock (PCC) and the unimproved track combination. To achieve this, the following types of measurements were made:

1) Track Geometry - These tests provide track dependent data, independent of the vehicle used. These data can be used to point out critical areas for track refurbishment. In addition, data will be compared with similar data taken after refurbishment.

2) Ride Roughness and Noise Levels - These tests provide data dependent on the vehicle-track combination.

The tests will be repeated several times during the rehabilitation to evaluate progress. After rehabilitation, the tests will again be performed with the same cars. Since ride roughness and noise level are a function of vehicle as well as track characteristics, these tests will also be made on the new vehicles which are being procured as part of the Green Line improvement program. Data will be collected for a matrix of the combination of old and new vehicles and unimproved and improved track. The new cars will not be available in time to be tested on all sections of the old track. However, the data collected should be sufficient to accomplish the objectives of evaluating the benefits from track improvement dollars versus vehicle dollars.

The track refurbishment and the construction of new power substations and repair shops will cost about 33 million dollars. T. K. Dyer, Inc. is under contract to the MBTA to conduct the track upgrading program on the four branches of the Green Line. All four branches are shown in the partial map of the MBTA rail system in Figure 1-1. The major effort will be on the Riverside line which winds through Brookline and Newton. A view of the Riverside Branch is shown in Figure 1-2. Rehabilitation will include replacement of much of the track and ties. The signal and power system is being designed by Gibbs and Hill. A new maintenance facility at the Riverside Terminal is being designed by Gannett, Fleming, Corddry, and Carpenter, Inc.

A joint effort, under UMTA sponsorship, between the Boston MBTA and the San Francisco Municipal Railway (MUNI) has produced specifications for new U. S. Standard Light Rail Cars. To satisfy UMTA's objectives, these specifications were written to meet the basic needs of any city which might want to replace existing fleets or buy new ones. A contract to build new light rail cars to these specifications was awarded in April, 1973 and the first cars will be delivered 20 months later. On the initial order, Boston will get 150 new cars and San Francisco will get 80. Four of the first ten cars built will be shipped to the High Speed Ground Test Center for shakedown and acceptance testing.

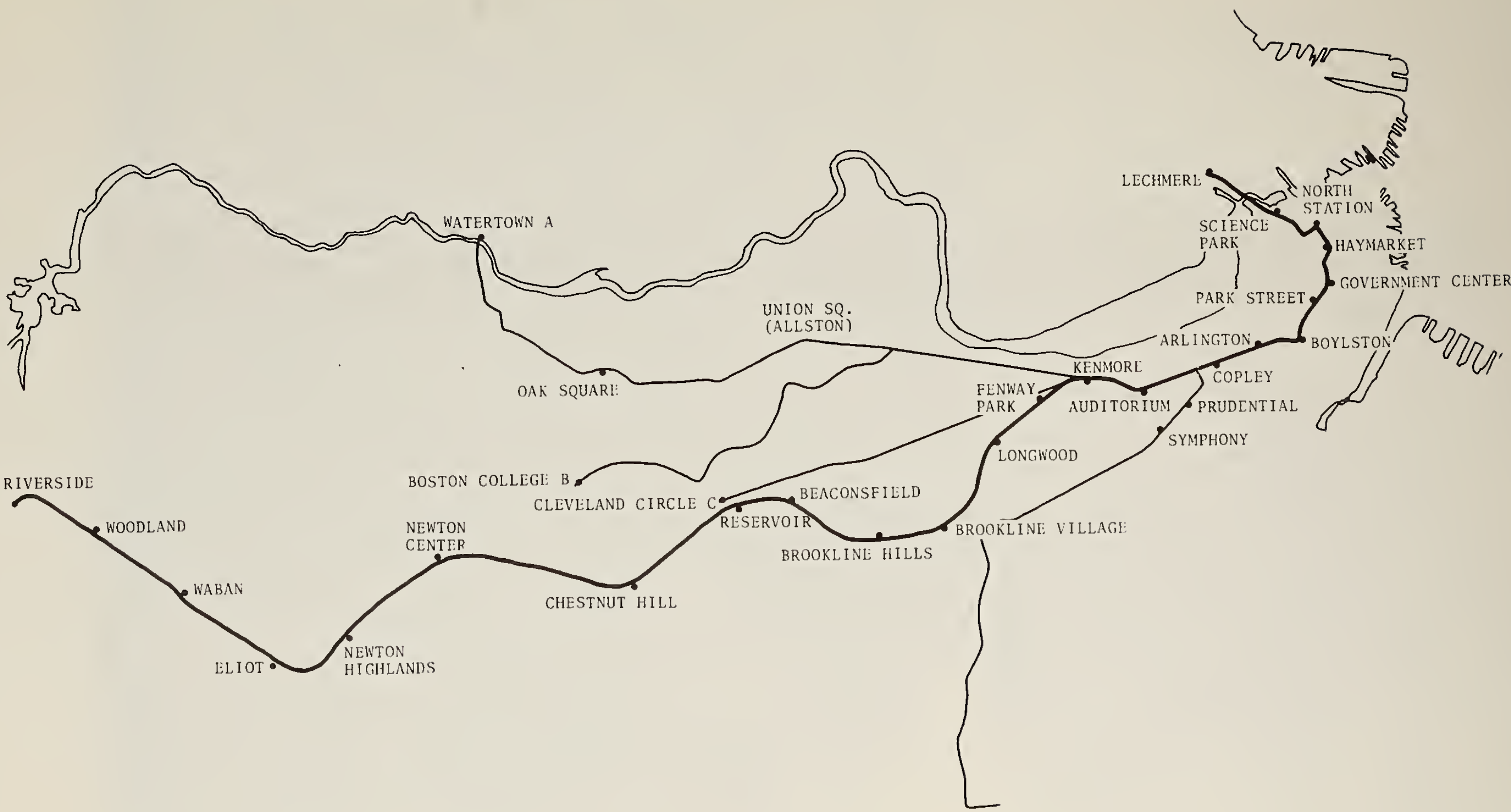


Figure 1-1 Map of MBTA Green Line

Figure 1-2 Typical Green Line Right of Way

The new MBTA cars will be faster and have more acceleration capability than those now in use. They will have air conditioning and tinted shatterproof windows and will also be quieter. Each car will be 70 feet long and articulated in the middle to facilitate the sharp turns in the Boylston and Tremont Tunnels. Greater access will be provided with four doors on each side. The passenger carrying capacity will be considerably greater than the PCC cars currently in operation.

The PCC car used for these tests (No. 3294) represents the most modern in use on the Green Line today. It was part of a 50 car order placed in 1950. They were built by Pullman-Standard and delivered beginning in April, 1951 - they are approximately 46 feet long. The first PCC car for Boston was built by the St. Louis Car Company and was delivered in 1937. It was scrapped in 1953. The 344-car fleet of PCC cars in service today dates back to 1941.

The results of the tests are presented in five volumes as follows:

- Volume I - Test Description
- Volume II - Track Geometry Data Plots
- Volume III - Eastbound Track Profile Computer Printout
- Volume IV - Westbound Track Profile Computer Printout
- Volume V - Gage Computer Printout

This volume, Volume I, describes the objectives, procedures, hardware, and software of the tests, and gives samples of the data. Volume II gives the analog plots of profile and gage for the 46 sections which make up the complete round trip from Riverside to Lechmere and return. Volume III gives the reduced profile data for the the 23 eastbound sections. Volume IV gives the companion profile data for the westbound sections. Volume V gives the reduced gage data for the complete round trip.

Each of the four data volumes contains a brief introduction and the applicable test procedure, plus the data. Thus, each volume can be used independently without frequent reference to other volumes.

2. DISCUSSION

Data was recorded during the week of December 10, 1972 on test runs on the Riverside Branch of the Green Line using the instrumented PCC car (NO. 3294). During six days of testing, five round trip runs between Riverside and Lechmere and four round trip runs between Riverside and Kenmore were made. The instrumentation used in this test is part of the ongoing program at the Transportation Systems Center (TSC) to develop prototype track diagnostic instrumentation and vehicle test instrumentation. The instrumentation developed in this program provides sufficient data in a single run over a section of track. A duplicate run is desirable to provide a check on the data. In this initial set of tests, additional runs were made to calibrate the instruments and evaluate the effect of day-to-day variations in the track and to evaluate the effect of speed on the track measurement system. The variations were minimal, and in general, the data is presented for only one run which is representative of the rest.

For data processing, presentation and discussion, the data has been broken into 46 segments corresponding to the 23 two-way sections of track joining each station with the next. Distances are referenced from each station along the track in the direction of normal vehicle travel. Table 2-1 shows the 71,000 foot line with the distances between each station. All are less than a mile in length with the exception of Newton Center to Chestnut Hill which is 7,700 feet. The shortest segment is 1,200 feet between Boylston Street and Park Street.

In preparing for the tests, a reconditioned truck was delivered by the MBTA to TSC where it was carefully fitted with all of the required external sensors and a complete system checkout was performed. The instrumented truck, shown in Figure 2-1, was returned to the MBTA where it was installed on the designated PCC car for testing (see Figure 2-2 for exterior and Figures 2-3 and 2-4 for interior views of the test vehicle). Prior to this, however, another street car was fitted with a light weight breakaway

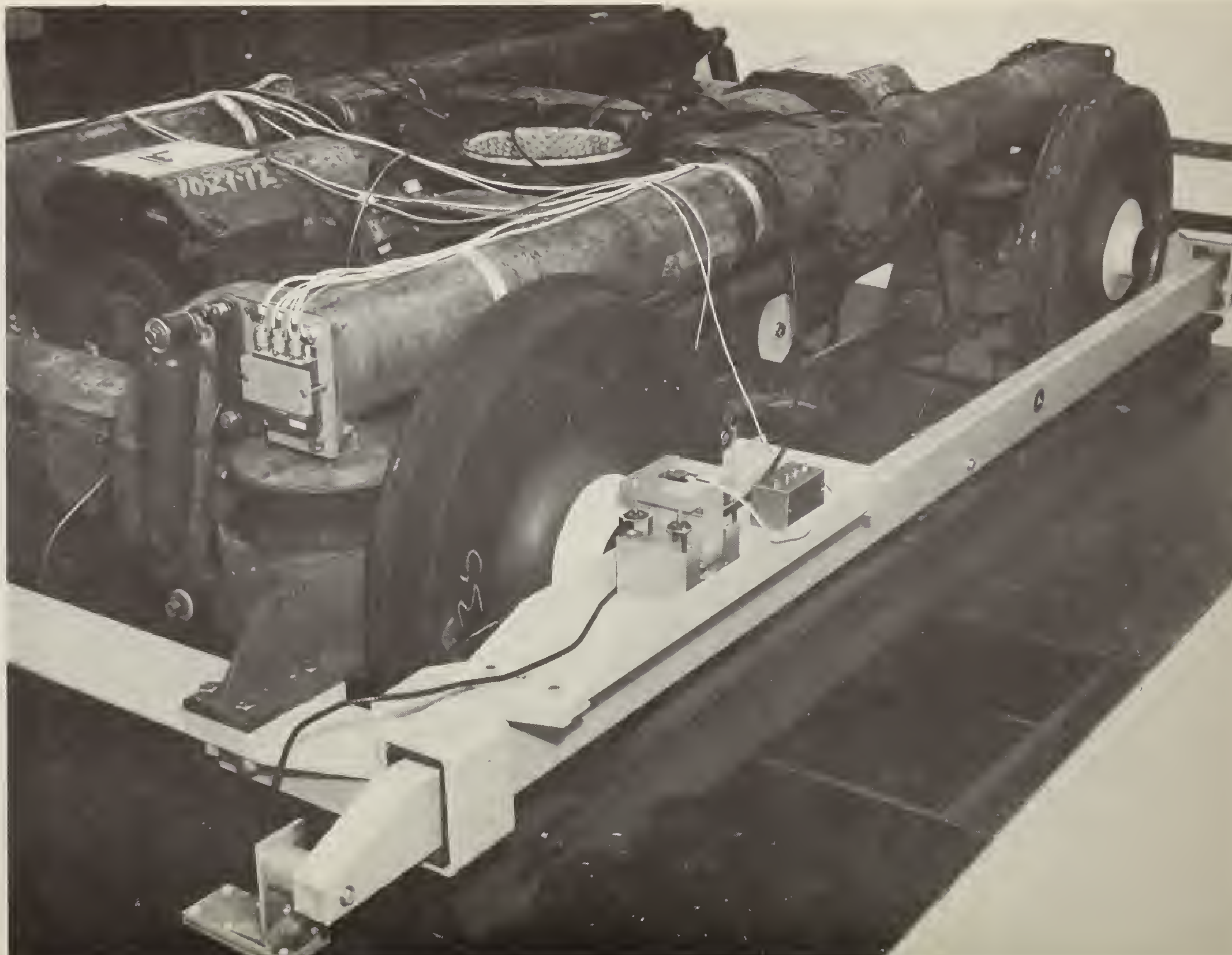


Figure 2-1 Instrumented Truck

Figure 2-2 Test Car

Figure 2-3 Interior View of Test Car

Figure 2-4 Interior View with Recorder

TABLE 2-1 STATION DISTANCES (FEET)

Station	Distance From Last Station	Cumulative Distance
Riverside	0	0
Woodland	2700	2700
Waban	4400	7100
Eliot	4600	11,700
Newton Highlands	4000	15,700
Newton Center	4300	20,000
Chestnut Hill	7700	27,700
Reservoir	5500	33,200
Beaconsfield	2300	35,500
Brookline Hills	4100	39,600
Brookline Village	2800	42,400
Longwood	3900	46,300
Fenway Park	2100	48,400
Kenmore	2900	51,300
Auditorium	2200	53,500
Copley	2600	56,100
Arlington	2000	58,100
Boylston	2100	60,200
Park Street	1200	61,400
Government Center	1500	62,900
Haymarket	1100	64,000
North Station	1800	65,800
Science Park	2100	67,900
Lechmere	3100	71,000

type wooden mock-up of the instrumentation frame and sensors and run on the selected track. This was done in order to ascertain the clearances required to insure there would be no interference with the safe operation of the car. As a final safety check, the first test run on the designated car was conducted at very low speeds between the non-revenue hours of 12 midnight and 6 a.m. Sunday morning during which numerous stops and careful visual checks were made. All subsequent testing was done during daylight hours.

To accomplish the objectives of these tests, the following data were collected:

- Midchord track profile - using the mid-ordinate-to-chord technique
- Track gage - measured by proximity probes
- Track roughness - as sensed by accelerometers mounted on the truck journal box
- Ride roughness - as sensed by linear and angular servo-accelerometers mounted on the car floor
- Noise level inside the car - measured by sound-level meters

These categories of measurements are defined by a procedure number which facilitates correlation of data with measurements made on other lines. A sequence number is used for discussion in this report. Table 2-2 correlates these numbers. Each test is documented in a self-contained subsection of this report in the Appendix. Although the tests are reported separately, all the data was recorded simultaneously so that any particular event could be correlated with other measurements.

The first three tests, sequence numbers 601, 602, and 603, relate to the objective of measuring the track-dependent characteristics. The gage measurement, 602, can be used directly to classify the track according to the standard definition spelled

TABLE 2-2 TEST SUMMARY

TEST SERIES VI, MBTA GREEN LINE, DECEMBER, 1972

SEQUENCE NO.	PROCEDURE NO.	TEST TITLE
17-72-601	PCC-TGC-6007-MBTA	Track Geometry - Midchord Profile
12-72-602	PCC-TGC-6008-MBTA	Track Geometry - Gage
12-72-603	PCC-TGA-6006-MBTA	Journal Box Acceleration
12-72-604	PCC- R -5002-MBTA	Ride Roughness
12-72-605	PCC- PN-5002-MBTA	Passenger Noise

NUMBERING SYSTEM EXPLANATION

12-72 - 601

Date ↓ ← 6th Test Series

PCC	- TGC-6008 -	MBTA
Car designation	Procedure	Test Location

TGC - Track Geometry - capacitance
TGA - Track Geometry - accelerometer
R - Ride Roughness
PN - Passenger Noise

out in the IRT publication, "Moving People Safely".* (Gage is defined as the distance between the rails measured 5/8 inch below the top of the rail - see Figure 2-5). These track classifications are used to establish allowable speeds:

Class 1	0 - 15 mph
Class 2	16 - 35 mph
Class 3	36 - 55 mph
Class 4	56 - 80 mph

In order to qualify as Class 4 track, the gage must lie between 56 and 57 inches. Class 3 track allows the gage to widen to 57.25 inches and Class 1 or 2 track must have the gage between 56 and 57.75 inches.

The gage measurement is plotted as a function of location for the Highland Branch (See Appendix C). With the aid of a computational algorithm, each section of track is categorized. A computer printout shows the location along the track of each point that the gage moves into a different gage tolerance zone.

The measurement of rail alignment is not provided in this report. (Alignment can be defined as the horizontal deviation of each rail from a given reference line.) The gage measurement coupled with double integration of a lateral accelerometer output will ultimately be used for obtaining alignment data. The data processing software to accomplish this is being developed.

The midchord profile measurement, 601, was made using a 10 foot (9 foot 10 inch) beam. (Profile can be defined as the vertical deviation of each rail from a given reference line.) Midchord profile is the midchord-to-ordinate distance measured in the vertical plane. The midchord definition is illustrated in Figure 2-6. Repeatable midchord data was collected and is presented in this report. The IRT track classification code uses a

*Institute for Rapid Transit, op. cit.

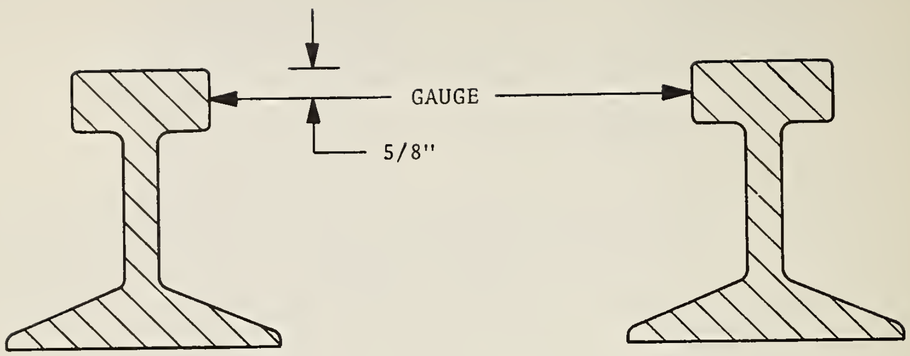


Figure 2-5 Measurement of Gage

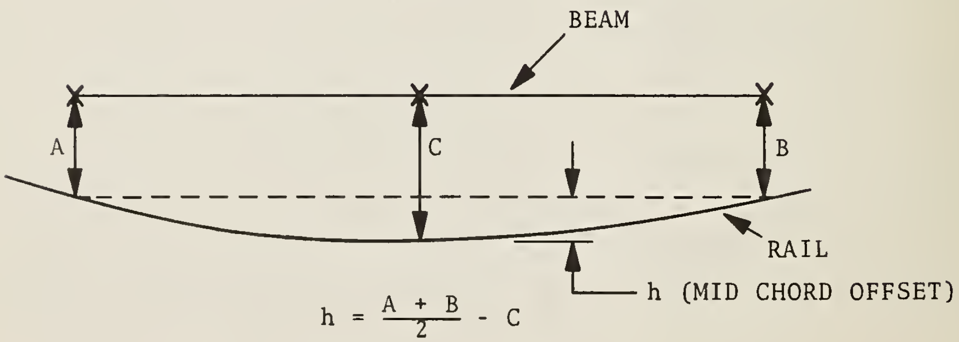


Figure 2-6 Measurement of Midchord Offset

62 foot chord reference. This re-emphasizes the requirement for a direct measurement scheme. The journal-box acceleration measurement, 603, was included to provide a direct measurement. Additional software development is again required. Processing the data from the journal box accelerometers will continue as part of the software development effort.

The ten foot beam data will serve to provide a comparison of profile between the different sections of track. An algorithm identifying different levels of midchord profile similar to that for gage was used. A plot of midchord profile versus distance is shown in Appendix B.

3. CONCLUSIONS

The first major test objective of identifying critical sections of track for improvement was accomplished through digital processing of the track geometry data to locate different levels of deviation from the nominal. Midchord profile and track gage were measured and the larger perturbations tabulated on computer printouts. The gage data were used to define the track classification according to IRT standards. In each of 23 of the 46 track sections, at least one gage reading was outside the allowable limits of 56 to 57 3/4 inches, thus indicating a need for visual inspection at the recorded defect points. The remainder of the track was Class II or better relative to gage requirements. These data are presented in Appendices B and C.

The second objective of the December tests, which was to obtain reference data relative to the track and vehicle characteristics prior to initiation of the refurbishment program, has been satisfied. The track geometry data presented in this report defines the characteristics of the existing track. Ride roughness (vibration) and noise data presented in Appendices E and F provide a definition of the vehicle/track characteristics prior to refurbishment.

Journal box acceleration data, both vertical and lateral, are presented in Appendix D. This meets the third stated test objective which was to provide data for development of the advanced track geometry system. The midchord profile scheme is an interim approach to track measurement which provided an expedient means for meeting the first two objectives of these tests. However, the flexibility afforded by a direct measurement scheme has prompted TSC to develop a system which utilizes the integrated output of journal box accelerometers. Contracts have been awarded for a data acquisition system and an instrument package. System integration and software development is being performed by TSC. The data collected here will be used for verification of the software that has been produced.

This direct approach will allow conversion of the profile data to midchord data of any desired length including the 62 foot length specified by the IRT Safety Guidelines.

The technology utilized for these tests was developed through a test program at HSGTC in Pueblo, Colorado. These Green Line tests represent the first track geometry measurements made by the Urban Rail Supporting Technology Program on an operating property. Certain phenomena observed in measurements made on the worn track warrant further investigation. In particular, the effect of vehicle loading and track/train dynamics on the gage measurement will be investigated. The results of these types of tests are not expected to modify the basic conclusions of this report, but rather to provide a better insight to aid in the interpretation of the data.

Several runs were made in this test series to check out the equipment and to collect redundant data. Satisfactory repeatability of the data on different runs was exhibited. Consequently, future track geometry tests with this equipment can be accomplished with one checkout run and two data collection runs. Ultimately, after more accumulated experience, one run will suffice.

Data processing for these tests was delayed because of software developments that were incorporated during the processing period. Track geometry data in the format presented here could be processed in a two week period under routine operating conditions for future Green Line tests. Processing of the track geometry measurements will eventually be performed in real time and data stored on tape. The processed data will then be printed out on board the train after completion of the run.

APPENDIX A

TEST APPROACH

The five tests making up the series covered by this report are listed below and discussed separately in the following Appendicies.

Track Geometry - Midchord Profile

Track Geometry - Gage

Journal-Box Acceleration

Ride Roughness

Interior Noise

Although the tests are reported separately, the approach used was to record all data simultaneously. Besides being more economical, simultaneous recording facilitates correlation of measurement for more detailed analyses that might be required at some later date.

The PCC street car used as the test vehicle is shown in Figure 2-3. The track diagnostic sensors are mounted on the rear truck. The instrumented rear truck is shown in Figure 2-2 in the laboratory prior to installation on the car. A layout of the instrumentation on the car is shown in Figure A-1.

Power generation equipment, signal conditioning, speed and distance equipment, data collection, and test monitoring are common for all tests. They will be discussed briefly in this introductory section and not repeated for each separate test.

Speed and Distance

To automatically provide a location reference signal, a capacitive probe is mounted on the transverse beam at the rear of the truck mid-way between the two rails. When the Automatic Location Detector (ALD) probe passes over the impedance bond associated with a signal, the rail at a turnout, or the asphalt pedestrain cross-walks at stations, sharp spikes are recorded on the magnetic tape and on the oscillograph chart.

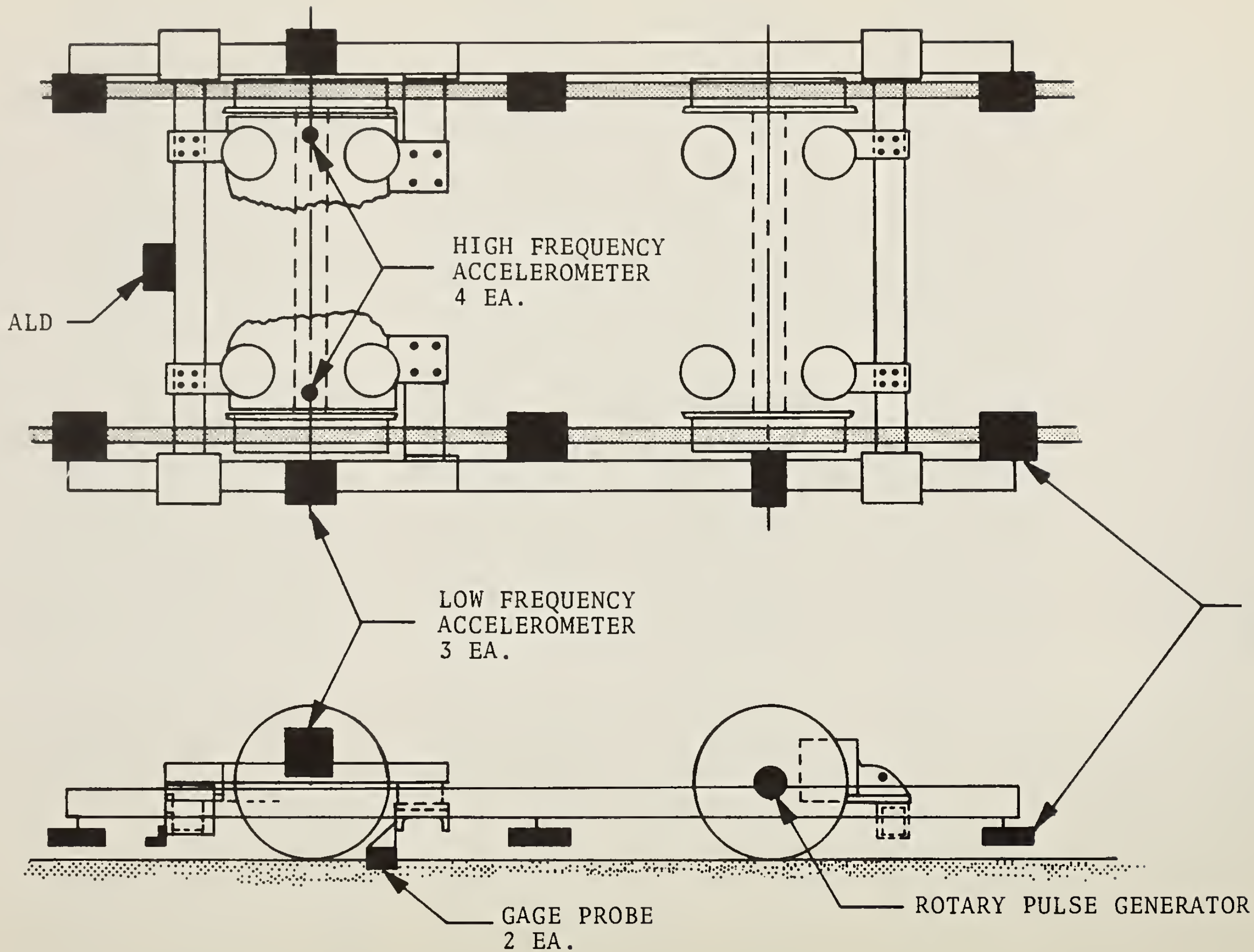


Figure A-1 Sensor Frame Configuration

To provide speed and distance data between ALD marks, a rotary pulse generator (RPG) is mounted on the left side profile beam and driven by the front axle of the instrumented truck. The RPG puts out 2048 pulses per revolution of the axle. This output is divided by 2 to produce 1024 pulses per revolution of the axle which is recorded on tape for future digital processing. The 2048 pulses/revolution are also divided to provide 8 pulses/foot to drive the chart recorder paper and 1 pulse/foot to drive the distance display pattern on the chart recorder.

All of the electronics for the sensors are contained in the rack. In addition, this rack contained a time-code generator, the FM multiplex equipment used in data acquisition, and a 7 channel monitorscope used to monitor data as it is recorded. On the bench next to the rack is shown the shock mounted, Honeywell H-5600, 1 inch magnetic tape recorder used to record all but the acoustic data taken in this test. Starting at the top of the rack, each chassis is identified as follows: ride roughness (linear) accelerometer signal conditioner; ride roughness filters; rms processor; angle accelerometer (ride roughness) signal conditioner; time code generator; RPG pulse processor (to provide speed and distance display voltage); event marker signal conditioner; FM discriminators (demultiplexer for monitoring); monitor scope; monitor switch (to determine which tape track is monitored); calibration panel; FM multiplex VCO assembly; capacitance probe electronics; piezo accelerometer signal conditioner; track roughness filters; track roughness (low frequency) servo-accelerometer signal conditioners.

Power Conditioning

The primary source of electrical power to operate the instrumentation and data acquisition equipment is a battery bank. The total load when all instrumentation and data acquisition equipment is operating is approximately 40 amperes at 30 volts. A 1 kw inverter provides the 115 vac power required by some of the instrumentation and data acquisition equipment. While operating above ground, a 1.75 kw gasoline-engine-powered alternator supplied power to the batteries through a 20 ampere power supply to extend the endurance of the batteries.

Instrumentation

The following instrumentation was used in the Green Line testing:

	# Req'd.	# Spares
Time code generator	1	0
Linear servoaccelerometers & g-monitors	6	0
Angular servoaccelerometers & scaling amplifier	3	1
Piezoaccelerometers & charge amplifiers	4	2
Rotary pulse generator	1	1
Capacitance probes (midchord profile)	6	9
Capacitance probes (gage)	2	8
Capacitance probes (ALD)	1	5
Sound level meter	2	0
Mechanical filter accelerometer mount	2	0
Electrical filters (track roughness)	3	0
Electrical filters (ride roughness)	3	0
RMS processor	3	3
Mid-chord summing amplifier	2	1
Gage summing amplifier	1	1

A signal-flow block-diagram of the instrumentation, data acquisition, monitor, and display equipment interconnection for the Green Line tests is shown in Figure A-2.

Data Acquisition and Display

Data was recorded using the following equipment:

FM Multiplex Equipment

Tri-Com, IRIG Constant Bandwidth
Six A-channels/track, Three B-channels/track
Four tracks of "A" format, two tracks of "B" format.

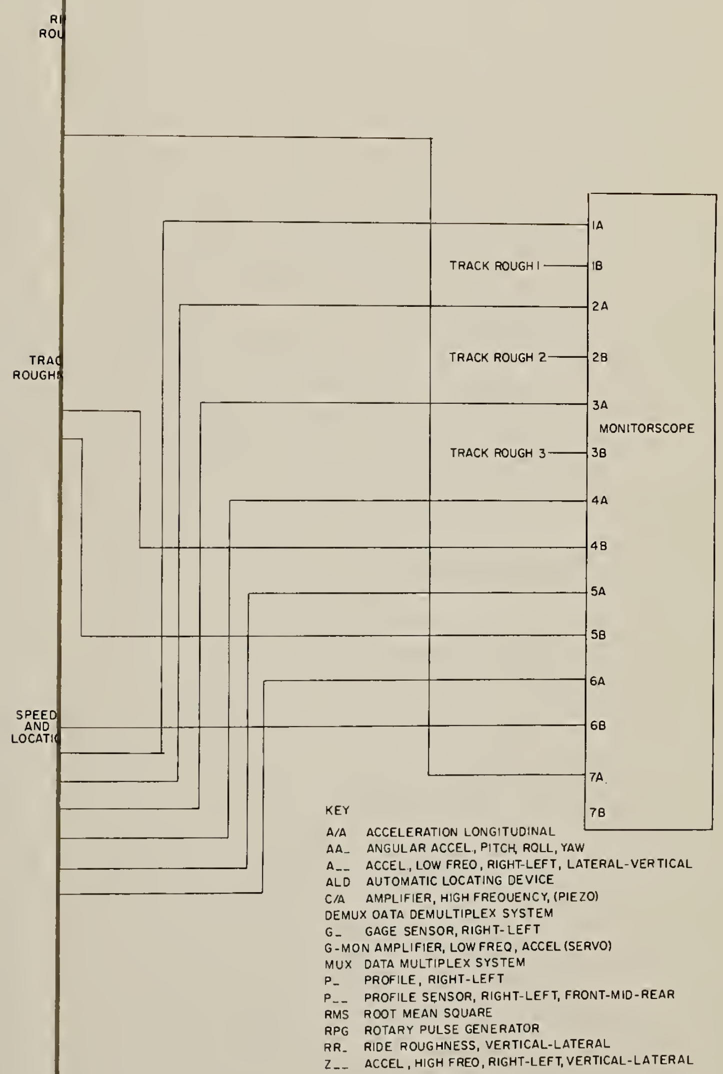


Figure A-2 Display Equipment Interconnection

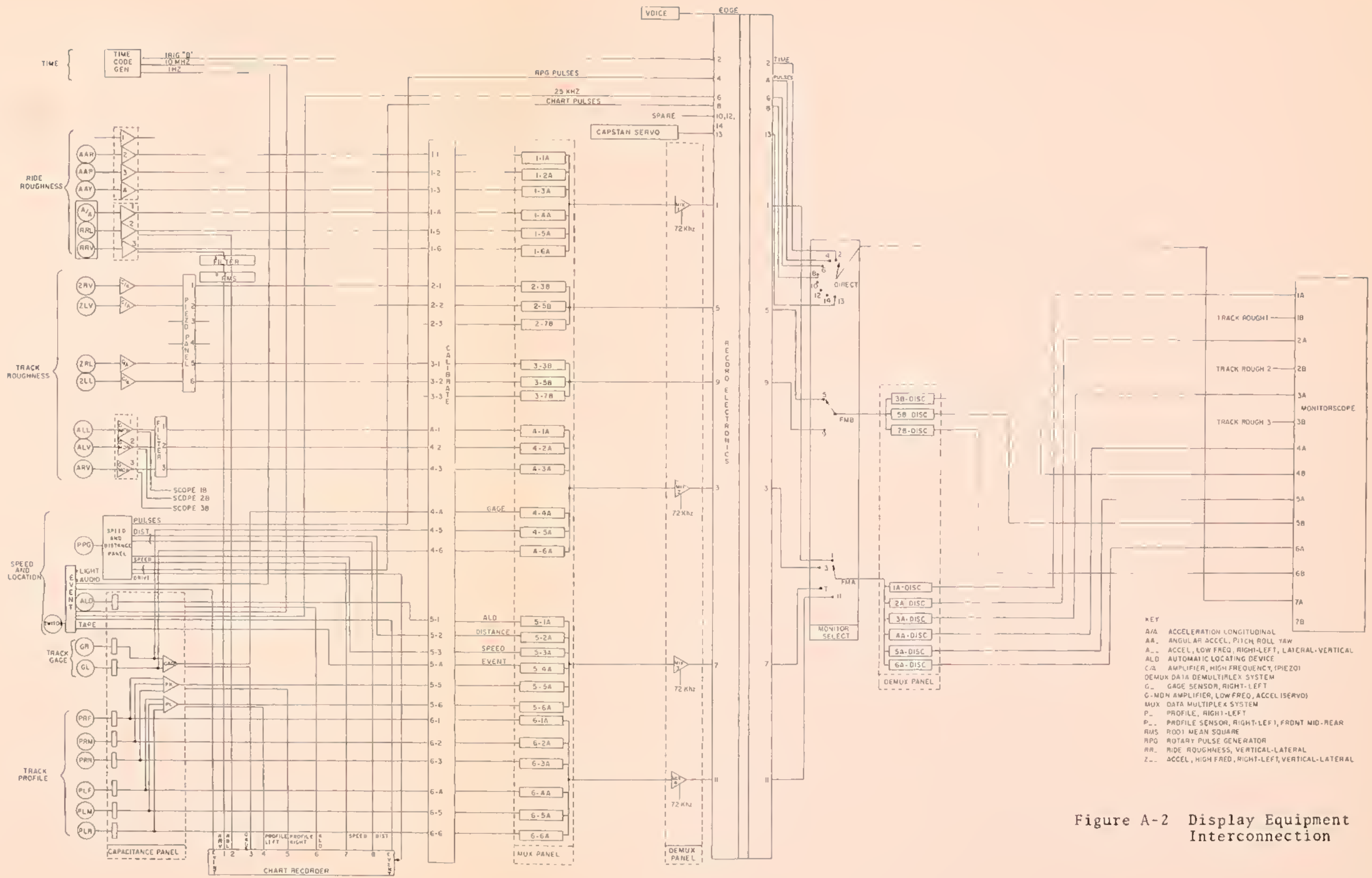


Figure A-2 Display Equipment Interconnection

Magnetic Tape Recorder

Honeywell, H-5600, 15 ips, direct record/reproduce
14 track IRIG format
1" tape, 10 1/2 dia w 3" NAB hub

Chart Recorder

Gould Brush 480 w incremental drive
8 channels with two event markers
frequency response ±2% DC to 100 Hz at 10 div pen displacement

Monitorscope

Vu-Data, MS200, 7 channel monitor oscilloscope
frequency response ±1 dB, DC-5 MHz
switchable to monitor any one track of tape being recorded

Test data is recorded on one inch wide, 14 track magnetic tape for subsequent processing at TSC. Six of the 14 tracks contain FM multiplexed data. On the other eight tracks, data is recorded directly. Four of the six multiplexed tracks contain six IRIG A constant bandwidth channels plus a 72 KHz reference frequency in the multiplex. The other two multiplexed tracks each contain three IRIG B constant bandwidth channels. The "A" channels are specified to have a 400 Hz data bandwidth, the "B" channels an 800 Hz data bandwidth. According to the Tri-Com specification, the low pass filter at the discriminator output has a response down 3 dB at data cutoff frequency and asymptotic to 30 dB per octave beyond cutoff. The assignment of tape tracks and data channel is given in Table A-1.

Data displayed on the chart recorder are the rms values of ride roughness vertical and lateral vibration accelerations, track gage, left and right midchord profiles, ALD marker, speed, and distance; One event-marker pen provides a mark every ten seconds. Another event marker pen is used to provide a manual indication of questionable midchord profile data. This observation is based on the presence of extraneous metal such as a guard rail in the field of the profile capacitance probes. The chart is driven at a speed proportional to ground distance covered.

TABLE A-1 MAGNETIC TAPE TRACK AND CHANNEL ASSIGNMENT

Tape Track No.	IRIG Channel No.	Data Recorded
1	1A	Angular Accelerometer, Roll
1	2A	Angular Accelerometer, Pitch
1	3A	Angular Accelerometer, Yaw
1	4A	Ride Roughness Acceleration, Longitudial
1	5A	Ride Roughness Acceleration, Lateral
1	6A	Ride Roughness Acceleration, Vertical
2		IRIG B Time Code
3	1A	Track Roughness Acceleration, lo freq, right vertical
3	2A	Track Roughness Acceleration, lo freq, left vertical
3	3A	Track Roughness Acceleration, lo freq, left lateral
3	4A	Track gage
3	5A	Distance right gage prove to right rail
3	6A	Distance left gage probe to left rail
4	--	RPG Pulses at 1024 PPR
5	3B	Track Roughness Acceleration, hi freq, right vertical
5	5B	Track Roughness Acceleration, hi freq, left vertical
5	7B	Spare
6	--	25 KHz reference frequency
7	1A	ALD trace
7	2A	Distance trace
7	3A	Speed
7	4A	Event marker
7	5A	Right rail mid-chord profile
7	6A	Left rail mid-chord profile
8	--	8 pulses/ft. of distance traveled
9	3B	Track roughness acceleration, hi freq, right lateral

TABLE A-1 MAGNETIC TAPE TRACK AND CHANNEL ASSIGNMENT (CONT)

Tape Track No.	IRIG Channel No.	Data Recorded
9	5B	Track roughness acceleration, hi freq, left lateral
9	7B	Spare
10	--	Spare
11	1A	Capacitance probe, right front
11	2A	Capacitance probe, right middle
11	3A	Capacitance probe, right rear
11	4A	Capacitance probe, left front
11	5A	Capacitance probe, left middle
11	6A	Capacitance probe, left rear
12	--	Spare
13	--	Capstan Servo
14	--	Spare

APPENDIX B

TRACK GEOMETRY - MIDCHORD PROFILE

MBTA Green Line Tests, Riverside Branch
December, 1972

SEQUENCE NO. 12-72-601
PROCEDURE NO. PCC-TGC-6007-MBTA

OBJECTIVE:

To measure midchord track profile on the Riverside Branch of the Green Line, prior to initiation of track rehabilitation. These data will help establish which sections of track most severely require rework. These data will also be used for comparison with data recorded after the track has been upgraded.

STATUS:

Midchord profile data (10 foot chord) has been collected and processed for the twenty six-plus miles of the Riverside Branch track. The data is presented in 46 sets with each set representing a one-way section of track between two adjacent stations. Plots of the midchord profile as a function of distance are contained in separate volumes. The data for one representative section of track is repeated in this Appendix.

Test Description

In this test series, midchord profile of each rail is measured continuously using capacitive proximity detectors. Three probes are mounted on straight beams that are located alongside the wheels of the instrumented truck. Each probe is centered over the top surface of the rail. The electronics associated with each probe puts out a voltage that is proportional to the distance between the probe and the rail. Thus, if the outputs of the two end probes are denoted A and B and the output of the center probe is denoted C, the mid-chord formula yields the midchord offset h as

$$h = \frac{A + B}{2} - C$$

(see Figure B-1). The midchord offset is the actual output of this measurement. The beam length used in this test series was 9 ft. 10 in.

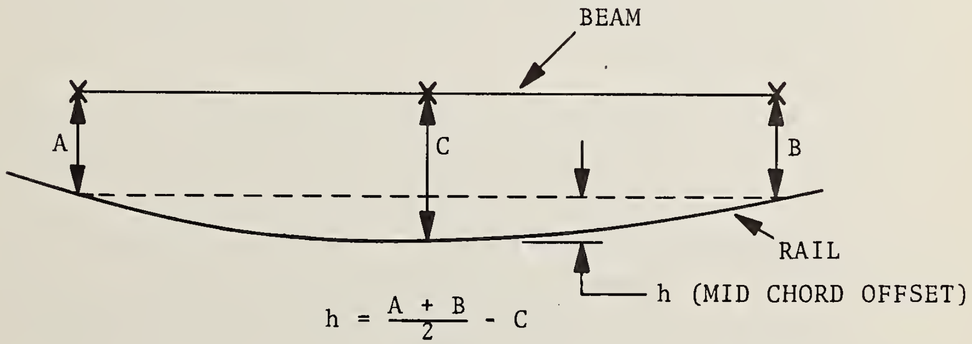


Figure B-1 Measurement of Midchord Offset

INSTRUMENTATION

The sensitive surface of a profile probe is constructed as follows: The inner foil is the detector surface. The outer foil is the guard ring. These probes were designed and built at TSC.

These profile probes were positioned 2 1/2 inches above the rail surface to clear all obstructions; however, one probe contacted a guard rail in Lechmere station. Evidently 2 1/2 inches clearance was not quite enough.

The electronics assembly used with each probe is located in the electronics rack in the car and utilizes the Lion Precision 300-1G Metrigap circuitry. The summing amplifier assembly to compute midchord offset was designed and built at TSC.

Test Procedures

The first step in each day's procedure is to calibrate the probes.

1. First the car is moved to a parking space outside of any building so that probe temperatures can approach the ambient. Probe electronics are turned on at the same time.

2. After allowing temperature equalization for one-half hour, each gage probe is taken off of the car and mounted on a calibration fixture described in Appendix C. The probe electronics are then trimmed to the desired gain and linearity.

3. After all probes are calibrated, the car is moved to a location where the running rails are free from asphalt cross-walks, paved areas, or guard rails. The distance between each probe face and the rail surface beneath it is measured. The electrical zero of the electronics is adjusted so that probe output corresponds to the measured distance.

4. At this point the mid-chord profile measurement system is ready to measure rail mid-chord offset in the vertical plane.

5. The car is run over the track to be measured at whatever speeds other parts of the test require because capacitive proximity measurements of a continuous target are not sensitive to vehicle speed.

Data

The midchord profile data were recorded on analog tape during the test runs in the form of the outputs of each of the capacitance probe circuits as well as the computed midchord value. The data was then digitized after passing it through a Butterworth low-pass four-pole filter, set for 30 Hz, and a unity gain amplifier. The tachometer pulses were divided down by a factor of 7810 and used to trigger the sampling of the Analog-to-Digital Converter. The resulting two samples-per-foot were used to scale the plotter output at 200 ft/inch.

An example of the processed data is shown in Figure B-2 for the section of track from Riverside Station to Woodland Station. Distance on the horizontal scale is referenced from zero at Riverside Station and increasing to 2700 feet at Woodland. A total of 46 charts like Figure B-2, corresponding to the 46 intervals between stations on a round trip between Riverside and Lechmere, are contained in separate volumes. To assure completeness, each set of data overlaps the adjoining sections.

Left and right midchord profiles are shown for the 10-foot beam. Vehicle speed (not shown) was intended to approximate typical revenue speed. The output of the automatic location detector indicates pulses where switches, grade crossings, etc., occur. The non-zero position of the event marker is used to indicate sections of the track where extraneous metal may be in the field of view of the capacitance probes. Midchord profile data in these regions is questionable, and track sections with apparent perturbations should be visually inspected.

The sampled data were processed to locate the largest profile perturbations (see Figures B-3 and B-4 pages B1 and C1 of each figure). The magnitude of the profile was divided according to zones of perturbation. The nominal zone within ± 0.25 inches midchord is defined as zone zero. Positive mid-chord measurements greater than 0.25 inches are defined by even numbered zones (e.g., 2 and 4). Negative midchord measurements less than 0.25 inches are defined by odd numbered zones. The size at the zones used here are defined as follows:

Zone	Mid-chord Reading
4	$0.75 \text{ in.} \le P$
2	$+0.25 \text{ in.} \le P < +0.75 \text{ in.}$
0	$-0.25 \text{ in.} < P < +0.25 \text{ in.}$
1	$-0.75 \text{ in.} < P \le -0.25 \text{ in.}$
3	$P \le -0.75 \text{ in.}$

Pages A on the printout charts show the location each time the profile reading enters a new zone. Pages B on the printout summarize the locations at which the peaks are reached in the extreme zones, 3 and 4. The magnitude of the peak is also given. Pages C on the printout summarize the section of track in terms of number of times each zone occurs and total number of feet in each zone. The complete profile printout data, pages A, B and C for the 46 sections of track are available in separate volumes.

The summary page, C, can be used for comparison of one section of track with another. Pages B, by giving the location of the most severe perturbations, can be used for locating areas for investigation and possible repairs.

NOTE: Figure B-2 has been reduced to 75% of normal size.

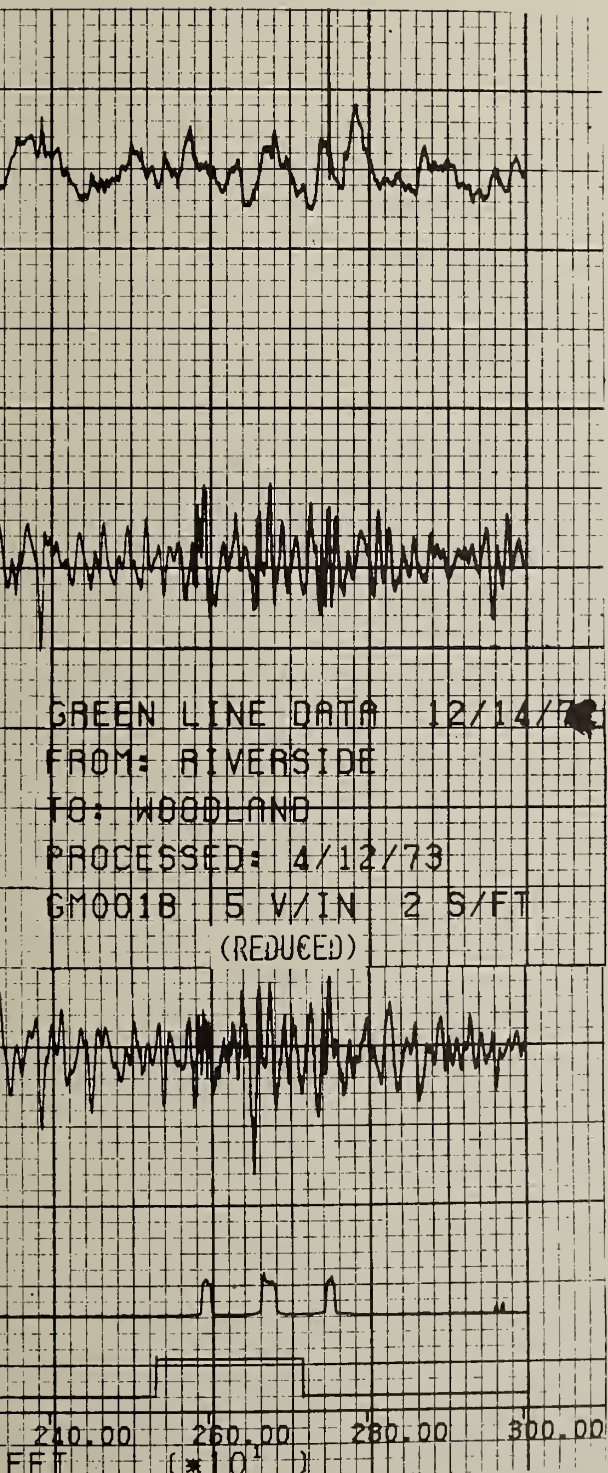


Figure B-2 Midchord Offset Data Plot, Riverside to Woodland

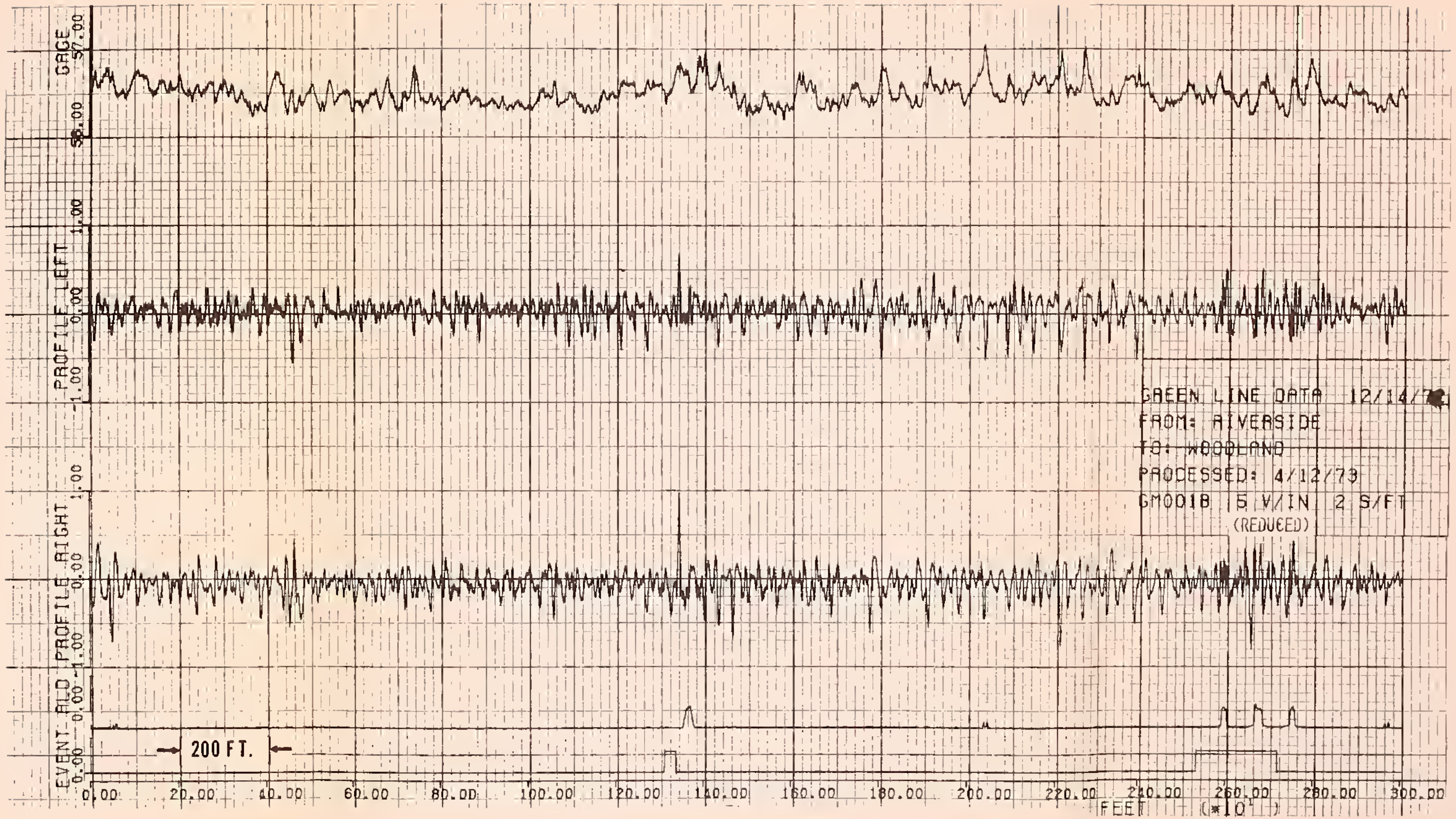


Figure B-2 Midchord Offset Data Plot, Riverside to Woodland

FROM - RIVERSIDE
TO - WOODLAND
LEFT PROFILE

FEET	ZONE	FEET	ZONE	FEET	ZONE	FEET	ZONE	FEET	ZONE
3.0	2	11.0	0	14.0	1	51.5	0	52.0	1
195.5	0	196.0	2	199.0	0	199.5	2	267.5	0
269.5	2	315.5	0	316.0	2	369.5	0	371.5	2
387.0	0	387.5	1	456.5	0	462.5	1	477.0	0
480.5	1	532.5	0	534.0	2	565.0	0	567.0	2
738.0	0	739.0	1	783.5	0	784.0	2	829.0	0
829.5	1	834.5	0	835.0	2	835.5	0	836.0	2
887.0	0	888.0	1	1061.0	0	1061.5	1	1065.5	0
1068.5	2	1090.0	0	1093.5	1	1120.0	0	1121.5	1
1126.5	0	1129.0	2	1142.5	0	1144.0	2	1149.5	0
1152.0	1	1209.0	0	1212.0	1	1267.5	0	1272.5	1
1340.5	0	1345.5	2	1367.5	0	1368.5	2	1431.0	0
1435.0	1	1489.0	0	1489.5	1	1491.5	0	1492.0	1
1613.5	0	1615.5	1	1616.0	0	1616.5	1	1643.0	0
1644.5	1	1740.5	0	1741.0	2	1756.0	0	1760.5	2
1788.0	0	1794.0	2	1801.5	0	1806.5	1	1888.0	0
1891.0	2	1909.5	0	1912.5	1	1919.5	0	1923.0	2
1967.5	0	1970.0	2	1975.0	0	1979.5	1	2037.0	0
2042.5	1	2087.5	0	2088.0	1	2088.5	0	2092.0	1
2102.5	0	2106.0	2	2115.5	0	2119.0	1	2122.0	0
2125.5	2	2145.5	0	2150.0	1	2207.5	0	2214.0	1
2250.5	0	2252.5	2	2254.5	0	2259.0	2	2261.0	0
2263.0	1	2263.5	3	2266.5	1	2301.5	0	2302.0	2
2302.5	0	2303.0	2	2325.5	0	2327.0	1	2330.5	0
2336.0	2	2372.5	0	2373.0	2	2373.5	0	2374.0	2
2386.5	0	2391.5	1	2467.0	0	2468.5	2	2520.0	0
2522.0	2	2585.5	0	2588.0	2	2588.5	0	2590.0	2
2592.5	0	2597.0	2	2600.5	0	2602.0	1	2608.0	0
2609.0	1	2633.5	0	2635.0	2	2655.5	0	2656.5	1

Figure B-3 (1 of 4) Left Track Profile

PAGE A 2

FROM - RIVERSIDE
TO - WOODLAND
LEFT PROFILE

FEET	ZONE	FEET	ZONE	FEET	ZONE	FEET	ZONE	FEET	ZONE
2658.0	0	2659.5	1	2660.5	0	2661.0	2	2662.0	0
2664.5	2	2674.0	0	2678.5	2	2692.0	0	2692.5	2
2726.5	0	2730.0	2	2738.5	0	2740.5	1	2746.5	0
2747.0	1	2749.0	0	2752.5	2	2754.0	0	2754.5	1
2758.5	0	2761.5	2	2812.5	0	2815.5	2	2957.0	0
2961.0	1	2976.5	0	2978.5	2				

Figure B-3 (2 of 4) Left Track Profile

FROM - RIVERSIDE
TO - WOODLAND
LEFT PROFILE

FEET	ZONE	MAX MAGNITUDE	FEET	ZONE	MAX MAGNITUDE	FEET	ZONE	MAX MAGNITUDE
2263.5	3	-0.758						

Figure B-3 (3 of 4) Left Track Profile

FROM - RIVERSIDE
TO - WOODLAND
LEFT PROFILE

ZONE	UPPER LIMIT	LOWER LIMIT	NO. OCCURANCES	TOTAL FT.
4	99.00	0.75	0	0.0
2	0.75	0.25	46	104.0
0	0.25	-0.25	85	2794.5
1	-0.25	-0.75	41	101.0
3	-0.75	-99.00	1	0.5

Figure B-3 (4 of 4) Left Track Profile

FROM - RIVERSIDE
TO - WOODLAND
RIGHT PROFILE

FEET	ZONE	FEET	ZONE	FEET	ZONE	FEET	ZONE	FEET	ZONE
5.5	0	10.0	1	15.5	0	21.5	2	47.0	0
53.5	1	56.5	0	60.0	2	107.5	0	110.5	1
156.5	0	160.0	1	182.0	0	184.0	1	238.5	0
243.0	1	246.0	0	247.5	2	278.5	0	281.0	1
285.5	0	286.0	2	342.5	0	346.0	1	384.5	0
390.0	1	436.0	0	439.5	1	443.0	0	444.5	2
450.5	0	455.0	1	462.0	0	463.5	2	467.5	0
468.0	1	473.5	0	483.0	1	516.0	0	518.0	1
601.0	0	605.0	1	605.5	0	606.0	1	630.0	0
630.5	1	650.0	0	652.5	1	716.5	0	720.5	1
773.5	0	778.0	1	934.5	0	938.0	1	967.5	0
968.0	1	1023.0	0	1027.0	1	1054.0	0	1058.5	1
1078.5	0	1080.0	1	1080.5	0	1081.0	1	1119.0	0
1119.5	1	1120.0	0	1120.5	1	1266.0	0	1272.0	1
1322.0	0	1328.0	1	1340.0	0	1341.5	2	1343.5	4
1346.0	2	1354.0	0	1354.5	1	1355.0	0	1358.5	1
1390.5	0	1391.0	1	1398.5	0	1399.0	1	1399.5	0
1403.0	1	1427.0	0	1427.5	2	1431.5	0	1437.0	1
1463.0	0	1469.0	1	1499.0	0	1499.5	1	1500.0	0
1500.5	1	1501.0	0	1501.5	1	1502.0	0	1502.5	1
1532.0	0	1532.5	1	1564.0	0	1564.5	1	1565.0	0
1568.5	1	1569.0	0	1569.5	1	1636.5	0	1642.5	1
1651.0	0	1651.5	1	1657.0	0	1657.5	2	1678.5	0
1680.0	1	1689.0	0	1693.0	1	1776.0	0	1781.5	1
1801.0	0	1805.5	1	1844.5	0	1845.5	1	1867.0	0
1867.5	1	1898.0	0	1898.5	1	1899.0	0	1899.5	1
1906.5	0	1913.0	1	1942.5	0	1947.0	1	1947.5	0
1948.0	1	1977.0	0	1982.0	1	2035.0	0	2040.0	1
2090.5	0	2095.5	1	2129.5	0	2130.0	1	2147.0	0

Figure B-4 (1 of 4) Right Track Profile

PAGE A 2

FROM - RIVERSIDE
TO - WOODLAND
RIGHT PROFILE

FEET	ZONE	FEET	ZONE	FEET	ZONE	FEET	ZONE	FEET	ZONE
2147.5	1	2148.0	0	2150.5	1	2155.5	0	2157.5	2
2163.0	0	2165.5	1	2166.0	0	2166.5	1	2207.0	0
2210.0	1	2210.5	3	2214.0	1	2226.0	0	2229.0	1
2254.5	0	2255.0	2	2258.5	0	2263.5	1	2323.0	0
2328.0	1	2332.5	0	2337.0	2	2347.0	0	2351.0	1
2386.0	0	2391.5	1	2392.0	0	2392.5	1	2420.0	0
2420.5	1	2449.0	0	2454.5	1	2540.0	0	2544.5	1
2580.0	0	2585.0	1	2603.0	0	2605.0	1	2605.5	0
2606.5	1	2607.5	0	2608.0	1	2640.0	0	2641.5	2
2651.5	0	2655.5	1	2656.5	3	2660.0	1	2661.0	0
2664.5	2	2675.5	0	2678.5	2	2681.5	0	2686.5	1
2687.0	0	2687.5	1	2715.0	0	2717.5	1	2728.0	0
2728.5	2	2733.5	0	2740.0	1	2750.0	0	2753.0	2
2768.5	0	2772.0	1	2772.5	0	2773.5	1	2817.5	0
2818.0	1	2829.0	0	2829.5	2	2836.5	0	2839.0	1
2839.5	0	2841.5	1	2865.0	0	2870.0	1	2870.5	0
2871.0	1	2964.0	0	2966.0	1				

Figure B-4 (2 of 4) Right Track Profile

FROM - RIVERSIDE
TO - WOODLAND
RIGHT PROFILE

FEET	ZONE	MAX MAGNITUDE	FEET	ZONE	MAX MAGNITUDE	FEET	ZONE	MAX MAGNITUDE
1343.5	4	0.960	2210.5	3	-0.768	2656.5	3	-0.807

Figure B-4 (3 of 4) Right Track Profile

FROM - RIVERSIDE
TO - WOODLAND
RIGHT PROFILE

ZONE	UPPER LIMIT	LOWER LIMIT	NO. OCCURANCES	TOTAL FT.
4	99.00	0.75	1	2.0
2	0.75	0.25	19	38.5
0	0.25	-0.25	111	2687.0
1	-0.25	-0.75	95	271.0
3	-0.75	-99.00	2	1.5

Figure B-4 (4 of 4) Right Track Profile

APPENDIX C

TRACK GEOMETRY - GAGE

MBTA Green Line Tests, Riverside Branch
December, 1972

SEQUENCE NO. 12-72-602

PROCEDURE NO. PCC-TGC-6008-MBTA

OBJECTIVE:

To measure track gage on the Riverside Branch of the Green Line, prior to initiation of track rehabilitation. These data will help establish which sections of track most severely require rework. It will also be used to classify track according to gage specifications in the IRT Safety Guidelines for Urban Rapid Transit Systems. These results will subsequently be compared with data collected after rehabilitation.

STATUS:

Gage data has been collected and processed for the Riverside Branch Track. The twenty-six-plus miles of track is presented in forty six sections of data in the form of gage versus distance and computer printout summaries. The complete data are contained in separate volumes. A representative section from Kenmore Square Station to Auditorium is shown in this appendix.

The computer printout gives the track classification according to IRT gage requirements. Half of the 46 sections have at least one gage reading that exceeds 57 3/4 inch or is less than 56 inches, thus making it unclassified. Twenty-two sections are Class II while one section is Class III.

Manual measurement of the gage to verify the automatically measured gage has revealed that the gage changes significantly in some places due to the vehicle loading. Further measurements may be made to provide improved understanding of the dynamic effects of vehicle loading on the gage data.

Test Description

In this test series, track gage is measured continuously using capacitive proximity detectors. The probes are located alongside the rails , one along each rail. The electronic circuit associated with each probe outputs a voltage proportional to the distance between the probe and the rail. By adding the two voltages, a sum voltage is obtained that is proportional to the difference between actual track gage and some known value of distance. The gage measuring system on this test put out zero volts for a track gage of 57 1/4 inches. This number is reached by measuring the distance between probe faces, 55 7/8 inches, and then adjusting the probe electronics so that an adequate displacement range is covered when the probes are mounted in the shadow of the wheel flange. Thus, each probe electronic system was set to operate at a sensitivity of 10 volts/inch and to put out zero volts when the probe face was 11/16 inch from the rail gage point.

Instrumentation

The gage probe was designed and built at TSC. It is thin enough (3/8" thick) to lie completely within the shadow of the wheel flange so that anything that the wheel flange clears will be cleared by the probe. In the event that the wheel flange rides up over an obstruction, the probe mount is designed to retract when it meets the obstruction and then spring back after the obstruction is passed.

The electronics assembly associated with each probe is located in the electronics rack in the car and utilizes the Lion Precision 300-1G Metrigap circuitry.

The summing amplifier was designed and built at TSC. It includes a scaling factor of 0.5 so that when gage data is recorded on magnetic tape or on the chart recorder, its scale factor is 5 volts/inch.

Test Procedure

The first step in each day's procedure is to calibrate the probes.

1. The car is moved to a parking space outside of any building so that the probe temperatures can approach the ambient and the probe electronics are turned on.

2. After allowing temperature equalization for one-half hour, each gage probe is taken off of the car and mounted on the calibration fixture. This calibration fixture has a sheet metal replica of the rail surface that is reciprocated in front of the probe to permit exercising its complete range. A linear potentiometer provides a signal proportional to the position of the slide on which the rail replica is mounted. This position signal drives the horizontal axis of a storage oscilloscope display. The probe electronics output drives the vertical axis of the same scope display. Hence, the scope displays probe output vs. distance of probe from its target. Turning on the electric drive motor of the Calibration Fixture allows this relationship to be displayed continuously as the trimpots on the probe electronics are adjusted to yield the desired gain and linearity from the circuit.

3. After all probes are calibrated, the car is moved to a location where the running rails are free from asphalt cross-walks or paved areas, or guard rails. Then, the distance between probe faces, the track gage at the probe locations, and the mean distance from the gage point of each rail to its corresponding probe face are measured. The electrical zero of each probe electronics is adjusted so that its output corresponds to the measured probe-to-gage-point distance and so that the electrical gage signal corresponds to measured gage.

4. At this point, the gage measurement system is ready to measure track gage.

5. The car is run over the track to be measured at any convenient speed, since capacitive proximity measurements are not sensitive to the speed in a direction normal to the measurement axis at which a continuous target passes in front of the probe.

Data

The gage data was recorded on analog tape in the form of capacitance probe circuit outputs, similar to the profile data. A sample section of track from Kenmore Square Station to Auditorium Station is shown here in Figure C-1. This section represents subsurface tracks. The statistical printout for the gage data is presented in the tabulated computer outputs on pages A, B and C of Figure C-2. The levels used for these outputs are summarized below along with the corresponding IRT track classification:

Zone		Gage G	Institute for Rapid Transit Track Classification
6		G≥57 3/4 in	Unclassified
4	57 1/4 in≤	G<57 3/4 in	Class 1 or 2
2	57 in≤	G<57 1/4 in	Class 3
0	56 1/4 in<	G<57 in	Class 4
1	56 <	G≤56 1/4 in	Class 4
3		G≤56 in	Unclassified

Page C of the figure provides a quick indication of the track classification relative to the IRT requirements for gage. Page B gives the location and magnitude of occurances in Zones 1, 3, 4 and 6. Page A shows the location that the gage changes from one zone to another.

The page C gage printouts for all 46 sections are summarized in Table C-1. The IRT class of each section is given based on a

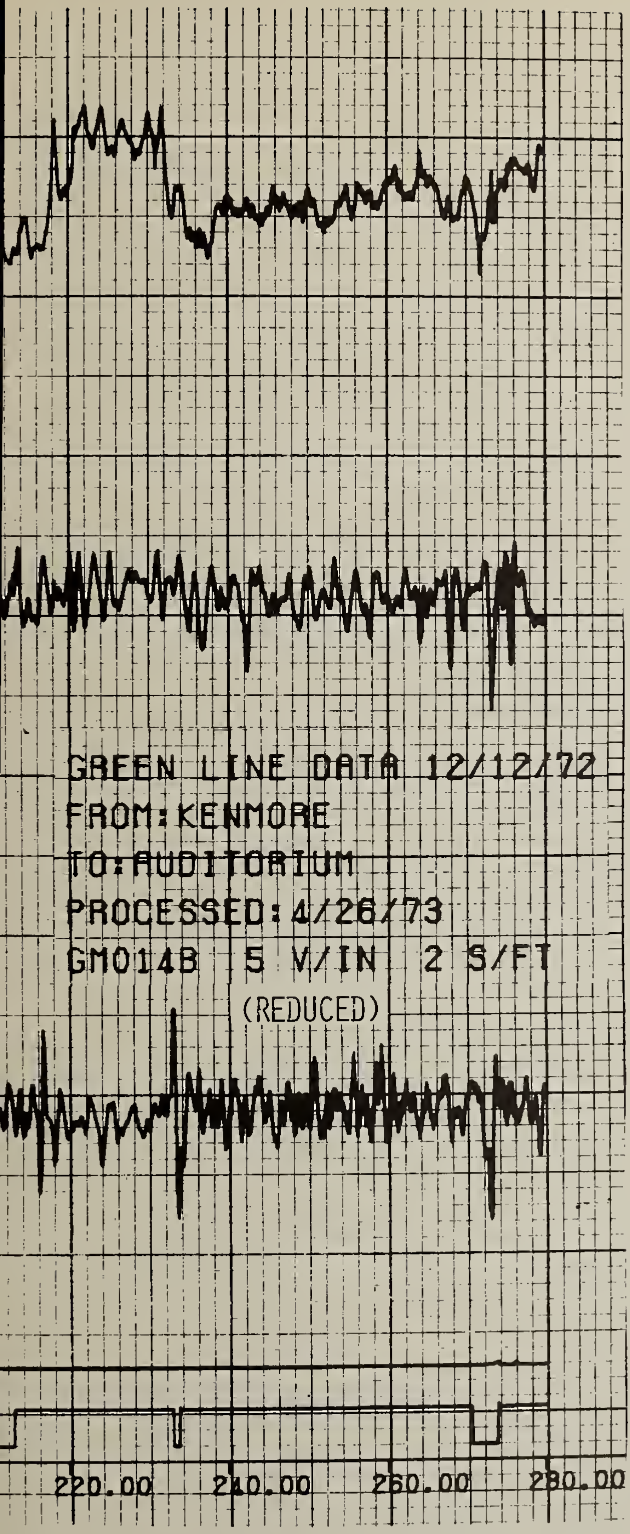


Figure C-1 Gage Data Plot

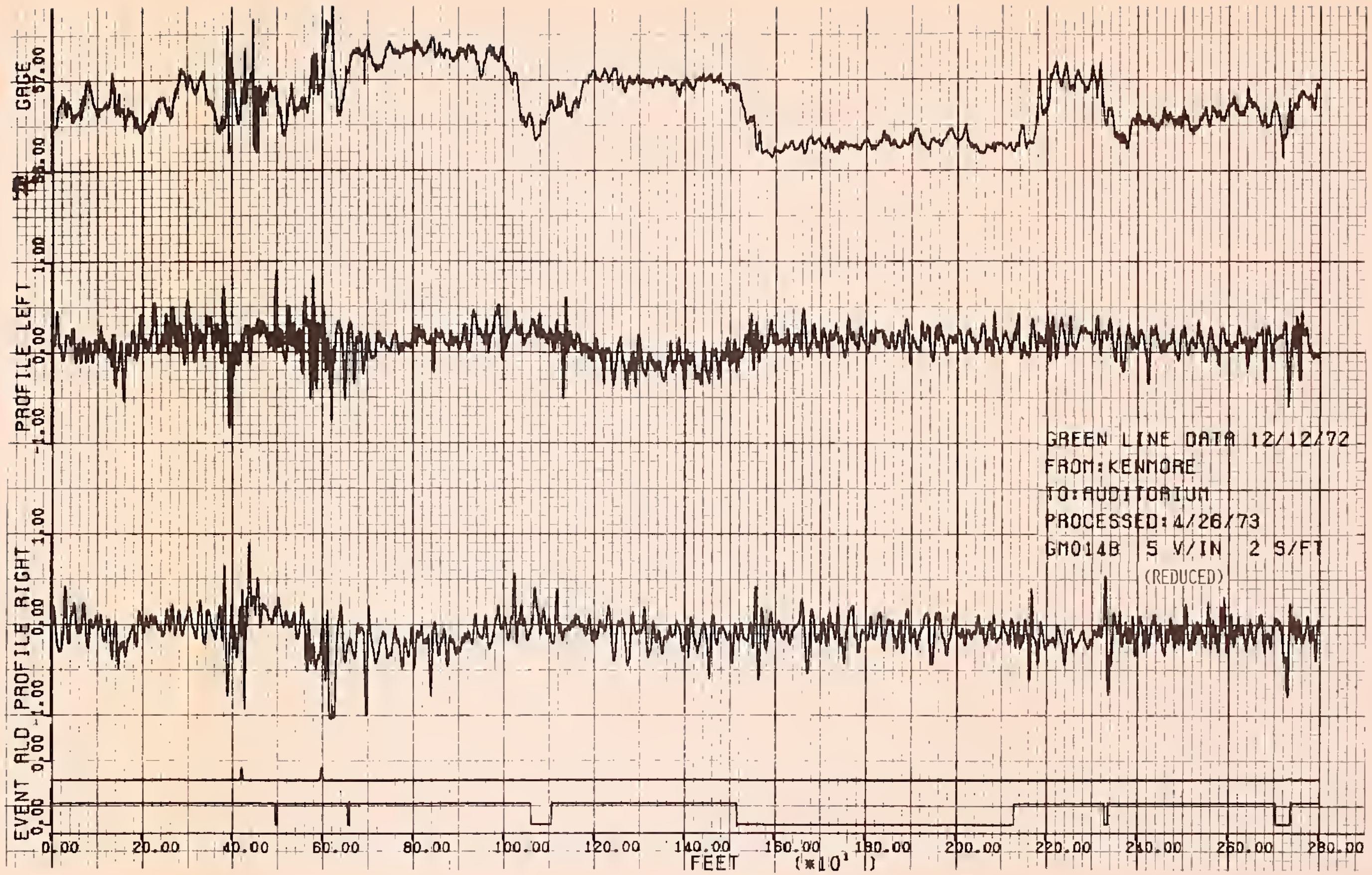


Figure C-1 Gage Data Plot

FROM - KENMORE
TO - AUDITORIUM
GAGE

FEET	ZONE	FEET	ZONE	FEET	ZONE	FEET	ZONE	FEET	ZONE
79.5	0	81.5	2	134.5	0	137.0	2	284.5	0
298.5	2	305.5	0	312.0	2	328.5	0	339.5	2
340.0	0	340.5	2	390.5	0	391.0	2	393.0	4
394.0	2	394.5	0	395.0	1	395.5	2	396.5	0
398.5	2	399.0	4	405.0	2	405.5	0	406.0	2
429.0	0	430.5	2	431.0	4	440.5	0	441.5	2
442.5	0	447.5	2	448.0	0	448.5	4	449.0	2
452.5	0	454.5	1	456.0	0	457.0	1	457.5	0
459.0	1	575.0	0	577.5	2	578.0	4	579.5	2
583.0	0	583.5	4	585.0	2	585.5	4	587.0	2
587.5	4	589.5	2	603.0	0	606.0	2	623.0	4
623.5	6	625.5	4	628.5	2	652.0	0	664.0	2
692.5	4	693.0	0	694.0	2	705.0	4	705.5	2
708.5	4	736.0	2	737.0	4	737.5	2	770.5	4
771.0	2	867.5	4	868.5	2	882.0	4	884.5	2
885.5	4	891.0	2	893.5	4	896.0	2	915.5	4
916.0	2	938.5	4	961.0	2	979.5	4	981.0	2
984.5	4	990.5	2	998.5	4	1015.5	2	1020.0	0
1030.0	2	1178.5	0	1179.5	2	1180.5	0	1183.5	2
1187.0	0	1211.0	2	1214.0	0	1230.5	2	1234.5	0
1251.5	2	1256.5	0	1262.5	2	1275.5	0	1279.0	2
1280.5	0	1282.0	2	1290.0	0	1297.5	2	1306.5	0
1310.0	2	1319.5	0	1321.5	2	1333.0	0	1341.0	2
1344.5	0	1348.0	2	1352.0	0	1365.5	2	1399.5	0
1401.0	2	1403.0	0	1404.5	2	1405.0	0	1406.5	2
1425.5	0	1435.0	2	1436.5	0	1445.0	2	1446.5	0
1447.0	2	1448.5	0	1459.5	2	1460.0	0	1462.5	2
1468.5	0	1474.5	2	1476.0	0	1481.5	2	1558.0	0
1561.0	1	1569.0	0	1598.5	1	1599.5	0	1618.5	1

Figure C-2 (1 of 4) Gage Data Printout

FROM - KENMORE
TO - AUDITORIUM
GAGE

FEET	ZONE	FEET	ZONE	FEET	ZONE	FEET	ZONE	FEET	ZONE
1625.5	0	1627.5	1	1643.0	0	1646.5	1	1647.5	0
1650.5	1	1662.0	0	1669.0	1	1711.0	0	1711.5	1
1727.5	0	1733.0	1	1737.0	0	1742.5	1	1748.0	0
1749.0	1	1781.0	0	1782.5	1	1786.5	0	1789.5	1
1812.5	0	1815.5	1	1820.5	0	1822.0	1	1875.5	0
1876.0	1	1935.0	0	1939.0	1	2036.5	0	2038.5	1
2046.5	0	2064.5	1	2074.5	0	2077.5	1	2081.0	0
2084.5	1	2108.5	0	2112.0	1	2123.5	0	2131.5	1
2155.5	0	2157.0	1	2184.5	0	2186.5	2	2209.5	0
2210.5	2	2211.0	0	2230.5	2	2236.5	0	2250.0	2
2264.5	0	2277.0	2	2298.5	0	2309.0	2	2316.5	0
2322.5	2	2377.5	0	2378.5	1	2719.0	0	2720.0	1

Figure C-2 (2 of 4) Gage Data Printout

PAGE B 1

FROM - KENMORE
TO - AUDITORIUM
GAGE

FEET	ZONE	MAX MAGNITUDE	FEET	ZONE	MAX MAGNITUDE	FEET	ZONE	MAX MAGNITUDE
393.0	4	57.603	395.0	1	56.198	399.0	4	57.252
431.0	4	57.357	448.5	4	57.674	454.5	1	56.235
457.0	1	56.203	459.0	1	56.234	578.0	4	57.265
583.5	4	57.282	585.5	4	57.273	587.5	4	57.288
623.5	6	57.837	692.5	4	57.360	705.0	4	57.445
708.5	4	57.267	737.0	4	57.253	770.5	4	57.432
867.5	4	57.477	882.0	4	57.355	885.5	4	57.252
893.5	4	57.266	915.5	4	57.371	938.5	4	57.396
979.5	4	57.398	984.5	4	57.281	998.5	4	57.375
1561.0	1	56.233	1598.5	1	56.146	1618.5	1	56.196
1627.5	1	56.245	1646.5	1	56.229	1650.5	1	56.238
1669.0	1	56.191	1711.5	1	56.250	1733.0	1	56.209
1742.5	1	56.195	1749.0	1	56.245	1782.5	1	56.237
1789.5	1	56.234	1815.5	1	56.230	1822.0	1	56.241
1876.0	1	56.247	1939.0	1	56.229	2038.5	1	56.241
2064.5	1	56.184	2077.5	1	56.236	2084.5	1	56.205
2112.0	1	56.231	2131.5	1	56.209	2157.0	1	56.243
2378.5	1	56.242	2720.0	1	56.145			

Figure C-2 (3 of 4) Gage Data Printout

PAGE C 1

FROM - KENMORE
TO - AUDITORIUM
GAGE

ZONE	UPPER LIMIT	LOWER LIMIT	% OF TOTAL	NO. OCCURANCES	TOTAL FT.
6	99.00	57.75	0.02	1	0.5
4	57.75	57.25	10.23	24	286.5
2	57.25	57.00	14.45	70	404.5
0	57.00	56.25	70.32	80	1969.0
1	56.25	56.00	4.98	30	139.5
3	56.00	-99.00	0.00	0	0.0

ZONES	IRT CLASS	TIGHT	WIDE	% OF TOTAL
0+1+2+4	1+2	56.00	57.75	99.98
0+1+2	3	56.00	57.25	89.75
0+1	4	56.00	57.00	75.30
6+3	BELOW STNDRD	56.00	57.75	0.02

Figure C-2 (4 of 4) Gage Data Printout

TABLE C-1 GREEN LINE TRACK GAGE DATA

	Track Section	IRT Class	Percentage of Track Meeting Gage Requirements IRT Class 4	3	2
1.	Riverside to Woodland	-	99.92	99.98	99.98
2.	Woodland to Waban	-	99.13	99.99	99.99
3.	Waban to Eliot	3	99.36	100	
4.	Eliot to Newton Highlands	2	94.94	99.95	100
5.	Newton Highlands to Newton Ctr.	2	95.24	99.60	100
6.	Newton Center to Chestnut Hill	2	92.47	99.57	100
7.	Chestnut Hill to Reservoir	-	92.20	98.76	99.94
8.	Reservoir to Beaconsfield	2	78.53	95.37	100
9.	Beaconsfield to Brookline Hills	2	92.53	99.26	100
10.	Brookline Hills to Brookline Vil.	2	94.37	99.52	100
11.	Brookline Vil. to Longwood	2	95.98	99.73	100
12.	Longwood to Fenway	2	95.92	99.51	100
13.	Fenway to Kenmore	-	92.24	97.18	99.99
14.	Kenmore to Auditorium	-	75.30	89.75	99.98
15.	Auditorium to Copley	-	91.31	99.40	99.97

TABLE C-1 GREEN LINE TRACK GAGE DATA (CONT)

Track Section	IRT Class	Percentage of Track Meeting Gage Requirements IRT Class 4	3	2
16. Copley to Arlington	-	99.26	99.96	99.99
17. Arlington to Boylston	-	93.48	99.31	99.96
18. Boylston to Park St.	-	83.46	99.07	99.93
19. Park St to Govt. Ctr.	2	85.62	98.46	100
20. Govt. Ctr. to Haymarket	2	97.64	99.71	100
21. Haymarket to No. Station	-	93.21	99.65	99.94
22. No. Station to Science Park	-	92.27	99.48	99.75
23. Science Park to Lechmere	-	95.06	99.95	99.98
24. Lechmere to Science Park	-	56.67	82.95	99.26
25. Science Park to No. Station	-	61.68	85.67	99.92
26. No. Station to Haymarket	-	59.21	82.66	97.34
27. Haymarket to Govt. Ctr.	-	52.39	78.69	99.94
28. Govt. Ctr. to Park St.	-	48.54	78.37	99.85
29. Park St. to Boylston	-	67.47	89.27	99.68
30. Boylston to Arlington	-	79.83	96.15	99.82

TABLE C-1 GREEN LINE TRACK GAGE DATA (CONT)

	Track Section	IRT Class	Percentage of Track Meeting Gage Requirements IRT Class 4	3	2
31.	Arlington to Copley	2	92.08	99.4	100
32.	Copley to Auditorium	2	91.67	97.48	100
33.	Auditorium to Kenmore	-	81.94	94.02	99.86
34.	Kenmore to Fenway	-	98.88	99.74	99.25
35.	Fenway to Longwood	-	98.49	99.90	99.99
36.	Longwood to Brookline Vil.	2	93.00	98.92	100
37.	Brookline Vil. to Brookline Hills	2	88.70	98.32	100
38.	Brookline Hills to Beaconsfield	2	88.12	98.06	100
39.	Beaconsfield to Reservoir	2	94.70	99.95	100
40.	Reservoir to Chestnut Hill	2	92.07	98.52	100
41.	Chestnut Hill to Newton Ctr.	2	94.19	99.20	100
42.	Newton Ctr. to Newton Highlands	2	97.75	99.94	100
43.	Newton Highlands to Eliot	2	95.78	99.83	100
44.	Eliot to Waban	2	99.49	99.98	100
45.	Waban to Woodland	2	99.42	99.98	100
46.	Woodland to Riverside	-	82.87	83.07	93.82

literal interpretation of the data. The section of track from Waban Station to Eliot Station is Class III. Twenty-two sections are Class II. The remaining 23 sections are below standard because of one or more places where the gage exceeds 57 3/4 inches or is less than 56 inches. However, of these sections, eleven have only one recorded defect. Many of the recorded defects occur in a region where extraneous metal such as guard rails may be effecting the recorded signal. A visual check of the track at these points is required to provide the final conclusion. The percentage of trackage that satisfies gage requirements provides a better measure of track quality. The percentage of the track in each section that meets the gage requirements for IRT Classes 2, 3 and 4 is also shown in Table C-1.

NOTE: Figure C-1 has been reduced to 75% of normal size.

APPENDIX D
JOURNAL BOX ACCELERATION

MBTA Green Line Tests, Riverside Branch
December, 1972

SEQUENCE NO. 12-72-603
PROCEDURE NO. PCC-TGA-6006-MBTA

OBJECTIVE:

To collect data for checkout of the software for integrating accelerometer outputs to obtain actual profile and alignment. Profile data obtained this way will be used to meet long range goals. From actual profile data, midchord profile data can be derived for comparison with measured midchord data (10 foot beam). In addition, 62 foot chord data can be computed for comparison with IRT Safety Guidelines.

STATUS:

Data was collected for vertical acceleration of the journal boxes on one axle and the lateral acceleration of the axle.

Processing of these data will include the following:

1. Computation of the profile of the rails using the vertical accelerometers.

2. Computation of the rail alignment using the lateral accelerometer and the capacitance gage probe output.

This processing will be carried out as part of the TSC software development effort and the resulting data will not be included as part of this report.

Test Description

It would be expected that irregularities in rail profile and alignment are randomly distributed in wavelength and amplitude with the exception of periodic irregularities at a wavelength equal to the distance between joints in jointed rail. Experience has shown that one accelerometer does not have sufficient dynamic range to sense all irregularities of interest. Therefore, two accelerometers are used to measure the accelerations of each point of interest. To measure higher frequency and higher magnitude acceleration, piezo accelerometers are rigidly attached to the top of the casting housing each journal of one axle. Vertical and lateral accelerations are measured at each location. An accelerometer mounting block is attached (with epoxy adhesive) to each journal box and the accelerometers are bolted to the mounting block. The mounting of the low frequency servo-accelerometers is somewhat more complex. A short beam is rigidly attached to the journal box casting. This beam is located alongside the wheel and just outboard of it, as shown in Figure 2-1. To this beam is bolted a vibration isolator (mechanical filter) accelerometer mount. A sensitive servo-accelerometer is bolted to the "sprung mass" portion of the mounting assembly. The servo-accelerometer mount used on the right side is shown in Figure 2-1. The corresponding servo-accelerometer mount used on the left side contains one design deficiency that will be removed on subsequent design modifications: that is that any rotation of the sprung mass is sensed as vertical and lateral accelerations. Both vibration isolators are "center-of-gravity" mounts which tend to minimize the coupling of vibrations from one mode to another.

The selection of the frequency range and "g" range for the low frequency servo-accelerometers is predicated on a few simplifying assumptions. First, it is assumed that the low frequency accelerometers will be investigating rail anomalies whose wavelengths are between 3 and 150 feet. Then, for analytic simplicity, it is assumed that the perturbations in rail contour are sinusoidal in form. This permits relating wavelength, speed, frequency, acceler-

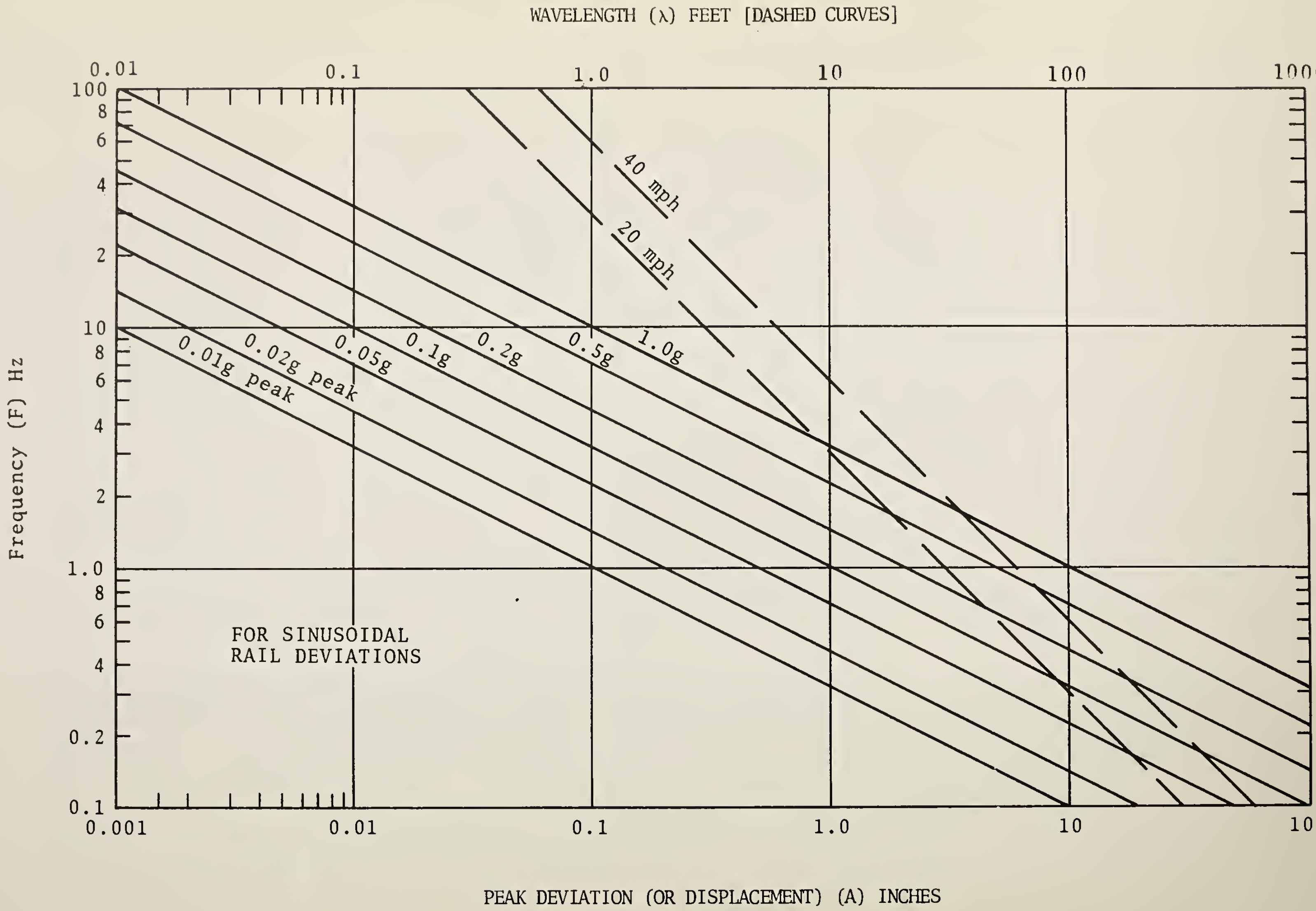


Figure D-1 Low Frequency Accelerometer Relationships ation, and peak deviation as shown in Figure D-1. This figure shows that to sense perturbations whose wavelengths are between 3 and 150 feet, at 20 mph, the frequency range from 0.2 to 10 Hz must be covered. A 1 g peak acceleration capability would permit the observation of the effects of peak deviations from 0.1 over 100 inches, depending on wavelength.

An area of current development at TSC is that of designing the best mechanical filter for the low frequency accelerometer mount. The filter must represent the best compromise between adequate shock isolation for the accelerometer, faithful signal transmission in the pass band, and signal attenuation outside the pass band. Further, the mount must minimize the coupling between the different modes of vibration. The mechanical filter mounts used for these tests represent only a first attempt toward a solution of this problem.

Instrumentation

The accelerometers used to measure the high frequency vibrations were Columbia Model 704 piezo accelerometers. Endevco Model 2642M26 charge amplifiers were used to scale the accelerometer output.

The low frequency accelerometers were Kistler/Endevco QA-116-15 Q-Flex servo-accelerometers. Endevco SC-116-2 "g" monitors were used as scaling amplifiers for the servoaccelerometers. During the first part of the week, Lord 100PDL-1 vibration isolators were used in the mechanical filter accelerometer mount. These isolators used a natural rubber elastomer. The acceleration frequency response for the 100 PDL-1 is shown in Figure D-2. This figure shows that the accelerometer mount, with 100 PDL-1 isolators installed, resonated at approximately 16-17 Hz and showed a resonant transmission peaking of around 10. For the December 14 (Thursday) and December 15 (Friday) runs, Lord HTO-1 vibration isolators were substituted. These use the Lord BTR elastomer which provides a higher damping coefficient than natural rubber. With the HTO-1 isolators installed, the accelerometer mounts display a

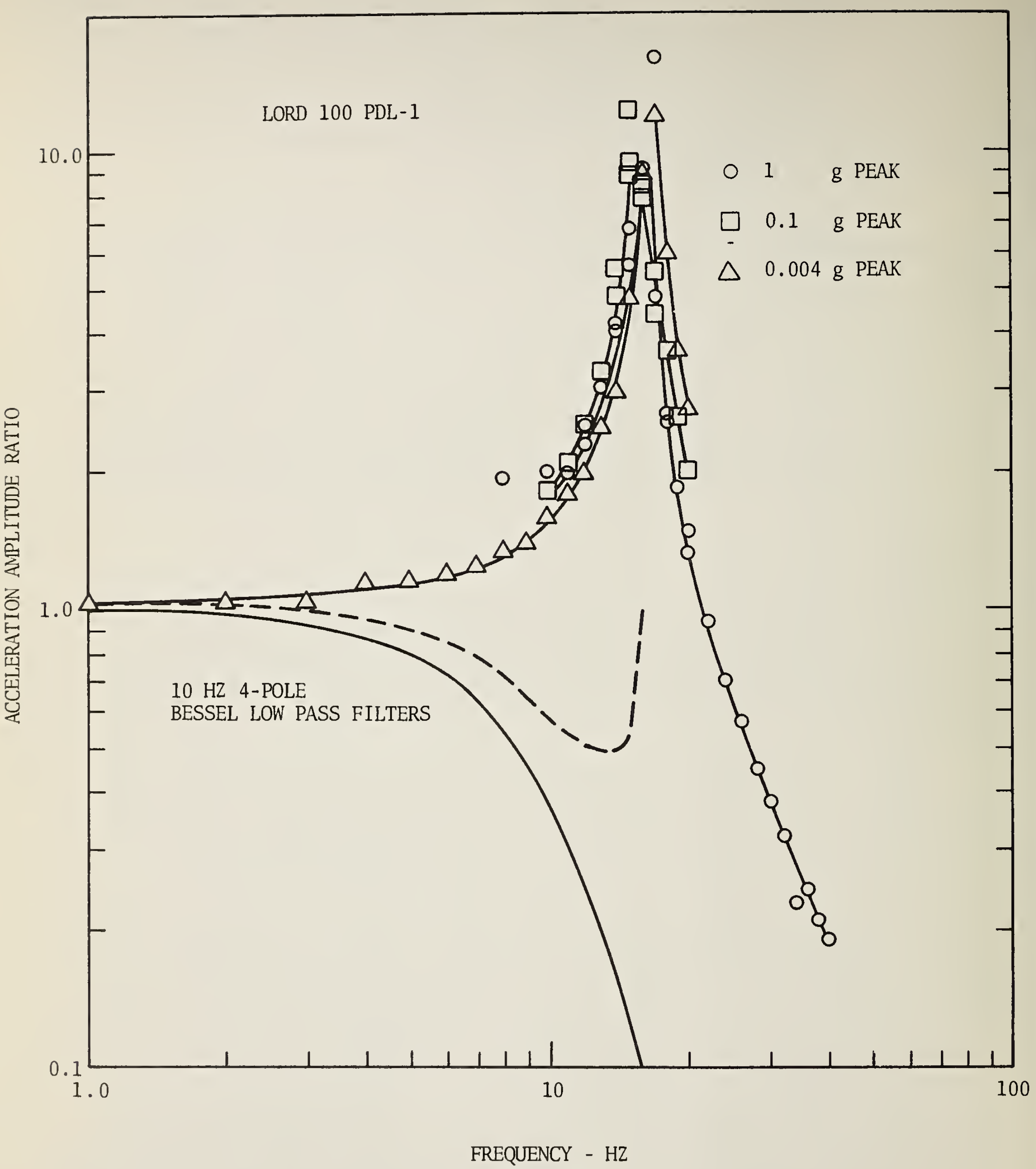


Figure D-2 Isolator Frequency Response

vertical acceleration resonance that varies from 40 to 85 Hz depending on amplitude. The output of each low frequency accelerometer scaling amplifier is passed through an electrical band pass filter having a pass band from 0.2 to 10 Hz. The band pass filter consists of a cascaded combination of high pass and low pass filters. The high pass filter is a Frequency Device Inc., Model 709H4L 0.2 Hz, 4-pole Bessel filter. The low pass filter is an Analog Devices, Inc., Model 730LTI 10 Hz, 4-pole Bessel filter. The frequency response for a 10 Hz 4-pole Bessel low pass filter is shown in Figure D-2. It can be seen that most, but perhaps not all, of the resonant peaking of the 100 PDL-1 isolator configuration is attenuated by the electrical filter.

Test Procedure

1. Since accelerometer calibration must be done in the laboratory using a shake table, the daily on-site calibration consists of turning on the accelerometers and manually actuating the vibration isolation mounts and monitoring the output signals.

2. To facilitate statistical analysis of the data, constant speed runs at 20 and 40 mph were specified. However, 40 mph could not be maintained consistantly. Constant speed runs of about 25 mph were used for the test.

Data

Representative journal box accelerometer data are shown in Figures D-3 and D-4 for samples of data including both rough and smooth track. The data is for the east-bound track of the Highland Branch from Signal 49, through Newton Highlands station, to Signal 47. The track from Signal 49 to Newton Highlands Station is fairly rough, while track through the station to Signal 47 is comparitively smooth. This track was traversed at approximately 25 miles per hour.

In order to interpret the recorded data, the frequency response of the oscillographic chart recorder must be considered. The frequency response ±2% of full scale is dc to 100 Hz for 10 divisions double amplitude. Frequency constraint was imposed on the piezo accelerometer data to reduce the magnitude of the blur around the zero g line on these chart records. The piezo signals were passed through 1-80 Hz band pass filters prior to recording on the charts. Each of these filters consisted of 1 Hz, single-pole, RC high pass filter in tandem with a 80 Hz, four-pole, Butterworth low-pass filter. The chart drive axis, (abscissa) is proportional to the distance travelled. The distance scale along the abscissa of these two figures (D-3 and D-4) is 2.5 feet traveled per millimeter or minor division of chart motion. The trace between the speed and automatic location detector channels is a one second time interval mark.

For the run from which the data of Figure D-3 was taken, the low frequency accelerometers were mounted using Lord 100PDL-1, low frequency (16 Hz), low damping (T_{max}=10), vibration isolators. What seems to predominate in the low frequency vertical accelerometer output is the transient response of the vibration isolated mount to a train of acceleration pulses. These pulses are observed to occur at spacing intervals of approximately 33 feet, and are presumed to be soft (or low) spots in the ballast at the points where the rail joints were previously welded. Since the transient response of the isolation mount obliterates much of the track accelerometer data, it is concluded that use of a low damped, low frequency vibration isolation is not appropriate for this application. The -0.25 g bias shown in the right journal box vertical low frequency accelerometer data is caused by a deteriorating oscillograph pen motor drive assembly.

Figure D-4 shows journal box acceleration data from a run over the same section of track at approximately the same speed, 25 mph, but with Lord HTO-1 vibration isolators used in the low frequency accelerometer mounts. The HTO-1 isolators provide a resonance frequency of 40 to 85 Hz, depending on amplitude, and a

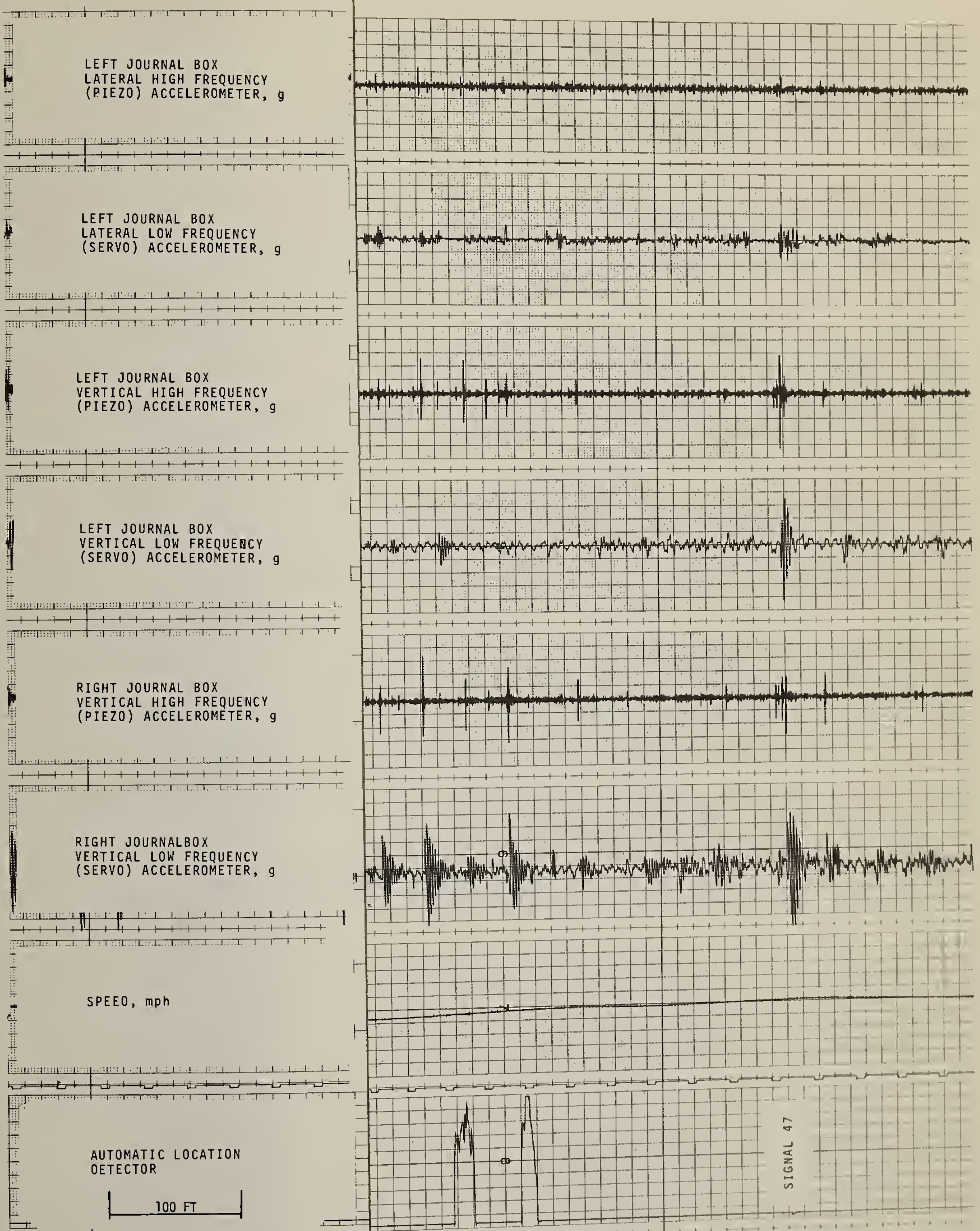


Figure D-3 Accelerometer Data

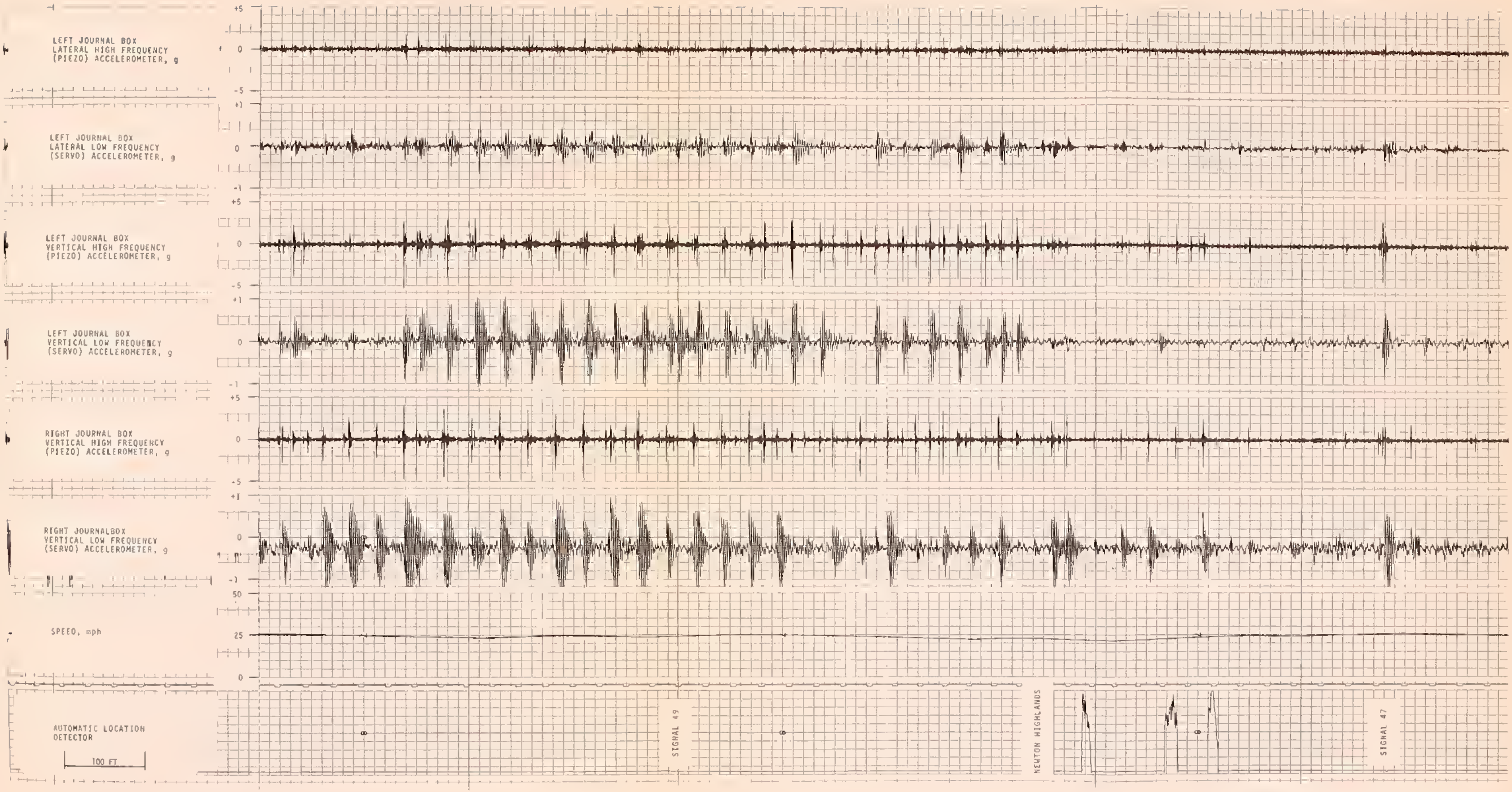


Figure D-3 Accelerometer Data

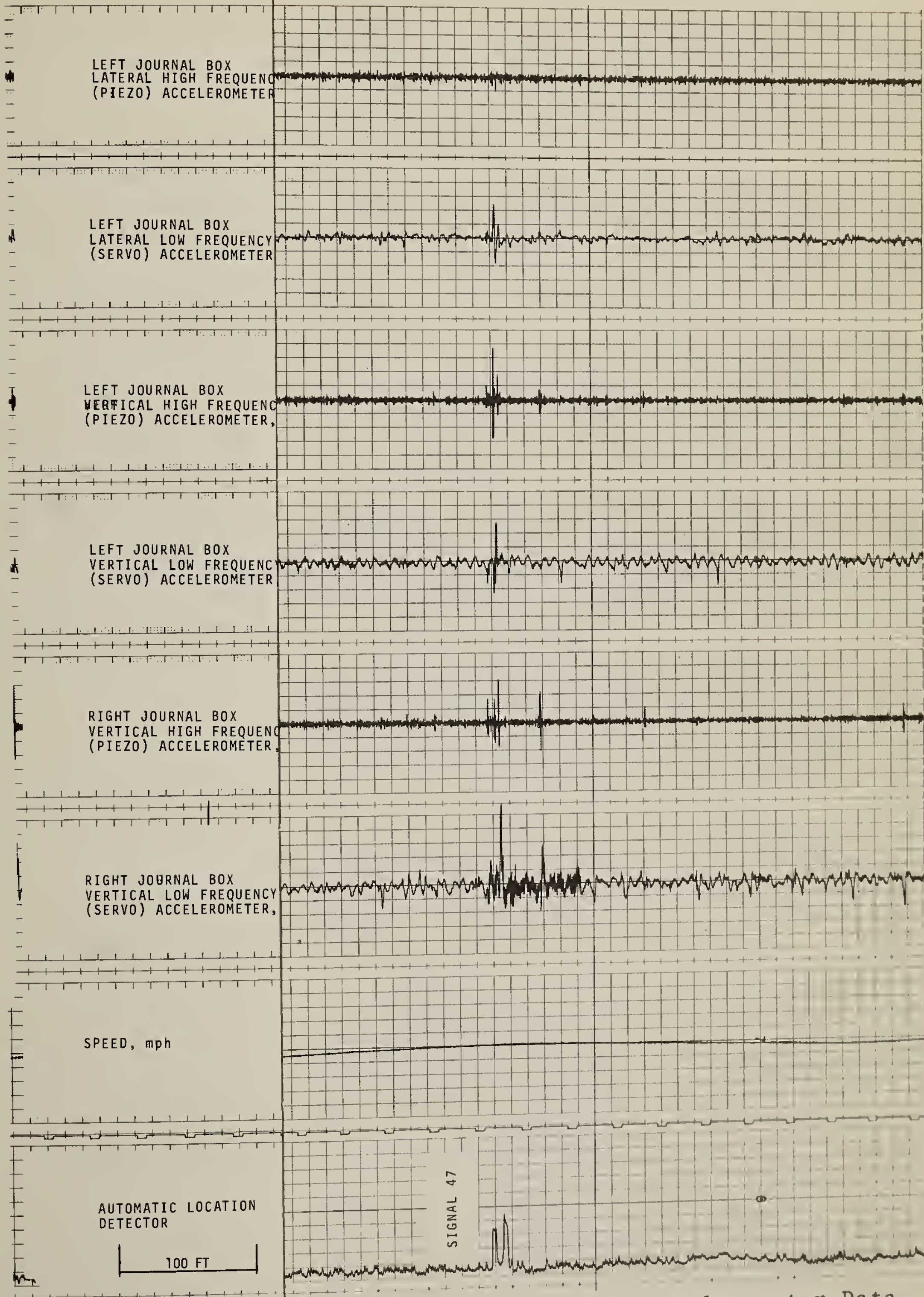


Figure D-4 Accelerometer Data

Figure D-4 Accelerometer Data

transmissability at resonance of T_{max} from 2.8 to 8, depending on amplitude. Figure D-4 shows that the transient response of the vibration isolated mount to a pulse of acceleration damps out within one cycle. Comparison of the peaks in the piezo and servo accelerometer data for the same axis of the same journal box shows the additional attenuation achieved by the added filtering used for the low frequency accelerometers. In fact, the piezo accelerometer data is significantly attenuated by the frequency response of the oscillographic chart recorders and the 80 Hz low pass filter. Monitoring the right journal box vertical piezo accelerometer data for the same section of track and the same run depicted here indicates that the larger pulses shown here actually approach 20 g in magnitude.

Between pulses, a ripple of periodic nature is indicated. It has an amplitude of 0.1 g and a typical wave length of about six to eight feet. At 25 mph, this translates into a frequency of about four to five Hz.

APPENDIX E

RIDE ROUGHNESS

MBTA GREEN LINE TESTS, RIVERSIDE BRANCH
DECEMBER, 1972

SEQUENCE NO. 12-72-604
PROCEDURE NO. PCC-PN-5002-MBTA

OBJECTIVE:

To measure vibrations in the car that would be experienced by a standing passenger on a PCC car on the Riverside Branch of the Green Line prior to initiation of track rehabilitation. These data subsequently will be compared with ride roughness data collected on a PCC car on the rehabilitated track. A similar comparison will be made with the new cars to be purchased as replacements for present rolling stock.

STATUS

Ride roughness data was sucessfully recorded for several runs. A representative run is presented in this appendix.

Test Description

Passenger ride roughness is measured using servoaccelerometers to measure the linear accelerations in three orthogonal directions of a plate resting on three conical points on the floor of the car. Since, in general, peak accelerations are considerably less than 1g, the sensor block is not expected to lift off the floor. Although linear accelerations are all that are required to define passenger ride roughness, angular acceleration data was also recorded to permit a more complete dynamic analysis of car body motions. Angular accelerations were recorded in each of three orthogonal planes. The ride roughness sensor plate was located on the centerline of the car, so that the sensors were 2 inches ahead of the center of the left side door. This location puts the ride roughness sensors 7'9" aft of the front truck pivot and 15' forward of the rear truck pivot.

Instrumentation

The linear accelerometers are a tri-axial package of Systron-Donner linear servo-accelerometers, model no. 5603-P2. The output voltage scale of these is 5 volts/g.

Angular accelerations were measured using Schaevitz angular servoaccelerometers, model no. ASMC 40-50. The operational amplifier scaling the accelerometer output yielded 0.96 volts/rad/sec^2 on the high gain setting and 0.48 volts/rad/sec^2 on the low gain setting.

Test Procedure

Since both types of accelerometers were of recent purchase, the manufacturers calibration was accepted.

Data was taken on both constant speed runs at 20-25 mph and 30 mph and on revenue speed profile runs.

Data

Figures E-1 and E-2 represent a ride roughness survey of the Green line from Riverside to Lechmere and return. The outputs

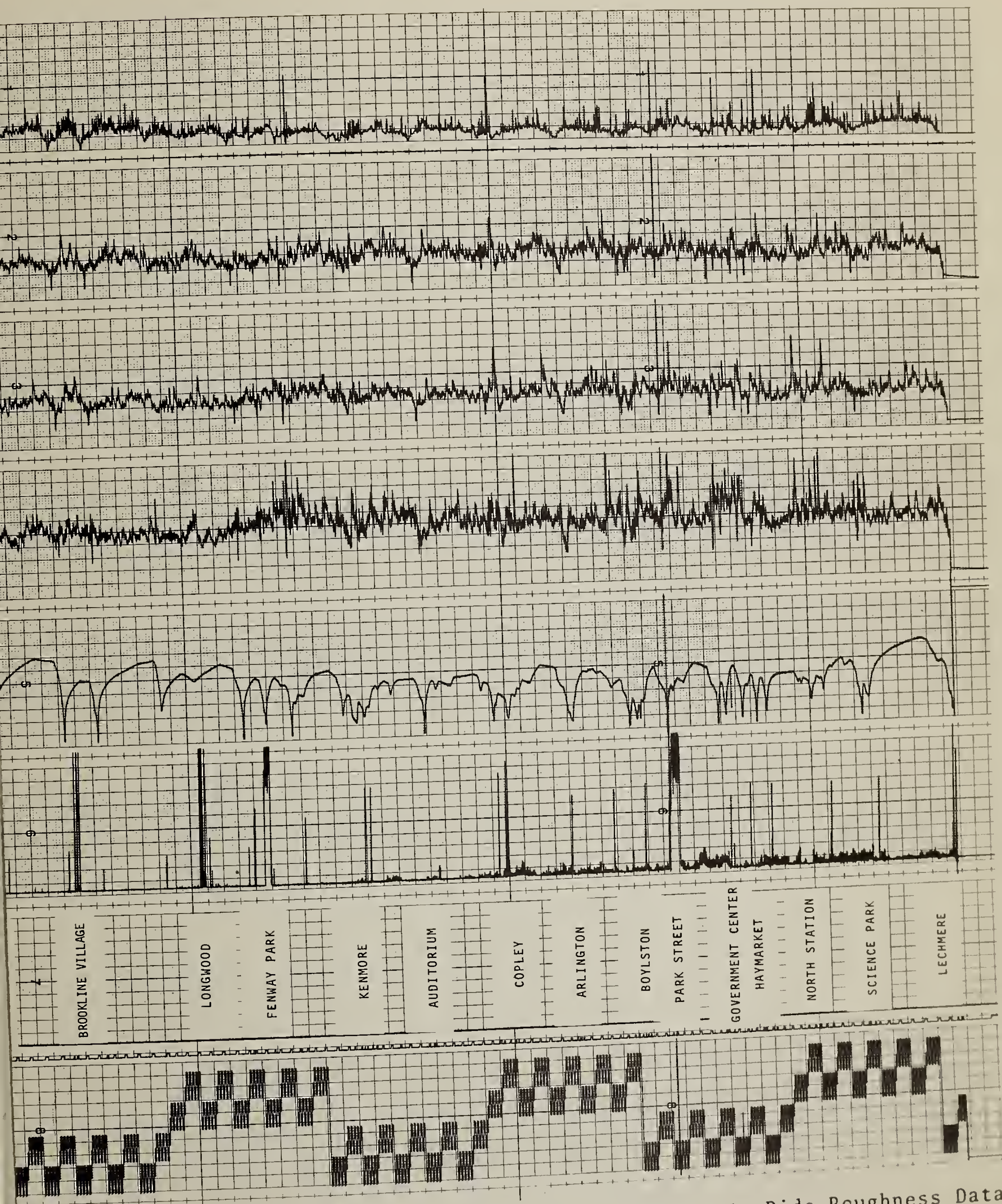


Figure E-1 Ride Roughness Data

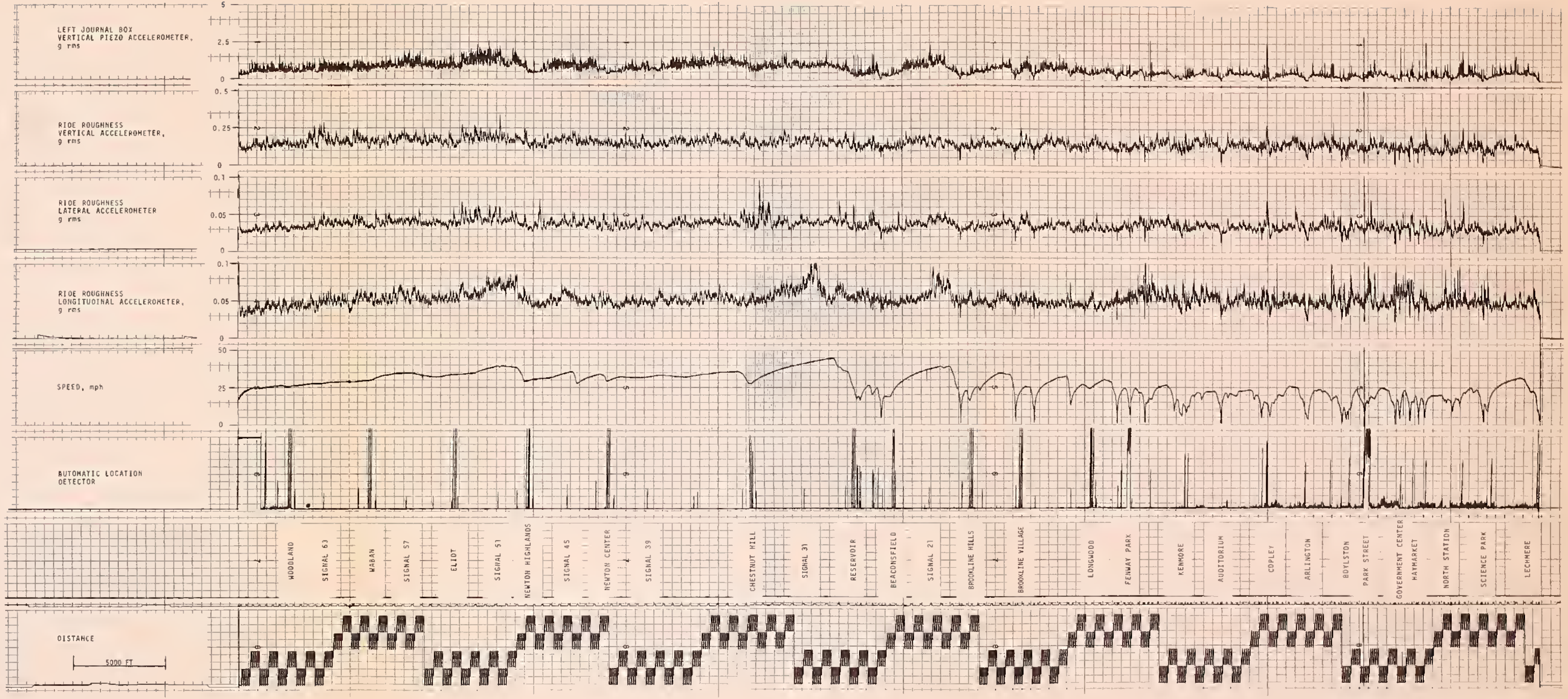


Figure E-1 Ride Roughness Data

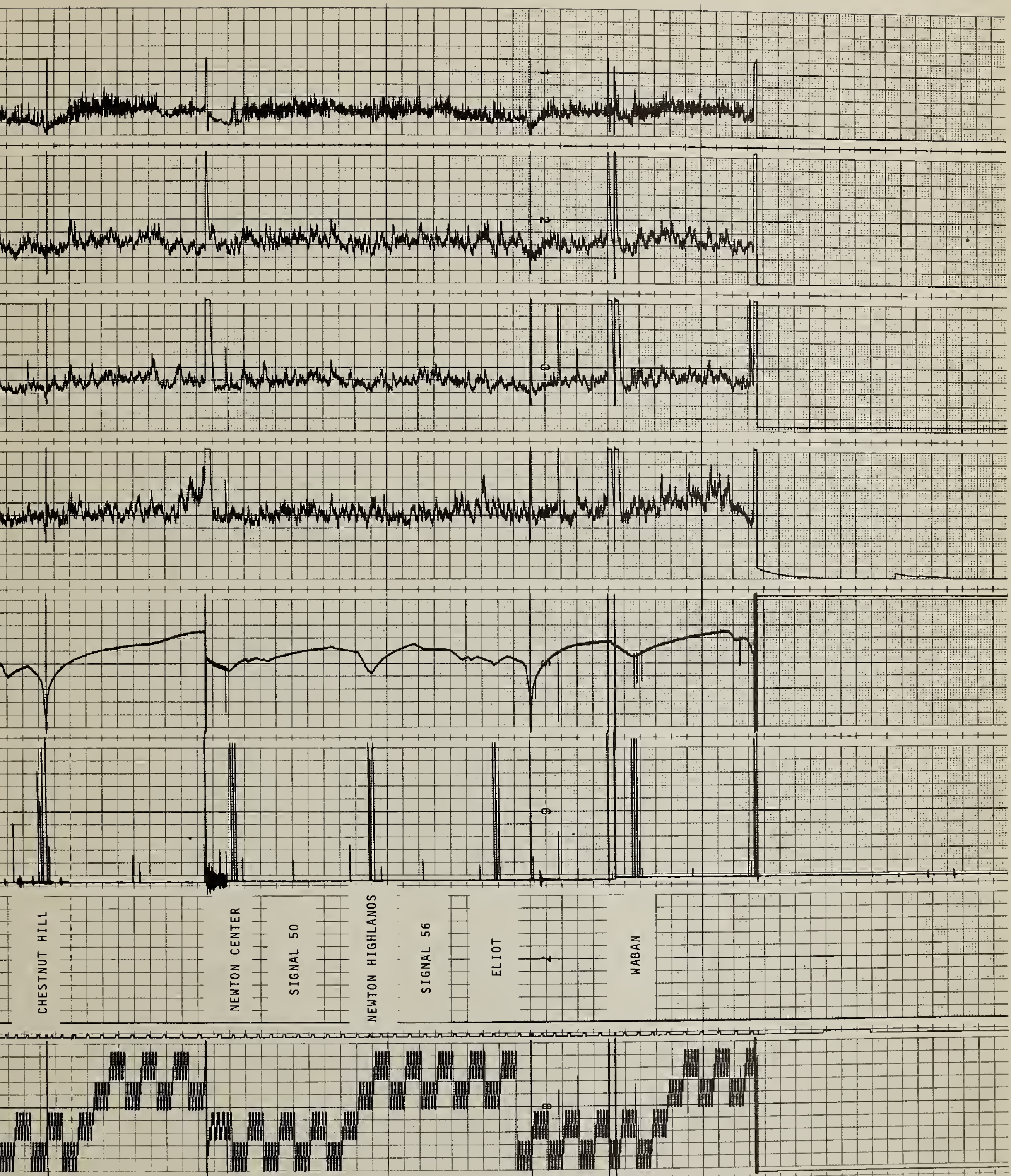


Figure E-2 Ride Roughness Data

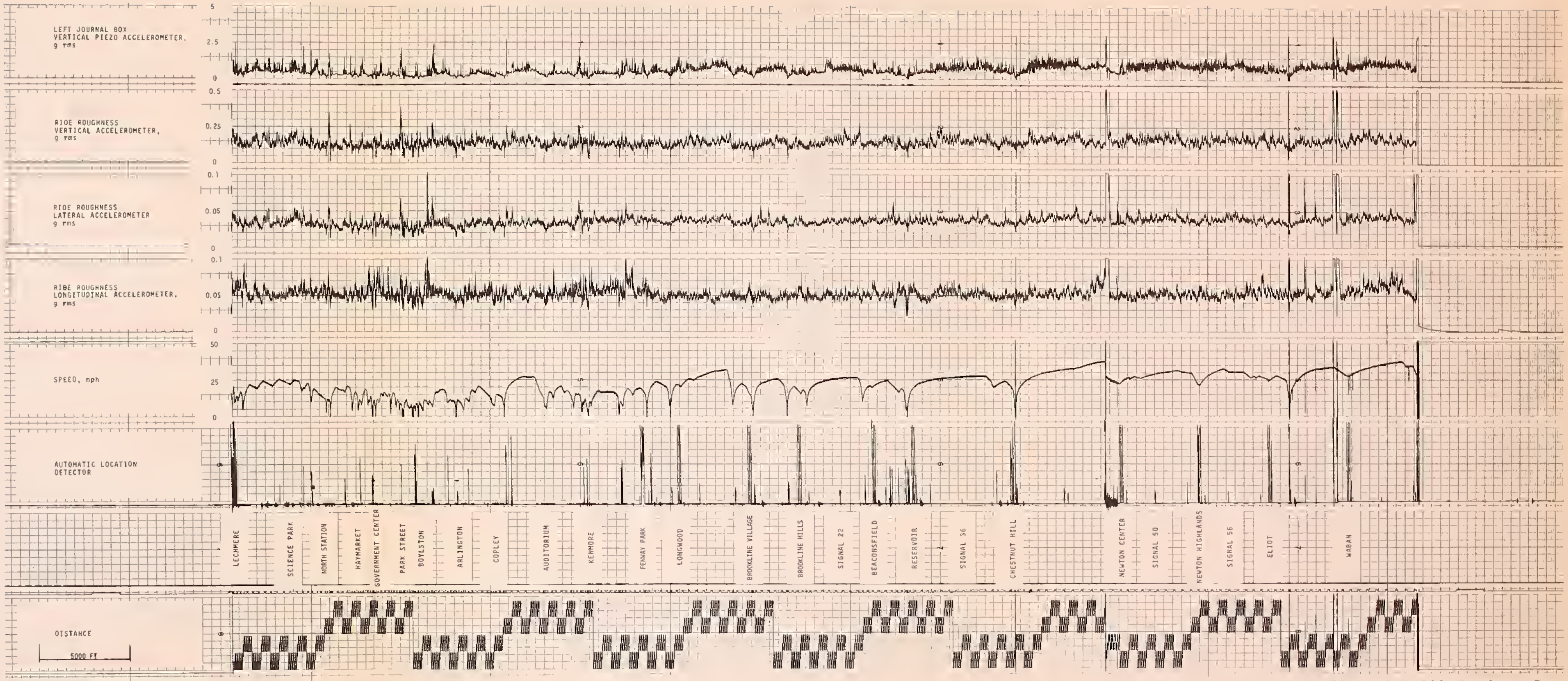


Figure E-2 Ride Roughness Data

from the ride roughness linear accelerometers are filtered by the 1 to 80 Hz bandpass filters described in Appendix D. The filter outputs are then fed into rms processor modules (Intronics model R310) having an averaging time contant of one second. The rms values of filtered ride roughness accelerations are plotted in Figures E-1 and E-2. A qualitative presentation of the correlation between track roughness and ride roughness is achieved by showing the rms acceleration sensed by the left journal box vertical piezo accelerometer. The recorded accelerometer signal is fed directly to an HP 3400A true-rms (thermocouple type) voltmeter. The output of the HP 3400A is inverted with a unity gain operational amplifier to provide the proper polarity for recording. In making comparisons between the journal box vertical piezo accelerometer and the vertical ride roughness accelerometer, consider that 1) the rms characteristics of the HP 3400A differ form the Intronics R310 and 2) the ride roughness signal was filtered before being rms processed, while the journal box acceleration signal was not.

Note that when the train stops, the journal box acceleration signal goes to zero, as expected, but the ride roughness vibration does not. This residual 0.03 to 0.04 g rms residual vibration level is presumed to be caused by machinery on board the car and/or by test crew or passengers walking around while the car is stopped. On board machinery would include the gasoline powered generator that was operated only while the test car was above ground (out of the tunnel).

In Figure E-1 there is one place, near Park Street station, where the traces make a large pulse. This is caused by the tape recorder being turned off. In Figure E-2, the tape recorder went off five times. Two of these times the tape recorder was turned off when the train stopped. The other three times, the tape recorder stopped itself while the train was moving and data was lost.

The distance scale on Figures E-1 and E-2 is one millimeter or minor division on the chart equals 100 feet traveled by the test car. The time marks on these two charts show 10 second intervals.

Figure E-3 and E-4 show samples of the data from Figure E-1 but with the distance scale expanded by a factor of ten. That is, one millimeter or minor division equals 10 feet of travel. Ten second time marks are shown on this chart also. Figure E-3 shows ride roughness data from the eastbound track between Waban and Newton Highlands. Figure E-4 shows similar data from the eastbound track in the tunnel between Auditorium and Park Street. Most of the Automatic Locating Device (ALD) blips in this latter figure are from rail at a turnout passing under the ALD probe. The pavement at Park Street is the cause of the last ALD blip.

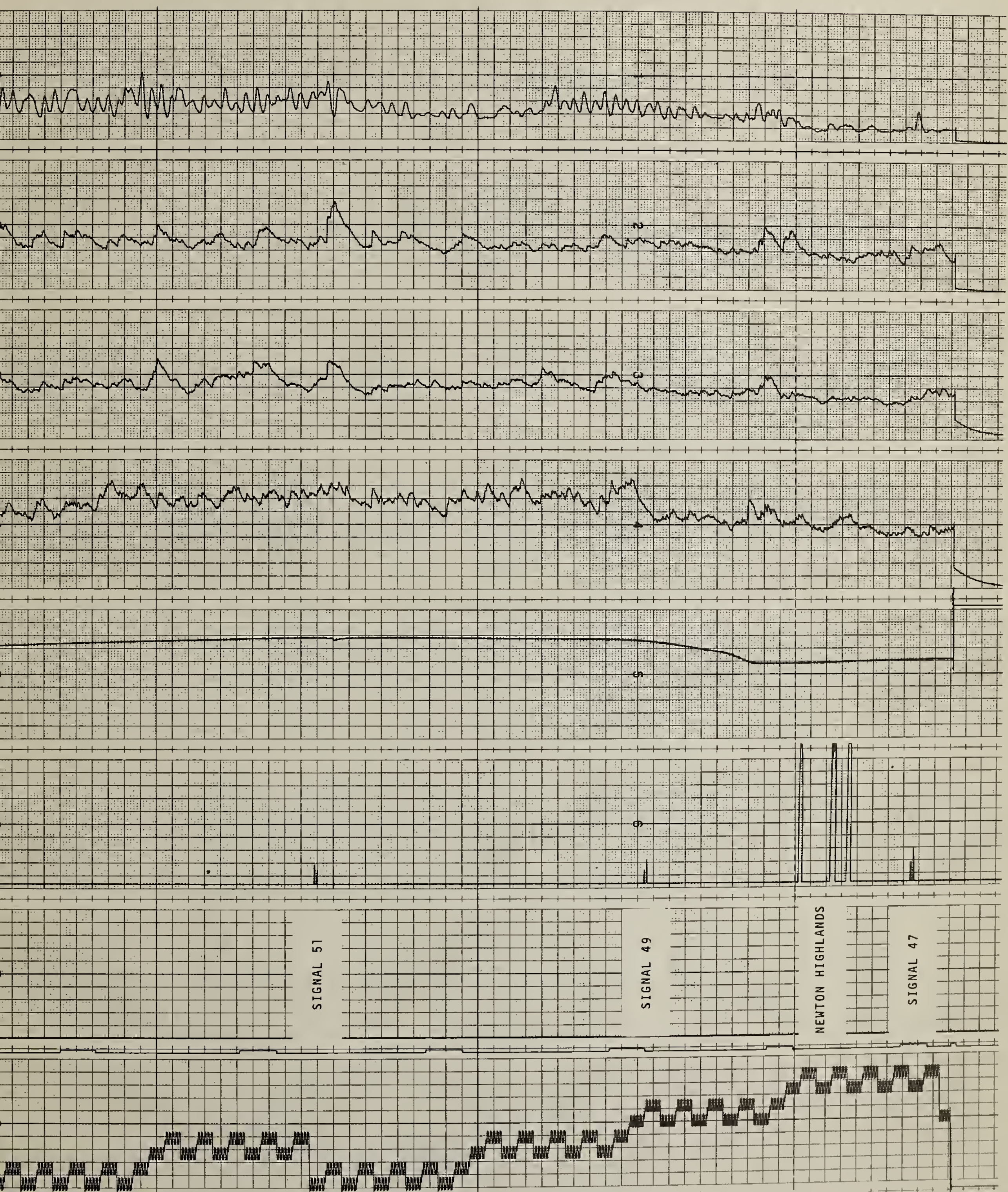


Figure E-3 Expanded Ride Roughness Data

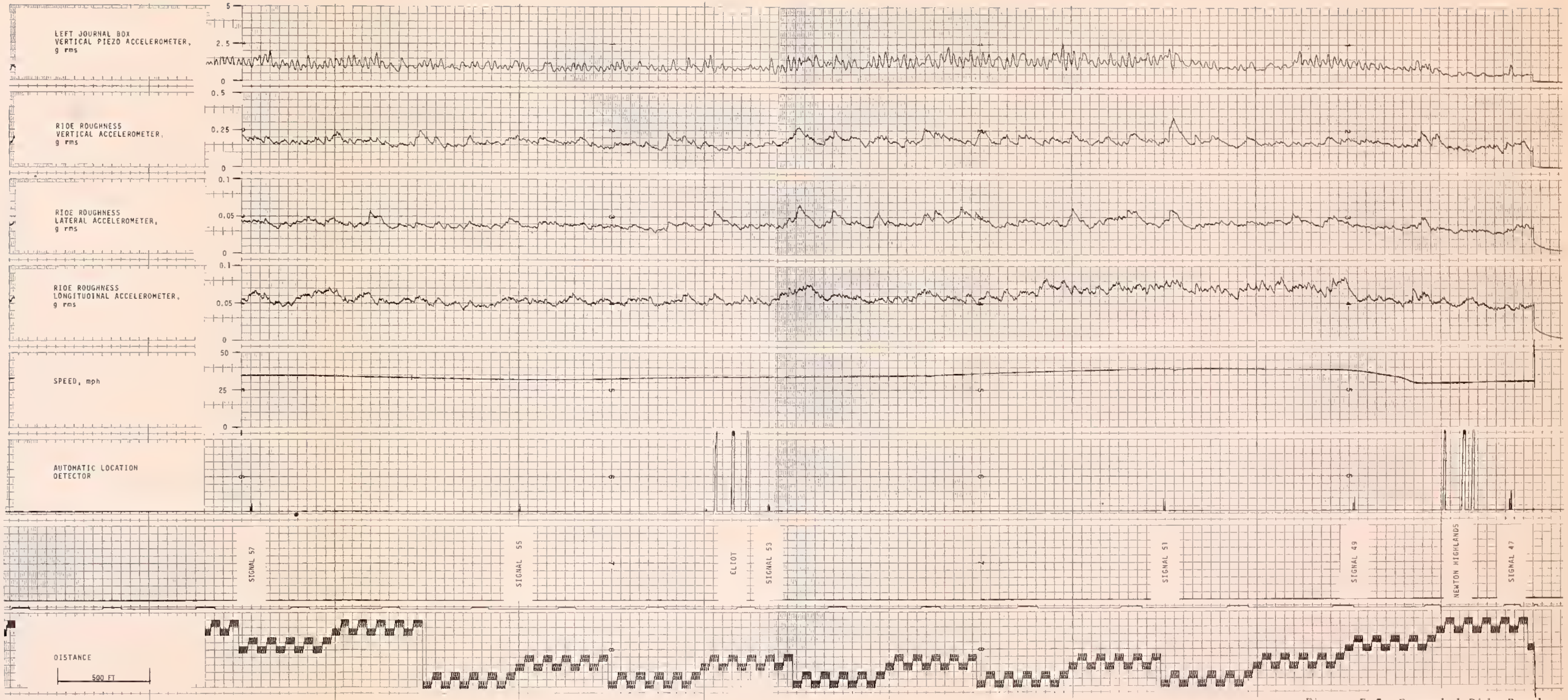


Figure E-3 Expanded Ride Roughness Data

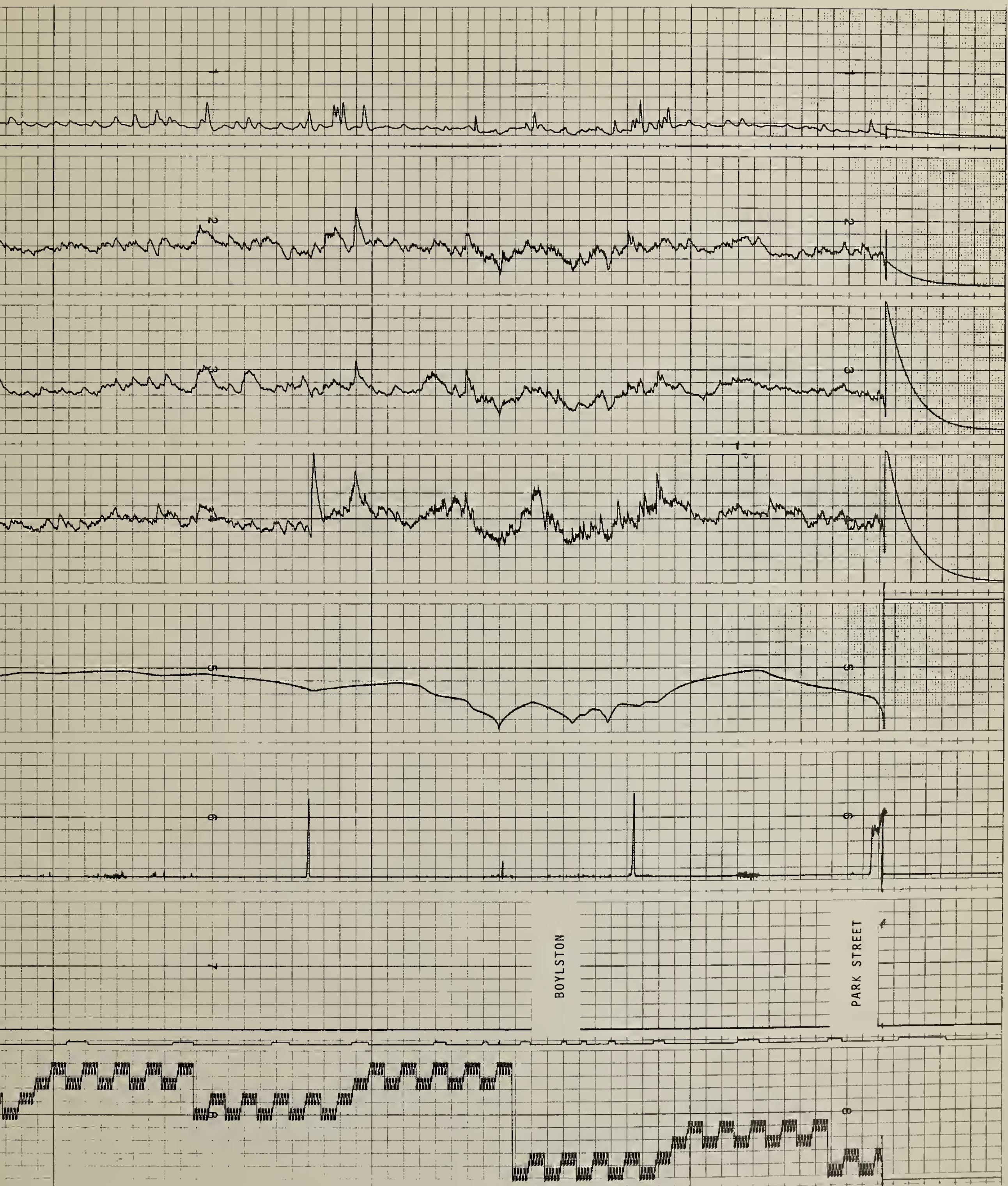


Figure E-4 Expanded Ride Roughness Data

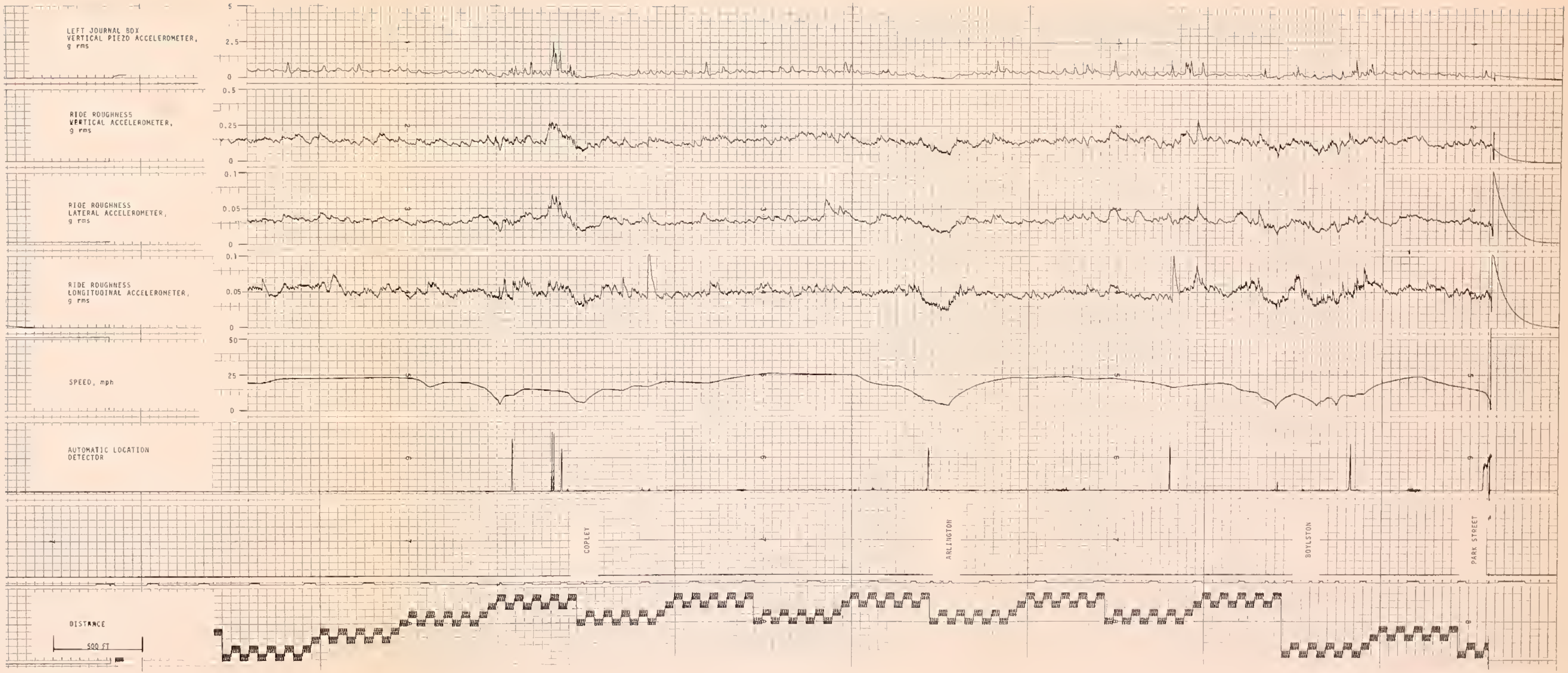


Figure E-4 Expanded Ride Roughness Data

APPENDIX F

INTERIOR NOISE

MBTA GREEN LINE TESTS, HIGHLAND BRANCH
DECEMBER 1972

SEQUENCE NO. 12-72-605
PROCEDURE NO. PCC-PN-5002-MBTA

OBJECTIVE:

To measure noise levels inside a PCC car traveling on the Highland Branch of the MBTA Green Line prior to initiation of track refurbishment. The data will subsequently be compared with levels measured in a PCC car on the refurbished track and with noise levels to be measured on new cars being purchased as part of the refurbishment program.

STATUS:

Noise level data was recorded on four runs, essentially two round trips emanating from the Riverside Station on the Highland Branch of the MBTA Green Line. A graphic recording of the noise level history is presented for a representative run. Statistical analyses for all four runs have been performed. One-third octave analyses of selected representative events have been performed.

The data was collected at typical revenue speeds which never exceeded 40 miles per hour. The noise level ranged from 67 dBA, when stopped at stations, to 106 dBA. The maximum level generated was the result of a "wheel squeal" during a short period between Government Center Station and the Park Street Station.

The data collection and processing used in this test utilizes proven technology on the TSC noise program.

Test Description

One microphone was set up in-car at a point centered over the front wheel trucks, thirty inches from the side of the car on the driver's side, and at a height of four feet off the floor approximately at ear level to a seated passenger. The "flat" unweighted analog signal was recorded on a magnetic tape recorder.

Noise data was recorded during four runs, essentially two round trips on the Highland Branch of the Green Line, as follows:

Run 1 - Newton Highlands to Lechmere Stations (gasoline generator ON)

Run 2 - Lechmere to Riverside Stations (gasoline generator ON)

Run 3 - Riverside to North Stations (Simulated revenue run, gasoline generator OFF)

Run 4 - North Stations to Riverside Station (Simulated revenue run, gasoline generator OFF)

Instrumentation

Figure F-1 depicts the noise data gathering equipment. A B & K model 4134 condensor microphone with the B & K model 2203 sound level meter comprise the basic acoustic measuring system. The sound level meter, mounted on a tripod, was strapped to a bar and attached to a seat in the car. The noise level data was recorded on a Nagra IV-S stereo tape recorder operating at 7 1/2 inches per second. The measuring system, with essentially a flat response from 25Hz to 18 KHz, has a dynamic range of 50dB.

The configuration of the noise data reduction system is shown in Figure F-2. The prerecorded noise data was 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.

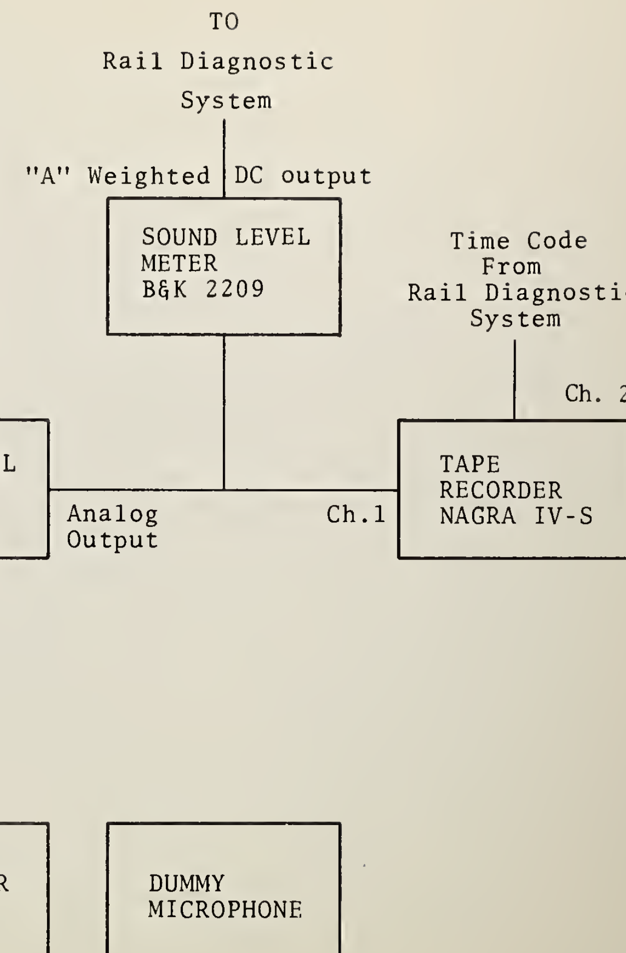


Figure F-1 Noise Measuring System

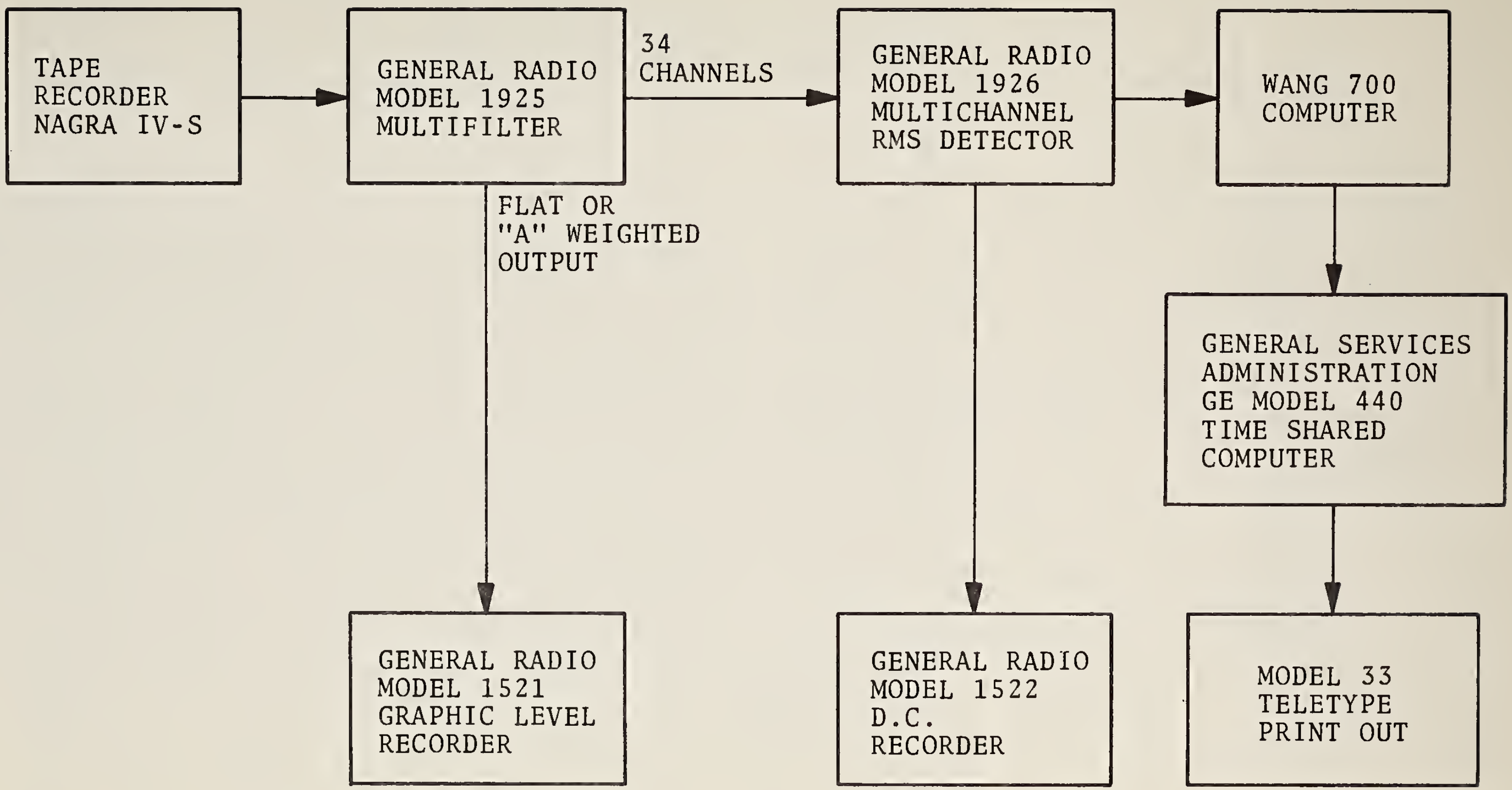


Figure F-2 Noise Data Reduction System

The GR 1925 mutlifilter contains a set of 30 parallel 1/3-octave band filter channels ranging from 25Hz to 20kHz, 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. All 34 outputs from the multifilter were 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 integrations or measurement periods are adjustable from 1/8 to 32 seconds.

Special selected events were 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 25Hz to 20kHz, including the flat (F) and "A" weighted outputs.

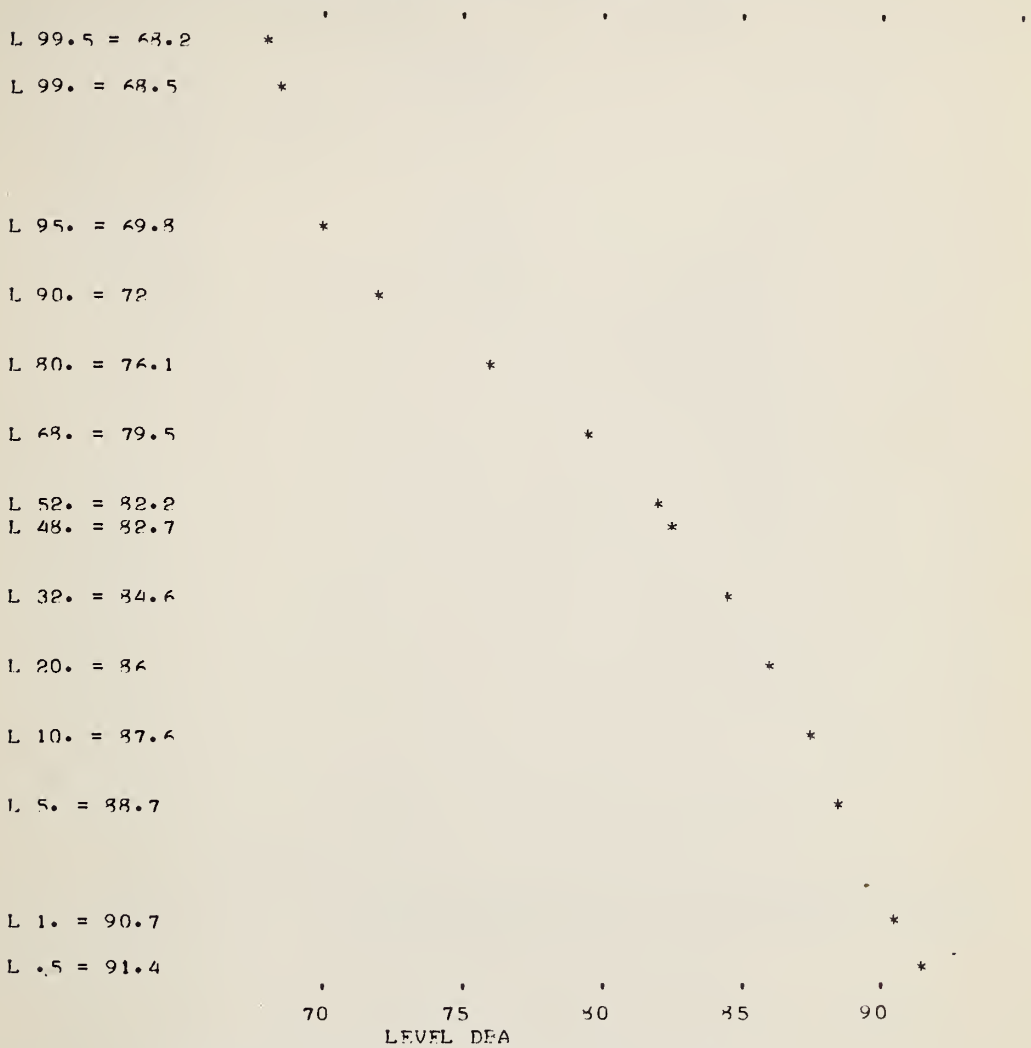
A statistical analysis of the measured noise was obtained by programming the detector to integrate for 1/8th second, compute the dB value of the "A" weighted filter output, and provide a binary coded decimal signal to the Wang Computing Calculator eight times every second. The computer counted and totaled the number of samples at each sound level for a selected time period. This data was entered into a time-shared computer to produce the statistical analysis printouts contained in Figures F-3 through F-6.

The statistical analyses contain a probability distribution of noise level (dBA) versus the percent of time the level is exceeded (percent). In addition, a histogram is presented of the level (dBA) versus the frequency of occurance.

Selected indices were also calculated and tabulated, e.g., average noise level, standard deviation, energy mean [L(EO)], range of values measured, median, selected percentiles and deciles, the Noise Pollution Level and Walsh-Healey Exposure index.

US DEPARTMENT OF TRANSPORTATION THU 12/21/72
TRANSPORTATION SYSTEMS CENTER 11:58
NOISE ASSESSMENT GROUP

NOISE DATA FROM RUN NO 1 OF THE PORTABLE NOISE STATION ON DEC 13 1972 FROM 10:05 TO 10:37, IN MBTA GREEN LINE CAR NO 3294 FROM NEWTON HIGHLANDS TO LECHMERE. GENERATOR ON
1/8 SECOND INTEGRATIONS, 8 PER SECOND)



LEVEL(DBA) VS PERCENT OF TIME LEVEL EXCEEDED

Run No. 1 Newton Highlands to Lechmere-Gasoline gen. On

Figure F-3 Noise Data

```
                                    PAGE 2

                       (RUN NO.       1       ( CONTINUED)          THU    12/21/72

1          96   0                      SAMPLES=                    15360
1          95   0                      AVERAGE=                    80.7   DBA
1          94   0                      STANDARD DEVIATION=         5.6   DBA
4          93   0                      L(EQ)=                      83.4   DBA*
29         92   0                      NOISE POLLUTION LEVEL=      97.7   DB
67         91   00                     L  1 =                      90.7   DBA**
174        90   000                    L  10 =                     87.6   DBA
320        89   0000                   L  50 =                     82.4   DBA
580        88   0000000                L  90 =                     72   DBA
885        87   0000000000             L  99 =                     68.5   DBA
1047       86   00000000000            WALSH HEALEY EXP.=          2.6 %
1229       85   0000000000000 00       RANGE=                      30 DB
1408       84   0000000000000000
1244       83   00000000000000
1214       82   00000000000000
1194       81   0000000000000
800        80   000000000
768        79   000000000
602        78   0000000
457        77   000000
426        76   00000
448        75   00000
368        74   00000
317        73   0000
338        72   0000
297        71   0000
389        70   00000
577        69   0000000
252        68   0000
27         67   0
1          66   0
DIST. DBA     0               10               20               30
                   FREQUENCY OF OCCURRENCE (PERCENT)

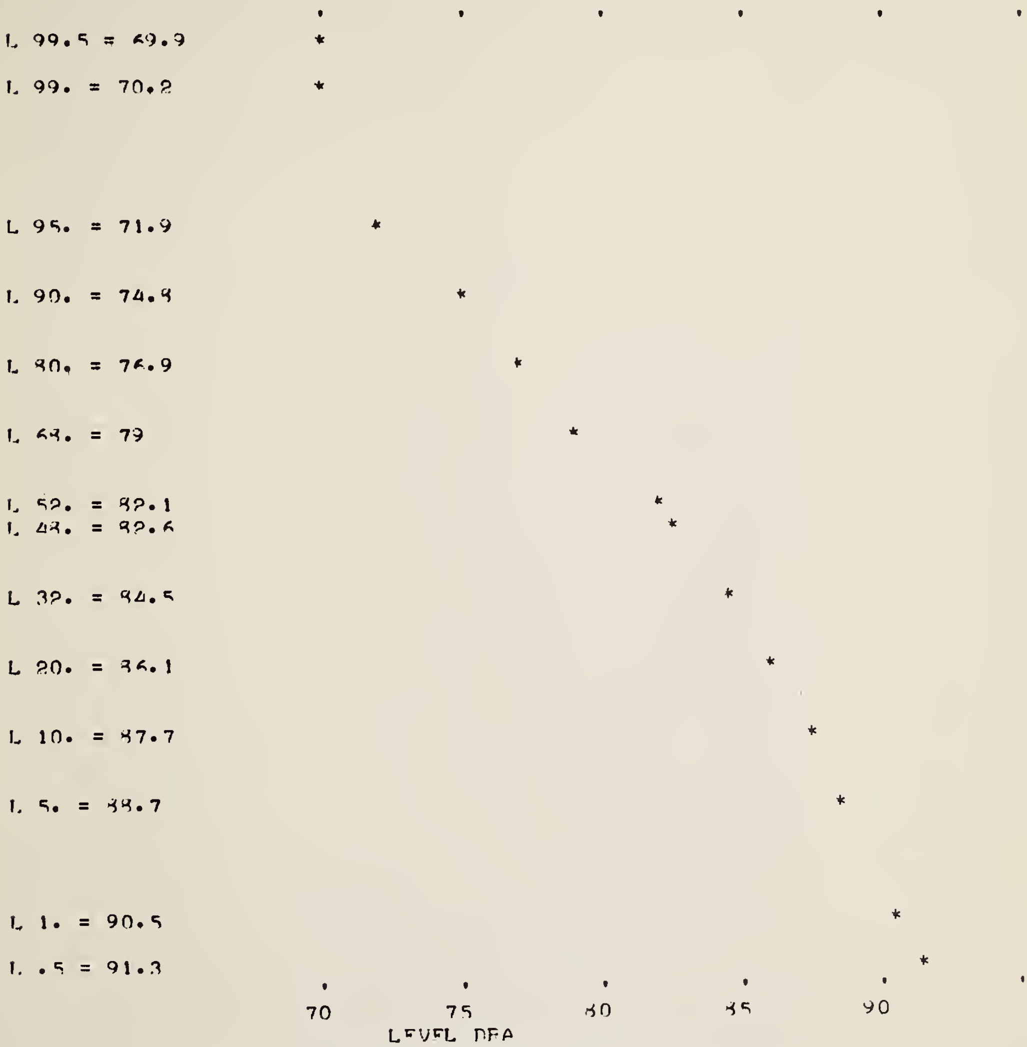
         LEVEL (DBA) VS FREQUENCY OF OCCURRENCE (PERCENT)

DBA - A-WEIGHTED DECIBELS RE- 20 MICRONEWTONS PER SQUARE METER
*-L(EQ) - MEAN-SQUARE A-WEIGHTED SOUND LEVEL.
**-L(X) - LEVEL EXCEEDED (X) PERCENT OF THE TIME.
```

Figure F-3 Noise Data (Continued)

US DEPARTMENT OF TRANSPORTATION THU 12/21/72
TRANSPORTATION SYSTEMS CENTER 11:37
NOISE ASSESSMENT GROUP

NOISE DATA FROM RUN NO 2 OF THE PORTABLE NOISE STATION ON DEC 13 1972 FROM 11:14 TO 12:02, IN MBTA GREEN LINE CAR NO 3294 FROM LECHMERE TO RIVERSIDE. GENERATOR ON
(1/8 SECOND INTEGRATIONS, 8 PER SECOND)



LEVEL(DBA) VS PERCENT OF TIME LEVEL EXCEEDED

Run No. 2 Lechmere to Riverside-Gasoline gen. On

Figure F-4 Noise Data

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                              PAGE 2

                  (RUN NO        2        CONTINUED)            THU    12/21/78

 1        103  0                      SAMPLES=                   23040
 1        102  0                      AVERAGE=                   81.1  DBA
 1        101  0                      STANDARD DEVIATION=        5  DBA
 1        100  0                      L(EQ)=                     83.5  DBA*
 1        99   0                      NOISE POLLUTION LEVEL=     96.3  DB
 1        98   0                      L  1 =                     90.5  DBA**
 3        97   0                      L  10 =                    87.7  DBA
 3        96   0                      L  50 =                    82.3  DBA
 6        95   0                      L  90 =                    74.8  DBA
 7        94   0                      L  99 =                    70.2  DBA
 10       93   0                      WALSH HEALEY EXP.=         2.3 %
 29       92   0                      RANGE=                     35 DB
 69       91   00
 203      90   00
 518      89   0000
 1064     88   00000000
 1296     87   0000000000
 1464     86   00000000000
 1696     85   000000000000
 2020     84   00000000000000
 1985     83   00000000000000
 1720     82   000000000000
 1480     81   00000000000
 1187     80   00000000
 944      79   0000000
 1176     78   000000000
 1424     77   0000000000
 1598     76   000000000000
 807      75   000000
 432      74   0000
 348      73   000
 390      72   0000
 606      71   00000
 478      70   0000
 118      69   00
 8        68   0
DIST. DBA      0              10              20              30
                  FREQUENCY OF OCCURRENCE (PERCENT)

        LEVEL (DBA) VS FREQUENCY OF OCCURRENCE (PERCENT)

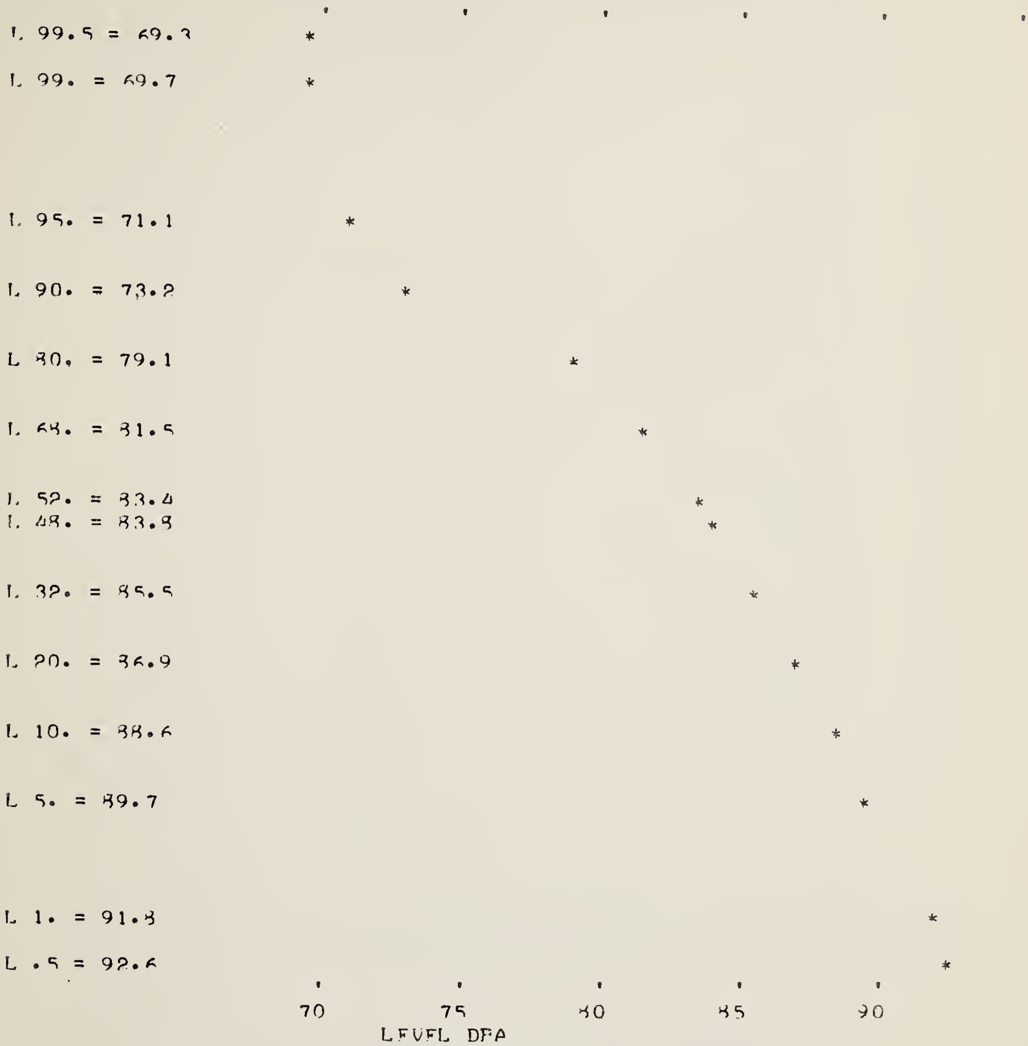
DBA - A-WEIGHTED DECIBELS RE- 20 MICRONEWTONS PER SQUARE METER
*-L(EQ) - MEAN-SQUARE A-WEIGHTED SOUND LEVEL.
**-L(X) - LEVEL EXCEEDED (X) PERCENT OF THE TIME.
```

Figure F-4 Noise Data (Continued)

US DEPARTMENT OF TRANSPORTATION
TRANSPORTATION SYSTEMS CENTER
NOISE ASSESSMENT GROUP

THU 12/21/72
11:43

NOISE DATA FROM RUN NO. 3 OF THE PORTABLE NOISE STATION ON DEC 14 1972 FROM 09:07 TO 09:47, IN MBTA GREEN LINE CAR NO 3294 FROM RIVERSIDE TO N STATION (UNDER).REVENUE SPEED PROFILE.(GEN OFF)
1/8 SECOND INTEGRATIONS, 8 PER SECOND)



LEVEL(DBA) VS PERCENT OF TIME LEVEL EXCEEDED

Run No. 3 Riverside to North Station-Gasoline gen Off

Figure F-5 Noise Data

```
                              PAGE 2

                  (RUN NO.        3        CONTINUED)        THU    12/21/72

2       99   0                        SAMPLES=                 19200
5       98   0                        AVERAGE=                 82.1  DBA
4       97   0                        STANDARD DEVIATION=      5.3  DBA
7       96   0                        L(EQ)=                   84.6  DBA*
8       95   0                        NOISE POLLUTION LEVEL=   98.2  DB
12      94   0                        L 1 =                    91.8  DBA**
21      93   0                        L 10 =                   88.6  DBA
92      92   00                       L 50 =                   83.6  DBA
221     91   000                      L 90 =                   73.2  DBA
395     90   0000                     L 99 =                   69.7  DBA
711     89   0000000                  WALSH HEALEY EXP.=       6 %
990     88   000000000                RANGE=                   32 DB
1289    87   00000000000
1533    86   0000000000000
1768    85   000000000000000
1811    84   000000000000000
1780    83   000000000000000
1673    82   00000000000000
1422    81   000000000000
967     80   000000000
705     79   0000000
491     78   00000
349     77   0000
265     76   000
234     75   000
248     74   000
294     73   000
425     72   0000
550     71   00000
609     70   000000
249     69   000
17      68   0
3       67   0
DIST. DBA    0               10              20              30
               FREQUENCY OF OCCURRENCE (PERCENT)

          LEVEL (DBA) VS FREQUENCY OF OCCURRENCE (PERCENT)

DBA - A-WEIGHTED DECIBELS RE- 20 MICRONEWTONS PER SQUARE METER
*-L(EQ) - MEAN-SQUARE A-WEIGHTED SOUND LEVEL.
**-L(X) - LEVEL EXCEEDED (X) PERCENT OF THE TIME.
```

Figure F-5 Noise Data (Continued)

US DEPARTMENT OF TRANSPORTATION THU 12/21/72
TRANSPORTATION SYSTEMS CENTER 12:07
NOISE ASSESSMENT GROUP

NOISE DATA FROM RUN NO 4 OF THE PORTABLE NOISE STATION ON DEC 14 1972 FROM 09:57 TO 10:39, IN MBTA GREEN LINE CAR NO 3294 FROM N STATION (UNDER) TO RIVERSIDE. REVENUE SPEED PROFILE (GEN OFF)
1/8 SECOND INTEGRATIONS, 8 PER SECOND)

L 99.5 = 69.2 *
L 99. = 69.5 *
L 95. = 71.1 *
L 90. = 73.1 *
L 80. = 77.6 *
L 68. = 80.1 *
L 52. = 82.4 *
L 48. = 82.9 *
L 32. = 84.9 *
L 20. = 86.4 *
L 10. = 87.9 *
L 5. = 88.9 *
L 1. = 91.1 *
L .5 = 92.3 *

70 75 80 85 90
LEVEL DBA

LEVEL(DBA) VS PERCENT OF TIME LEVEL EXCEEDED

Run No. 4 North Station to Riverside - Gasoline Gen. ON

Figure F-6 Noise Data

PAGE 2

(RUN NO. 4 CONTINUED) THU 12/21/72

DIST.	DBA	FREQUENCY OF OCCURRENCE (PERCENT) 0 . . . 10 . . . 20 . . . 30
1	106	0
0	105	0
1	104	0
0	103	0
1	102	0
2	101	0
3	100	0
3	99	0
4	98	0
12	97	0
8	96	0
13	95	0
10	94	0
20	93	0
33	92	0
93	91	00
216	90	000
512	89	00000
938	88	00000000
1220	87	0000000000
1463	86	000000000000
1750	85	00000000000000
1530	84	0000000000000
1649	83	0000000000000
1574	82	0000000000000
1484	81	000000000000
1178	80	0000000000
1153	79	0000000000
922	78	00000000
672	77	000000
490	76	00000
435	75	0000
391	74	0000
343	73	0000
410	72	0000
615	71	000000
600	70	000000
315	69	000
40	68	0
1	67	0

SAMPLES= 20160
AVERAGE= 81.3 DBA
STANDARD DEVIATION= 5.3 DBA
L(EQ)= 84 DBA*
NOISE POLLUTION LEVEL= 97.6 DB
L 1 = 91.1 DBA**
L 10 = 87.9 DBA
L 50 = 82.7 DBA
L 90 = 73.1 DBA
L 99 = 69.5 DBA
WALSH HEALEY EXP.= 3.6 %
RANGE= 39 DB

LEVEL (DBA) VS FREQUENCY OF OCCURRENCE (PERCENT)

DBA - A-WEIGHTED DECIBELS RE- 20 MICRONEWTONS PER SQUARE METER
*-L(EQ) - MEAN-SQUARE A-WEIGHTED SOUND LEVEL.
**-L(X) - LEVEL EXCEEDED (X) PERCENT OF THE TIME.

Figure F-6 Noise Data (Continued)

Test Procedure

A calibration signal was recorded on tape before and after each run. The calibrator, a General Radio Model #1562A, generates an acoustic signal of 1000Hz at a level of 114 dB re $20\mu N/m^2$. Placing the calibrator directly on the microphone, the signal is first used to adjust the gain controls of the sound level meter and tape recorder to utilize their optimum range. Then, the calibration signal is recorded to provide an acoustic reference in the laboratory for reduction of the data to be recorded.

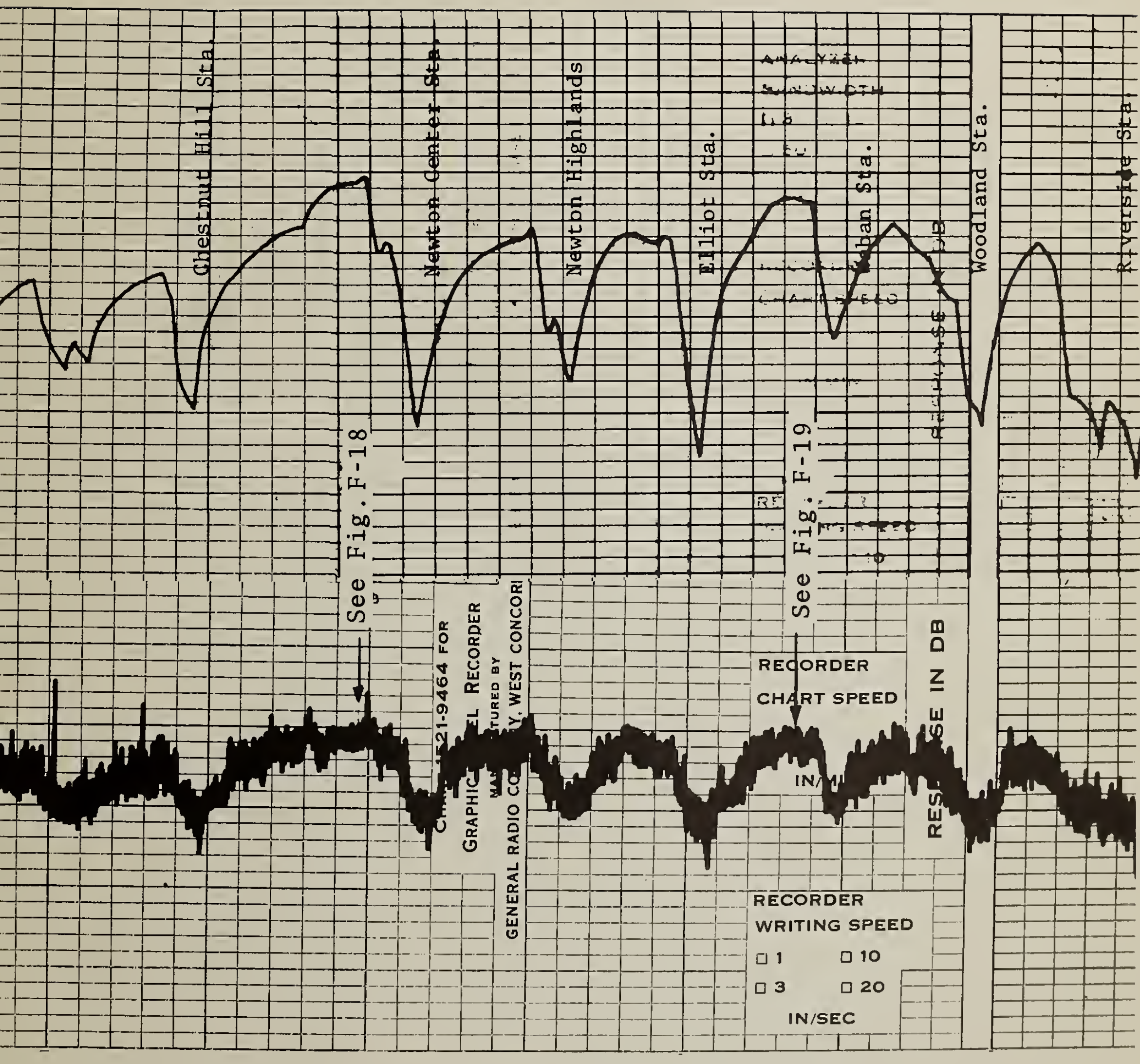
The tape recorder is turned on and noise data is recorded continuously for each run. At the conclusion of the run the calibrator is again placed on the microphone and the calibration signal recorded to check system stability.

Data

Figures F-3 through F-6 contain statistical data from each of the four test runs. The first page of the statistical data is a probability distribution of noise level (dBA) versus the percent of time during the run that a particular level was exceeded. For example in Figure F-3, L90=72 means that 90 percent of the time the level 72dBA was exceeded during Run no. 1. The second page of the statistical data is a histogram of the levels measured (dBA), in 1/8 second increments, versus the frequency of occurance (percent) of these levels. Also included in tabular form are calculated noise indices.

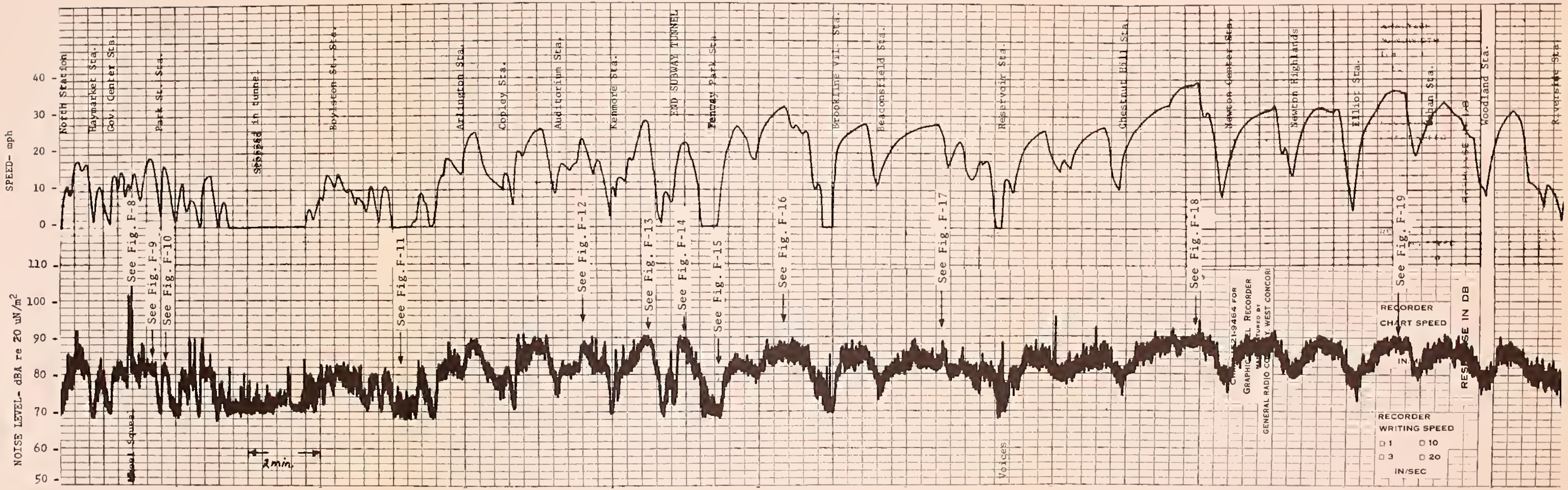
Figure F-7 is a graphic recording of the noise level time history (dBA vs time) of Run no. 4 which is representative of all four runs. Manually superimposed on this chart is coincident speed data obtained from the rail diagnostic system. Stations and events of interest have been identified on the time history.

Figure F-8 through F-19 contain 1/3 octave frequency spectra of data measured at selected points during Run no. 4. The time history Figure F-7 has been marked to indicate the point for which the spectra applies.



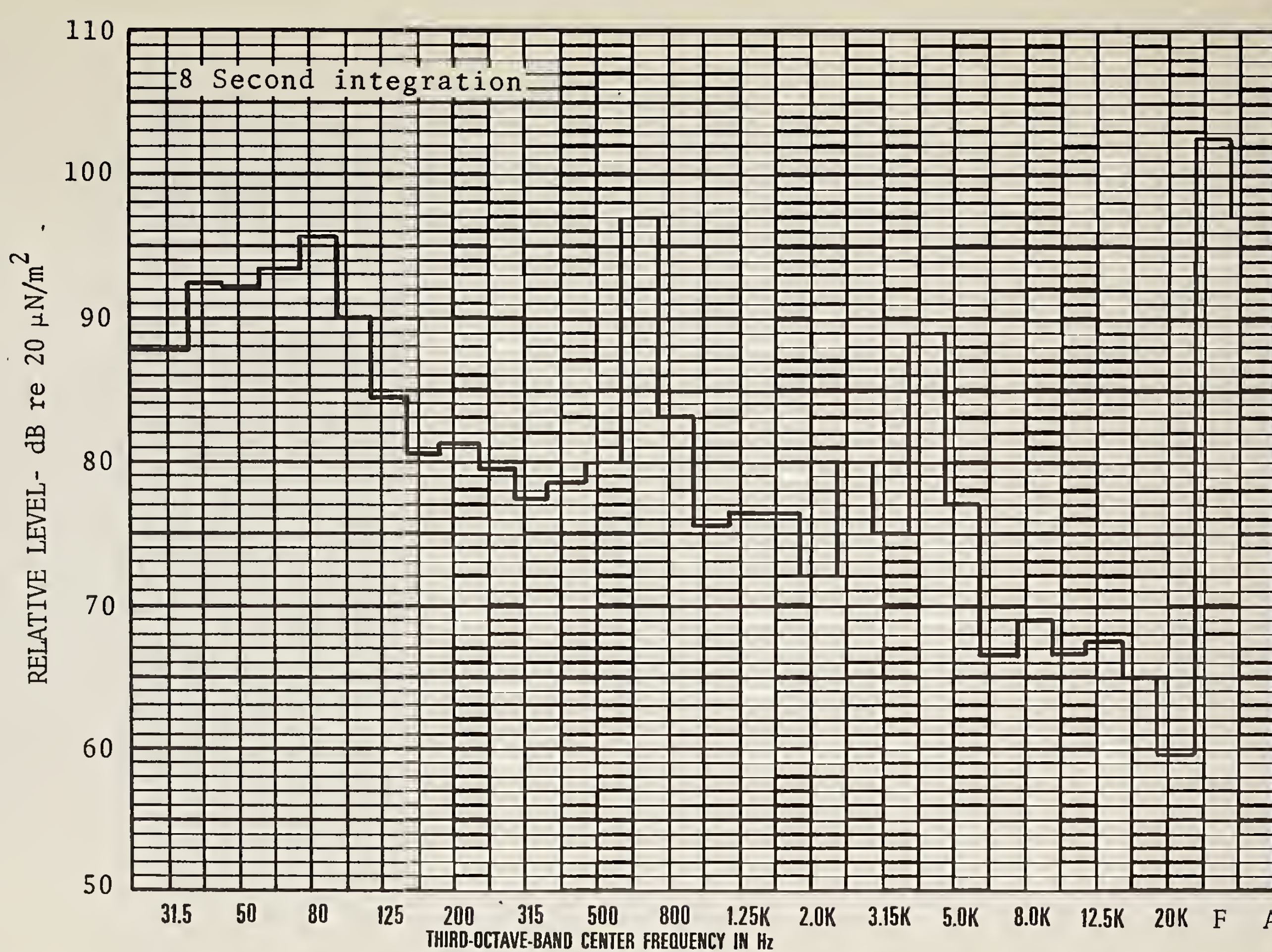
Run #4, North Station to Riverside MBTA Green Line Dec 15,1972.

Figure F-7 Noise Time History



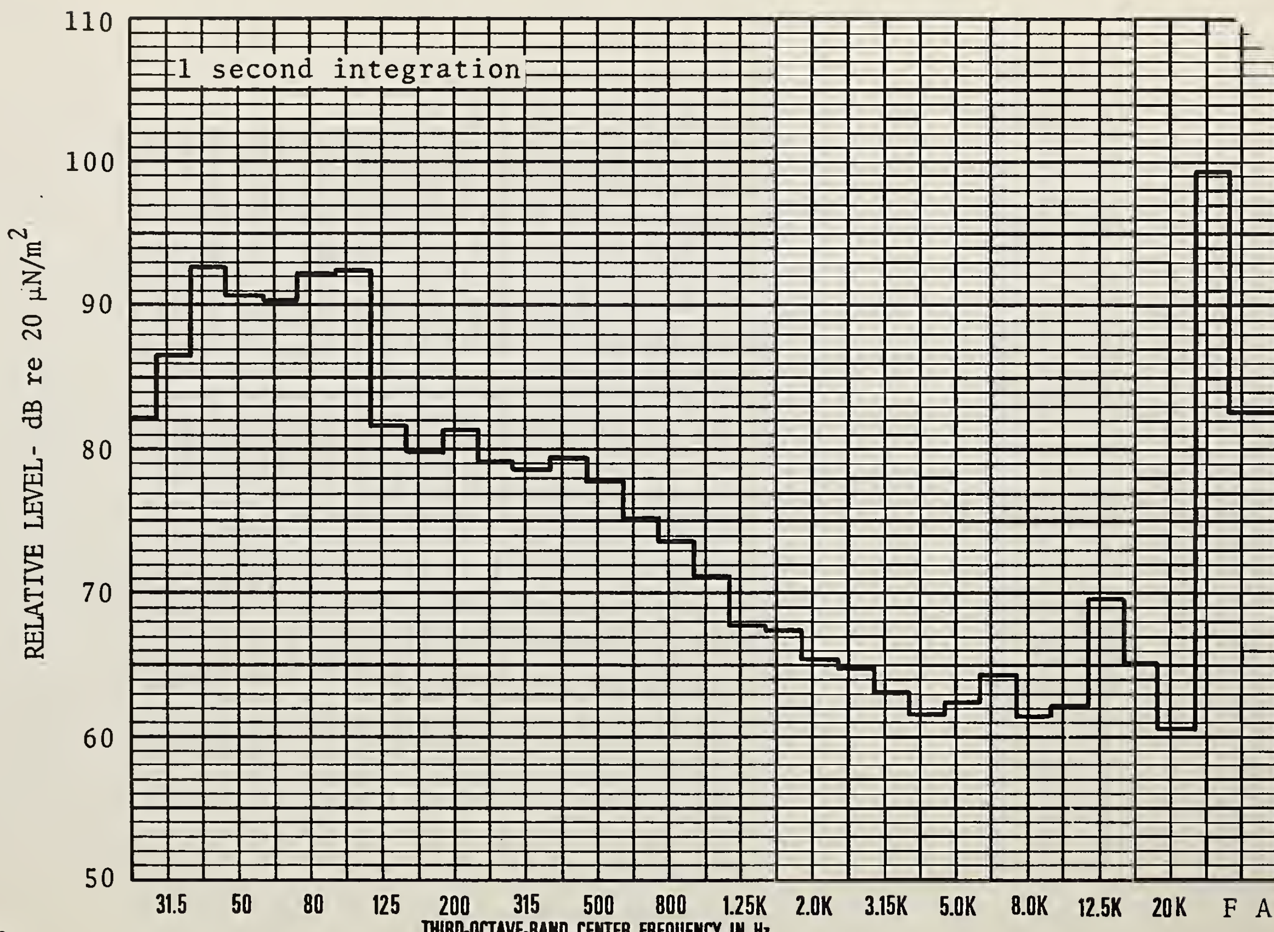
Run #4, North Station to Riverside MBTA Green Line Dec 15,1972.

Figure F-7 Noise Time History



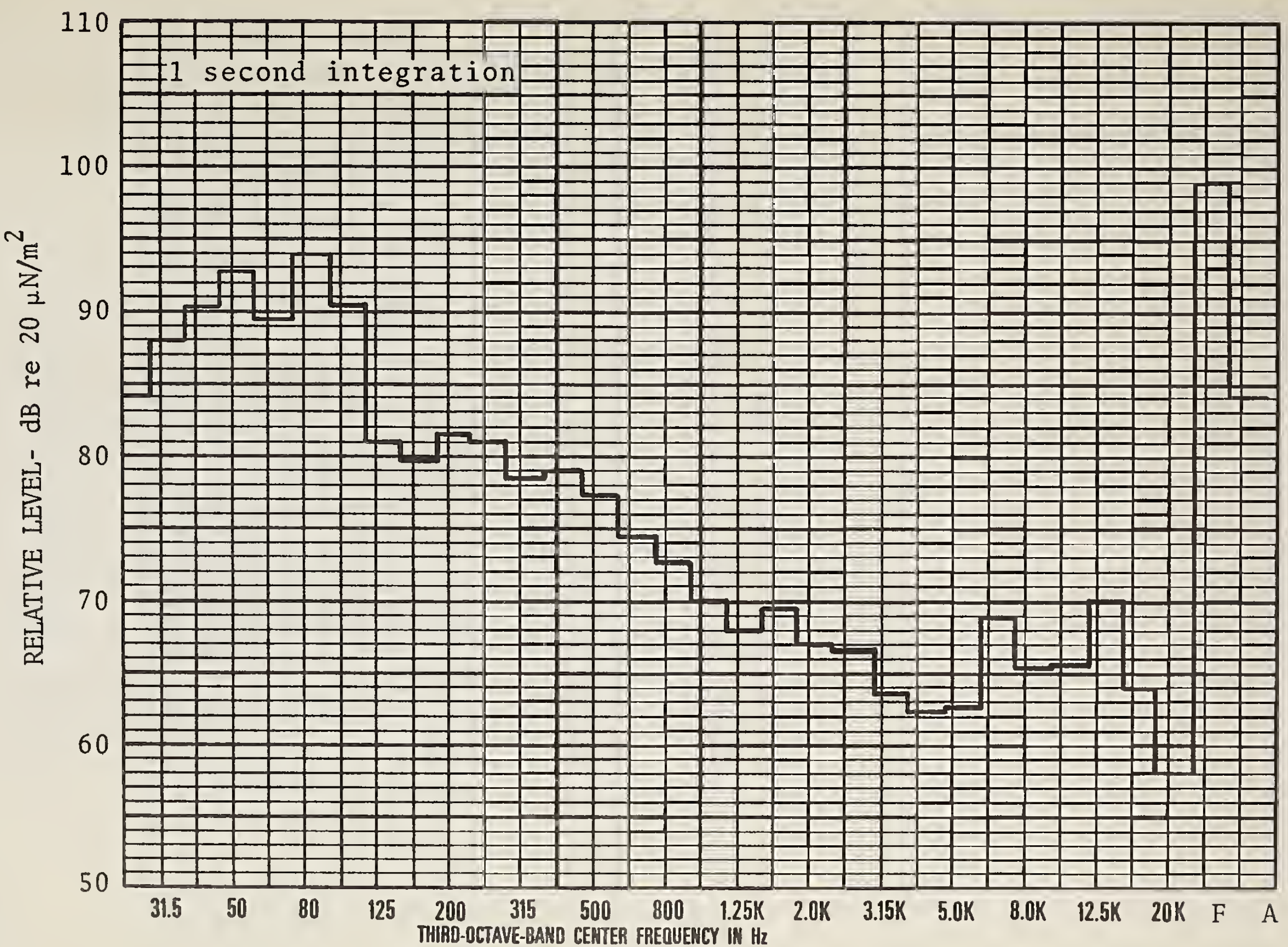
Wheel Squeal - 11 mph.
12/15/72

Figure F-8 Noise Spectra



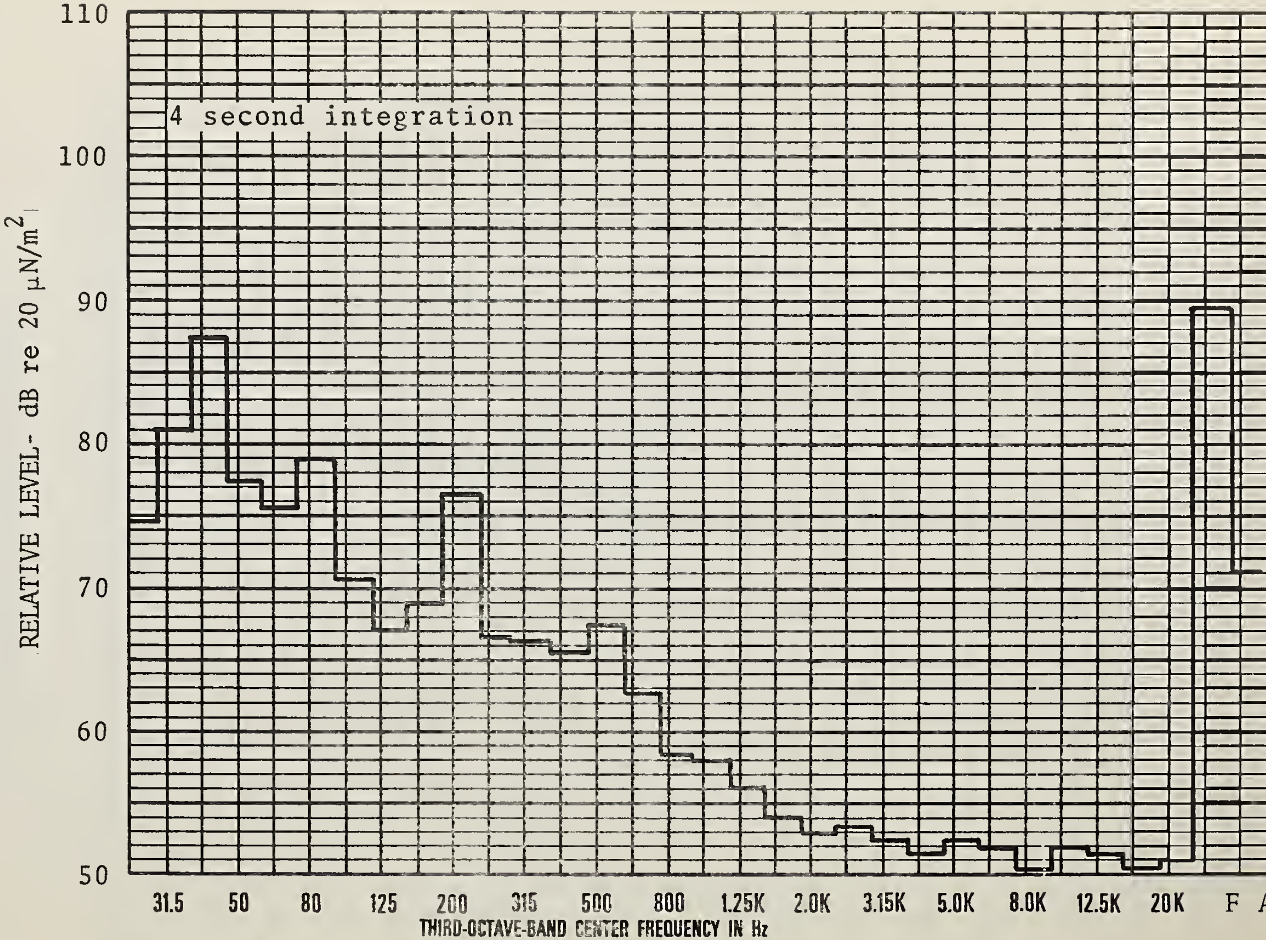
19 mph.
12/15/72

Figure F-9 Noise Spectra



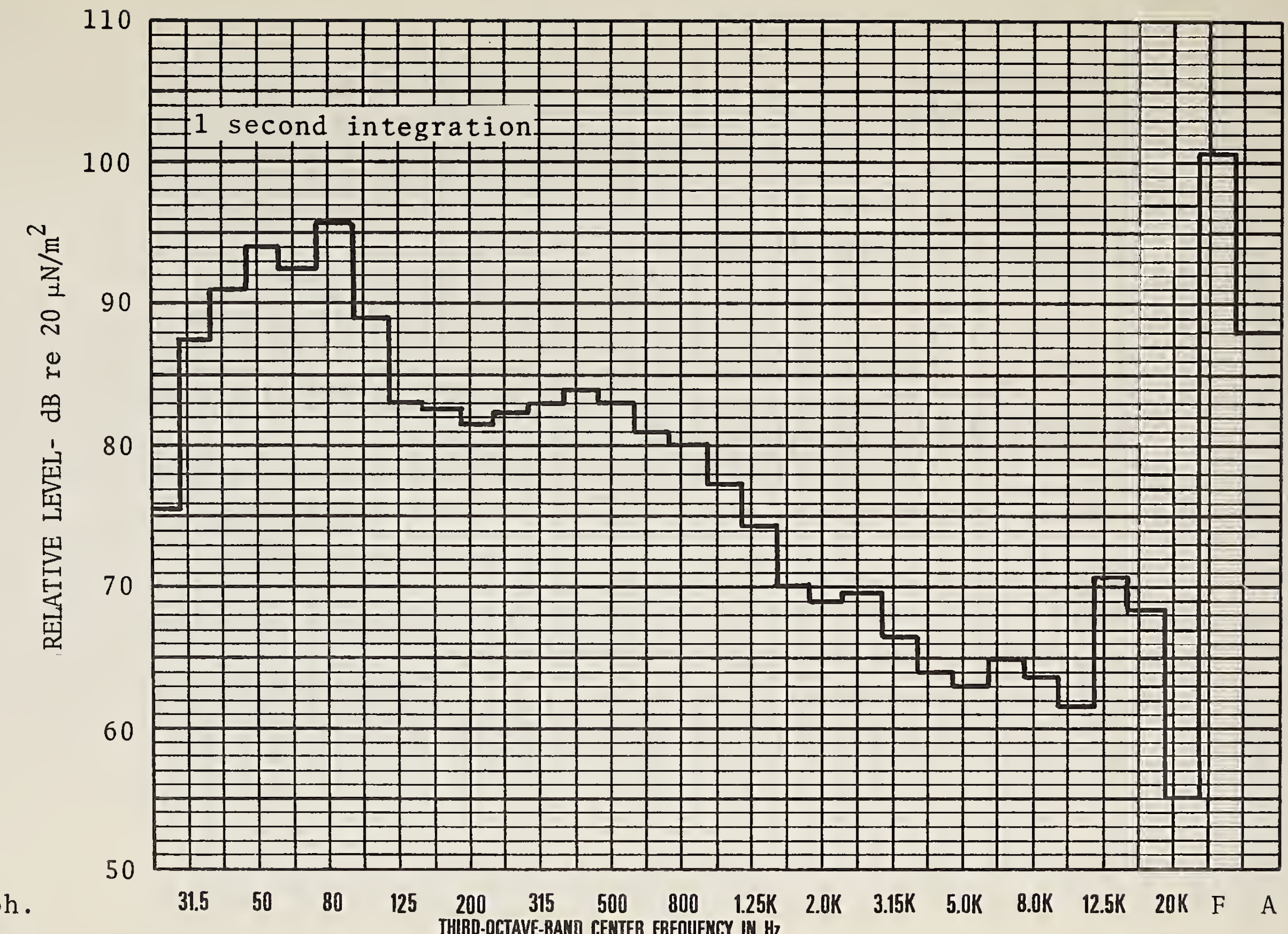
17 mph.
12/15/72

Figure F-10 Noise Spectra



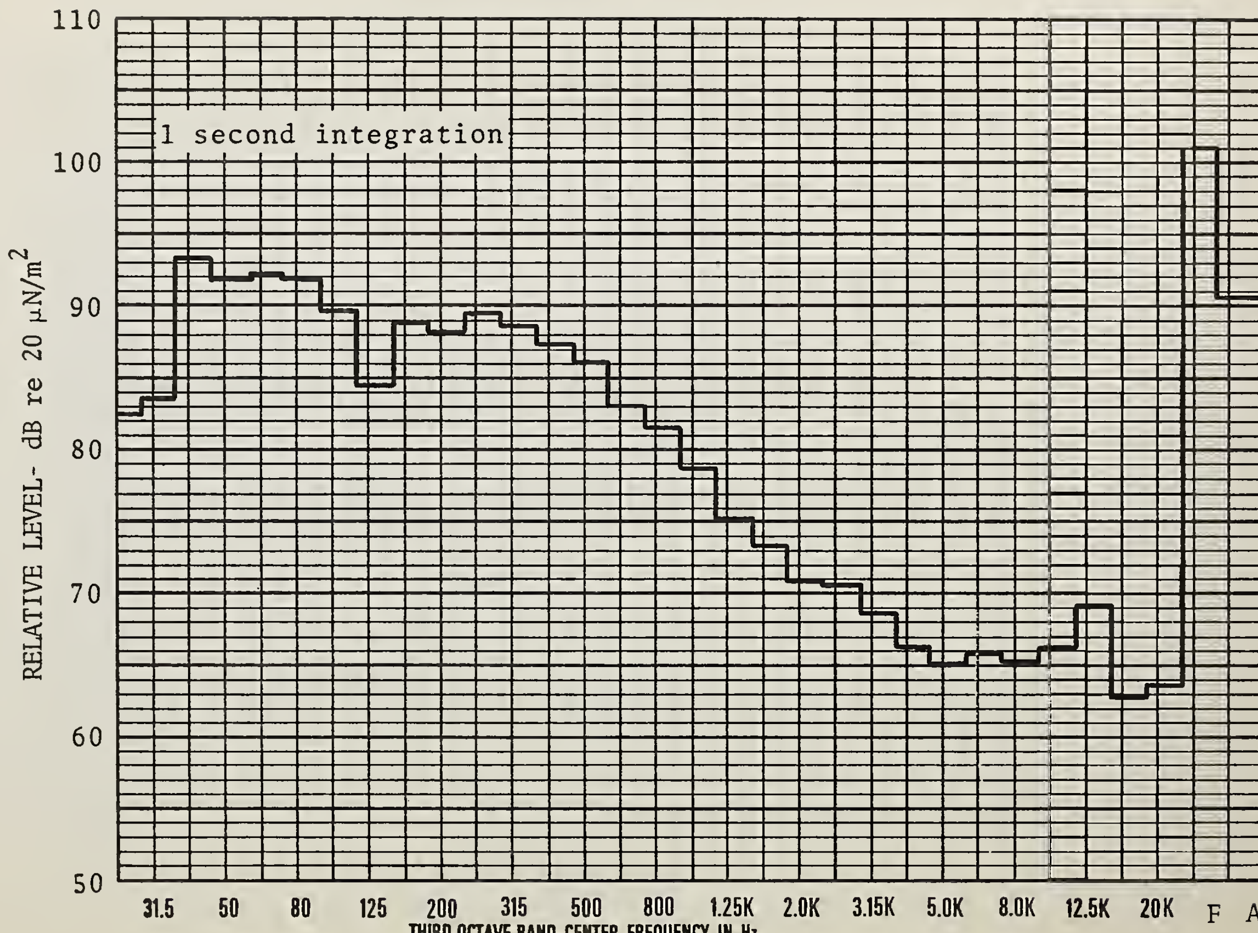
Stopped in Subway Tunnel
12/15/72

Figure F-11 Noise Spectra



13 mph.
12/15/72

Figure F-12 Noise Spectra



28 mph.
12/15/72

Figure F-13 Noise Spectra

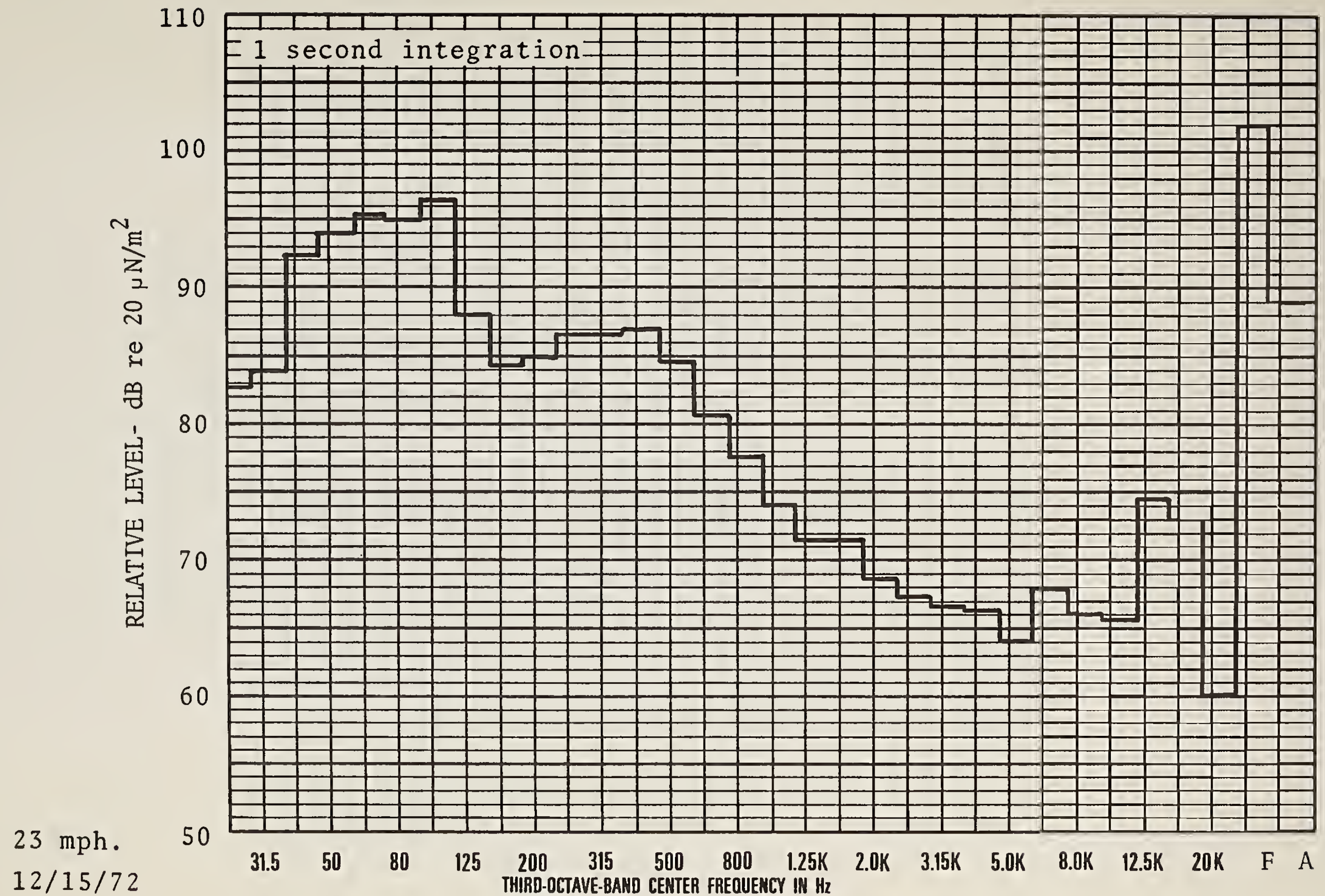
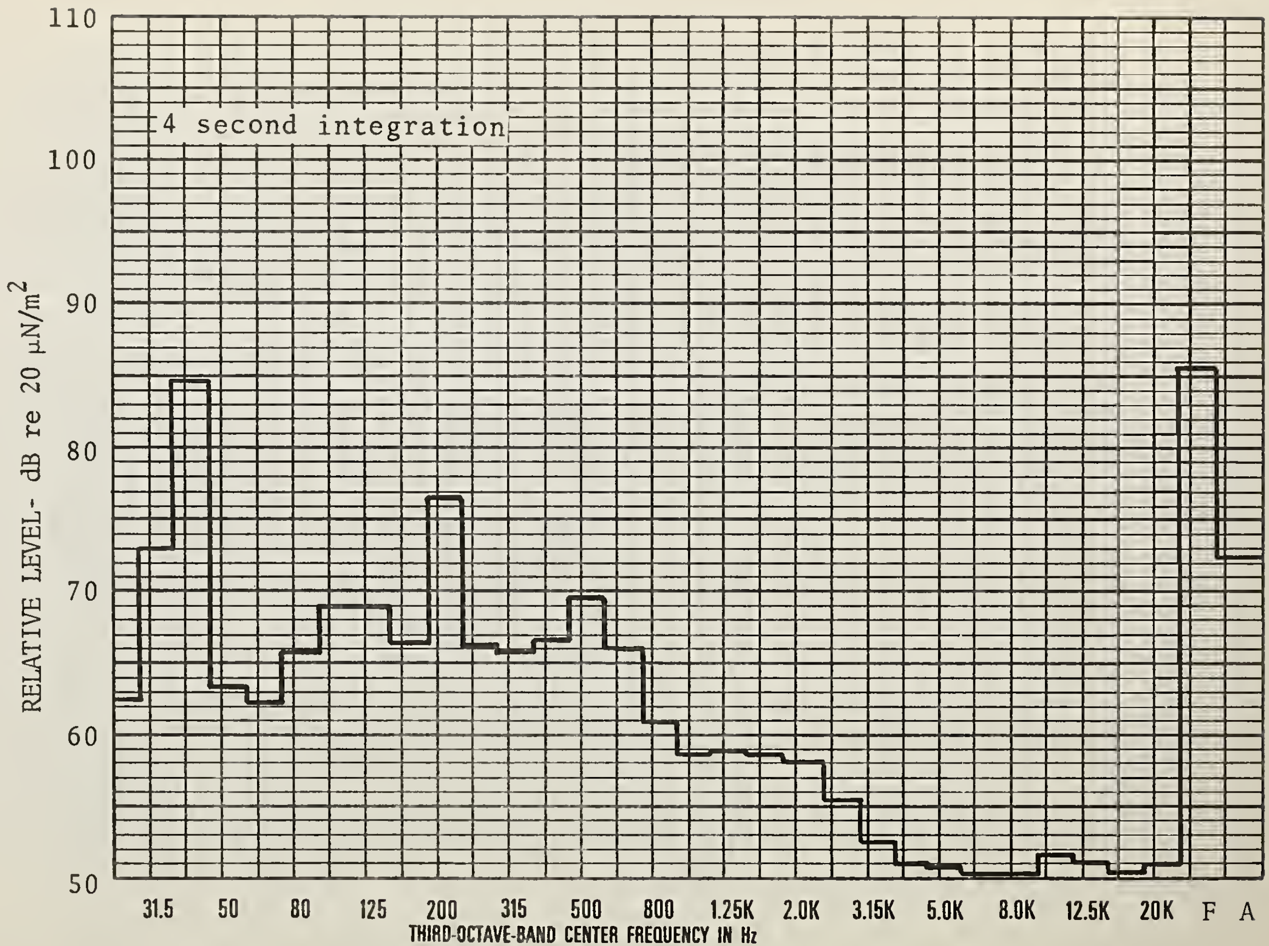
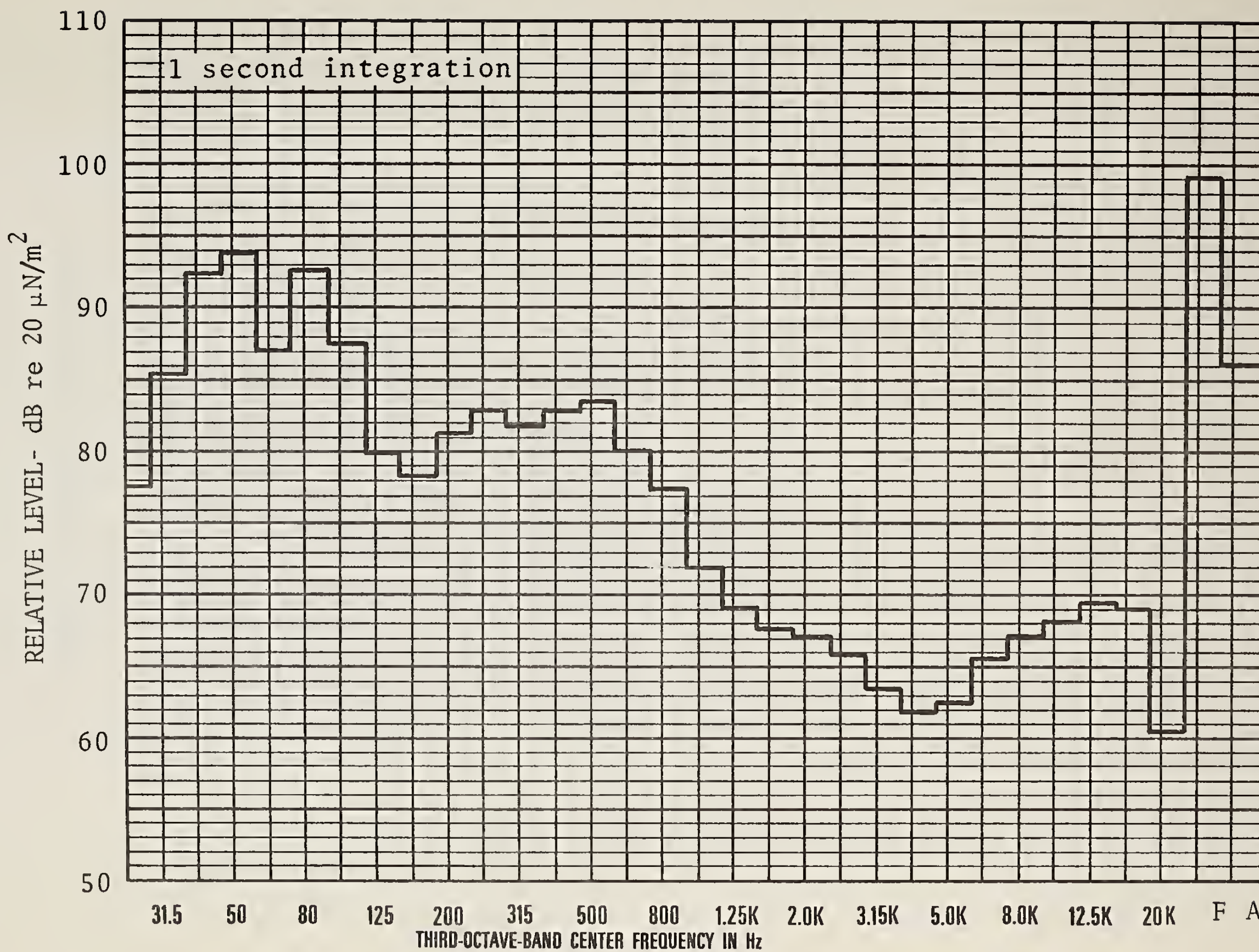


Figure F-14 Noise Spectra



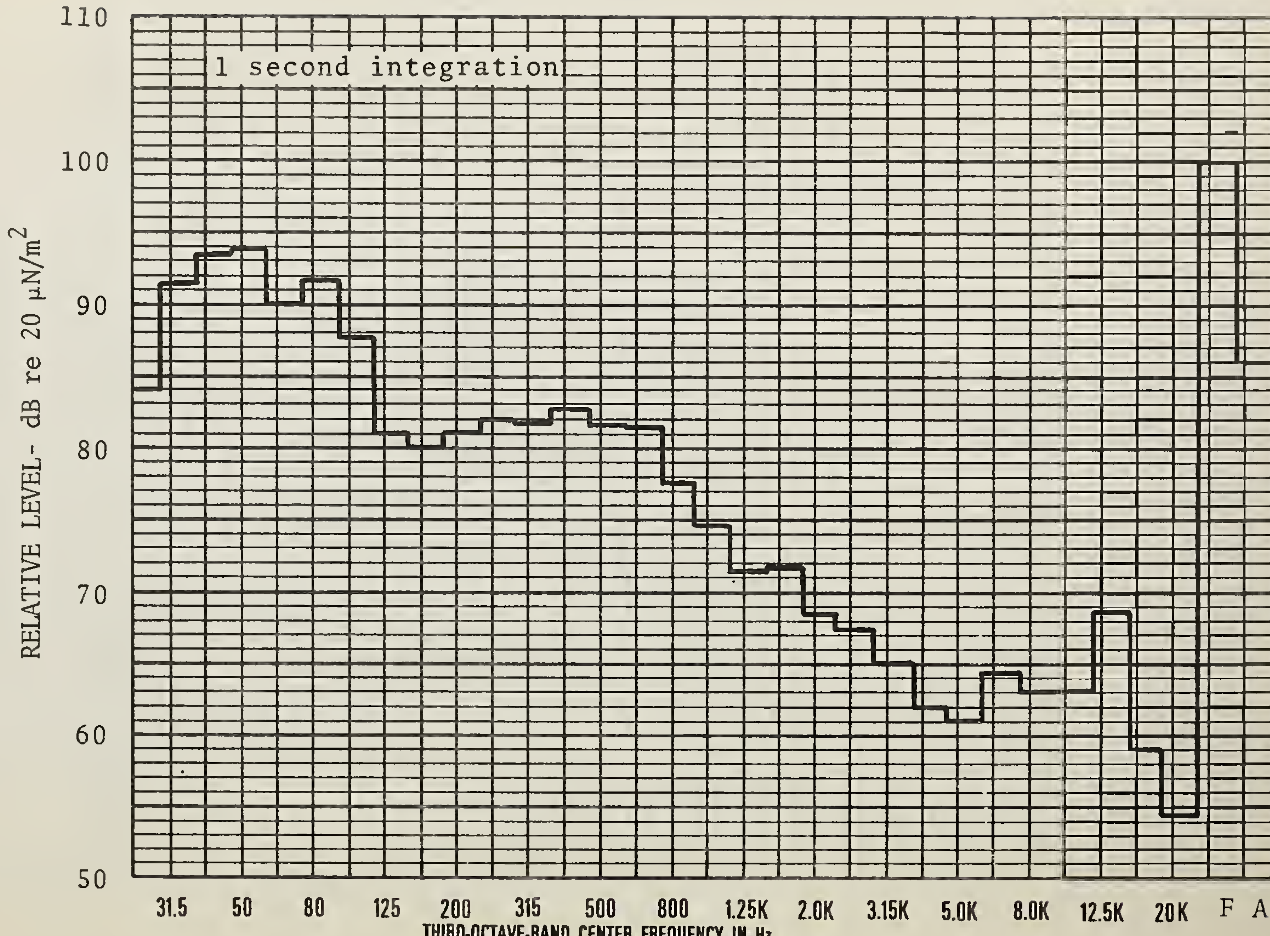
Stopped in Station, Surface Line
12/15/72

Figure F-15 Noise Spectra



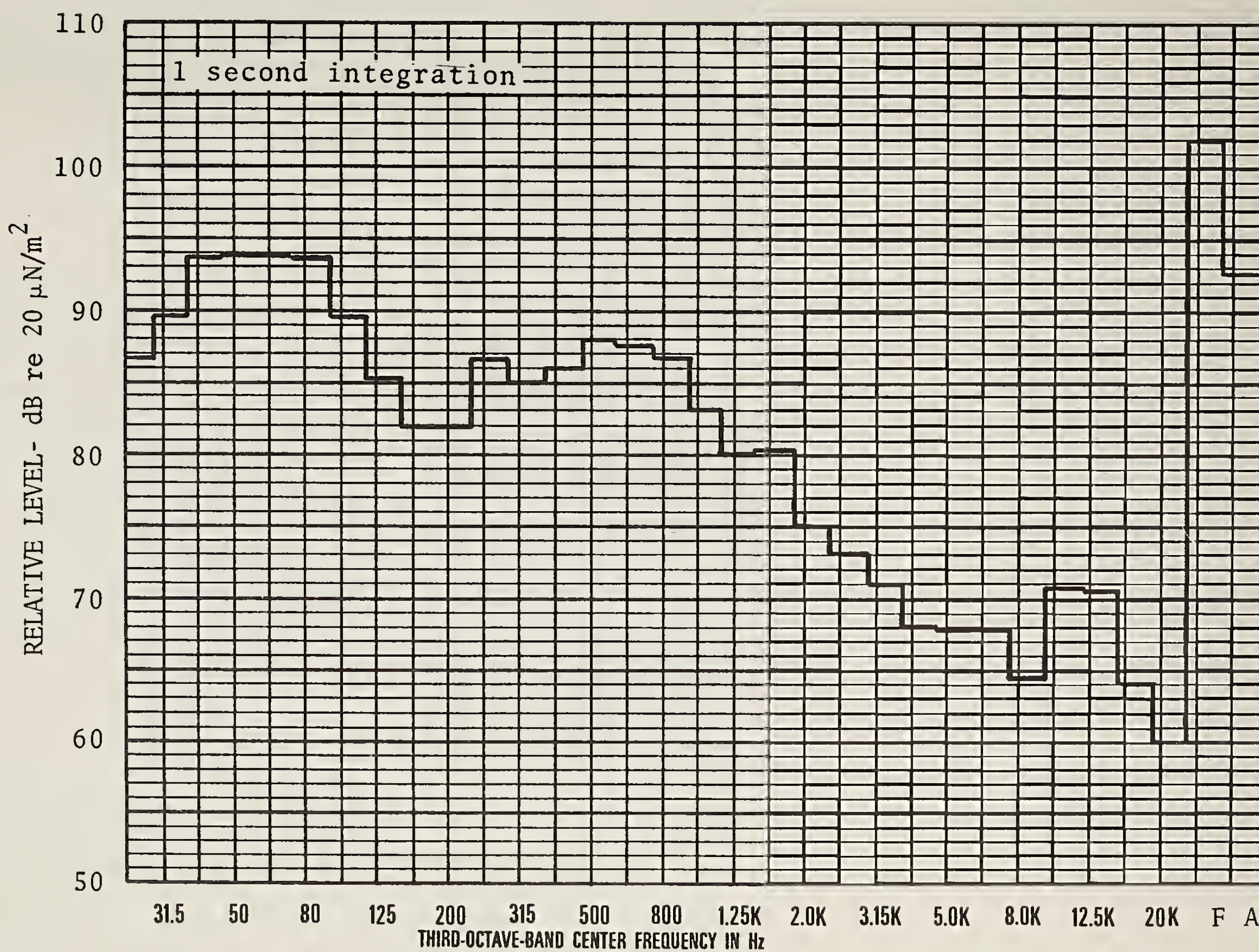
32 mph
12/15/72

Figure F-16 Noise Spectra



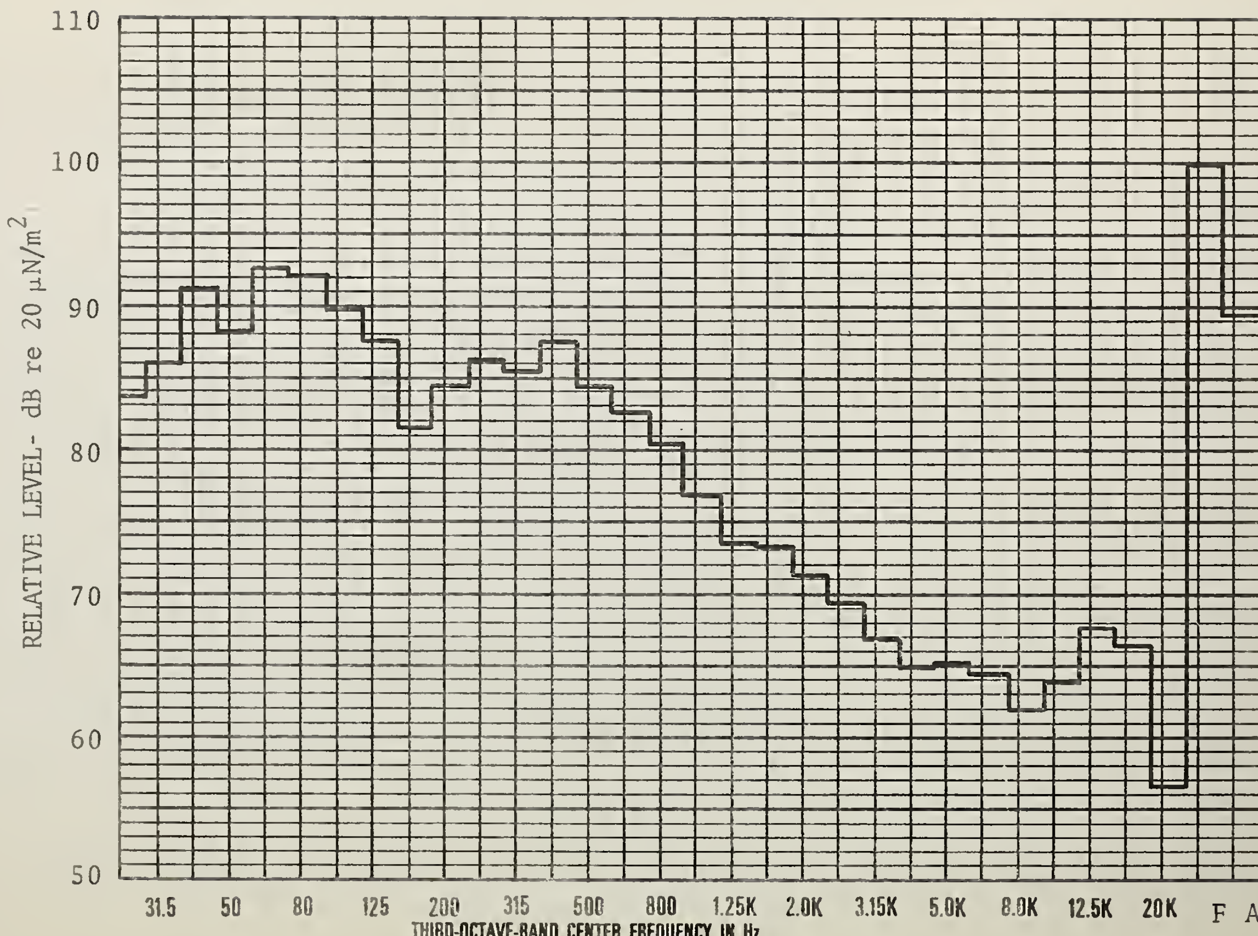
28 mph.
12/15/72

Figure F-17 Noise Spectra



39 mph
12/15/72

Figure F-18 Noise Spectra



36 mph.
12/15/72

Figure F-19 Noise Spectra