U.S. Department
of Transportation
Federal Railroad Administration

The Safety of Highway - Railroad Grade Crossings

Office of Research and
Development
Washington, DC 20590

Study of the Acoustic Characteristics of Railroad Horn Systems

DOT/FRA/ORD-93/25
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Final Report
July 1993

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The U.S. Department of Transprotation, Research and Special Programs Administration, Volpe National Transportation Systems Center, in support of the Federal Railroad Administration is conducting a research program with the goal of reducing the number of fatalities and injuries at higway-railroad grade crossings. As part of this program, the Volpe Center's Noise Measurement and Assessment Facility is conducting a study to determine the effectiveness of railroad horn systems. This document is the first publication supporting this study. It presents the results of acoustic measurements performed in Council Bluffs, Iowa, Jacksonville, Florida, Cambridge, Massachusetts, and Omaha, Nebraska, to determine the acoustic characteristics of several types of railroad horn systems. Data obtained includes frequency spectrum, directivity, drop-off rate, maximum A-weighted sound level, and sound exposure level.

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PREFACE

This document presents the results of a study of the acoustic characteristics of railroad horn systems, conducted by the U.S. Department of Transportation, Research and Special Programs Administration, Volpe National Transportation Systems Center (Volpe Center), in support of the Federal Railroad Administration (FRA), Equipment and Operating Practices Research Division. The horn systems tested were two Leslie three-chime, a Nathan five-chime, and a prototype Automated Horn System (AHS). The AHS is an alternative audible warning system being evaluated by the Union Pacific Railroad. Acoustic data were obtained by the Volpe Center's Acoustics Facility through field measurements conducted in a Union Pacific rail yard located in Council Bluffs, Iowa, a Florida East Coast Railway rail yard located in Jacksonville, Florida, a Massachusetts Bay Transportation Authority (MBTA) rail yard located in Cambridge, Massachusetts, and the AK-SAR-BEN racetrack parking lot located in Omaha, Nebraska.

The authors would like to thank the following people for their contributions to this measurement program: Mr. Merrill J. "Andy" Anderson of Railroad Consulting Services for his help in identifying and preparing measurement sites in Nebraska and Iowa, as well as providing field support during the measurements; Mr. Cliff Shoemaker of the Union Pacific Railroad for scheduling the use of the locomotive and taking time out of his busy schedule to provide field support in Council Bluffs; Mr. Hank Dickinson and Mr. Jerry Hall of the Florida East Coast Railway for scheduling the use of the locomotive and the rail yard; Mr. Neil Mullaney of the MBTA for scheduling the use of the locomotive and crew, and for his help in identifying the measurement site. The authors would also like to thank Ms. Anya A. Carroll of the Volpe Center for her continuing support throughout this research effort.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (ha) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

$[(x - 32)(5/9)]^\circ\mathrm{F} = y^\circ\mathrm{C}$

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

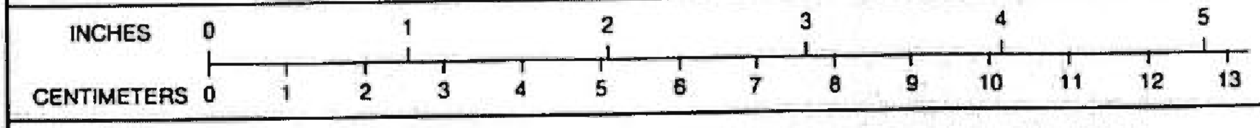
VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

$[(9/5)(y + 32)]^\circ\mathrm{C} = x^\circ\mathrm{F}$

QUICK INCH-CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10286.

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EXECUTIVE SUMMARY

In support of the Federal Railroad Administration, studies are being conducted to evaluate the potential effectiveness of options to reduce the number of fatalities and injuries at highway-railroad grade crossings. One of the options being considered is the improvement of the effectiveness of railroad horn systems with a minimization of the resulting impact on the community noise environment.

This document, the first in a series under this study, presents the results of measurements of the acoustic characteristics of railroad horn systems. The railroad horn systems chosen for testing were a Leslie RSL-3L-RF and a Leslie RS-3L (both three-chime), a Nathan K-5-LA (five-chime), and a prototype Automated Horn System (AHS). These horn systems were chosen on the basis of their availability and are representative of the horn systems being used throughout the United States. Other documents in this series will examine the acoustic characteristics of these horn systems along with the acoustic characteristics of motor vehicles to determine the resulting effectiveness in warning the motorist of an oncoming train.

Acoustic measurements were conducted with the conventional horn systems mounted in their normal location atop a stationary locomotive, and with the AHS mounted at its intended height above ground level. Acoustic data collected on a 30.5m circle around each horn system provided information on the spectral output of the system, the directivity of the source, the drop-off rate, the maximum sound level produced, and the sound exposure level.

An analysis of the data collected for the conventional horn systems showed differences occur between the three-chime and five-chime due to the number of horns in each. The five-chime creates a broadband signal which is more efficient at higher frequencies. Since high frequency sounds are not normally contained in the background noise that exists in most motor vehicles and communities, the higher frequency content of the sound produced by the five-chime horn is more likely to overcome any existing background noise and attract the motorist's attention. The maximum sound level produced and the directivity of the horn systems were affected by their placement atop the locomotive. It is concluded that: (1) the horn system be placed as far front and as high as possible on the locomotive to produce maximum sound output forward of the locomotive; and, (2) five-chime horn systems be used to produce maximum sound output at higher frequencies.

An analysis of the data collected for the Automated Horn System showed the frequency spectrum of the horn system is quite different from that of conventional horn systems and may not be recognized as a railroad horn. Consistent with its mounting to face oncoming traffic, the directivity pattern of the AHS showed that most of its sound energy is directed forward toward the advancing motorist. It is concluded that the number of horns be increased from one to two or three to broaden the bandwidth of the sound produced and increase the warning effectiveness.

1. Introduction

The Federal Railroad Administration (FRA), working with the Federal Highway Administration (FHWA), the Federal Transit Administration (FTA), the National Highway Traffic Safety Administration (NHTSA), and the Association of American Railroads (AAR) have selected and prioritized several potential approaches to reducing the number of fatalities and injuries at highway-railroad grade crossings. Research is being conducted to determine the validity of each approach. In support of this effort, the Volpe Center's Acoustics Facility is conducting a study with the goal of optimizing the performance of railroad horn systems, while minimizing their resulting community noise impact. This study was prompted by a previous study(1) which found that after six years of enforcement of the nighttime train horn ban by the Florida East Coast Railway Company, the accident rate at impacted crossings had tripled.

This document, the first in a series, presents the results of a study of the acoustic characteristics of railroad horn systems. The objective of this study was to create a database, through a literature search and field measurements, of acoustic information on conventional locomotive horns. Acoustic information was also collected for an alternative warning system, a prototype Automated Horn System (AHS). Acoustic data were obtained in Council Bluffs, Iowa, on March 19, 1992; Omaha, Nebraska on March 19, 1992; Cambridge, Massachusetts, on June 3, 1992; and Jacksonville, Florida, on July 7, 1992. These data will be used in later reports to: (1) determine the effectiveness of railroad horn systems in penetrating a vehicle and warning a motorist of the impending arrival of a train; and, (2) determine the resulting community noise impact of these horn systems.

2. Background

The use of a horn as audible warning at railroad grade crossings dates back to the era of steam locomotives when the audible warning sound was a whistle produced by a column of steam resonating in a metal tube. This resonating column of steam produced a very distinctive sound which is the basis for the sound of conventional horn systems. Conventional locomotive horn systems consist of a group of horns which operate using compressed air to vibrate a metal diaphragm. The first compressed-air powered horn systems incorporated five horns operating at five distinct frequencies to replicate the sound of a steam whistle.(2) It was later found that three horns could also approximate this sound. The prevalent convention is to call each horn which comprises the assembly a "chime". Thus, a three-chime is comprised of three separate horns and a five-chime is comprised of five separate horns. It has been found that domestic railroads still use either three or five chimes in the horn systems used on road locomotives.

A review of the literature has revealed that there is little information on the acoustic characteristics of railroad horn systems and much of the data is outdated or incomplete. Two publications were helpful in defining human response to railroad horns and areas which needed further investigation: A study reported in May 1971(3) collected data for eight types of horn systems used at that time and conducted empirical surveys which rated the horns on their effectiveness and "nuisance value" (i.e., community noise impact). The horn systems used in this survey included synthesized electronic sounds as well as locomotive horns. The survey concluded that the five-chime horn is more effective and less "annoying" than the three-chime. A study reported in 1972(4) concluded that "Improvements to audible warning without degradation of the total environment can be made by a reappraisal and redesign of certain existing train hooter [horn] systems. Also wayside audible warning devices can be located further down the roadway...".

Three domestic manufacturers of locomotive horn systems were identified:

(1) Leslie Controls, Inc., Parsippany, NJ.
(2) Nathan Manufacturing Division, Wenger Machinery Corp., Cold Spring Harbor, NY.
(3) Prime Manufacturing Corporation, Oak Creek, WI.

After investigation of product literature from Leslie Controls and Nathan Manufacturing, it was found that the horn systems were all similar in nature, that is, the frequency combinations used for the chimes in the horn assembly did not vary greatly and their combined overall sound pressure level rating was the same. The frequency combinations for three chime horn systems are:

(1) 255, 311, and 440 Hz,
(2) 311, 370, and 480 Hz or
(3) 311, 370, and 494 Hz.

The frequency combinations for five chime horn systems are:

(1) 255, 311, 370, 440, and 554 Hz or
(2) 311, 370, 415, 494, and 622 Hz.

The individual chimes comprising the horn system are configured in one of two ways: (1) all chimes facing forward; or, (2) a portion of the individual chimes facing forward and a portion facing to the rear. The second type is normally used on bi-directional locomotives which do not have horns on both ends of the engine.

The locomotive horn systems tested were two 3-chimes, Leslie Model RSL-3L-RF and Model RS-3L, and a 5-chime, Nathan Model K-5-LA.

2.1 Leslie RSL-3L-RF

The individual chimes comprising the Leslie RSL-3L-RF operated at frequencies of 255, 311, and 440 Hz. The horn system is rated by the manufacturer to have a sound level output of 114 dB at 30.5m with a 100 psi air supply(5). In this Model, the 255 and 311 Hz chimes are mounted facing the front of the locomotive (i.e., the usual direction of travel); the 440 Hz chime is mounted facing the rear of the locomotive. The horn system was located in the center of the locomotive behind an auxiliary electrical cabinet, 4.4 m above ground level, 12.3 m (40 ft, 5 in) from the front of the locomotive. Figure 1 shows the Leslie RSL-3L-RF as it was mounted on the locomotive. The locomotive, provided by the Union Pacific Railroad, is a General Electric Dash-8-40CW (Dash-8), used for freight operations.

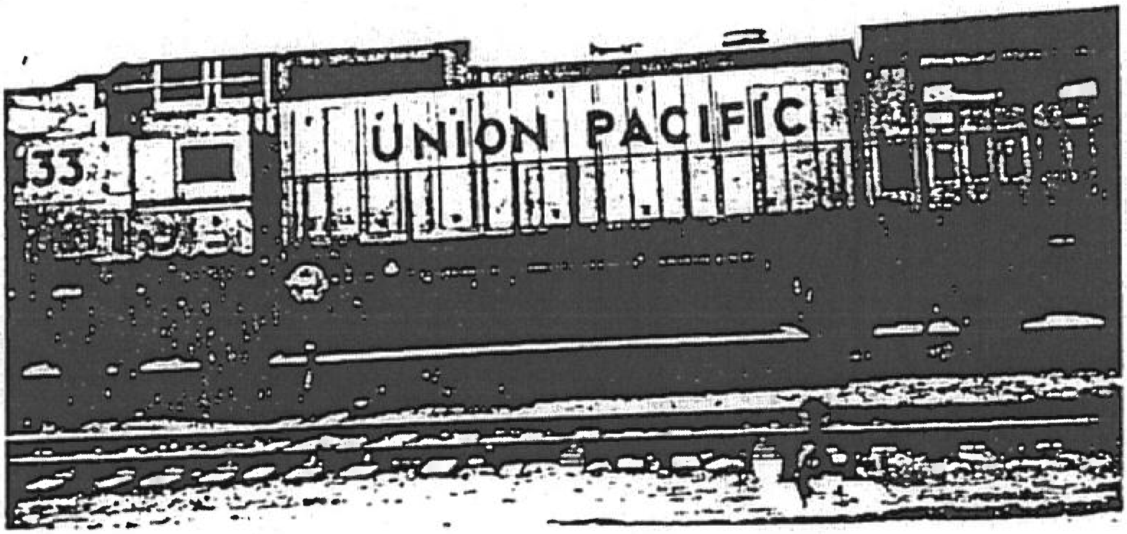


Figure 1 - LESLIE RSL-3L-RF

2.2 Leslie RS-3L

The individual chimes comprising the Leslie RS-3L operated at frequencies of 255, 311, and 440 Hz. The horn system is rated by the manufacturer to have a sound level output of 114 dB at 30.5m with a 100 psi air supply(5). On the locomotive tested, a regulator was installed on the compressed air supply to reduce the sound level output by approximately 10 dB at 30.5m, in order to minimize community noise impact. In this Model, all chimes are mounted facing the front of the locomotive. The horn system was mounted on the front of the locomotive, 4.6 m above ground level, 2.6 m from the front of the locomotive. Figure 2 shows the Leslie RS-3L as it was mounted on the locomotive. The locomotive, provided by the Florida East Coast Railway, is a General Motors GP40, used for freight operations.

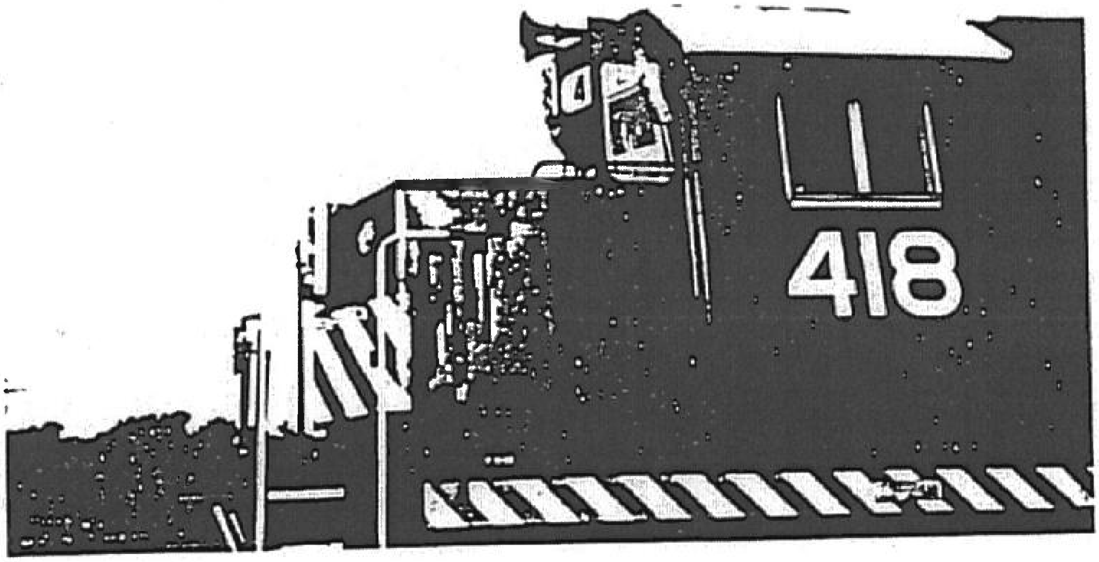


Figure 2 - LESLIE RS-3L

2.3 Nathan K-5-LA

The individual chimes comprising the Nathan K-5-LA operated at frequencies of 311, 370, 415, 494, and 622 Hz. The horn system is rated by the manufacturer to have a sound level output of 113 dB at 30.5m with a 100 psi air supply(6). In this Model, all chimes are mounted facing the front of the locomotive. The horn system was mounted on the front center of the locomotive, 4.7 m above ground level. Figure 3 shows the Nathan K-5-LA as it was mounted on the locomotive. The locomotive, provided by the Massachusetts Bay Transportation Authority, is a Morrison-Knudson F-40 PH-2M, used for short-line passenger operations.

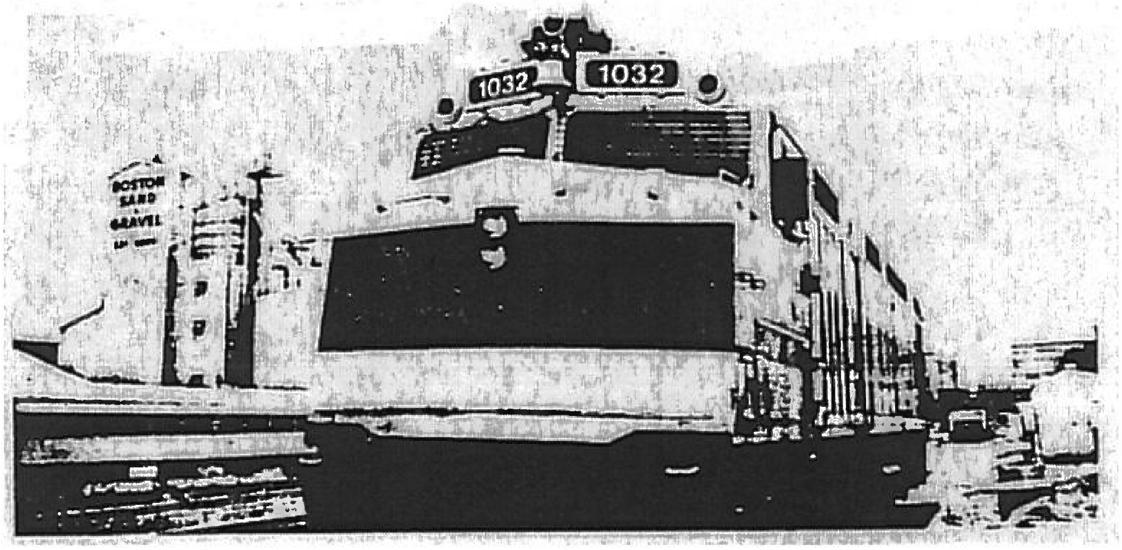


Figure 3 - NATHAN K-5-LA

2.4 Automated Horn System

The prototype Automated Horn System (AHS) is a railroad horn system, designed by Railroad Consulting Services, which is intended to supplement or replace conventional on-board locomotive horns. It is an example of a type of alternative system whose objective is to increase the audible warning effectiveness at grade crossings while minimizing community noise impact. The system consists of a single electronic horn to be placed directly at grade crossings and directed down approaching roadways. The horn, Model 56, manufactured by Federal Signal Corporation, operated at a frequency of 330 Hz and is rated by the manufacturer to have a sound level output of 108 dB at 3.5 m(7). During testing, the system was powered by a standard 12 volt battery and mounted atop a van, 2.1 m above ground level. Figure 4 shows the AHS as it was mounted.

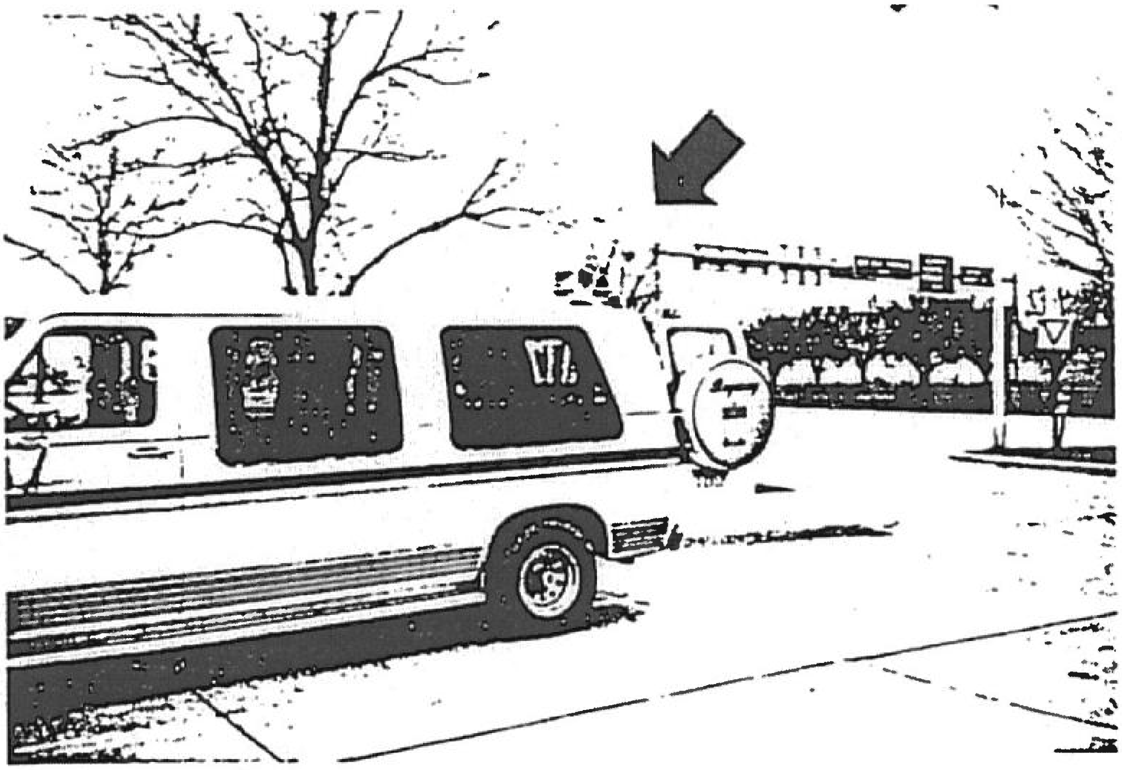


Figure 4 - AUTOMATED HORN SYSTEM

3. Data Acquisition Equipment

3.1 Acoustic Data Acquisition Systems

The acoustic characteristics of all horn systems were determined with the equipment described in detail in the following sections. At all locations, multiple sound level meter systems and a single digital recording system were deployed. The purpose of the sound level meter systems was to collect and store the sound level over time. The purpose of the digital recording system was to record the acoustic signal for off-line sound level and frequency analysis. The sound level meter systems and digital recording systems are shown diagrammatically in Figure 5.

3.1.1 Sound Level Meter Systems

The sound level meter systems consisted of the following components: (1) A General Radio Model 1962-9610 random incidence electret microphone, fitted with a Brüel and Kjær Model UA0237 (7.6 cm diameter) windscreen; (2) a Larson-Davis Model 827-0V preamplifier; and, (3) a Larson-Davis Model 820 Type I Precision Integrating Sound Level Meter / Environmental Noise Analyzer (LD820) conforming to ANSI S1.4-1971 requirements. The microphone/preamplifier assembly was mounted on a tripod at a height of 1.2 meters above ground level and oriented for grazing incidence. A 15.25 m cable connected the microphone / preamplifier assembly to the sound level meter.

The LD820 was operated in the "slow" sound level meter response mode, and was programmed to internally A-weight and store the acoustic level time history, one data record every 1/8 second, over the entire period of data acquisition. The data stored in the LD820, including calibration data, were downloaded into an AST Premium Exec Model 386SX/20 portable notebook computer after each

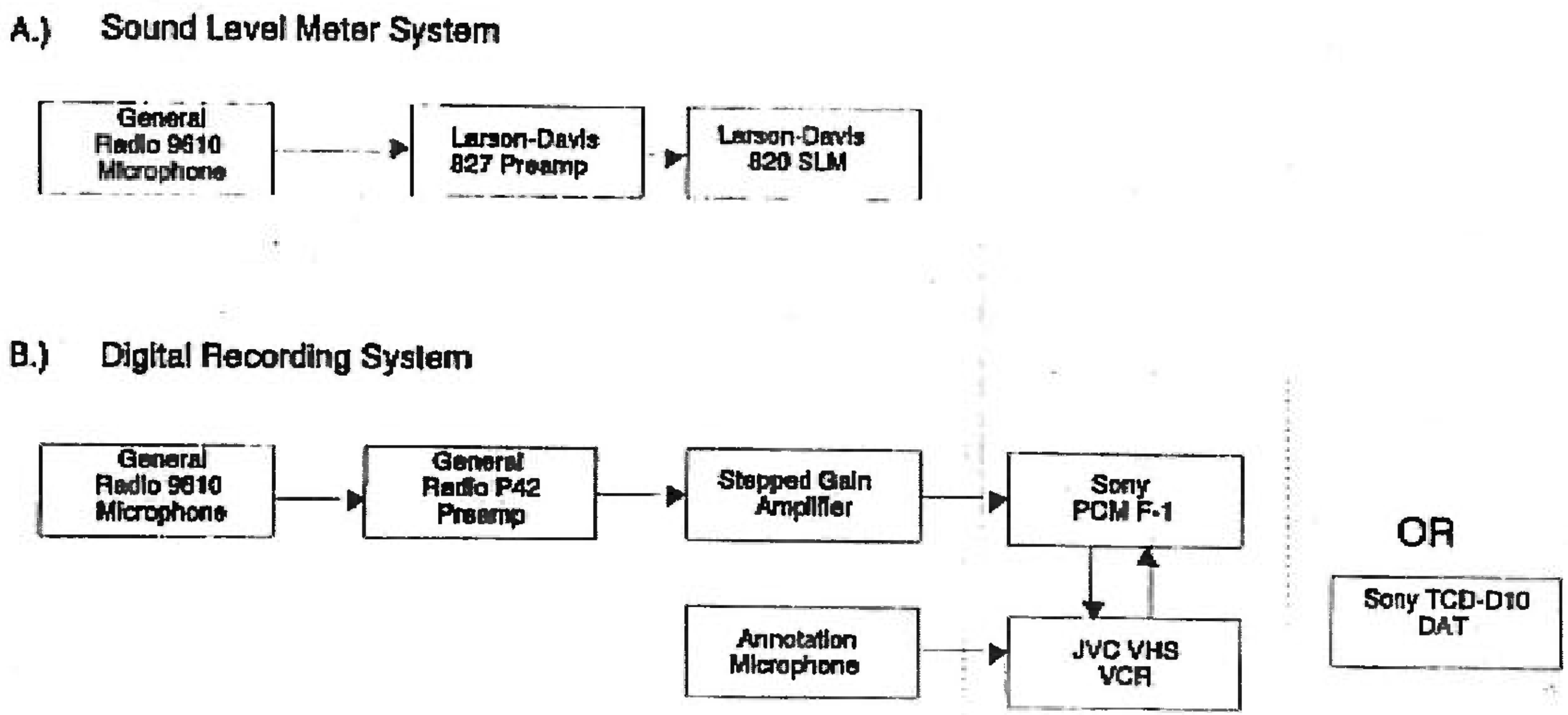


Figure 5. Acoustic Data Acquisition Systems

test and subsequently stored on floppy diskette for off-line analysis.

3.1.2 Digital Recording Systems

The digital recording system consisted of the following components: (1) A General Radio Model 1962-9610 random incidence electret microphone, fitted with a Brüel & Kjær Model UA0237 (7.6 cm diameter) windscreen; (2) a General Radio Model 1560-P42 preamplifier; (3) a stepped gain amplifier; (4) a Sony Model PCM-F1 Digital Audio Processor (PCM-F1); (5) a JVC Model BR-6200U video cassette recorder (VCR); and, (6) an annotation microphone. A Sony Model TCD-D10 ProII Digital Audio Tapecorder (DAT) was used in place of the PCM-F1 and the VCR, for the July 7 measurements. For both systems, the microphone/preamplifier assembly was mounted on a tripod at a height of 1.2 meters above the ground, and oriented for grazing incidence. A 61m cable connected the microphone/preamplifier assembly to the recording instrumentation.

When using the PCM-F1/VCR system, the signal from the microphone was split into two channels, each was low-pass filtered (22 kHz anti-alias filter), digitized at a rate of 44.056 kHz and recorded on video channels 1 and 2 with a 10 dB gain offset between channels. Additional recording gains were provided using the stepped-gain conditioning amplifier and fine tuned (prior to system calibration) using the PCM-F1 variable gain adjustment so that the best possible signal-to-noise ratio would be achieved while allowing enough "head room" to comply with applicable distortion avoidance requirements. Voice annotation was recorded on audio channel 1.

When using the DAT, the signal from the microphone was low pass filtered (24 kHz anti-alias filter), digitized at a rate of 48 kHz and recorded on channel 1. Additional recording gains were provided using the stepped-gain conditioning amplifier and fine tuned (prior to system calibration) using the DAT's variable gain adjustment so that the best possible signal-to-noise ratio would be achieved while allowing enough "head room" to comply with applicable distortion avoidance requirements. Voice annotation was recorded on channel 2.

3.2 Meteorological Data Acquisition Systems

Meteorological conditions were monitored throughout the data acquisition period to insure the reliability of the data collected. A hand-held anemometer was used to monitor wind speed, and a sling psychrometer was used to monitor temperature and relative humidity. During the Leslie RSL-3L-RF three-chime data acquisition period, the average temperature was 13.3 °C, with a relative humidity of 40% and a wind speed of seven to nine knots from the northwest. During the Leslie RS-3L three-chime data acquisition period, the average temperature was 27.8 °C with a relative humidity of 84% and no wind. During the Nathan five-chime data acquisition period, the average temperature was 25.5 °C with a relative humidity of 47% and a wind speed of zero to nine knots from the northwest. During the AHS data acquisition period, the average temperature was 14.4 °C, with a relative humidity of 60% and a wind speed of zero to nine knots from the north-northwest (see Figures 6, 8, and 9 for wind directions relative to the microphone arrays).

4. Experimental Procedure

4.1 Test Sites/Microphone Locations

Following is a description of the test sites and microphone locations used in this study. In each case, the terrain of the test site is described, as well as the positions of the data acquisition systems at the site.

4.1.1 Leslie RSL-3L-RF Test Site

The Leslie three-chime horn was tested in an isolated section of a Union Pacific rail yard, located in Council Bluffs, IA. The horn system was mounted atop the lead locomotive of a three locomotive consist. No trains were allowed to run within 305m of the subject locomotive, eliminating the possibility of acoustic contamination from other acoustic sources. The ground surrounding the locomotive consisted of dirt and loose gravel.

Acoustic data acquisition systems (as described in Section 2.2) were placed on a 30.5m circle centered on the horn system at 22.5° increments (measured counterclockwise from the front of the locomotive). In addition, data acquisition systems were placed 61.0m from the horn system at 0° and 90°. Because of instrumentation limitations, the data acquisition systems were deployed in two configurations. Configuration 1 consisted of six systems; five were placed 30.5m from the source at 0°, 22.5°, 45°, 67.5°, and 90°, and one was placed 61.0m from the source at 0°. Configuration 2 also consisted of six systems; four were placed 30.5m from the horn system at 90°, 112.5°, 135°, and 157.5°, and two were placed 61.0m from the horn system at 0° and 90°. Note that the data acquisition systems at 0°, 61.0m and 90°, 30.5m remained in the same positions for Configurations 1 and 2. The data from these two systems were used to provide a level control between configurations tested. Figure 6 is a diagram of the test site.

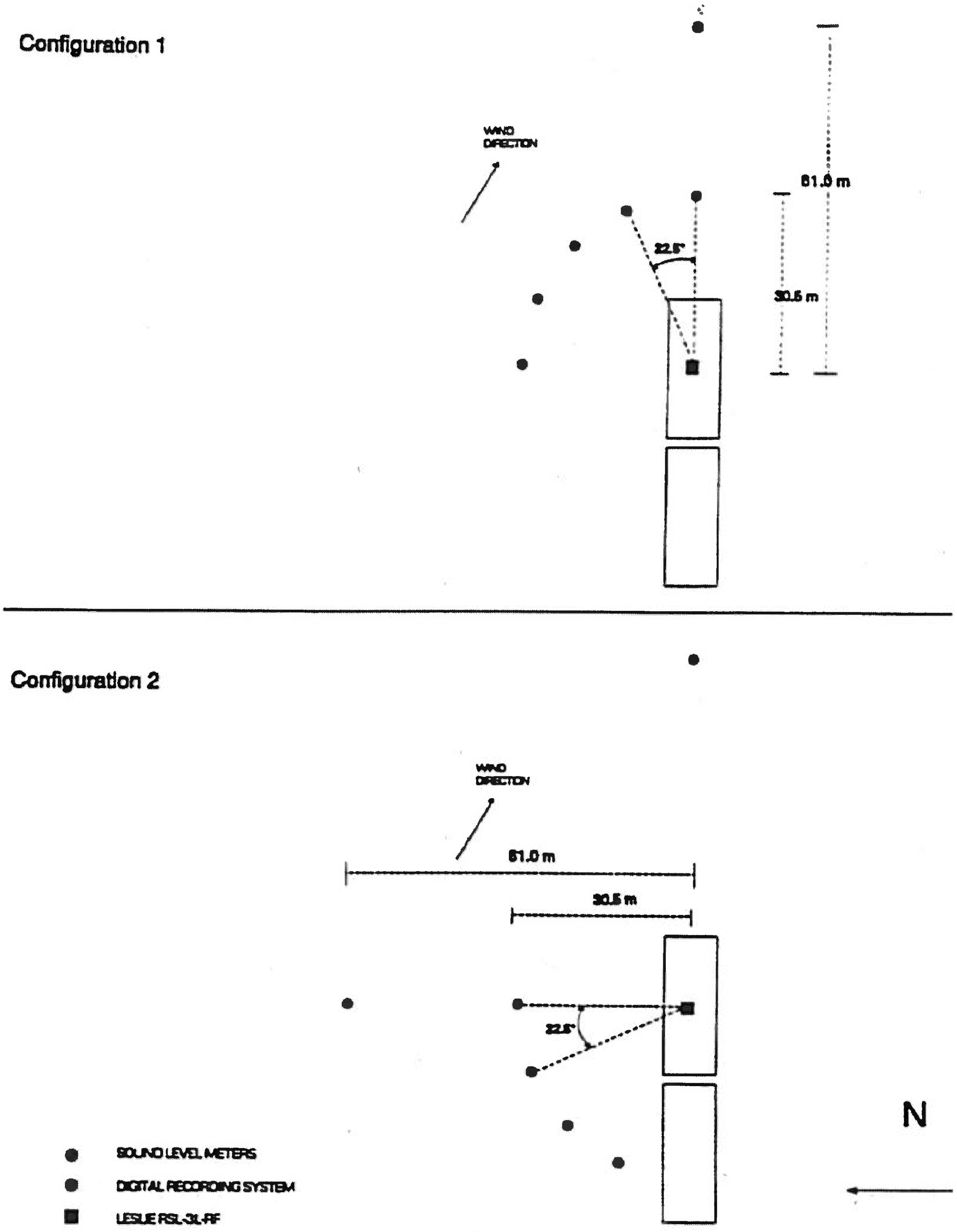


Figure 6. Union Pacific Rail Yard, Council Bluffs, IA
Data Acquisition System Locations

4.1.2 Leslie RS-3L Test Site

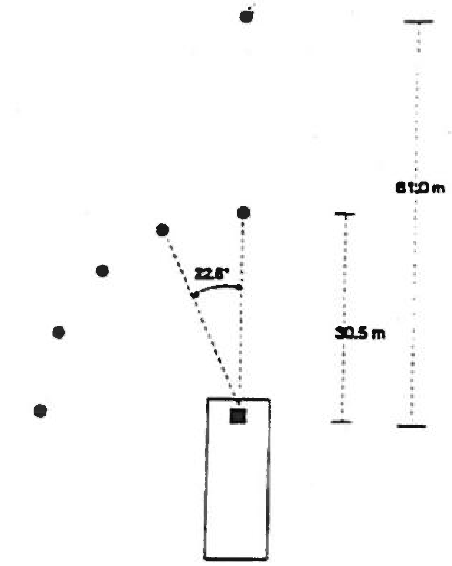
The Leslie RS-3L three-chime horn system was tested in an isolated section of a Florida East Coast Railway rail yard, located in Jacksonville, FL. No trains were allowed to run in that section of the rail yard, eliminating the possibility of acoustic contamination from other sources. The ground surrounding the locomotive consisted of dirt and loose gravel.

Acoustic data acquisition systems (as described in Section 2.2) were placed on a 30.5m circle centered on the horn system at 22.5° increments (measured counterclockwise from the front of the locomotive). In addition, data acquisition systems were placed 61.0m from the horn system at 0° and 90°. Because of instrumentation limitations, the data acquisition systems were deployed in two configurations. Configuration 1 consisted of six systems; five were placed 30.5m from the source at 0°, 22.5°, 45°, 67.5°, and 90°, and one was placed 61.0m from the source at 0°. Configuration 2 also consisted of six systems; four were placed 30.5m from the horn system at 112.5°, 135°, 157.5°, and 180°, and two were placed 61.0m from the horn system at 0° and 90°. Note that the data acquisition system at 0°, 61.0m remained in the same positions for Configurations 1 and 2. The data from this system was used to provide a level comparison between configurations tested. Figure 7 is a diagram of the test site.

4.1.3 Nathan K-5-LA Test Site

The Nathan five-chime horn system was tested in an Massachusetts Bay Transportation Authority rail yard located in Cambridge, Massachusetts. During testing, the yard and surrounding facilities were actively being used. Acoustic data were recorded when there

Configuration 1



Configuration 2

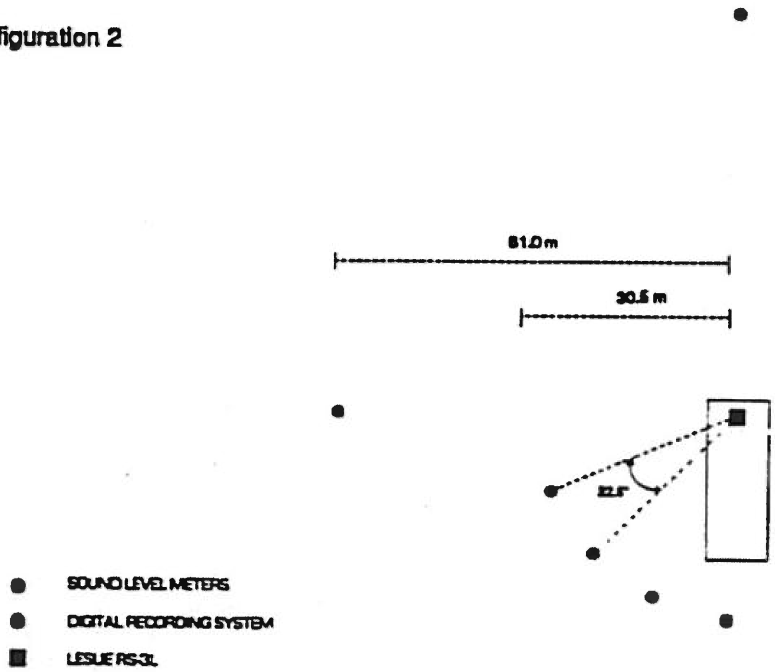


Figure 7. Florida East Coast Railway Rail Yard, Jacksonville, FL
Data Acquisition System Locations

were no trains or vehicles passing the test site, thus eliminating any contamination from other acoustic sources. The ground surrounding the test site consisted of dirt, loose gravel, and paved roadways.

Acoustic data acquisition systems were placed on a 30.5m circle centered on the horn system at 0°, 45° and 90° (measured counter-clockwise from the front of the locomotive). In addition, a data acquisition system was placed 61.0m from the horn system at 0°. Because of site limitations, the system at 45° was actually placed 26 m from the center of the device; measured data was subsequently corrected to 30.5m. Figure 8 is a diagram of the test site.

4.1.4 Automated Horn System Test Site

The automated horn system was tested in the parking lot of the AK-SAR-BEN racetrack, Omaha, NE. The parking lot was flat concrete and contained no obstructions. Cars were allowed to pass on a road parallel to the lot 100 m from the AHS. Traffic on this road was sparse and data was recorded with no vehicles passing the test site thus eliminating any contamination of the data.

Acoustic data acquisition systems were placed on a 30.5m circle centered on the AHS at 22.5° increments (measured clockwise from the centerline of the horn). In addition, a data acquisition system was placed 61.0m from the AHS at 0°. Figure 9 is a diagram of the test site.

4.2 TEST PROCEDURE

The acoustic measurements of both the locomotive horn systems and the AHS were conducted in two parts. The first consisted of

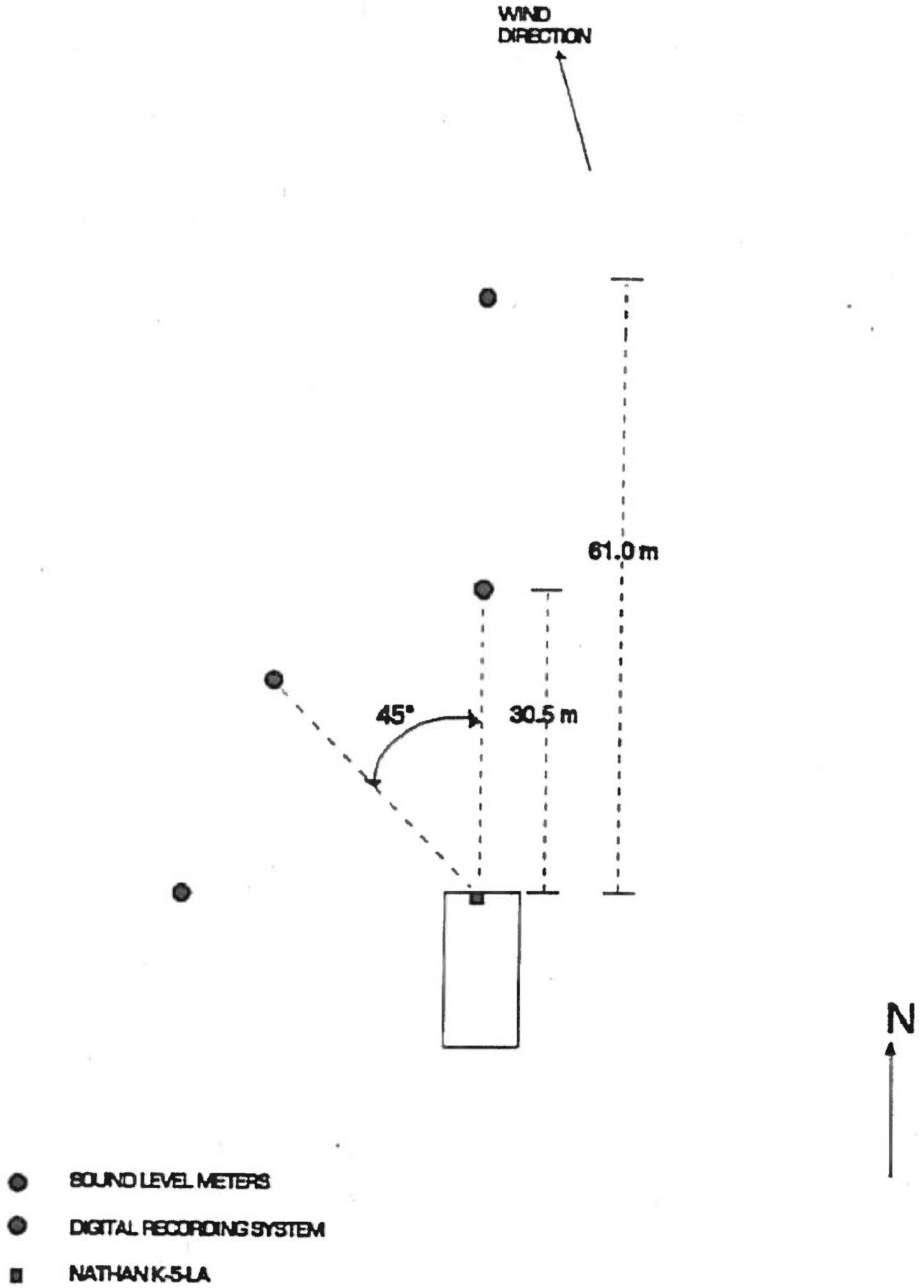


Figure 8. MBTA Rail Yard, Cambridge, MA
Data Acquistion System Locations

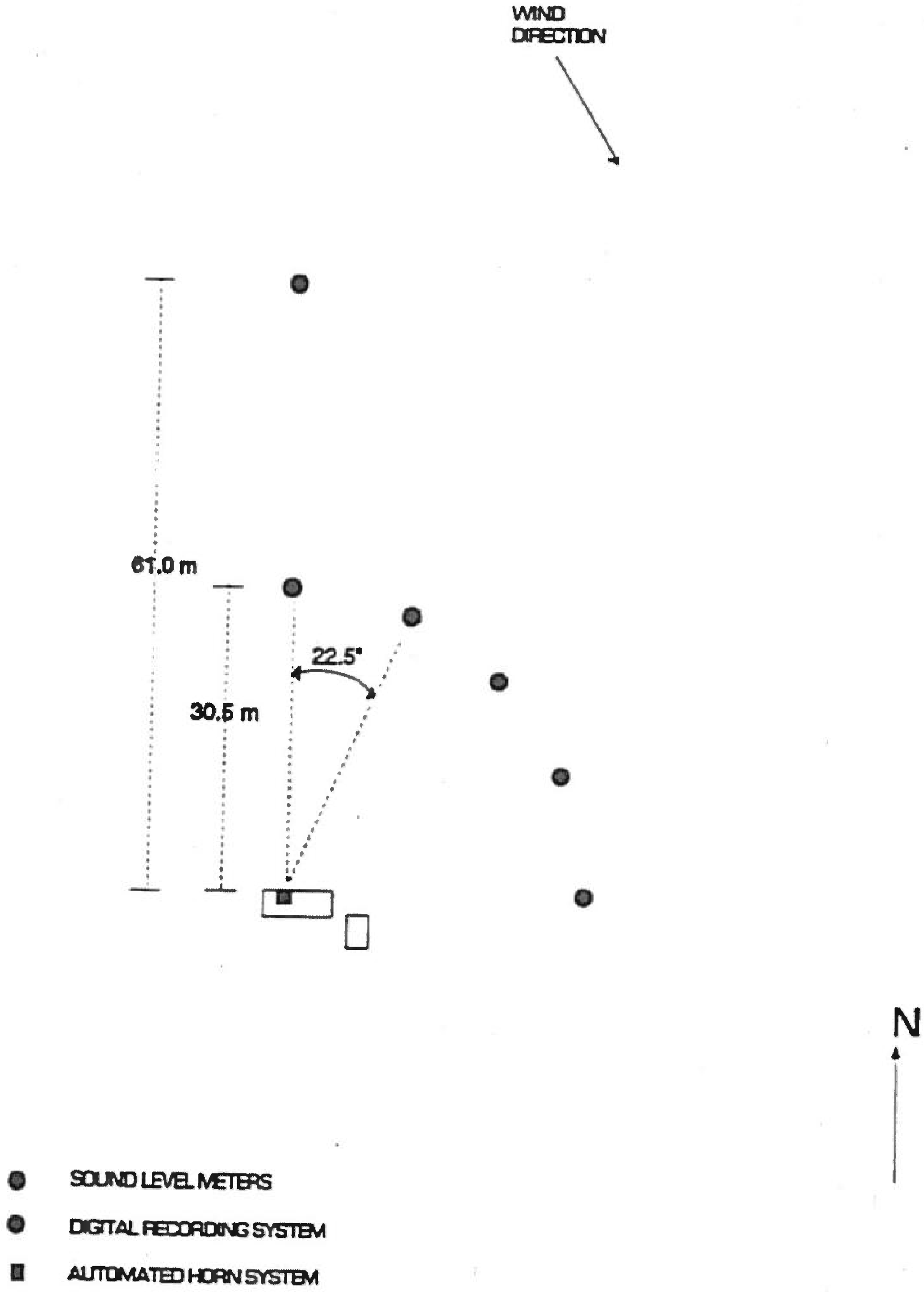


Figure 9. AK-SAR-BEN Racetrack, Omaha, NE
Data Acquistion System Locations

acoustic measurements of a series of three continuous signaling blasts, each having a duration of 15 to 20 seconds. The second consisted of acoustic measurements of a series of three "typical" signaling cycles. Each cycle consisted of a series of four blasts; 2 long (approximately 5 seconds), one short (1-2 seconds), and one long, each separated by a short pause. For this study, all horn systems were manually operated. Acoustic data was simultaneously measured at the six measuring stations deployed (see Section 3.1). All measuring systems were time synchronized with a master clock.

Each system was calibrated using a General Radio Model 1562-A sound level calibrator with an output sound pressure level of 114 dB (re: 20 µPa) at 1000 Hz. The microphones and calibrators are calibrated annually and checked prior to field measurements at the Acoustics Facility. Calibrator and microphone calibration is traceable to the National Institute of Standards and Technology. Calibration was performed at the beginning and end of the data acquisition period at each test site and prior to testing after the systems were moved to the second test configuration at the Leslie horn system test sites. Pink noise (i.e., noise having equal energy in each 1/3 octave band) from a Cetec Ivie IE-20B random noise generator was recorded on the digital recording system at the beginning of each data acquisition period and used for off-line frequency response adjustments.

5. Acoustic Data Reduction

5.1 SOUND LEVEL METER DATA

As stated in Section 3.1.1, the A-weighted 1/8-second time history data stored by the LD820 was downloaded into a portable notebook computer and stored on floppy diskette on-site. These data were transferred into a laboratory computer for processing. After calibration adjustments were applied to the data, the precise start and duration of each event was identified in the base of raw sound level meter data.

5.2 MAGNETIC TAPE RECORDED DATA

Digital tape recordings were analyzed at the Volpe Center's Acoustics Facility in Cambridge, Massachusetts. The start of each event processed was selected by first listening to the recorded data to insure that no extraneous sounds contaminated the data to be analyzed. The recorded data (acoustic, calibration and pink noise data) were processed through a Brüel & Kjær model 2131 Digital Frequency Analyzer. The digitized one-third octave sound pressure level data from the analyzer were stored in a laboratory computer in contiguous 1/8-second linear data records. System gain, calibration and pink noise signal adjustments were applied to the acoustic data. The acoustic data were tested against ambient noise levels, which consist of both background noise at the test site and the electronic noise floor of the recording and analysis systems, to insure there were no contaminations of the acoustic data. Ambient noise levels were less than 60 dB at the test sites in NE, IA and FL, and less than 75 dB at the test site in MA. Corrected data records were exponentially averaged over the period of each event to achieve slow sound level meter response characteristics. The corrected and averaged one-eighth second records of one-third octave data for each event comprised the stored base of raw data.

5.3 DATA PROCESSING

The raw data files from Sections 5.1 and 5.2, presented in Section 6 and Appendix A and B, were processed as follows:

The raw data files were broken down into three categories of events: (1) Continuous signals; (2) Signaling cycles; and, (3) Signaling cycle components (long or short). Events from all three categories were processed over the 10 dB down duration (i.e., the duration defined by the point where a level of 10 dB below the max was first attained to the point when a level of 10 dB below max was last attained). Processing yielded the following set of data:

- Frequency Spectra - One-third octave data from digital tape was used to generate a three event average of the time averaged frequency spectra (level vs. frequency) of the continuous signal over the 10 dB down duration. Data are used to compare the frequency content of each horn system and determine which is most effective.

- Equivalent A-weighted sound level (L_{eq}) - L_{eq} is the energy average of the one-eighth second records which comprise the event defined by 10dB down duration.

- Directivity plot - A directivity plot (on polar coordinates) was generated using the three event arithmetic average of the L_{eq} of the continuous events at each measurement position. A line of constant distance connects each sound level point resulting in a constant distance contour. This contour is used to determine if the sound energy is being most efficiently directed towards its intended receivers.

- Drop-off rate - Acoustic drop-off rates are a measure of how much a sound level will be decreased after propagating over a given distance. Typically, drop-off rates are given as a number of dB for every doubling of distance from source to receiver. In this way, the sound level at any number of distances from the source can be determined.

- Maximum A-weighted sound level (L_{Amax}) - L_{Amax} is the maximum level observed during the period of the event. The maximum A-weighted sound level is used to characterize each of the four components of the signaling cycle as well as the continuous signal. This is used to determine if each component of the signaling cycle reaches its maximum possible sound level.

- Spectral time history - A three-dimensional spectral time history (level vs. frequency vs. time) of a representative signaling cycle was generated using the linear one-eighth second data records from digital tape. This is used to show the changes in the frequency characteristics of a signal over time.

- Sound exposure level (SEL) - SEL is defined as the integral of the A-weighted level over time with a reference duration of one second. It is generally used to characterize the noise exposure of a single event where the acoustic levels vary substantially over time, such as the signaling cycle.

6. ACOUSTIC DATA ANALYSIS

6.1 LESLIE RSL-3L-RF

6.1.1 Continuous Signal

The average frequency spectrum (at 0 degrees, 61.0m) of the Leslie three-chime horn system is shown in Figure 10. The dominant frequency components of the horn system occur in the region above and including the 250 Hz band, encompassing the fundamental frequencies of each chime (255, 311, and 440 Hz), and several harmonics (frequency multiples of the fundamental) of each chime. The peak sound level occurs in the 800 Hz band. It is noted that there is no dominant tone in the sound of this horn system (i.e., the spectra is essentially broadband). Levels below 200 Hz are mainly comprised of locomotive-engine noise, and do not have an effect on the overall A-weighted sound level.

The A-weighted directivity characteristic of the Leslie three-chime horn system when mounted on the Dash-8 locomotive is shown in Figure 11. The directivity characteristics are assumed to be symmetric about the longitudinal axis of the locomotive as represented by dashed lines. It is noted that the sound energy emission characteristic of the horn system is more efficient toward the side (45° - 135°) and rear (135° - 180°) of the engine than the front. This peculiarity is caused by the location of the horn system (behind an auxiliary electrical cabinet in the center of the locomotive) on the engine. The cabinet acts as a reflective sound barrier and reduces the energy which propagates forward of the locomotive. As a result, the level measured in front of the engine was approximately 6 dB lower than at the sides and approximately 8 dB lower than the level measured at the rear. Correspondingly, the listener will perceive the horn system to be almost twice as loud to the rear of the locomotive than to the front(8). The levels

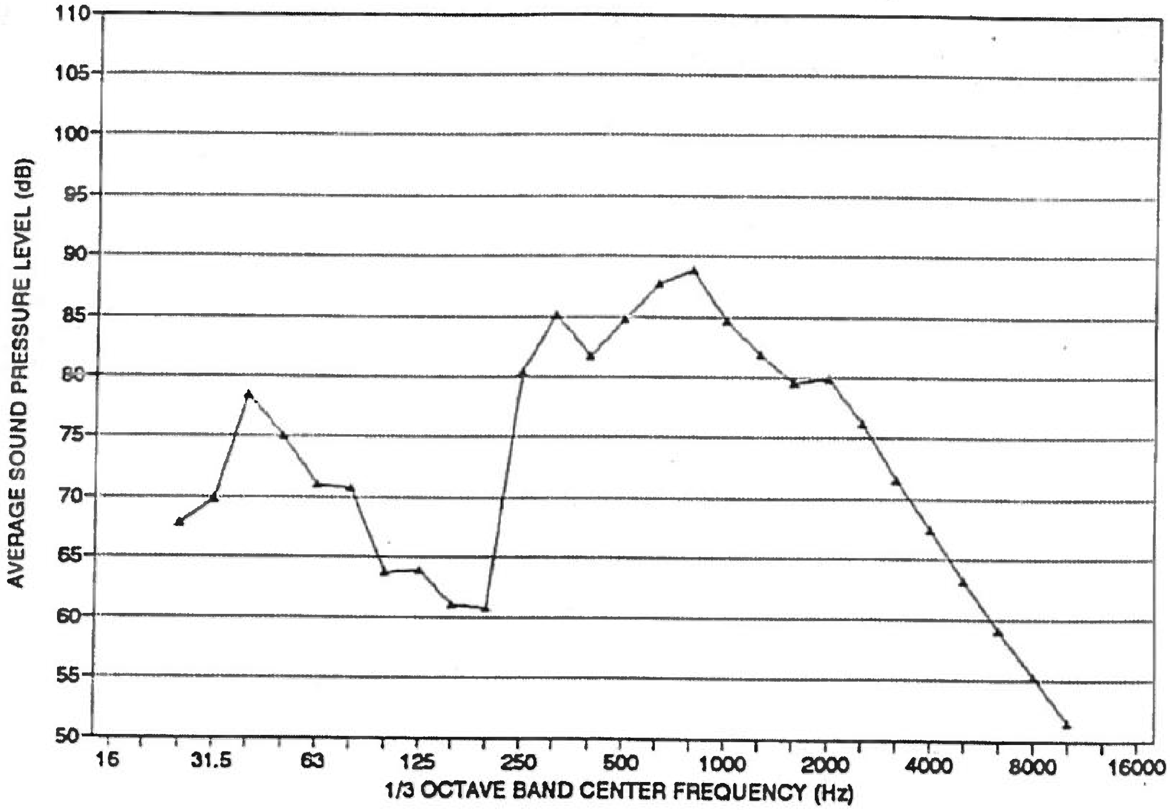


Figure 10. Leslie RSL-3L-RF Frequency Spectrum

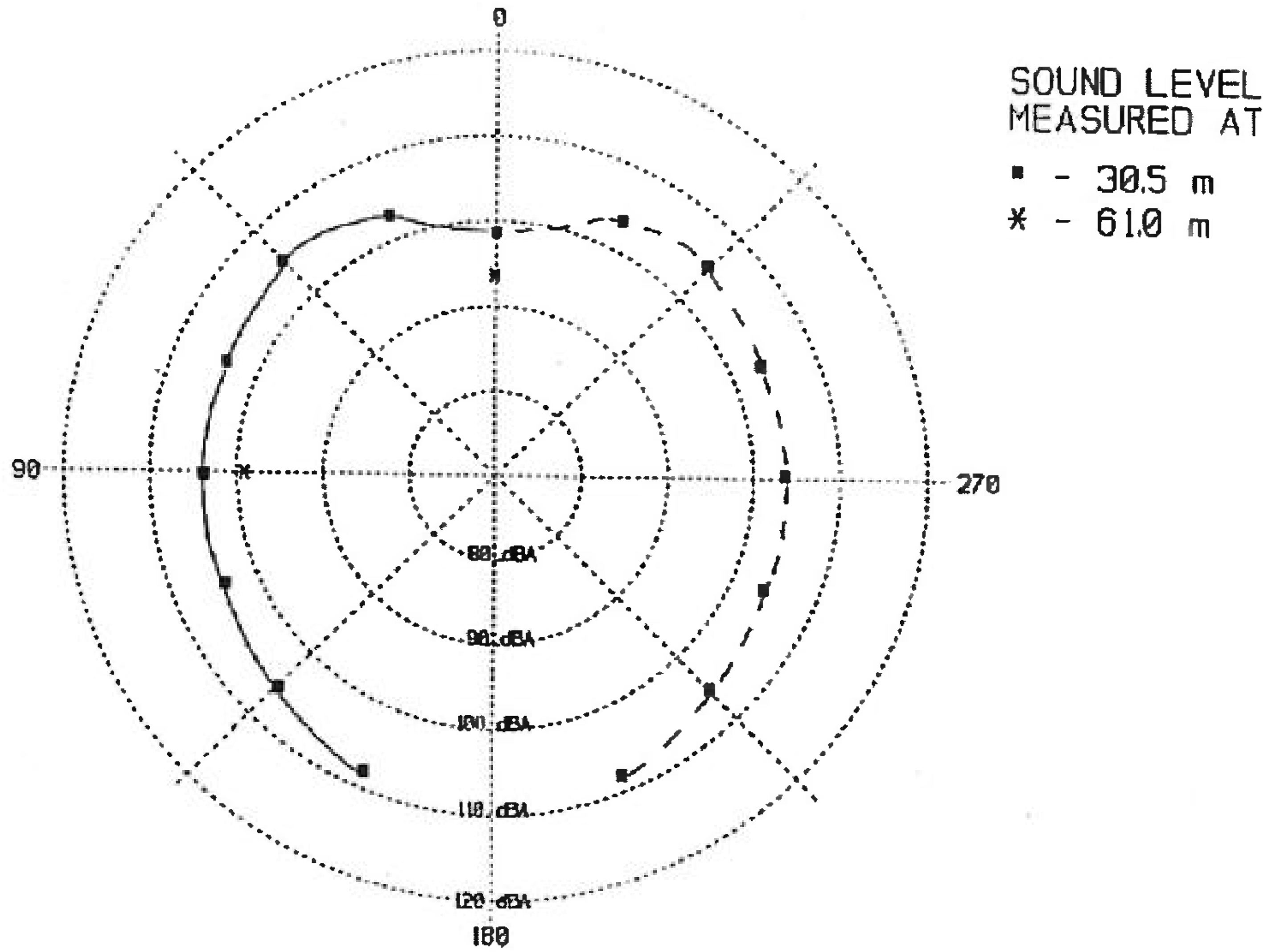


Figure 11. Leslie RSL-3L-RF Directivity
(Constant Distance Contour)

at 61.0m are 4.7 dB lower than at 30.5m, corre3sponding to a drop-off rate of 4.7 dB for every doubling of distance.

A maximum A-weighted level of 99.0 dB (arithmetically averaged over three test runs) was measured at 30.5m forward of the horn system. A level of 96.6 dB was obtained by extrapolating to a position 30.5m forward of the locomotive. This is in compliance with the Federal Railroad Administration's regulation specifying a minimum sound level of 96 dB, 30.5m forward of the locomotive(9).

6.1.2 Signaling Cycle

The maximum sound level and duration of each component (i.e., long or short), arithmetically averaged over the three runs of the signaling cycle, are shown in Table 1.

Table 1 - LESLIE RSL-3L-RF
Sound Level of Signaling Cycle by Component
Microphone Location: 0 degrees, 30.5m

COMPONENT	L_{Amax} (dB)	DURATION (sec)
1.) Long	99.4	4.92
2.) Long	99.3	4.79
3.) Short	97.4	1.38
4.) Long	99.0	7.04

It is noted that the maximum sound level of the "short" component is approximately 2.0 dB lower than the "long" components. This is a result of the two second averaging time inherent to slow scale averaging. Figure 12 is a spectral time history plot of the signaling cycle which visibly shows the stability of the signal over time of both the long and short components.

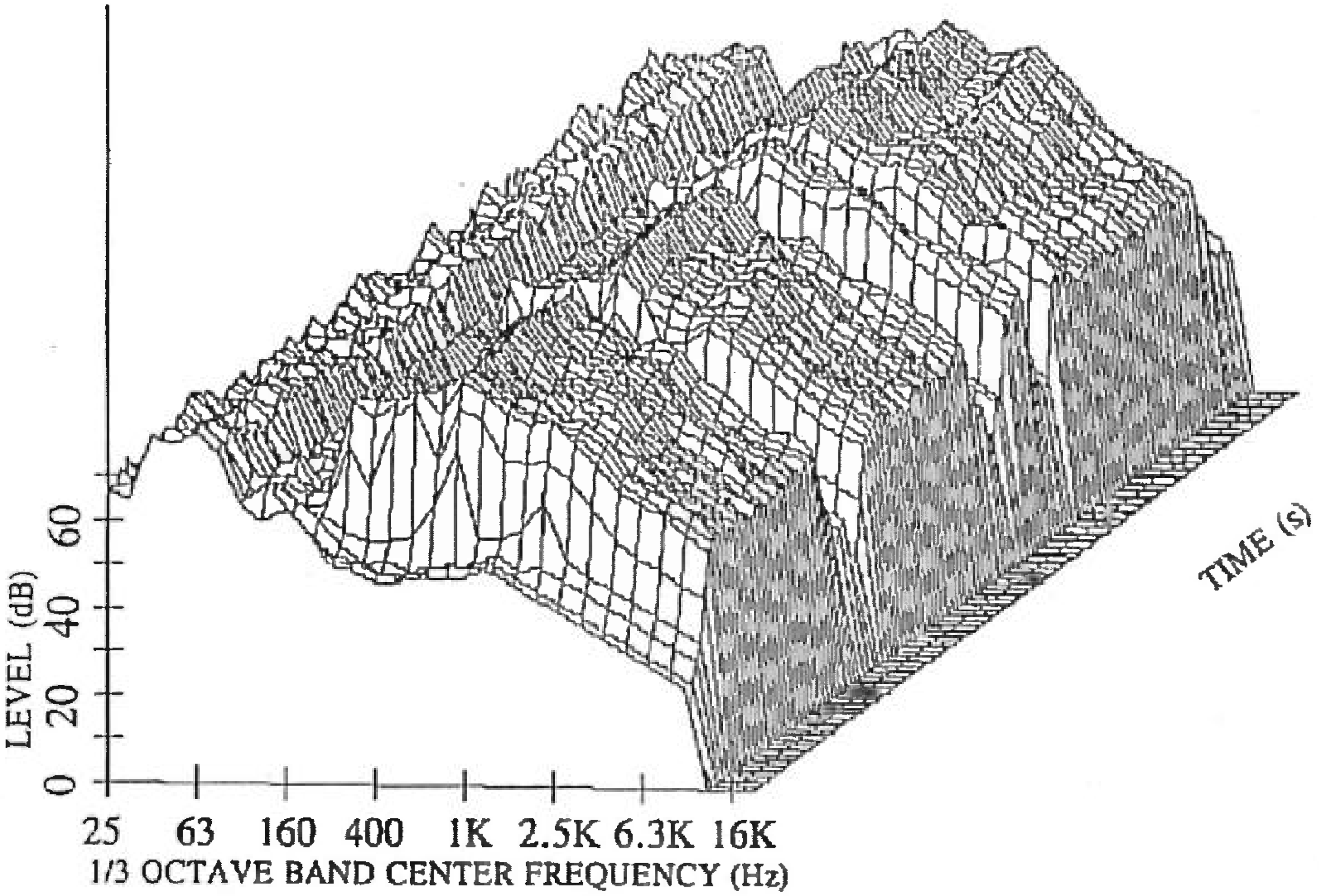


Figure 12. Leslie RSL-3L-RF

Spectral Time History, Signaling Cycle

6.2 LESLIE RS-3L

6.2.1 Continuous Signal

The average frequency spectrum (at 0°, 61.0m) of the Leslie RS-3L is shown in Figure 13. The dominant frequency components of the horn system occur in the region above and including the 250 Hz band, encompassing the fundamental frequencies of each chime (255, 311, and 440 Hz), and several harmonics (frequency multiples of the fundamental) of each chime. The peak sound level occurs in the 500 Hz band. It can be seen that in this instance, the 311 Hz chime is less efficient than the 255 and 440 Hz chimes, causing the spectra to be less broadband in nature.

The A-weighted directivity characteristic of the Leslie RS-3L when mounted on the GP40 locomotive is shown in Figure 14. (Note: the directivity characteristics are assumed to be symmetric about the longitudinal axis of the locomotive as represented by dashed lines). It is noted that the sound energy emission characteristic of the horn system is more efficient toward the front (0° - 22.5°) than the side or the rear. The significant drop in level (8 dB) from the side to the rear of the locomotive is caused by the fact that the line of sight to the horn system is broken by the locomotive.

The levels at 61.0m are 8.3 dB lower than at 30.5m, corresponding to a drop-off rate of 8.3 dB for every doubling of distance.

A maximum A-weighted level of 101.0 dB (arithmetically averaged over five test runs) was measured at 30.5m forward of the horn system. A level of 100.3 dB was obtained by extrapolating to a position 30.5m forward of the locomotive. This is in compliance with the Federal Railroad Administration's regulation specifying a minimum sound level of 96.0 dB, 30.5m forward of the locomotive(9).

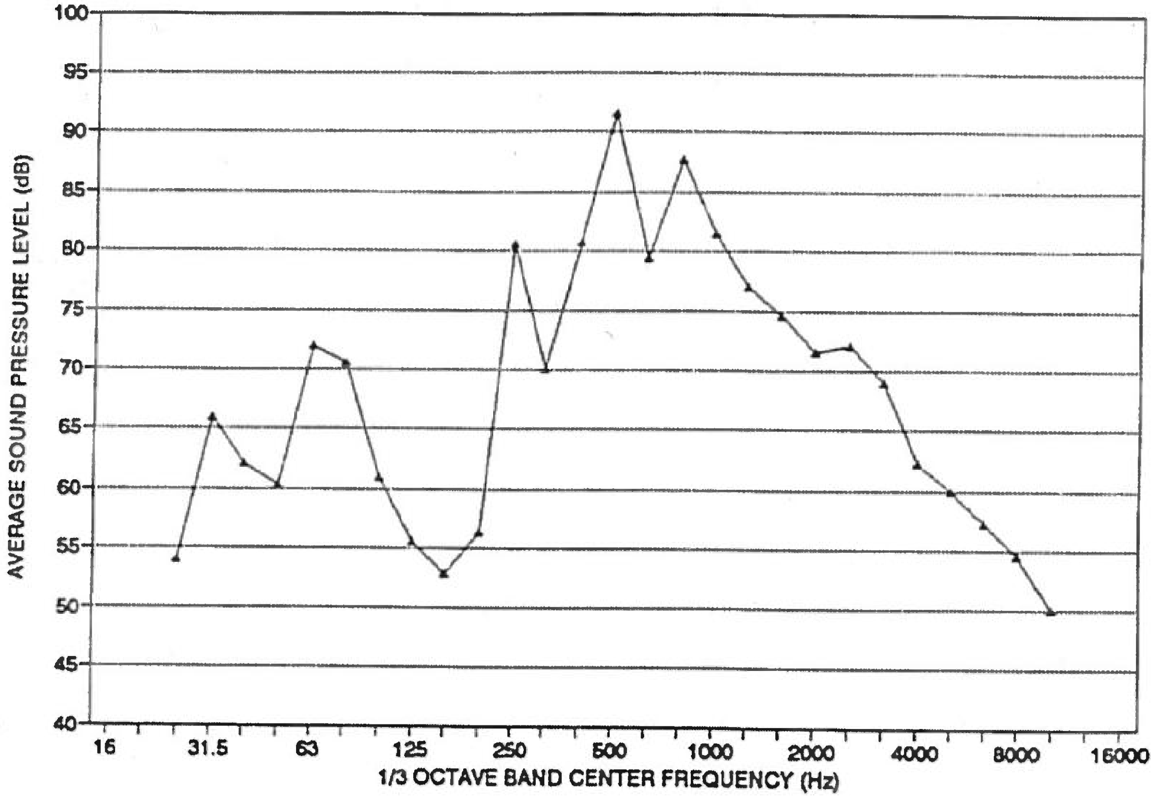


Figure 13. Leslie RS-3L Frequency Spectrum

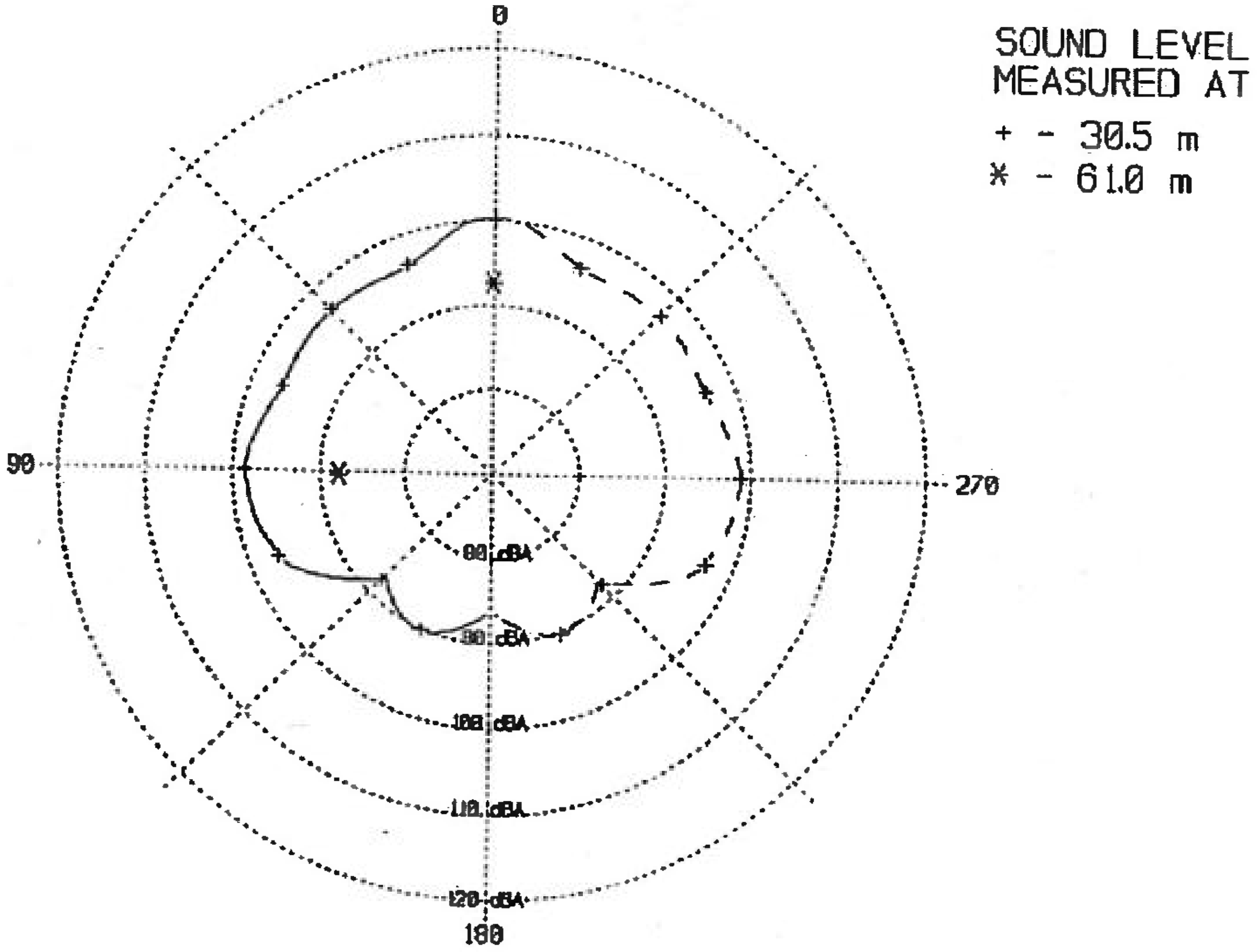


Figure 14. Leslie RS-3L Directivity
(Constant Distance Contour)

6.2.2 Signaling Cycle

The maximum sound level and duration of each component (i.e., long or short), arithmetically averaged over the three runs of the signaling cycle, are shown in Table 2.

Table 2 - LESLIE RS-3L
Sound Level of Signaling Cycle by Component
Microphone Location: 0 degrees, 30.5m

COMPONENT	L_{Amax} (dB)	DURATION (sec)
1.) Long	100.2	4.2
2.) Long	100.1	4.1
3.) Short	96.6	2.16
4.) Long	100.6	5.71

It is noted that the maximum sound level of the "short" component is approximately 4.0 dB lower that the "long" component. This is a result of: (1) the two second averaging time inherent to slow scale averaging; and, (2) the fact that for approximately the first second of the blast not all chimes are sounding at their maximum efficiency. Figure 15 is a spectral time history plot of the signaling cycle which visibly shows the signal variation over time.

6.3 NATHAN K-5-LA

6.3.1 Continuous Signal

The average frequency spectrum (at 0 degrees, 61.0m) of the Nathan five-chime horn system averaged over the three test runs is shown

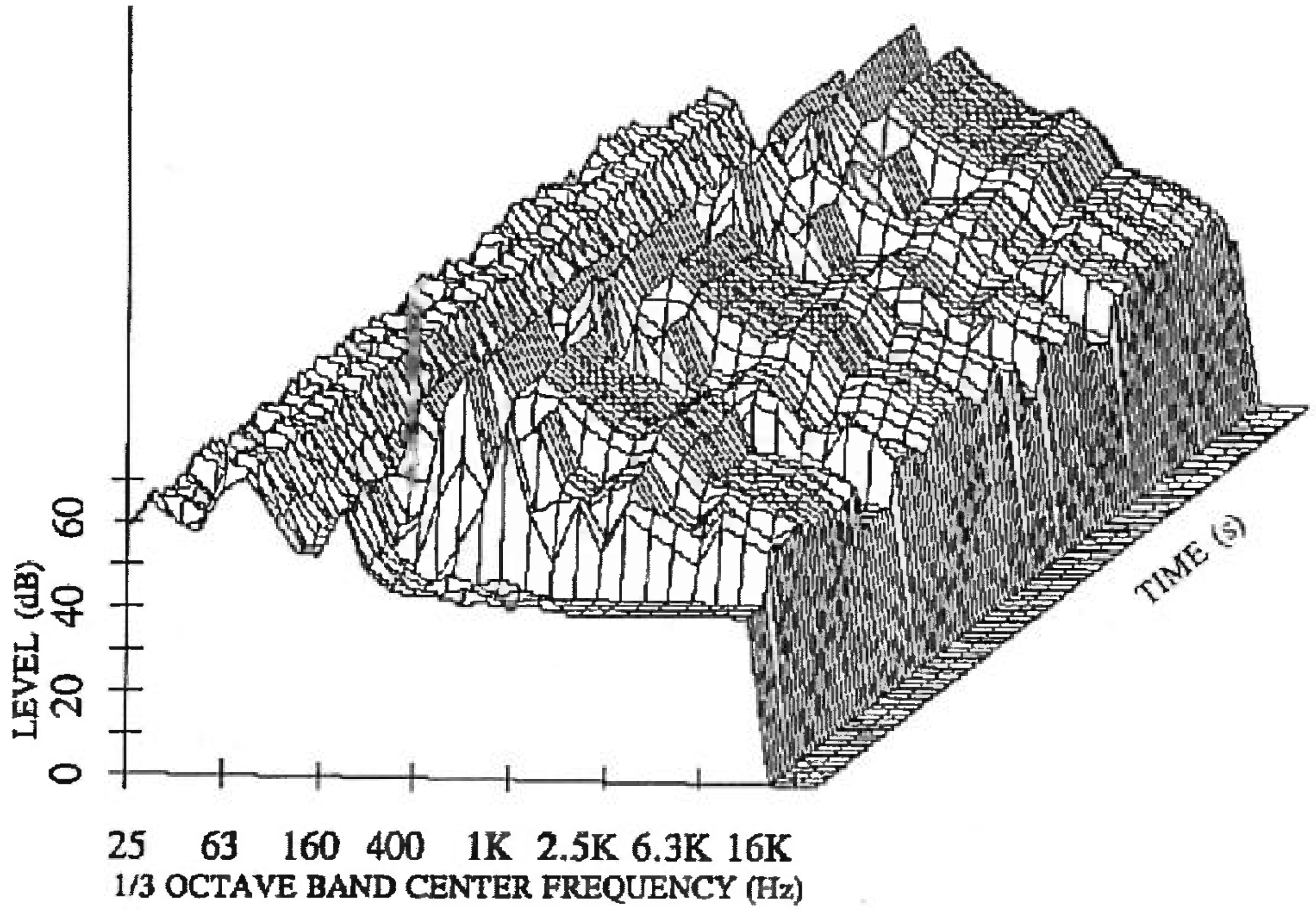


Figure 15. Leslie RS-3L
Spectral Time History, Signaling Cycle

in Figure 16. The dominant frequency components of the horn system occur throughout the region above and including the 315 Hz band, encompassing the fundamental frequencies of each chime (311, 370, 415, 494, and 622 Hz), and several harmonics (frequency multiples of the fundamental) of each chime. Peak sound levels occur throughout the region from 800 Hz to 2500 Hz. It is noted that there is no dominant tone in the sound of this horn system (i.e., the spectra is essentially broadband). Levels below 250 Hz are mainly comprised of locomotive-engine noise.

The A-weighted directivity characteristic of the Nathan five-chime horn system when mounted on the Dash-8 locomotive is shown in Figure 17 (Note: the directivity characteristics are assumed to be symmetric about the longitudinal axis of the locomotive as represented by dashed lines). The data measured at 45° was extrapolated from 26 m to 30.5m for consistency with the other measurement positions. Extrapolation was performed using the measured drop-off rate of 5 dB for every doubling of distance. It is noted that the sound energy emission characteristic of the horn system is more efficient toward the front (0° - 45°) of the engine than the side (45° - 90°). The level measured in front of the engine was approximately 5 dB higher than at the sides. The levels at 61.0m are 4.9 dB lower than at 30.5m, corresponding to a drop-off rate of 4.9 dB for every doubling of distance.

A maximum A-weighted level of 114.2 dB (averaged over three test runs) was measured at 30.5m forward of the horn system. Since the horn system was positioned at the extreme front of the locomotive, this is also the level 30.5m forward of the locomotive. This is well within the limits of the Federal Railroad Administration's regulation specifying a minimum sound level of 96 dB, 30.5m forward of the locomotive(9).

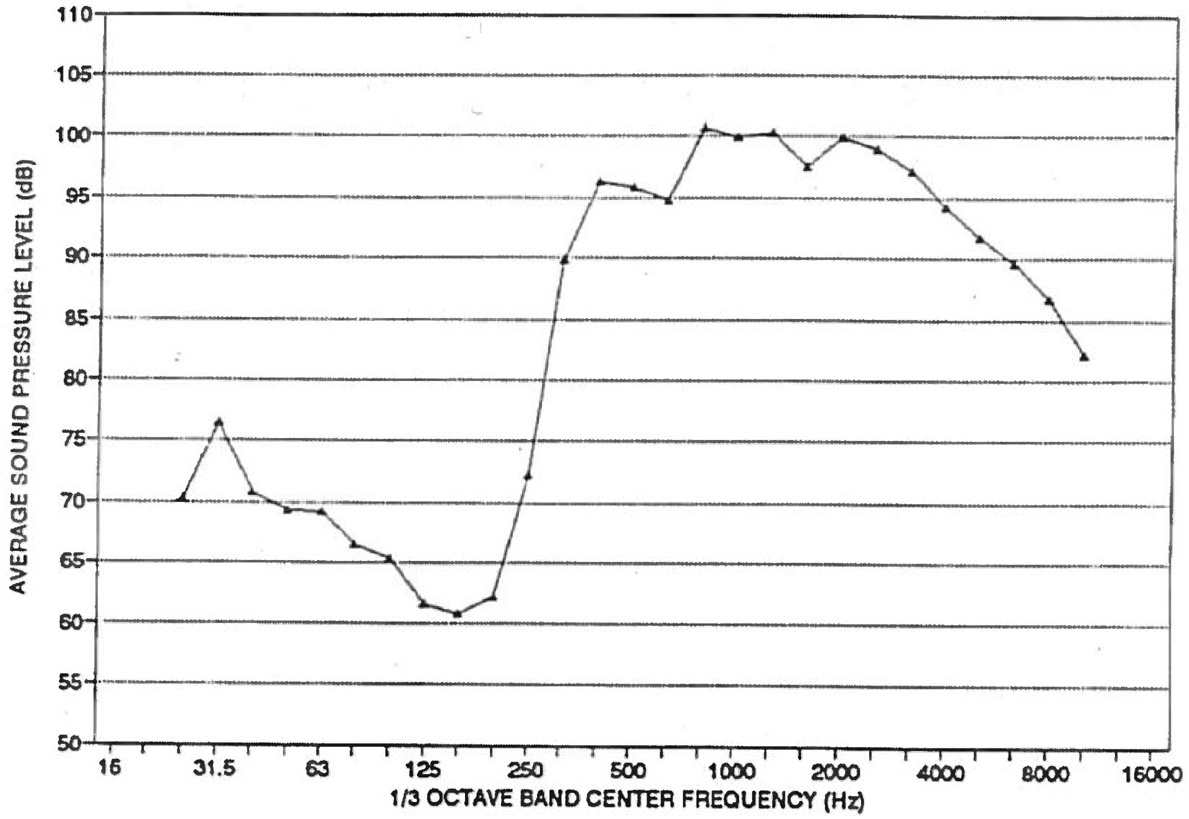


Figure 16. Nathan K-5-LA Frequency Spectrum

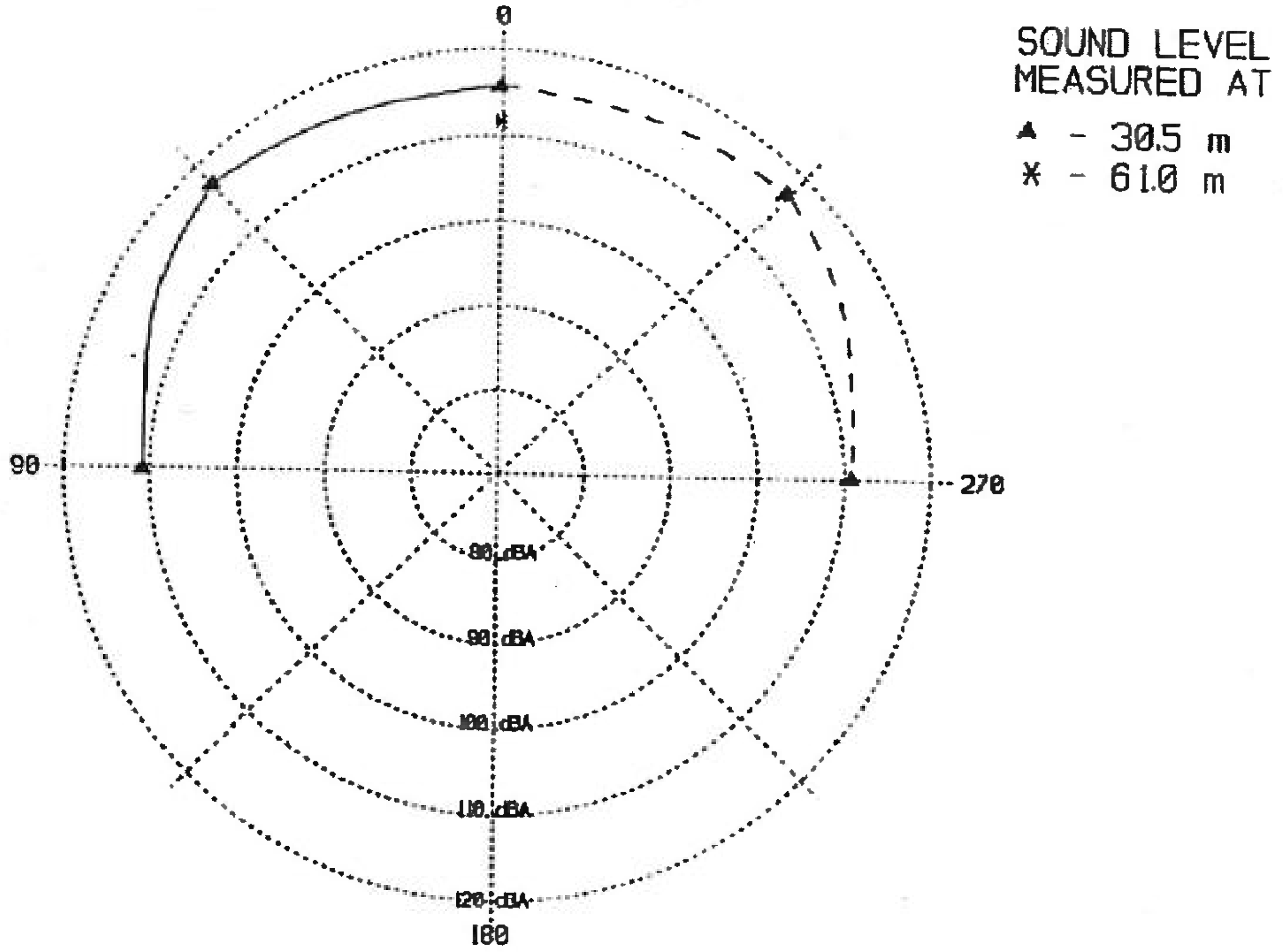


Figure 17. Nathan K-5-LA Directivity
(Constant Distance Contour)

6.3.2 Signaling Cycle

The maximum sound level and duration of each component (i.e., long or short), arithmetically averaged over the three runs of the signaling cycle, are shown in Table 3.

Table 3 - NATHAN K-5-LA
Sound Level of Signaling Cycle by Component
Microphone Location: 0 degrees, 30.5m

COMPONENT	L_{Amax} (dB)	DURATION (sec)
1.) Long	114.6	5.00
2.) Long	115.4	6.00
3.) Short	111.9	2.75
4.) Long	115.1	5.88

It is noted that the maximum sound level of the "short" component is approximately 3.0 dB lower than the "long" components. This is a result of the two second averaging time inherent to slow scale averaging. Figure 18 is a spectral time history plot of the signaling cycle which visibly shows the stability of the signal over time of both the long and short components.

6.4 AUTOMATED HORN SYSTEM

6.4.1 Continuous Signal

The frequency spectrum of the AHS can be seen in Figure 19. The dominant frequency components of the AHS occur in the region above and including the 315 Hz band and are pure tone in nature. The

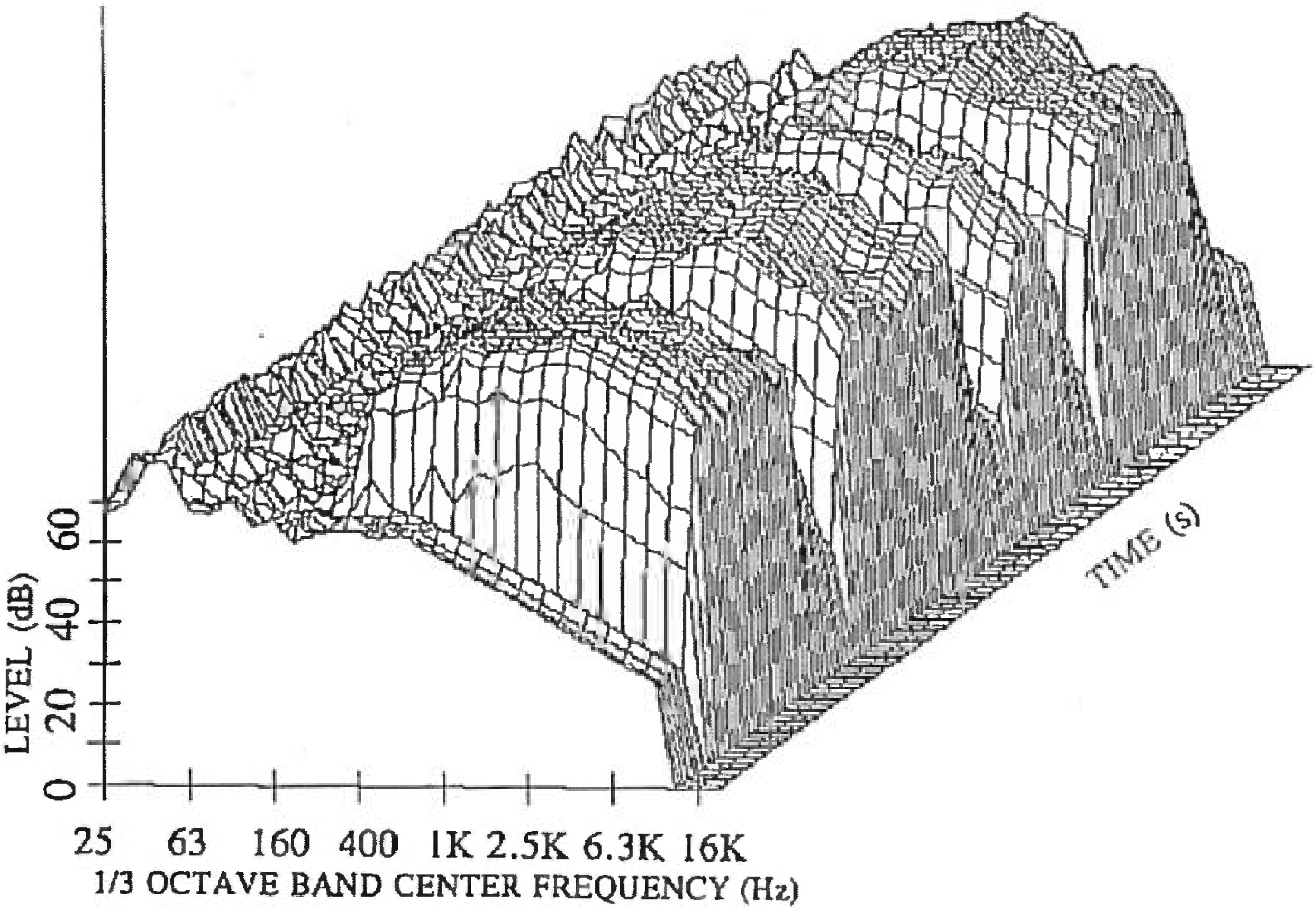


Figure 18. Nathan K-5-LA

Spectral Time History, Signaling Cycle

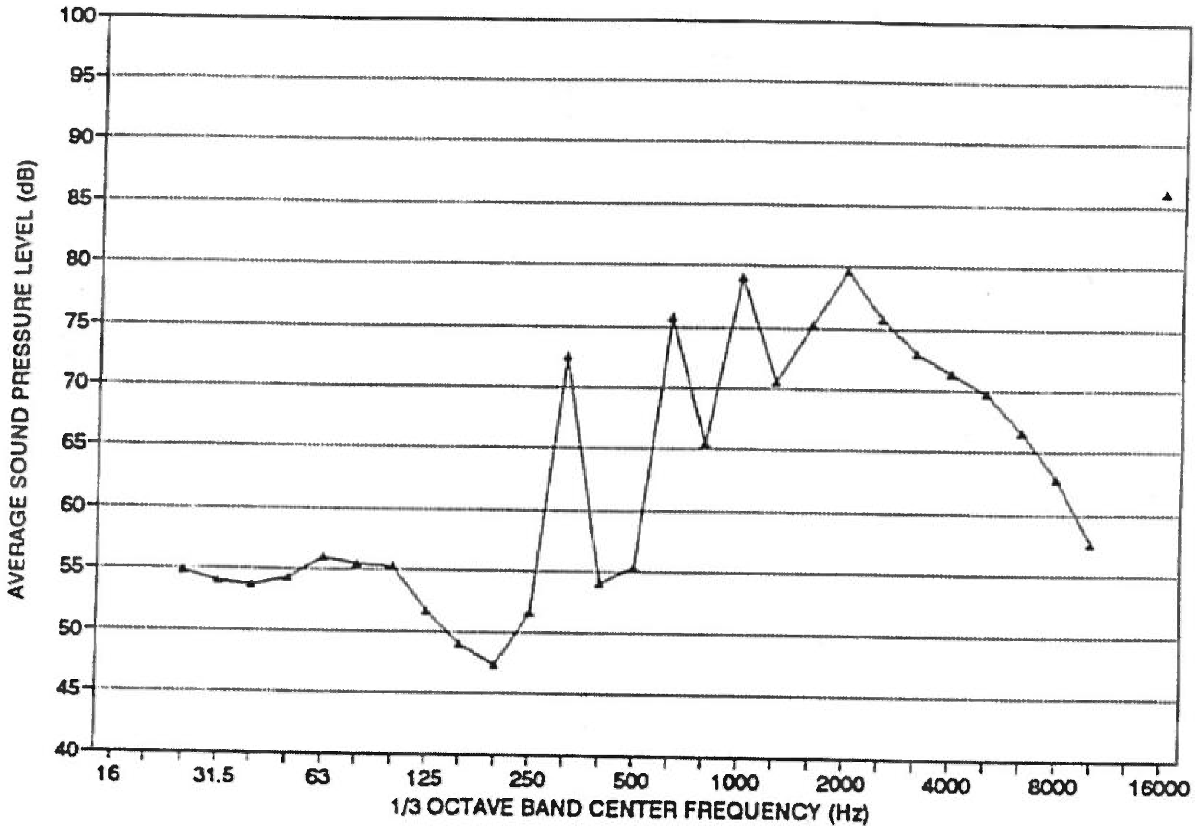


Figure 19. Automated Horn System Frequency Spectrum

fundamental frequency of the horn (330 Hz) and its associated harmonics (660 Hz, 990 Hz, etc.) are clearly visible.

The directivity pattern of the AHS is shown in Figure 20 (Note: the directivity characteristics are assumed to be symmetric around the centerline of the horn as represented by the dashed line). Due to measurement constraints, the sound level aft of the horn system was not measured. It is noted that the horn emits most of its energy in the forward direction (0° - 45°). The emission characteristic forward of the horn is 5-8 dB more efficient than at the side. The level at 61.0m is 3.3 dB lower than at 30.5m, corresponding to a drop-off rate of 3.3 dB for every doubling of distance.

A maximum A-weighted level of 87.0 dB was measured 30.5m forward of the horn. The FRA standard for audible warning devices does not apply in this situation. At this time, no FRA standard exists for the AHS type of warning device. Development of a standard must be based on the minimum stopping distance of motor vehicles and the sound pressure level required for the warning signal to be audible to a motorist.

6.4.2 Signaling Cycle

The equivalent sound level, maximum sound level, and duration of each component, arithmetically averaged over the three runs of the AHS signaling cycle, are shown in Table 4.

It is noted that the maximum sound level of the "short" component is approximately 2.0 dB lower than the "long" components. This is a result of the two second averaging time inherent to slow scale averaging. Figure 21 shows the spectral time history of the signaling cycle which visibly shows the stability of the signal over time of both the long and short components.

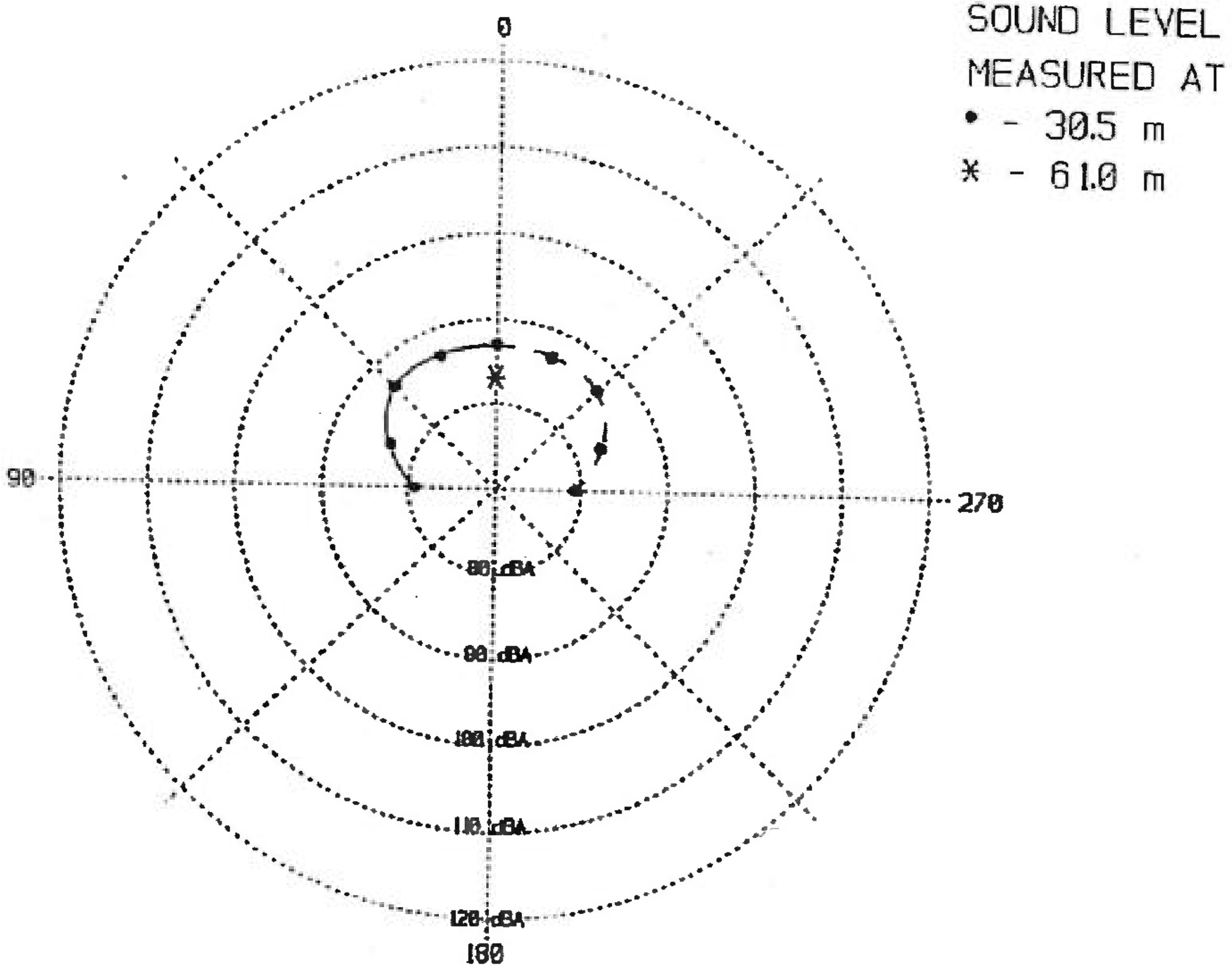


Figure 20. Automated Horn System Directivity
(Constant Distance Contour)

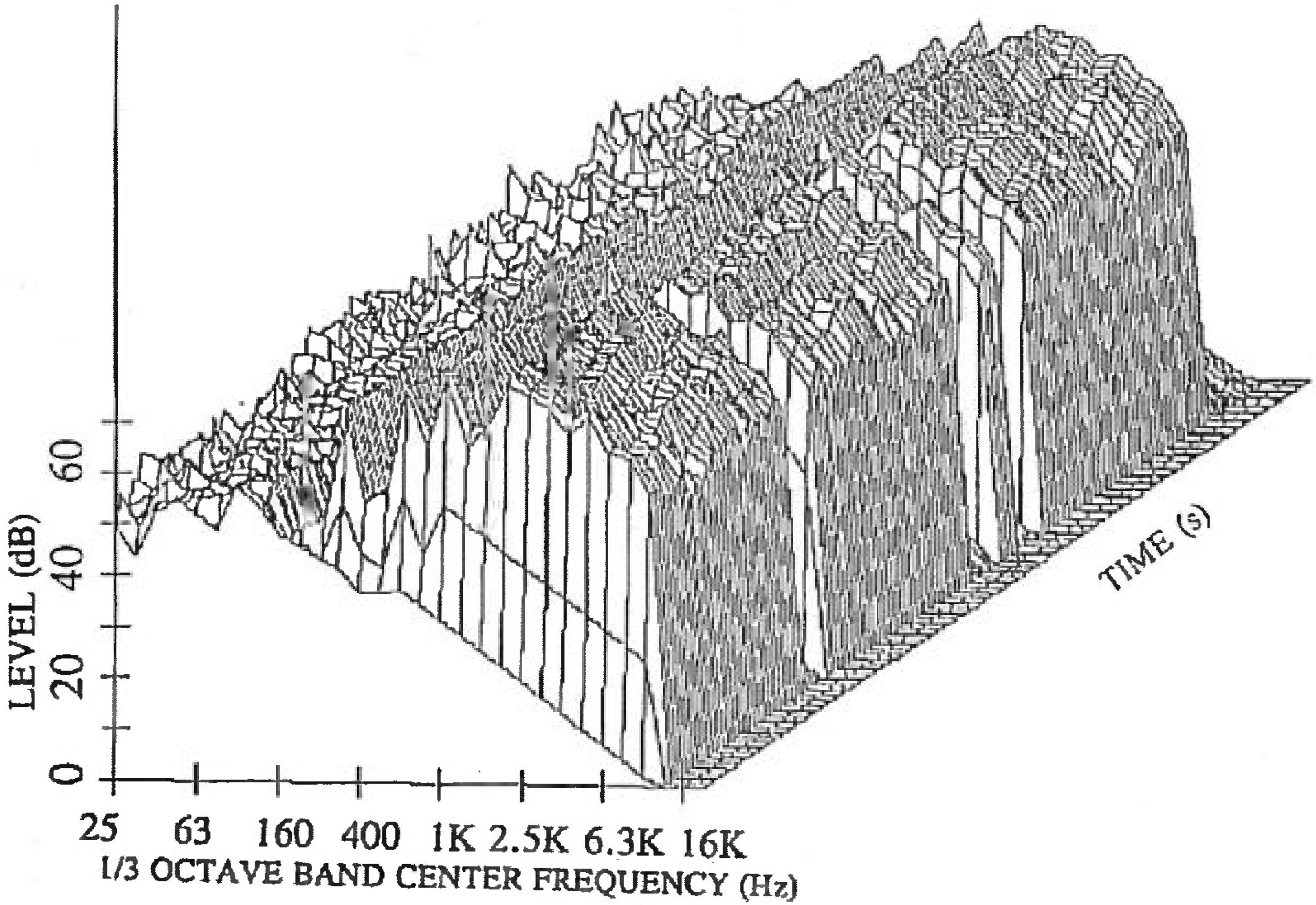


Figure 21. Automated Horn System
Spectral Time History, Signaling Cycle

Table 4 AUTOMATED HORN SYSTEM
Sound Level of Signaling Cycle by Component
Microphone Location: 0 degrees, 30.5m

COMPONENT	L_{Amax} (dB)	DURATION (sec)
1.) Long	86.9	5.19
2.) Long	86.8	5.25
3.) Short	85.0	1.29
4.) Long	86.9	6.17

7. DISCUSSION

The effectiveness of a railroad horn system is determined by its ability to be detected and recognized as the warning signal which is synonymous with the impending arrival of a train. The following sections discuss the ability of the horn systems selected for this study to meet this criteria.

7.1 FREQUENCY SPECTRA

An analysis of the frequency spectra of the conventional horn systems tested shows that differences occur between the three-chime and five-chime due to the number of chimes in each system. The five-chime creates a broadband signal which is more efficient at frequencies above 1000 Hz. A signal which has a wide frequency range will be more likely to overcome any existing background noise to which the receiver is exposed. Thus, the sound produced by the five-chime horn system is more likely to attract motorist attention than the three-chime horn system.

As noted in Section 6, the AHS produces one discrete tone and its associated harmonics, whereas the three-chime, five-chime and other conventional locomotive horn systems produce several tones and their harmonics which together create a broadband signal. This characteristic broadband signal is what alerts a listener that a "train" is approaching. A signal comprised of only one tone and its associated harmonics will require considerable public education before it will be recognized as the warning signal which is synonymous with the impending arrival of a locomotive.

The tonal signal produced by the AHS will result in a different comminuty noise response than conventional horn systems. "Laboratory studies and case-histories have shown that a noise containing a pure-tone component produces a greater subjective response than a noise having the same broad-band frequency distribution but without the pure-tone component."(10) Therefore, a tonal signal will be perceived by the community as more annoying than a broadband signal.

7.2 DIRECTIVITY

The directivity of conventional horn systems is greatly influenced by the placement of the horn system on the locomotive. This can be seen by the low forward efficiency of the horn system mounted in the center of the Dash-8 and the low rear efficiency of the horn system mounted on the front of the GP40. Extreme care should be taken when deciding where to mount the horn systems atop a locomotive; the line of sight from the horn system to the approaching motorist should not be interrupted in order for the horn system to have maximum effectiveness. An earlier measurement program to determine the optimum placement of the horn system stated that it should be placed "as high and as far front as reasonably practicable"(11). This study took into account the effectiveness of the horn system at the crossing as well as the loudness inside the locomotive cab.

The directivity characteristics of the AHS are an improvement over conventional horn systems because most of its energy is emitted forward of the horn and can be aimed according to individual situations. Because the AHS will be located at the crossing instead of on the moving locomotive, the effective warning distance could be improved with an increase in the sound pressure level it produces. In contrast to conventional practice, where the community impacted by the sound output from railroad horns extends from whistle post to whistle post, the AHS only impacts the portion of the community in the immediate vicinity of the crossing. Therefore, the community noise impact around a grade crossing will be minimized.

7.3 SIGNALING CYCLES

An analysis of signaling cycles shows that in some instances, the chimes do not reach their maximum sound output for up to one second after actuation. This causes the "short" component of the cycle to be noticeably quieter (up to 4 dB less) than the "long" components.
In order to be most effective, all components of the signaling cycle must reach their maximum sound output.

7.4 DROP-OFF RATE

A drop-off rate of 6 dB for a doubling of distance due to spherical spreading is typical for a point source such as a railroad horn system. However, a variation in this drop-off rate can be caused by the different ground surfaces and meteorological conditions which are encountered at each measurement site. A signal which propagates over acoustically soft ground surfaces (i.e., loose dirt, grass) can have a 1.5 dB increase in drop-off rate due to the absorptive nature of the ground. A tonal signal which propagates over acoustically hard ground surfaces (i.e., asphalt, water) can be affected by destructive interference due to the reflective nature of the ground surface. This destructive interference can cause up to a 3 dB reduction in drop-off rate. Conditions in which the wind is blowing can affect the sound by refracting the wave. When the wind is blowing from source to receiver, the waves can be refracted downward, causing a decrease in drop-off rate. When the wind is blowing from receiver to source, the waves can be refracted upward, causing an increase in drop-off rate. Temperature and relative humidity have a negligible effect on the drop-off rate when the distance from source to receiver is under 100m, unless a temperature inversion exists.

As stated in Sections 6.1.1, 6.2.1, 6.3.1, and 6.4.1, the measured drop-off rates for the four horn systems tested are: (1) 4.7 dB for the Leslie RSL-3L-RF; (2) 8.3 dB for the Leslie RS-3L; (3) 4.9 dB for the Nathan K-5-LA; and, (4) 3.3 dB for the Automated Horn System. The deviation in drop-off rates with soft ground effects from the expected 7.5 dB for the Leslie RSL-3L-RF and the Nathan K-5-LA may be attributed to wind conditions where the wind was blowing from source to receiver. The increase in drop-off rate with soft ground effects from the expected 7.5 dB for the Leslie RS-3L may be attributed to a temperature inversion, although no upper level temperature measurements were made for confirmation. The decrease in drop-off rate from the expected 6 dB for the Automated Horn System may be attributed to hard ground effects. Reflections from the hard ground surface may have caused destructive interference at the 30.5m microphone position.

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APPENDIX A

Sound Levels of Continuous Signal

Tables A-1 through A-4 contain the sound levels of the continuous signal at each measurement position. The following abbreviations are used:

L_{Amax} - Maximum A-weighted sound level - the maximum sound level observed during the period of the event.

L_{eq} - Equivalent A-weighted sound level - the energy average of the one-eighth second records which constitute the event.

TABLE A-1

LESLIE RSL-3L-RF

Microphone Location	L_{Amax} (dBA)*		L_{eq} (dBA)*	
	Average	Std Dev	Average	Std Dev
0.0° 30.5m	99.0	0.6	97.7	0.9
22.5° 30.5m	102.6	0.6	101.4	0.4
45.0° 30.5m	104.6	0.1	103.6	0.1
67.5° 30.5m	103.7	0.2	102.7	0.5
90.0° 30.5m	103.9	0.2	102.8	0.2
112.5° 30.5m	104.3	0.3	103.2	0.3
135.0° 30.5m	105.7	0.9	104.5	0.5
157.5° 30.5m	108.6	0.4	107.4	0.4
0.0° 61.0m	94.5	1.1	93.0	0.8
90.0° 61.0m	98.9	0.9	97.5	0.5

*Slow Scale Response

TABLE A-2

LESLIE RS-3L

Microphone Location	L_{Amax} (dBA)*		L_{eq} (dBA)*	
	Average	Std Dev	Average	Std Dev
0.0° 30.5m	101.0	0.3	100.3	0.1
22.5° 30.5m	96.8	0.2	96.0	0.1
45.0° 30.5m	97.5	0.1	96.8	0.1
67.5° 30.5m	97.0	0.2	96.3	0.2
90.0° 30.5m	99.3	0.3	98.6	0.2
112.5° 30.5m	97.1	0.2	96.3	0.2
135.0° 30.5m	88.5	0.5	87.6	0.4
157.5° 30.5m	90.9	0.4	89.8	0.4
180.0° 30.5m	88.2	0.1	86.3	0.8
0.0° 61.0m	92.9	0.5	92.0	0.4
90.0° 61.0m	89.5	0.3	88.6	0.2

*Slow Scale Response

TABLE A-3

NATHAN K-5-LA

Microphone Location	L_{Amax} (dBA)*		L_{eq} (dBA)*	
	Average	Std Dev	Average	Std Dev
0.0° 30.5m	115.9	0.4	114.2	0.2
45.0° 30.5m	117.1	0.3	116.0	0.1
90.0° 30.5m	110.7	0.3	109.5	0.3
0.0° 61.0m	111.6	0.3	109.1	0.2

*Slow Scale Response

TABLE A-4

AUTOMATED HORN SYSTEM

Microphone Location	L_{Amax} (dBA)*		L_{eq} (dBA)*	
	Average	Std Dev	Average	Std Dev
0.0° 30.5m	87.0	0.3	85.8	0.3
22.5° 30.5m	86.8	0.8	85.3	0.5
45.0° 30.5m	86.6	0.9	85.2	0.4
67.5° 30.5m	83.1	0.6	81.7	0.3
90.0° 30.5m	79.3	0.5	78.0	0.4
0.0° 61.0m	84.1	1.4	82.5	1.2

*Slow Scale Response

APPENDIX B

Sound Levels of Signaling Cycle Components

Tables B-1 through B-8 contain the sound levels measured during each component of the signaling cycle at the 0° and 90° measurement positions. The following abbreviations are used:

SEL - Sound Exposure Level - The integral of the A-weighted level over time with a reference duration of one second.

L_{Amax} - Maximum A-weighted sound level - the maximum level observed during each component of the signaling cycle.

Dur - Duration - The amount of time from the point when a level of 10 dB below the max. was first attained to the point when a level of 10 dB below max. was last attained.

TABLE B-1

LESLIE RSL-3L-RF

Microphone Location: 0°, 30.5m

	TOTAL		LONG		LONG		SHORT		LONG	
	SEL (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)
Avg	109.7	18.1	99.4	4.9	99.3	4.8	97.4	1.4	99.0	7.1
Std Dev	0.9	0.4	0.4	0.3	0.4	0.1	0.5	0.3	0.1	0.1

*Slow Scale Response

TABLE B-2

LESLIE RSL-3L-RF

Microphone Location: 90.0°, 30.5m

	TOTAL		LONG		LONG		SHORT		LONG	
	SEL (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)
Avg	114.3	18.1	103.4	4.9	103.4	4.3	100.5	1.3	103.6	7.1
Std Dev	0.2	0.7	0.3	0.3	0.4	0.1	0.5	0.3	0.3	0.1

*Slow Scale Response

TABLE B-3

LESLIE RS-3L

Microphone Location: 0°, 30.5m

	TOTAL		LONG		LONG		SHORT		LONG	
	SEL (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)
Avg	109.7	16.3	100.2	4.2	100.1	4.1	96.6	2.2	100.6	5.7
Std Dev	0.7	0.5	0.6	0.2	0.5	0.3	2.2	0.7	0.1	0.1

*Slow Scale Response

TABLE B-4

LESLIE RS-3L

Microphone Location: 90.0°, 30.5m

	TOTAL		LONG		LONG		SHORT		LONG	
	SEL (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)
Avg	108.5	16.2	98.6	4.0	98.7	4.3	96.4	2.3	98.8	5.7
Std Dev	0.6	0.9	0.1	0.2	0.6	0.3	1.1	0.5	0.3	0.3

*Slow Scale Response

TABLE B-5

NATHAN K-5-LA

Microphone Location: 0°, 30.5m

	TOTAL		LONG		LONG		SHORT		LONG	
	SEL (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)
Avg	124.6	21.0	114.6	5.0	115.4	6.0	111.9	2.8	115.1	5.9
Std Dev	0.2	1.2	0.7	0.1	0.8	0.1	0.6	0.1	0.7	0.3

*Slow Scale Response

TABLE B-6

NATHAN K-5-LA

Microphone Location: 90.0°, 30.5m

	TOTAL		LONG		LONG		SHORT		LONG	
	SEL (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)
Avg	119.9	21.0	109.6	5.7	109.3	5.9	106.1	2.8	108.6	6.6
Std Dev	0.4	1.4	0.7	0.7	0.4	0.2	1.6	0.1	0.9	0.4

*Slow Scale Response

TABLE B-7

AUTOMATED HORN SYSTEM

Microphone Location: 0°, 30.5m

	TOTAL		LONG		LONG		SHORT		LONG	
	SEL (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)
Avg	97.7	15.5	86.9	5.2	86.8	5.1	85.0	1.3	86.9	6.2
Std Dev	0.7	1.3	0.0	0.1	0.1	0.6	0.6	0.2	0.3	1.3

*Slow Scale Response

TABLE B-8

AUTOMATED HORN SYSTEM

Microphone Location: 90.0°, 30.5m

	TOTAL		LONG		LONG		SHORT		LONG	
	SEL (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)	L_{Amax} (dBA)*	Dur (sec)
Avg	90.8	21.2	79.0	6.0	79.1	5.8	77.1	1.7	78.7	7.6
Std Dev	0.2	0.6	0.3	0.1	0.7	0.3	0.7	0.1	0.4	0.6

*Slow Scale Response