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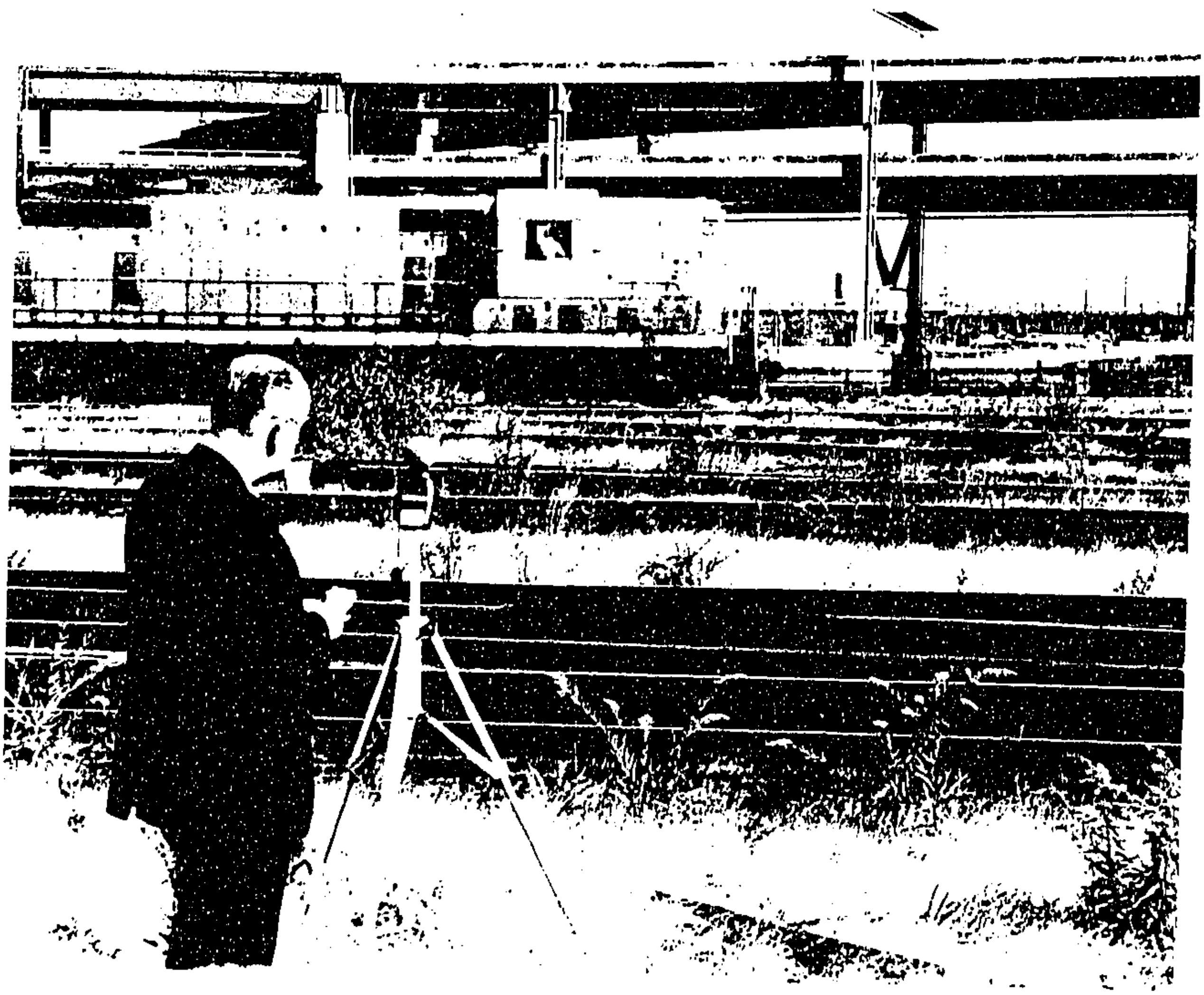
Handbook for Measuring Compliance With the Interstate Rail Carrier Noise Emission Standards



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HANDBOOK FOR MEASURING COMPLIANCE WITH THE INTERSTATE RAIL CARRIER NOISE EMISSION STANDARDS

Myles Simpson, David Conant, and Richard Burke

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Prepared for:

Environmental Protection Agency (ANR-490)
Office of Noise Abatement and Control
401 M Street, S.W.
Washington, DC 20460

FOREWORD

This handbook describes procedures for measuring compliance with EPA's Noise Emission Standards, which set limits on the noise of locomotives, switcher locomotives, rail cars, active retarders, car-coupling impacts, and locomotive load cell test stands.

The Federal Railroad Administration will be promulgating compliance regulations in the near future for enforcement of the EPA Emission Standards. This handbook specifically addresses noise measurement procedures and is directed towards compliance officers, railroad personnel, local residents, and others to permit an assessment of the noise emissions from a railyard.

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1. INTRODUCTION

1.1 Background

On 4 January 1980, the Environmental Protection Agency (EPA) published a final rule in the *Federal Register* (45FR1252) revising 40CFR Part 201, Noise Emission Standards for Transportation Equipment; Interstate Rail Carriers. This regulation incorporates the noise emission standards for locomotives and rail cars, originally promulgated on 31 December 1975 (41FR2184), as well as noise emission standards for four specific noise sources occurring within railyards: active retarders, car-coupling impacts, switcher locomotives, and locomotive load cell test stands. This particular rule, which sets standards for source noise emissions, is considered the first of two parts. The second part, the property line noise standard, is scheduled for promulgation in January 1981.

The purpose of this handbook is to provide guidelines and step-by-step procedures for measuring compliance with these specific standards. This handbook is directed at compliance officers, railroad personnel, local residents, and other concerned individuals interested in assessing whether or not the noise emissions from a particular railyard facility exceed the regulatory levels. In recognition of the varied backgrounds of potential users, the handbook has been written to permit persons without much experience in noise measurements to follow the various procedures for determining compliance with the regulation.

1.2 Overview of Standards

The Interstate Rail Carrier Noise Emission Standards apply to stationary and moving locomotives, switcher locomotives, moving rail cars, retarders, car-coupling operations, and locomotive load cell test stands. Table 1 summarizes the standards for these noise sources. As can be seen from the table, the standards can be separated into those that apply at 30 m (100 ft) from the particular noise source, and those that apply on receiving property.

Three measurement procedures are included in the regulation as follows:

1. Measurement at a 30 m (100 ft) distance of the noise from locomotive and rail car operations and locomotive load cell test stands;
2. Measurement on receiving property of retarder and car-coupling noise;
3. Measurement on receiving property of locomotive load cell test stand and switcher locomotive noise.

The three procedures are necessary because different noise measures are associated with the various standards. For measurements at 30 m (100 ft), the maximum sound level (L_{max}) is determined and compared with the standard. For retarder and car-coupling operations, the adjusted average maximum sound level ($L_{adj\ ave\ max}$)* is measured on receiving property and compared with the standard. Finally, for locomotive load cell test stands and switcher locomotives, the statistical sound level exceeded 90% of the time (L_{90}) is measured on receiving property and compared with the standard.

*The adjusted average maximum sound level is the energy average of the measured maximum sound levels, adjusted to one measurement per minute.

TABLE 1. SUMMARY OF NOISE STANDARDS, 40 CFR PART 201.

Paragraph and Section	Noise Source	Noise Standard — A-Weighted Sound Level in dB	Noise Measure*	Measurement Location
	All Locomotives Manufactured on or Before 31 December 1979†			
201.11(a)	Stationary, Idle Throttle Setting	73	L_{max} (slow)	30 m (100 ft)
201.11(a)	Stationary, All Other Throttle Settings	93	L_{max} (slow)	30 m (100 ft)
201.12 (a)	Moving	96	L_{max} (fast)	30 m (100 ft)
	All Locomotives Manufactured After 31 December 1979†			
201.11(b)	Stationary, Idle Throttle Setting	70	L_{max} (slow)	30 m (100 ft)
201.11(b)	Stationary, All Other Throttle Settings	87	L_{max} (slow)	30 m (100 ft)
201.12(b)	Moving	90	L_{max} (fast)	30 m (100 ft)
201.11(c) and 201.12(c)	*Additional Requirement for Switcher Locomotives Manufactured on or Before 31 December 1979 Operating in Yards Where Stationary Switcher and other Locomotive Noise Exceeds the Receiving Property Limit of*	65	L_{90} (fast)**	Receiving Property
201.11(c)	Stationary, Idle Throttle Setting	70	L_{max} (slow)	30 m (100 ft)
201.11(c)	Stationary, All Other Throttle Settings	87	L_{max} (slow)	30 m (100 ft)
201.12(c)	Moving	90	L_{max} (fast)	30 m (100 ft)
	Rail Cars†			
201.13	Moving at Speeds of 45 mph or Less	88	L_{max} (fast)	30 m (100 ft)
201.13	Moving at Speeds Greater than 45 mph	93	L_{max} (fast)	30 m (100 ft)
	Other Yard Equipment and Facilities			
201.14	Retarders	83	$L_{adj\ ave\ max}$ (fast)	Receiving Property
201.15	Car-Coupling Operations	92	$L_{adj\ ave\ max}$ (fast)	Receiving Property
201.16	*Locomotive Load Cell Test Stands, Where the Noise from Locomotive Load Cell Operations Exceeds the Receiving Property Limits of*	65	L_{90} (fast)	Receiving Property
201.16(a)	Primary Standard	78	L_{max} (slow)	30 m (100 ft)
201.16(b)	Secondary Standard if 30-m Measurement Not Feasible	65	L_{90} (fast)	Receiving Property Located more than 120 m from Load Cell

*L_{max} = Maximum sound level; L_{90} = Statistical sound level exceeded 90% of the time; $L_{adj\ ave\ max}$ = Adjusted average maximum sound level.
†These sources were regulated in the original (31 December 1975) regulation.
**Specification of "fast" reflects a correction to the regulation. See footnote, p. 4.

Noise levels are measured with either "fast" or "slow" meter response on the sound level meter, as shown on Table 1. Slow response is used for all 30 m (100 ft) measurements of stationary sources (all stationary locomotives and locomotive load cell test stands). For all 30 m (100 ft) measurements of moving sources (all locomotives and rail cars), and all measurements made on receiving property, fast response is used.*

Table 1 shows that the standard for each noise source applies either at 30 m (100 ft) or on receiving property, except for locomotive load cell test stands and switcher locomotives, which have values listed for both the 30 m (100 ft) distance and receiving property. For these two noise sources, the receiving property measurement is used as a trigger; i.e., measurements are obtained on receiving property, and only if the receiving property limit is exceeded are compliance measurements obtained at the 30 m (100 ft) distance and compared to the standard. The regulation also permits measurement of the noise from locomotive load cell test stands on receiving property more than 120 m (400 ft) from the test stand, if site conditions at 30 m (100 ft) from the test stand do not permit compliance measurements to be obtained at that distance.

1.3 Organization of Handbook

The next section briefly highlights the major sources of sound found in and around a railroad yard. Section 3 provides detailed procedures for conducting compliance measurements for

*This discussion concerning the use of fast and slow response, as well as the procedures throughout this handbook, reflect the requirements of the regulation as modified by a Technical Amendment scheduled for promulgation in January 1981. This amendment is designed to correct certain typographical errors in the published regulation, dealing with selection of fast vs slow response.

each of the standards included in the regulation. Included in this section are step-by-step techniques, as well as several examples illustrating the procedures. Section 4 provides additional examples and practical measurement hints.

Blank copies of the various log sheets and work sheets are provided in Appendix A. As an aid to the user of this handbook who may be unfamiliar with conducting noise measurements, Appendix B provides a brief background discussion of the basics of sound, followed in Appendix C by a discussion of the use of sound level meters.

2. RAILROAD SOUND SOURCES

The sounds that are observed in the vicinity of a railroad yard are extremely varied in terms of their amplitude, frequency, and time characteristics. Since the different measurement procedures incorporated within the noise emission regulation were developed to handle the varied time characteristics of the different rail sources covered by the regulations, these sources will be categorized in this section by their time characteristics.

In broad terms, the sounds from a railyard can be classified into those that do not change appreciably with time (steady-state sounds), and those that do change with time (time-varying sounds). In real-world situations, completely steady-state sounds rarely exist; even if the sound energy output of a mechanical device was constant with time, propagation path effects would cause the signal received at the microphone to vary with time. Thus, several of the rail sources will fall within a classification of "nearly" steady state.

Time-varying sources range from sources whose noise levels vary quite slowly with time to those that vary abruptly with time.

2.1 Nearly Steady-State Railroad Sources

Included in this category are stationary devices with fairly constant sound energy output, such as stationary locomotives, stationary switcher locomotives, and locomotive load cell test stands. Figure 1 shows several time-history tracings for such sources. The primary noise source is the diesel engine, which generates sound over a fairly wide range of frequencies. The particular noise level observed depends primarily upon the throttle setting at which the locomotive is being operated.

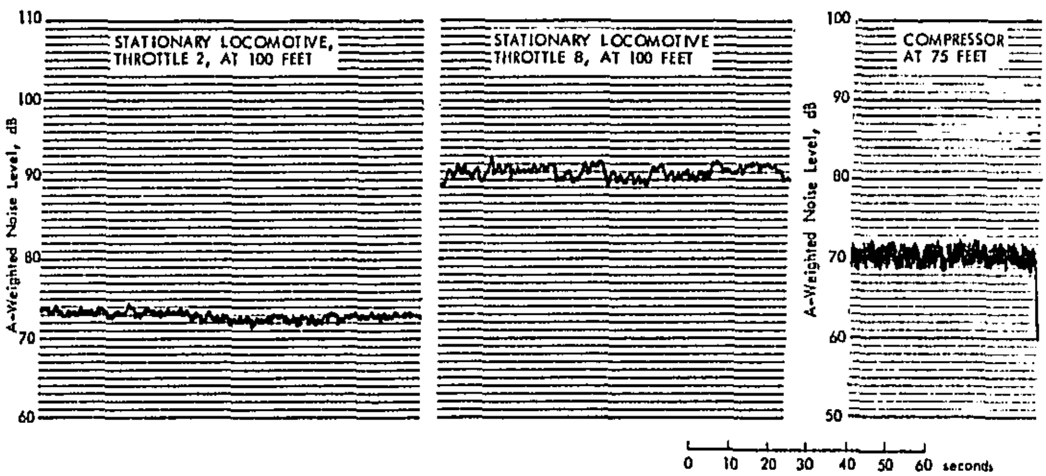


FIG. 1. NEARLY STEADY-STATE TIME HISTORY PATTERN OF STATIONARY RAIL SOURCES.

2.2 Time-Varying Railroad Sources

Time-varying sources whose noise levels change fairly slowly with time include moving locomotives, moving switcher locomotives, and moving rail cars. For these sources, noise levels increase as the moving vehicles approach the observer, reach a maximum at the closest point of approach, and then decrease as the vehicles pass by. For moving locomotives and moving switcher locomotives, the primary source of noise is again the diesel engine, while for moving rail cars, the major noise source is the wheel/rail interface. Figure 2 illustrates the time-history pattern of these sources.

Time-varying sources whose noise levels change rather abruptly include retarders and car-coupling operations. For both of these sources, A-weighted noise levels may increase dramatically (20 to 30 dB) in a fraction of a second above the previous background level. The noise levels from retarders, generated as the wheels of the rail cars are clamped by the retarders, are perceived as high-pitched squeals. Most of the sound energy in retarder squeals are concentrated in the 2,000 to 4,000 Hz region.

As cars couple, the resulting impacts generate high-level, short-duration noises over the entire audible frequency range, but with much energy in the low-frequency portion of the spectrum. Figure 3 and 4 contain sample time-history traces for retarder squeals and car-coupling impacts, respectively.

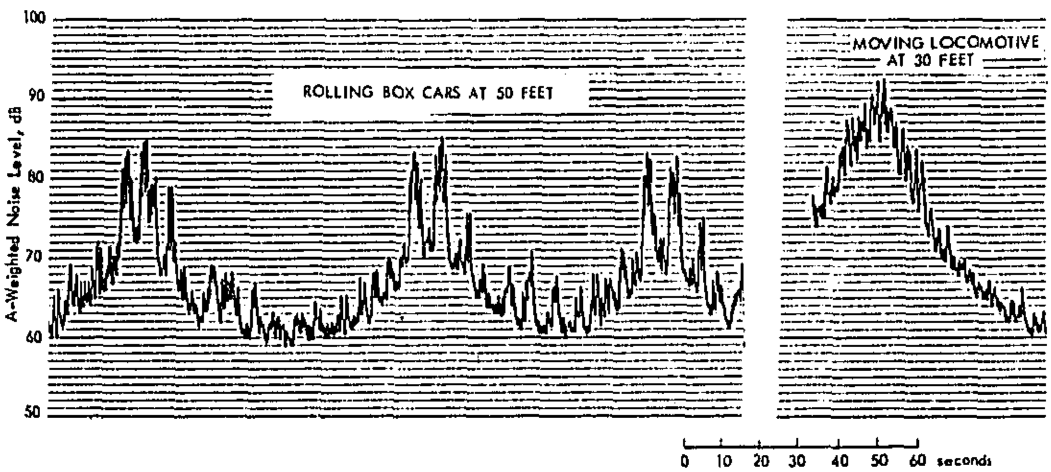


FIG. 2. TIME-VARYING TIME HISTORY PATTERN OF MOVING RAIL SOURCES.

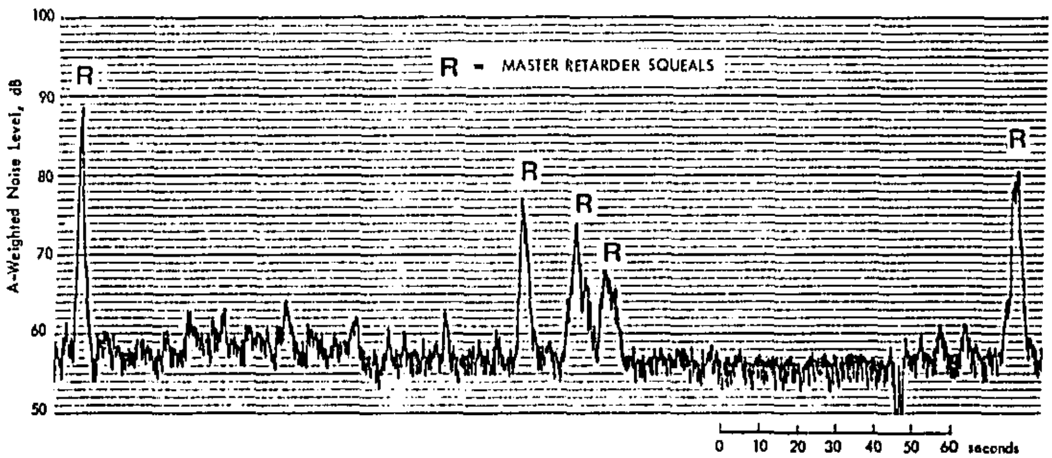


FIG. 3. TIME-VARYING TIME HISTORY PATTERN FOR RETARDERS.

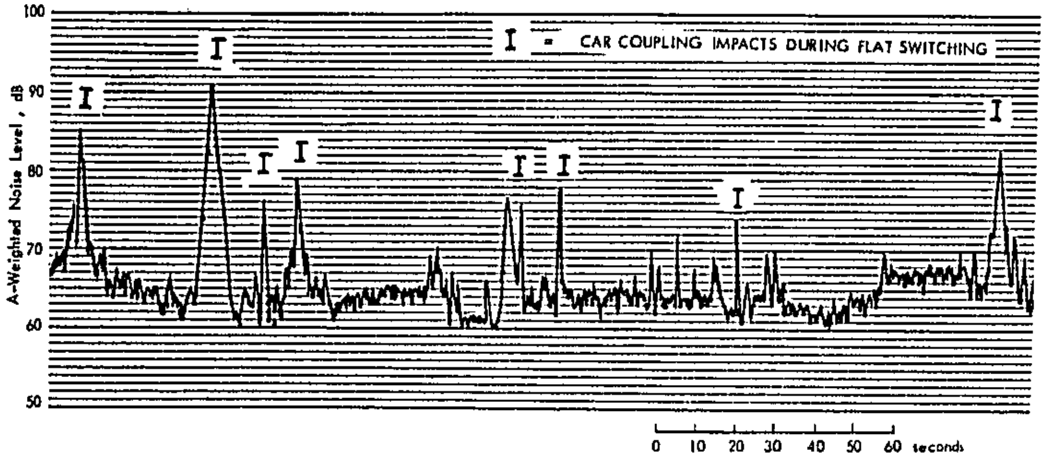


FIG. 4. TIME-VARYING TIME HISTORY PATTERN FOR CAR-COUPLING IMPACTS.

3. PROCEDURES FOR COMPLIANCE MEASUREMENTS

3.1 Selection of Measurement Sites and Times

3.1.1 Where to measure

Compliance measurements are obtained either at a 30 m (100 ft) distance from specific railroad sources or on receiving property. The noise of stationary locomotives, moving locomotives, and moving rail cars is measured at 30 m (100 ft), while the noise of retarders and car-coupling operations is measured on receiving property.

The noise of stationary switcher locomotives and locomotive load cell test stands is initially measured on receiving property; if the noise emission limits for these sources are exceeded, measurements are then obtained for compliance determination at 30 m (100 ft) from stationary switchers, moving switchers, and locomotive load cell test stands. Thus, the property line measurements of the noise of stationary switcher locomotives and locomotive load cell test stands serve as a "trigger" mechanism. Noise measurements on railroad property of these sources need not be obtained if the receiving property noise levels are below the limits in the regulation. However, if the receiving property noise levels are in excess of the limits, compliance with the standards must be judged by measuring the noise levels at the 30 m (100 ft) distance.

Further, for locomotive load cell test stands, in the event that the site conditions at 30 m (100 ft) from the test stand do not permit measurements to be obtained, compliance with the locomotive load cell test stand noise standards is judged by obtaining noise measurements on receiving property more than 120 m (400 ft) from the test stands. The various measurement site location requirements for the individual railroad sources are summarized in Table 2.

TABLE 2. SUMMARY OF MEASUREMENT LOCATION REQUIREMENTS.

Source	Measurement Location
Stationary Locomotives Moving Locomotives Moving Rail Cars	30 m (100 ft)
Retarders Car Coupling Operations	Receiving Property
Stationary Switcher Locomotives Locomotive Load Cell Test Stands	Receiving Property If Limit is Exceeded ↓
Stationary Switcher Locomotives Moving Switcher Locomotives Locomotive Load Cell Test Stands	30 m (100 ft) If Test Stand Measurement Site is Unacceptable ↓
Locomotive Load Cell Test Stands	>120 m (400 ft) on Receiving Property

With regard to measurement at the 30 m (100 ft) distance, Fig. 5 illustrates the measurement location relative to the specific noise source being measured. Criteria with regard to site conditions at the 30 m (100 ft) measurement location are discussed in Sec. 3.3.1.

For measurements on receiving property, specific measurement locations should be selected on the basis of some understanding of the types of activities conducted at the railyard, the location within the yard of specific noise sources and activities, and the presence of other noise sources that might interfere with the measurements. Quite often, discussion with local residents will provide insight into areas in the vicinity of the yard at which the noise of specific sources is likely to be observed. Selection of specific measurement locations is not, therefore, a haphazard, random, or necessarily speedy process. The individual interested in obtaining compliance measurements should plan to spend anywhere from several hours to perhaps a full day observing railyard operations, pinpointing on a map the location of specific sources and activities, and simply listening to the noise environment at a number of locations around the yard. Armed with some knowledge of the yard's activities and the information gained from discussion with local residents and surveillance of the yard itself, the reader can select receiving property measurement locations appropriate for measurement of the sources under consideration (i.e., where the highest noise levels could be expected from these sources).

The regulation defines "receiving property" as "any residential or commercial property that receives the sound from railroad facility operations,... ." Residential and commercial property are defined in the regulation according to various standard land use codes. The portion of Sec. 201.1 that provides specific details of these definitions is reproduced below.

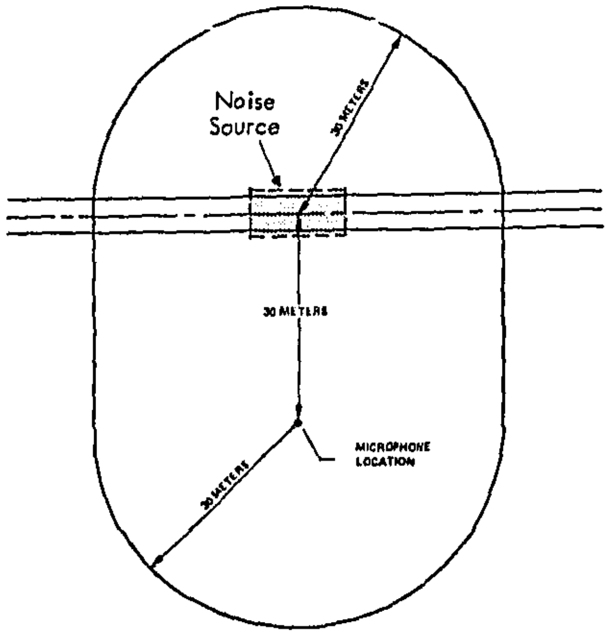


FIG. 5. MEASUREMENT SITE LOCATION AND TEST SITE CLEARANCE REQUIREMENTS FOR 30 m (100 ft) MEASUREMENTS.

(v) "Commercial Property" means any property that is normally accessible to the public and that is used for any of the purposes described in the following standard land use codes (reference *Standard Land Use Coding Manual*. U.S. DOT/FHWA, reprinted March 1977): 53–59, Retail Trade; 61–64, Finance, Insurance, Real Estate, Personal, Business and Repair Services; 652–659, Legal and other professional services; 671, 672, and 673 Governmental Services; 692 and 699, Welfare, Charitable and Other Miscellaneous Services; 712 and 719, Nature exhibitions and other Cultural Activities; 721, 723, and 729, Entertainment, Public and other Public Assembly; and 74–79, Recreational, Resort, Park and other Cultural Activities.

(w) "Receiving Property" means any residential or commercial property that receives the sound from railroad facility operations, but that is not owned or operated by a railroad; except that occupied residences located on property owned or controlled by the railroad are included in the definition of "receiving property." For purposes of this definition railroad crew sleeping quarters located on property owned or controlled by the railroad are not considered as residences. If, subsequent to the publication date of these regulations, the use of any property that is currently not applicable to this regulation changes, and it is newly classified as either residential or commercial, it is not receiving property until four years have elapsed from the date of the actual change in use.

(x) "Residential Property" means any property that is used for any of the purposes described in the following standard land use codes (ref. *Standard Land Use Coding Manual*. U.S. DOT/FHWA Washington, D.C., reprinted March,1977): 1, Residential; 651, Medical and other Health Services; 68, Educational Services; 691, Religious Activities; and 711, Cultural Activities.

3.1.2 When to measure

Anytime. The regulation places no restriction on the hours during which measurements may be obtained. Since at many railyards activities occur on a 24-hr basis, measurements may be obtained at any time of the day or night and on any day of the week or weekend.

3.1.3 Interfering noises

For both 30 m (100 ft) and receiving property measurements, the reader must always be aware of the noise of other sources which could adversely affect the compliance determination. At 30 m (100 ft), other railyard equipment may interfere with the desired measurements; on receiving property, interfering sources might include traffic, aircraft, garden equipment, or TV/radio/hi-fi equipment. When interfering sources are intermittent (such as occasional aircraft), it may be possible to conduct compliance measurements between the extraneous noises.

Both the 30 m (100 ft) measurement procedure and the procedure for measuring retarder and car-coupling sounds specify that background noise levels be at least 10 dB below the railyard source level being measured. The procedure for measuring the noise of stationary switcher locomotives and locomotive load cell test stands involves measurement of the total noise environment and then testing to ensure that a nearly steady state environment has been measured. These requirements on the background noise at a measurement position emphasize the importance of careful selection of location and time of compliance measurement, based on knowledge of yard sources and activity and site characteristics.

3.2 General Documentation Requirements

Explicit requirements for documentation for standards other than the locomotive and rail car standards will be defined in the forthcoming compliance regulations to be promulgated by the Federal Railroad Administration (FRA). The FRA promulgated compliance regulations for locomotives and rail cars on 23 August 1977 (42 FR 42343). Guidelines for the type of information that should be collected and documented are provided in the following:

1. General Information. This includes the date, time, and location of the measurements, as well as the name of the individual conducting the measurements.

2. Noise Source Identification. Identify the specific rail noise source being measured (including serial number), as well as other noise sources (rail or nonrail) that may be observed at the measurement site during the measurements.

3. Site Conditions. Describe the ground cover, presence of buildings or other obstacles in the vicinity of the measurement microphone, and obstacles that shield the noise source from view, etc. A photograph of the site and the noise source being measured, as taken from the measurement location, would also be helpful.

4. Map of Area. The map should show the location of the various noise sources contributing to the noise environment, the location of the measurement microphone, and other site characteristics that would be useful to document.

5. Measurement Equipment. List the type and serial number of all the noise measurement equipment utilized.

6. Calibration Information. Document the calibration level of the noise instrumentation at the beginning and conclusion of the measurements. If the measurements occur over an extended period of time, several calibrations should be performed and documented.

7. Weather Conditions. Measure and document the temperature, relative humidity, wind conditions, and sky conditions (sunny, hazy, cloudy, etc.) at frequent intervals during the measurements.

3.3 Source Measurements at 30 m (100 ft) Distance

The information described in this section applies to measurement of the noise levels due to stationary locomotives, moving locomotives, and moving rail cars. This information also applies to the measurement of the noise levels due to stationary switcher locomotives, moving switcher locomotives, and locomotive load cell test stands, if measurement of the noise of stationary switcher locomotives and/or locomotive load cell test stands on receiving property exceed the receiving property source standards for these sources.

3.3.1 Criteria for site conditions, weather conditions, and background noise

These criteria are designed to ensure that the noise levels measured by the measurement microphone are not unduly influenced by the conditions at the site itself, effects due to weather, or the noise of other sources in the vicinity of the microphone. Reproduced below from Sec. 201.23 are the specific criteria governing measurements at the 30 m (100 ft) distance.

§ 201.23 Test Site, weather conditions and background noise criteria for measurement at a 30 meter (100 feet) distance of the noise from locomotive and rail car operations and locomotive load cell test stands.

(a) The standard test site shall be such that the locomotive or train radiates sound into a free field over the ground plane. This condition may be considered fulfilled if the test site consists of an open space free of large, sound reflecting objects, such as barriers, hills, signboards, parked vehicles, locomotives or rail cars on adjacent tracks, bridges or buildings within the boundaries described by Figure 1, as well as conforms to the other requirements of this § 201.23.

(b) Within the complete test site, the top of at least one rail upon which the locomotive or train is located shall be visible (line of sight) from a position 1.2 meters (4 feet) above the ground at the microphone location, except as provided in paragraph (c) of this section.

(c) Ground cover such as vegetation, fenceposts, small trees, telephone poles, etc., shall be limited within the area in the test site between the vehicle under test and the measuring microphone such that 80 percent of the top of at least one rail along the entire test section of track be visible from a position 1.2 meters (4 feet) above the ground at the microphone location; except that no single obstruction shall account for more than 5 percent of the total allowable obstruction.

(d) The ground elevation at the microphone location shall be within plus 1.5 meters (5 feet) or minus 3.0 meters (10 feet) of the elevation of the top of the rail at the location in-line with the microphone.

(e) Within the test site, the track shall exhibit less than a 2 degree curve or a radius of curvature greater than 873 meters (2,865 feet). This paragraph shall not apply during a stationary test. The track shall be tie and ballast, free of special track work and bridges or trestles.

(f) Measurements shall not be made during precipitation.

(g) The maximum A-weighted fast response sound level observed at the test site immediately before and after the test shall be at least 10 dB(A) below the level measured during the test. For the locomotive and rail car pass-by tests this requirement applies before and after the train containing the rolling stock to be tested has passed. This background sound level measurement shall include the contribution from the operation of the load cell, if any, including load cell contribution during test.

(h) Noise measurements may only be made if the measured wind velocity is 19.3 km/hr (12 mph) or less. Gust wind measurements of up to 33.2 km/hr (20 mph) are allowed.

Paragraphs (a), (b), (c), and (d) define site conditions to minimize the possibility of undue reflection, absorption, and/or shielding occurring within the test site that could affect the measurement at the microphone. Paragraph (e), which limits the radius of curvature of the track and the track construction, is included to eliminate the possibility that the noise level generated by moving locomotives or rail cars is influenced by the track itself. Paragraphs (f) and (h) put restrictions on the weather conditions during which measurements may be made. Again, this is to ensure the integrity of the measured noise levels.

Paragraph (g) requires that the sound level observed at the test site before and after the tests be at least 10 dB below the level measured during the test. As described in Appendix B of this handbook, if the background noise levels are within 10 dB of the levels measured during the test, the measured levels would include the contribution of the background noise. This requirement is included to ensure that the noise levels measured are due solely to the railroad noise source being tested for compliance.

3.3.2 Measurement procedures

The procedures listed in the following section are applicable to the measurement at 30 m (100 ft) of the noise of moving and stationary locomotives and switcher locomotives, moving rail cars, and locomotive load cell test stands. The procedures are generalized to include all of the sources, with comments concerning specific procedures for specific sources included as appropriate.

Step 1. Select Measurement Location. For moving locomotives, switcher locomotives, and rail cars, the measurement location selected is on a line perpendicular to the track, at a point 30 m (100 ft) from the track centerline (see Fig. 5). For stationary locomotives, stationary switcher locomotives, and locomotive load cell test stands, the microphone location must, in addition, be at the longitudinal midpoint of the locomotive. Survey the site to determine compliance with the site criteria discussed previously. Observe weather conditions to determine whether the weather criteria are also met. Identify the presence of other sources that might interfere with the desired compliance measurements. Make an initial assessment of whether the background noise is sufficiently low to permit the compliance measurements (by spot-checking on a sound level meter, or by simply listening to the noise environment at the site in the absence of the source under consideration). For measurement of the noise of moving locomotives, moving switcher locomotives, and moving railcars, observe the track condition to ensure that the track is reasonably well maintained.

Step 2. Set Up Measurement Equipment. Assemble the instrumentation in accordance with the manufacturer's recommendations and instructions. Position the microphone 1.2 m (4 ft) above the ground. Check all connections, and test the power supplies of all equipment that is battery operated.

Step 3. Calibrate Instrumentation. Following the manufacturer's instructions, use a calibrator of known acoustic output to calibrate the measurement system. Note on the log sheet the time and level of calibration.

Step 4. Measure Noise Levels. Using the A-weighting scale and the fast meter response, measure the maximum sound level occurring immediately before the test, and tabulate on the log sheet. During the test, do not stand between the microphone and the source under test. Either Type 1 or Type 2 sound level meter may be used (Type 1 is preferred, however).

4.a Stationary locomotives, stationary switcher locomotives, and locomotive load cell test stands. Using the A-weighting scale and the slow meter response, observe the sound level meter for 30 sec after the test throttle settings are established. Tabulate the maximum sound level observed during that period on the log sheets. During these tests, all cooling fans are to be operating.

4.b Moving rail cars. Using the A-weighting scale and fast meter response, observe the sound level meter as the train passes by. After the locomotives have passed a distance of 152.4 m (500 ft) or 10 rail cars beyond the measurement microphone, and no other locomotives are located within the same distance of the measurement point, the maximum sound level that occurs during the rail car passby shall be noted on the log sheets. The noise levels are not to be recorded if brake or wheel squeal is present; if this occurs, the measurements should be repeated.

4.c Moving locomotives and switcher locomotives. Using the A-weighting scale and the fast meter response, observe the sound level as the locomotive approaches and passes the microphone location. The maximum noise level observed shall be noted on the log sheet.

Using the A-weighting scale and the fast meter response, measure the sound level immediately after the test and verify that the before and after background sound levels are at least 10 dB below the levels measured during the test.

Step 5. Calibrate Instrumentation. After the test, calibrate the instrumentation in the same manner as performed in step 3 above. If the meter indicates a significantly different reading than the initial calibration (greater than ± 1 dB), a malfunction in instrumentation may have occurred (particularly if the time between initial and final calibrations is within 1 to 2 hr). Determine the cause of the malfunction, and repeat the measurements if necessary.

Step 6. Disassemble Equipment.

Step 7. Maintain Documentation. During steps 1 through 6 above, document essential items wherever possible.

A suggested log sheet is provided in Fig. 6 with space available to document several of the items discussed in Sec. 3.2 above. Figure 7 is an example of a sample log sheet filled out for the measurement of a moving locomotive.

3.4 Source Measurements on Receiving Property

The procedures in this section are applicable to measurements of the noise of retarders and car-coupling operations for compliance determination, measurements of the noise of stationary switcher locomotives and locomotive load cell test stands prior to conducting compliance measurements at 30 m (100 ft) from the sources, and measurement of the noise of locomotive load cell test stands on receiving property more than 120 m (400 ft) from the stand when 30 m (100 ft) measurements are not possible.

1. Enter the position (address or position number), your name, the day and date, and the type and serial number of the measurement instrumentation on the Log Sheet.
2. Enter the calibration level at the start of the measurements, and the time at which the measurement period begins.
3. For each measurement, enter the time of measurement, an event number, and the source type and serial number of each source being measured.
4. Measure the maximum A-weighted sound level (fast for moving sources, slow for stationary sources).
5. Enter the measured sound level and whether fast or slow meter dynamics were utilized.
6. At the conclusion of the measurements enter the end time, and the calibration level.
7. Enter météorological data on the Log Sheet, and draw a simple sketch of the measurement site including microphone location, location of noise source(s) measured, etc.

FIG. 6a. INSTRUCTIONS FOR USE OF "LOG SHEET FOR SOURCE NOISE MEASUREMENTS AT 30 m (100 ft)."

POSITION________ ENGR________ TIME: BEGIN ______ END________

DAY________ DATE________ CAL: BEGIN ______ END________

MIC: TYPE______ SN________ DRY BULB______ WET BULB______

SLM: TYPE______ SN________ REL.HUMD.______ SKY________

CALIB: TYPE______ SN________ WIND SPEED______ DIRECTION______

NOTES AND SKETCH: WEATHER CONDITIONS MET: Yes[ ] No[ ]

MICROPHONE POSITION MET: Yes[ ] No[ ]

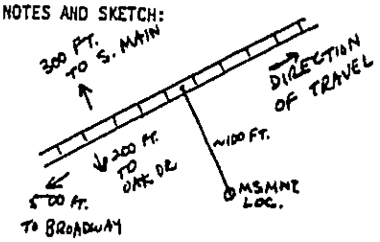
Time	Event No.	Source	Serial No.	L_{Max}	Fast/ Slow	COMMENTS

FIG. 6b. LOG SHEET FOR SOURCE NOISE MEASUREMENTS AT 30 m (100 ft).

LOG SHEET FOR SOURCE NOISE
MEASUREMENTS AT 30 METERS (100 ft)

POSITION A ENGR M. SMITH TIME: BEGIN 0800 END 1130
DAY FRI DATE 2 APR 80 CAL: BEGIN 114.0 END 114.4
MIC: TYPE 2011 SN 123456 DRY BULB 50° WET BULB 40°
SLM: TYPE 4120 SN 654321 REL. HUMD. ______ SKY OVERCAST
CALIB: TYPE 6200 SN 246810 WIND SPEED 5 DIRECTION S

NOTES AND SKETCH:



WEATHER CONDITIONS MET: Yes[✓] No[ ]
MICROPHONE POSITION MET: Yes[✓] No[ ]
CAL AT 1000 – 114.2 dB

Time	Event No.	Source	Serial No.	L_{Max}	Fast/ Slow	COMMENTS
0800	–	BACKGROUND		63 dBA	F	QUIET AT THIS SITE; OCCASIONAL
						VEHICLES IN DISTANCE
0820	1	2 LOCOS	4139 + 5323	83	F	SPEED ~ 20 MPH
1000	2	MOVING TRAIN	LOCO'S – 8878 + 9999	86	F	~50 RAIL CARS, @ ~82 dBA
1130	3	MOVING TRAIN	LOCO'S – 1239 + [illegible]	88	F	~50 RAIL CARS, @ ~86 dBA
1145	–	BACKGROUND		61	F	STILL QUIET; NOISE LEVELS
						TYPICALLY 50-55 ALL MORNING

FIG. 7. EXAMPLE OF USE OF LOG SHEET.

3.4.1 Criteria for site conditions and weather conditions

Site conditions and weather conditions allowable during receiving property measurements are defined in Sec. 201.25 and reproduced below.

§ 201.25 Measurement location and weather conditions for measurement on receiving property of the noise of retarders, car coupling, locomotive load cell test stands, and stationary locomotives.

(a) Measurements must be conducted only at receiving property measurement locations.

(b) Measurement locations on receiving property must be selected such that no substantially vertical plane surface, other than a residential or commercial unit wall or facility boundary noise barrier, that exceeds 1.2 meters (4 feet) in height is located within 10 meters (33.3 feet) of the microphone and that no exterior wall of a residential or commercial structure is located within 2.0 meters (6.6 feet) of the microphone. If the residential structure is a farm home, measurements must be made 2.0 to 10.0 meters (6.6 to 33.3 feet) from any exterior wall.

(c) No measurement may be made when the average wind velocity during the period of measurement exceeds 19.3 km/hr (12 mph) or when the maximum wind gust velocity exceeds 32.2 km/hr (20 mph).

(d) No measurement may be taken when precipitation, e.g., rain, snow, sleet, or hail, is occurring.

Paragraph (a) restricts noise measurements to "receiving property measurement locations." These locations are defined in more detail in Sec. 3.1. Paragraph (b) limits the presence of vertical obstructions (that exceed 1.2 m or 4 ft in height) within 10 m or 33.3 ft of the microphone. Excluded from this constraint is a facility boundary noise barrier or the wall of a residential or commercial unit. If such a residential or commercial unit wall is present, the measurement microphone must be located at least 2 m (6.6 ft) away from the wall. If a farm home is the residential structure on the receiving property, noise measurements are constrained to between 2.0 and 10.0 m (6.6 and 33.3 ft) from any wall of the residential structure.

Paragraphs (c) and (d) define the weather conditions during which measurements may occur so that adverse weather conditions do not unduly affect the noise measured at the microphone.

3.4.2 Measurement procedures for retarder and car-coupling noise

The procedures that follow are applicable to the measurements on receiving property of the noise of retarders and car-coupling operations. The procedures are nearly identical for both sources; specific differences are highlighted where they occur.

Step 1. Select Measurement Location. For measurement of the noise of both retarder and car-coupling impacts, the measurement location must be on receiving property (see Sec. 3.1 for a definition of receiving property and guidelines for selecting suitable locations). For car-coupling impact measurements only, the receiving property measurement location must be at least 30 m (100 ft) from the centerline of the nearest track on which car couplings occur and are measured. Note that the measurement location may be closer than 30 m (100 ft) from tracks on which car couplings occur if the noise of these coupling impacts is not included in the noise measurements acquired at the selected measurement location. Survey the site to determine compliance with site criteria discussed above. Observe weather conditions to determine whether the weather criteria are also met. Identify the presence of other sources that might interfere with the desired compliance measurements.

Step 2. Set Up Measurement Equipment. Assemble the instrumentation in accordance with the manufacturer's recommendations and instructions. Position the microphone between 1.2 and 1.5 m (4 and 5 ft) above the ground, and in accordance with the manufacturer's recommendations in order to ensure Type 1 or Type 2 performance. Check all connections and test the power supply of all equipment that is battery operated.

Step 3. Calibrate Instrumentation. Following the manufacturer's instructions, use a calibrator of known acoustic output to calibrate the measurement system. Note on the log sheets the time and level of the calibration.

Step 4. Measure Noise Levels. Noise levels are to be measured using the A-weighting scale and the fast meter response with either a Type 1 or Type 2 sound level meter (Type 1 is preferred, however). During the test, no one may stand between the microphone and the noise source being measured. Further, the manufacturer's recommendations concerning the positioning of people relative to the microphone must be followed in order to ensure Type 1 or Type 2 performance.

4.a Note on a log sheet the time at which measurements begin.

4.b For each retarder or car-coupling sound, read the maximum A-weighted sound level (fast) that occurs during each sound, and note the level on a log sheet. Retarder and car-coupling sounds are defined as sounds that are heard and identified as either retarder or car-coupling sounds, and that cause the sound level to increase by at least 10 dB above the level observed immediately before the sound. Thus, the background noise level should be continuously monitored on the sound level meter and kept in mind so that the maximum sound level observed for a particular retarder or car-coupling sound can be compared to this background level. If this maximum sound level is at least 10 dB above the background level, it qualifies as a valid retarder or car-coupling sound and can be noted on the log sheet.

4.c Every retarder or car-coupling sound that occurs (and qualifies by virtue of its level relative to the background level) should be measured and noted on the log sheet.

4.d After 30 consecutive retarder or car-coupling sounds are so measured, if the measurement period has been at least 60 min, the measurements are complete. If 60 min have not elapsed, continue to measure every consecutive retarder or car-coupling sound until at least 60 min have elapsed. If more than 240 min elapse, and 30 retarder or or car-coupling sounds are not measured, the measurements may not be used for compliance purposes. An alternate measurement period should be selected during which 30 consecutive retarder or car-coupling sounds can be measured during a 60- to 240-min period.

4.e Note on the log sheet the time at which measurements conclude, and the number of measurements obtained.

Step 5. Determine the Adjusted Average Maximum A-Weighted Sound Level. From the 30 or more measured maximum sound levels due to retarders or car couplings, the energy-average level (energy average of these 30 or more levels) should be determined. If a Type 2 sound level meter was used to obtain the measurements, and the measurements were of retarder sounds, subtract 4 dB from the energy-average maximum sound level. If a Type 2 sound level meter was used to obtain the measurements, and the measurements were of car-coupling sounds, subtract 2 dB from the energy-average maximum sound level. Determine the ratio of the number of measurements, n, to the measurement duration in minutes, T. With this value of n divided by T, refer to Table 3 to select the appropriate adjustment, C, that must be applied to the energy-average maximum level. The summation of this adjustment, C and the energy-average maximum level, results in the adjusted average maximum level.

TABLE 3. ADJUSTMENT TO $L_{ave\ max}$ TO OBTAIN $L_{adj\ ave\ max}$ FOR RETARDERS AND CAR-COUPLING IMPACTS.*

$\frac{n}{T} = \frac{\text{number of measurements}}{\text{measurement duration (min)}}$	C = Adjustment in dB
0.111 to 0.141	-9
0.142 to 0.178	-8
0.179 to 0.224	-7
0.225 to 0.282	-6
0.283 to 0.355	-5
0.356 to 0.447	-4
0.448 to 0.562	-3
0.563 to 0.708	-2
0.709 to 0.891	-1
0.892 to 1.122	0
1.123 to 1.413	+1
1.414 to 1.778	+2
1.779 to 2.239	+3
2.240 to 2.818	+4
2.819 to 3.548	+5
3.549 to 4.467	+6

*$L_{adj\ ave\ max} = L_{ave\ max} + C$ in dB.

Values in Table 3 were calculated from $C = 10 \log n/T$ with intervals selected to round off values to the nearest whole decibel. The table may be extended or interpolated to finer interval gradations by using this defining equation.

Step 6. Calibrate Instrumentation. After the test, calibrate the instrumentation in the same manner as performed in step 3 above. If the meter indicates a significantly different reading than the initial calibration (greater than ± 1 dB), a malfunction in instrumentation may have occurred (particularly if the time between initial and final calibrations is within 1 to 2 hr). Determine the cause of the malfunction and repeat the measurements, if necessary.

Step 7. Disassemble Equipment.

Step 8. Maintain Documentation. During steps 1 through 7 above, document essential items wherever possible.

Figure 8 is a suggested log sheet for documenting several of the items discussed in Sec. 3.2 above, as well as tabulating the 30 or more individual maximum sound levels measured during the test.

As an aid in the determination of the adjusted average maximum sound level, Fig. 9 is a worksheet that may be used in conjunction with Fig. 8 to approximate both the energy-average sound level, and the adjustments to the energy-average sound level (thereby replacing Table 3). Figures 10 and 11 are examples of the use of Figs. 8 and 9.

For the reader who is familiar with the use of hand-held scientific calculators, the energy-average maximum sound level may be determined more precisely as follows:

$$L_{ave\ max} = 10 \log \frac{1}{n} \sum_{i=1}^{n} 10^{L_{max_i}/10} \quad ,$$

1. Enter the position (address or position number), your name, the day and date, and the type and serial number of the measurement instrumentation on the Log Sheet.

2. The Log Sheet permits tabulation of the maximum noise levels of individual retarder or car coupling sounds occuring over a 35 dB range. Conduct a few preliminary measurements to establish the range of expected noise levels, then label the left "Noise Level" scale to correspond to this range.

3. Enter the calibration level at the start of the measurements, and the time at which the retarder or car coupling measurements begin.

4. For each retarder or car coupling sound, measure the maximum A-weighted sound level (fast).

5. Put a check mark in one of the boxes corresponding to the measured sound level.

6. At the conclusion of the measurements enter the end time, and the calibration level.

7. Count the number of check marks for each sound level, and enter in the right-hand "Total No." column.

8. Enter meteorological data on the Log Sheet, and draw a simple sketch of the measurement site including microphone location, location of noise source(s) measured, etc.

FIG. 8a. INSTRUCTIONS FOR USE OF "LOG SHEET FOR RETARDER AND CAR-COUPLING NOISE MEASUREMENTS."

POSITION__________ ENGR__________ TIME: BEGIN ______ END__________

DAY__________ DATE__________ CAL: BEGIN ______ END__________

MIC: TYPE________ SN__________ DRY BULB________ WET BULB________

SLM: TYPE________ SN__________ REL.HUMD.________ SKY________

CALIB: TYPE________ SN__________ WIND SPEED________ DIRECTION________

WEATHER CONDITIONS MET: Yes[ ] No[ ]

NOTES AND SKETCH:

MICROPHONE POSITION MET: Yes[ ] No[ ]

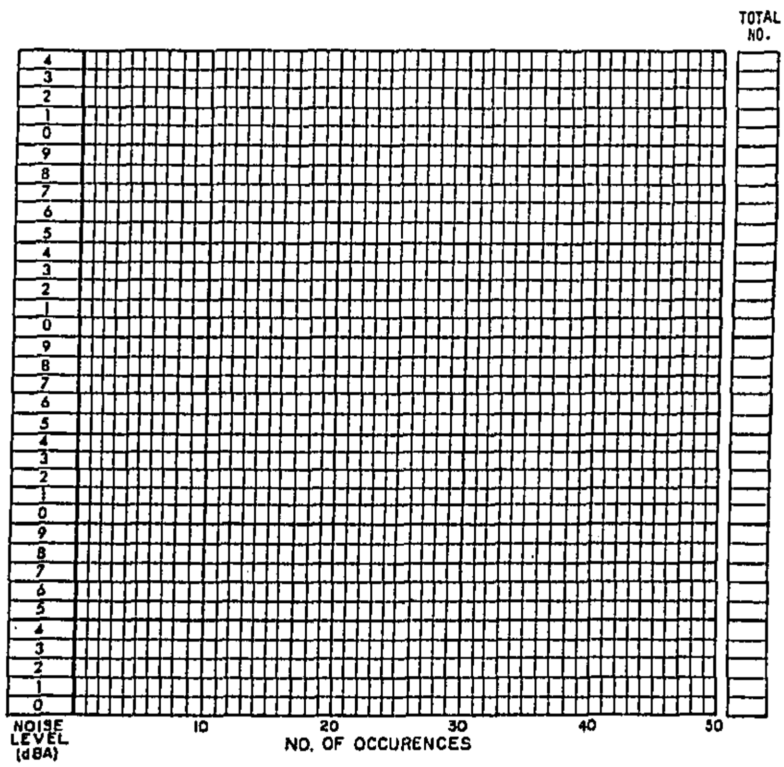


FIG. 8b. LOG SHEET FOR RETARDER AND CAR-COUPLING NOISE MEASUREMENTS.

1. Label the left-hand "Noise Level" scale in the same manner as the "Log Sheet for Retarder and Car Coupling Noise Measurements".
2. From the same Log Sheet, transfer the numbers in the "Total No." column to the second column on the Calculation Sheet,add them together and enter the sum in the "n" box.
3. At each decibel level, multiply the number of measurements by the value shown in the third column of the Calculation Sheet. Round off the product to the nearest integer and tabulate in the last column of the Calculation Sheet.
4. Add together the numbers in the last column and enter in the "Sum" box.
5. Divide the sum by the total number of measurements(n) and enter in the appropriate box.
6. Locate this value of Sum ÷ n on the left scale of the first nomograph. Read the corresponding noise level (to the nearest dB) on the right scale, and enter in the box as shown.
7. The $L_{ave\ max}$ is the sum of the Baseline Level (the lowest level on the Noise Level scale) and the level in the box determined in Step 6.
8. Divide n by the Measurement Duration T (in minutes, determined from the Begin and End time on the Log Sheet).
9. Locate this value of n ÷ T on the left scale of the second nomograph. Read the corresponding noise level (to the nearest dB) on the right scale, and enter in the box as shown.
10. The $L_{ave\ max\ adj}$ is the sum of the $L_{ave\ max}$ (Step 7) and the level in the box determined in Step 9.

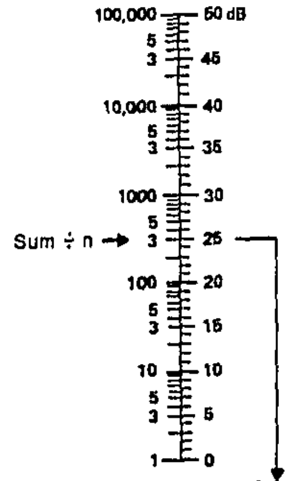
FIG. 9a. INSTRUCTIONS FOR USE OF "ADJUSTED AVERAGE MAX LEVEL CALCULATION SHEET FOR RETARDER AND CAR-COUPLING SOUNDS."

ADJUSTED AVERAGE MAX LEVEL CALCULATION SHEET
FOR RETARDER AND CAR COUPLING SOUNDS

POSITION__________ENGR__________ TIME: BEGIN______END__________

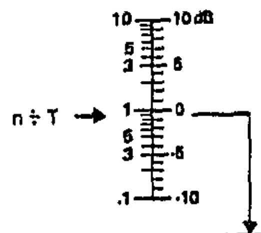
DAY______________DATE__________ MEASUREMENT DURATION, T______min.

Noise Level, dB	Total No.				Relative Energy
4		x	2½	=	000
3		x	2	=	000
2		x	1½	=	000
1		x	1¼	=	000
0		x	1	=	000
9		x	8	=	00
8		x	6½	=	00
7		x	5	=	00
6		x	4	=	00
5		x	3	=	00
4		x	2½	=	00
3		x	2	=	00
2		x	1½	=	00
1		x	1¼	=	00
0		x	1	=	00
9		x	8	=	0
8		x	6½	=	0
7		x	5	=	0
6		x	4	=	0
5		x	3	=	0
4		x	2½	=	0
3		x	2	=	0
2		x	1½	=	0
1		x	1¼	=	0
0		x	1	=	0
9		x	8	=	
8		x	6½	=	
7		x	5	=	
6		x	4	=	
5		x	3	=	
4		x	2½	=	
3		x	2	=	
2		x	1½	=	
1		x	1¼	=	
Baseline Level 0		x	1	=	
n =			Sum =		
n ÷ T =			Sum÷n =		



$L_{ave\ max}$ = Baseline Level + [ ]

= _______ dB



$L_{adj\ ave\ max} = L_{ave\ max}$ + [ ]

= _______ dB

FIG. 9b. ADJUSTED AVERAGE MAX LEVEL CALCULATION SHEET FOR RETARDER AND CAR-COUPLING SOUNDS.

LOG SHEET FOR RETARDER AND CAR-COUPLING
NOISE MEASUREMENTS

POSITION B ENGR M. SMITH TIME: BEGIN 1900 hrs END 2000
DAY THURS DATE 1 APR 80 CAL: BEGIN 114.0 END 114.2
MIC: TYPE 2011 SN 123456 DRY BULB 65° WET BULB 60°
SLM: TYPE 4120 SN 654321 REL.HUMD. ____ SKY SUNNY, CLEAR
CALIB: TYPE 6200 SN 246810 WIND SPEED 2 DIRECTION N
NOTES AND SKETCH: WEATHER CONDITIONS MET: Yes[✓] No[ ]
MICROPHONE POSITION MET: Yes[✓] No[ ]

MASTER RETARDER + GROUP
RETARDER SQUEALS
20 FT. SOUTH OF SOUTHERN
PROPERTY LINE AT 19th AVE.
(SEE MAP)

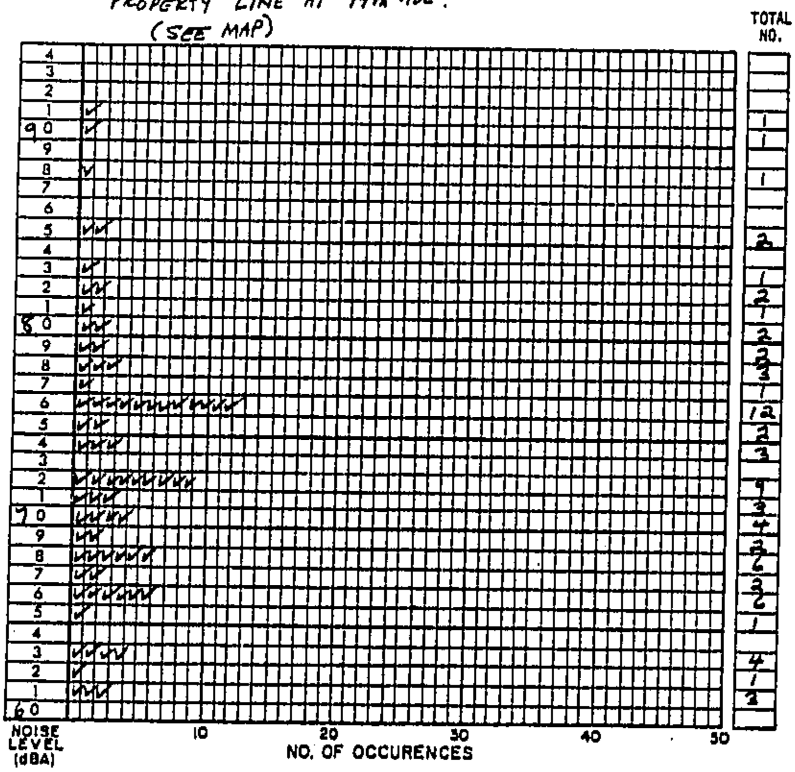


FIG. 10. EXAMPLE OF USE OF LOG SHEET.

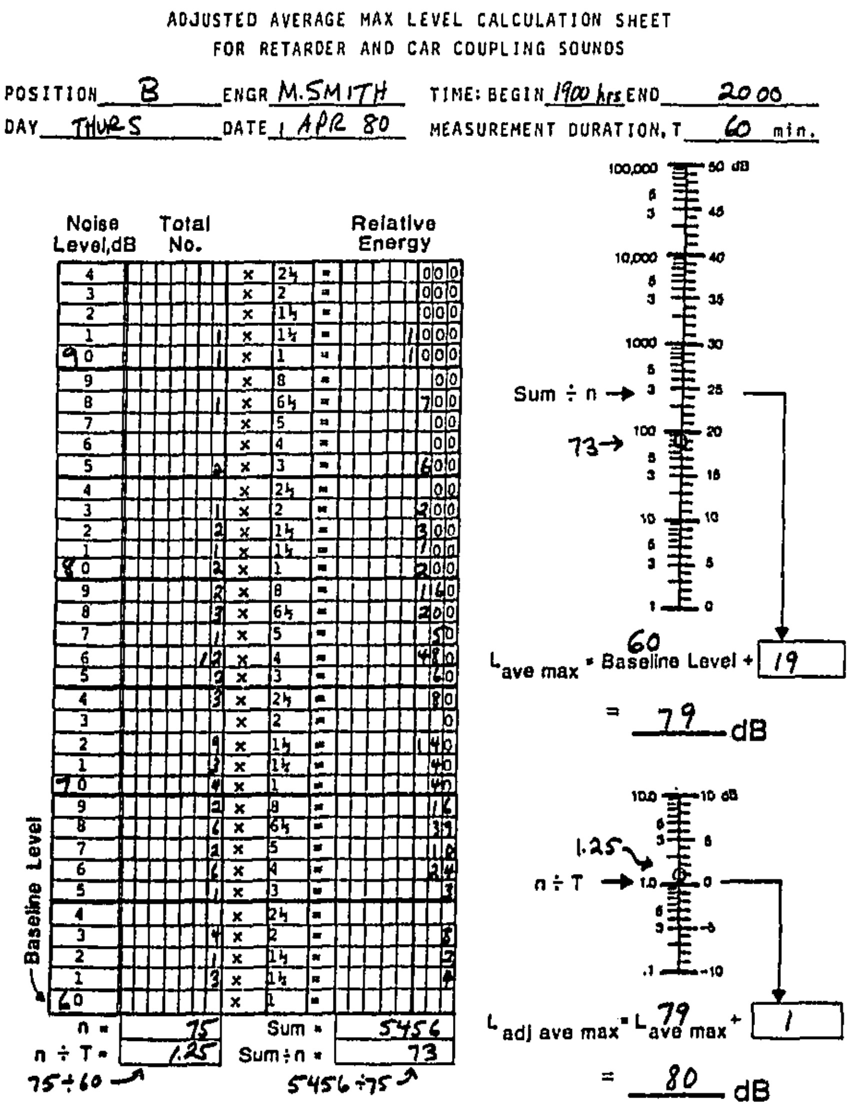


FIG. 11. EXAMPLE OF USE OF CALCULATION SHEET.

where the L_{max_i} are the individual maximum level readings, and n is the total number of measurements. As shown in Table 3, the adjusted average maximum is

$$L_{adj\ ave\ max} = L_{ave\ max} + C ,$$

where $C = 10 \log \frac{n}{T}$. Here T is the measurement period in minutes. Figure 12 lists the steps to be followed to perform these calculations and provides an example.

3.4.3 Measurement procedures for switcher locomotives and locomotive load cell test stand noise

The procedures that follow are applicable to the measurements on receiving property of the noise of stationary switcher locomotives and locomotive load cell test stands, including measurements of the noise of locomotive load cell test stands more than 120 m (400 ft) from the test stand on receiving property.

These procedures involve the measurement of the total noise environment at the particular microphone location, analysis of the measured noise levels to verify that the noise environment is nearly steady state, and determination of the applicability of the 30 m (100 ft) source standards for switcher locomotives and locomotive load cell test stands based on the presence of either or both of the sources during these measurements.

Step 1. Select Measurement Location. For measurement of the noise of stationary switcher locomotives or locomotive load cell test stands, or both, the measurement location must be on receiving property (see Sec. 3.1 for a definition of receiving property and guidelines for selecting suitable locations). When

The steps to calculate $L_{ave\ max}$ are as follows:

1. Divide the value of each L_{max_i} by 10, to yield $L_{max_i}/10$.
2. Determine the antilog of $L_{max_i}/10$, or $10^{(L_{max_i}/10)}$.
3. Add together all n values of $10^{(L_{max_i}/10)}$.
4. Divide this sum by n.
5. Take the logarithm and then multiply by 10.

Note: If a particular value of L_{max_i} occurs more than once, it is not necessary to go through steps 1 and 2 each time. If L_{max_i} occurs m times, then after obtaining $10^{(L_{max_i}/10)}$, simply multiply by m before including in the sum.

The steps to calculate the adjustment C are as follows:

1. Divide the total number of measurements n by the total measurement period in minutes, T.
2. Take the logarithm of $\frac{n}{T}$ and then multiply by 10.

Add together $L_{ave\ max}$ and C to yield the $L_{adj\ ave\ max}$.

Example:

For the 75 measured L_{max} values shown in Fig. 10, the calculations are as follows:

$$10^{91/10} = 1258925416$$
$$10^{90/10} = 1000000000$$
$$10^{88/10} = 630957346$$
$$2 \times 10^{85/10} = 632455532$$
$$\vdots \qquad \vdots$$
$$3 \times 10^{61/10} = \underline{3776776}$$
$$5703906358 \div 75 = 76052071$$

$$L_{ave\ max} = 10 \log (76052071) = 78.8$$

$$\frac{n}{T} = \frac{75}{60} = 1.25$$

$$C = 10 \log (1.25) = 1$$

$$L_{adj\ ave\ max} = 78.8 + 1 = 79.8$$

FIG. 12. PROCEDURE FOR DETERMINING $L_{adj\ ave\ max}$ WITH A HAND-HELD CALCULATOR.

selecting locations for the measurement of these sources, a chosen location should be one in which the observer can identify the principal direction of the nearly steady-state sounds by listening to the sounds and localizing the apparent sources. These sounds should be observed to be the major sources of nearly steady-state sound at the measurement location. If the observer can clearly localize the sources as coming from one or more sets of stationary switcher locomotives and/or locomotive load cell test stands, then the measurement location may be used. When measurements of the noise of locomotive load cell test stands at 30 m (100 ft) are required, but conditions at the site do not meet the site criteria, measurements may be taken more than 120 m (400 ft) from the test stand on receiving property. The 120 m (400 ft) distance is measured from the centerline of the track on which the locomotive under test is located, and the longitudinal midpoint of the locomotive. Survey the site to determine compliance with the site criteria discussed previously. Observe weather conditions to determine whether the weather criteria are also met. Identify the presence of other sources that might interfere with the desired compliance measurements.

Step 2. Set Up Measurement Equipment. Assemble the instrumentation in accordance with the manufacturer's recommendations and instructions. Position the microphone between 1.2 and 1.5 m (4 and 5 ft) above the ground, and in accordance with the manufacturer's recommendations in order to ensure Type 1 or Type 2 performance. Check all connections and test the power supply of all equipment that is battery operated.

Step 3. Calibrate Instrumentation. Following the manufacturer's instructions, use a calibrator of known acoustic output to calibrate the measurement system. Note on the log sheet the time and level of calibration.

Step 4. Measure Noise Levels. Noise levels are to be measured using the A-weighting scale and the fast* meter response, with either a Type 1 or Type 2 sound level meter (Type 1 is preferred, however). During the test, no one may stand between the microphone and the noise source(s) being measured. Further, the manufacturer's recommendations concerning the positioning of people relative to the microphone must be followed in order to ensure Type 1 and Type 2 performance. When the noise of one or more switcher locomotives and/or locomotive load cell test stands is observed at the measurement location, noise measurements are to be obtained as follows:

4.a Note on the log sheet the time at which measurements begin.

4.b At a rate of at least once each 10 sec, read the A-weighted sound level (fast), and note the level on the log sheet. Continue the measurements until 100 measurements are obtained. This corresponds to a measurement duration of 16-2/3 min, if measurements are obtained at 10 sec intervals. Measurements may be obtained at more frequent intervals, as long as the total measurement duration is at least 15 min. (Note that the noise levels may be measured by direct reading of a sound level meter at regular intervals, by using a statistical distribution analyzer, or by any other equivalent device that is capable of determining

*Specification of "fast" reflects a correction to the regulation. See footnote, p. 4.

the appropriate statistics of the noise level distribution, provided that the measurement instrumentation conforms to Type 1 or Type 2 requirements.)

4.c List the measured noise levels in ascending order. Note the 10th highest reading, the 90th reading, and the 99th reading. These noise levels correspond respectively to levels exceeded 10%, 90%, and 99% of the time (L_{10}, L_{90}, and L_{99}).

4.d If the numerical difference between the L_{10} and the L_{99} levels is 4 dB or less, the measurements are complete. Such a condition will occur when the noise environment is nearly steady state. If this difference is greater than 4 dB, the noise environment is not sufficiently steady state for the purposes of this measurement procedure. In this case, an additional series of measurements may be obtained, and the 10%, 90%, and 99% levels determined accordingly. For example, the 20th, 180th, and 198th noise levels would correspond to the L_{10}, L_{90}, and L_{99} levels for a total sample of 200 measurements. If the numerical difference between the L_{10} and L_{99} for the entire set of measurements is 4 dB or less, the measurements are now complete. (Note that the 4-dB difference test must be applied to measurements conducted over a continuous period of time, in which at least 100 measurements are obtained over a period of at least 15 min. Noise levels measured before and after such a time period may be excluded from the analysis.)

4.e If the measurements are successfully completed such that the numerical difference between the L_{10} and L_{99} levels is 4 dB or less, the measured value of the L_{90} is termed the "validated" L_{90}.

Step 5. For measurements of the noise of stationary switcher locomotives and locomotive load cell test stands at an arbitrary location on receiving property, if the validated L_{90} is 65 dB or less, the sources being measured are in compliance with the regulation. If the validated L_{90} exceeds 65 dB, the further evaluation described below must be conducted. For measurements of the noise of locomotive load cell test stands at 120 m (400 ft) from the stand, if the validated L_{90} is 65 dB or less, the locomotive load cell test stand is in compliance with the regulation. If the validated L_{90} exceeds 65 dB, the locomotive load cell test stand is not in compliance with the regulation.

Step 6. The validated L_{90} measured thus far may be due to the noise of either stationary switcher locomotives, locomotive load cell test stands, or a combination of these. The following steps are necessary to sort out the possible noise sources contributing to the measured noise level.

6.a If only stationary locomotives, including at least one switcher locomotive, are present, since the L_{90} exceeds 65 dB, additional compliance measurements at the 30 m (100 ft) measurement location are required, relative to the standards in Sec. 201.11(c) and Sec. 201.12(c).

6.b If only a locomotive load cell test stand and the locomotive being tested are present and operating, since the measured L_{90} exceeds 65 dB, additional compliance measurements at the 30 m (100 ft) measurement location are required, relative to the standards in Sec. 201.16.

6.c If both a locomotive load cell test stand and the locomotive being tested are present, and stationary locomotives including at least one switcher locomotive are present, subtract 3 dB from the measured L_{90} noise level. If this level is 65 dB or less, both of these sources are in compliance with the regulation. If this level exceeds 65 dB, additional compliance measurements at the 30 m (100 ft) measurement location are required, relative to the standards in Sec. 201.11(c), Sec. 201.12(c), and Sec. 201.16.

6.d If both a locomotive load cell test stand and the locomotive being tested are present and operating, and stationary locomotives including at least one switcher locomotive are present, the noise environment may be observed to change as the operation of the locomotive load cell test stand changes. If a change as large as 10 dB is observed to occur as operation of the locomotive load cell test stand changes, conduct a second series of measurements as described in step 4 above to determine a new validated L_{90} corresponding to the new noise environment. If the new validated L_{90} is at least 10 dB above the earlier validated L_{90}, the new higher value of L_{90} is to be used. If this new value of L_{90} is 65 dB or less, the locomotive load cell test stand is in compliance with the regulation. If the new value of L_{90} exceeds 65 dB, additional compliance measurements at the 30 m (100 ft) measurement location are required, relative to the standard in Sec. 201.16.

Step 7. Calibrate Instrumentation. After the test, calibrate the instrumentation in the same manner as performed under step 3 above. If the meter indicates a significantly different reading than the initial calibration (greater than ± 1 dB), a malfunction in the instrumentation may have occurred (particularly if the time between initial and final calibration is within 1 to 2 hr). Determine the cause of the malfunction, and repeat the measurements, if necessary.

Step 8. Disassemble Equipment.

Step 9. Maintain Documentation. During steps 1 through 8 above, document the essential items wherever possible. When one or more noise sources are in operation (i.e., stationary switcher locomotives as well as locomotive load cell test stands), documentation of noise source information is required. This includes the approximate location of all stationary switchers and all locomotive load cell test stands present, the location of the microphone on a drawing of the railroad facility and surrounding area, and the distances between the microphone location and each of the sources. Additional rail and nonrail noise sources must also be identified and documented.

Step 10. Influence of Background Noise. Measurement of the nearly steady-state noise due to stationary switcher locomotives and/or a locomotive load cell test stand was obtained on the belief that these sources are the dominant sources of noise at the measurement location. If it is desired to verify this belief, measurement may be conducted on subsequent days at the same time of day as that of the initial measurements, when all other conditions are believed to be acoustically similar to those of the original measurements, except that the noise sources that were measured initially are no longer in operation (because they have been moved or turned off). If any L_{90} measured at the same receiving property location when these sources are not operating is not at least 5 dB below the measured validated L_{90} resulting from the noise sources being measured, the validated L_{90} cannot be used for the purposes of the regulation.

Figure 13 is a suggested log sheet for documenting several of the items discussed in Sec. 3.2 above, as well as tabulating the 100 or more sequential sound levels measured during the test. Figure 14 is an example of the use of Fig. 13.

3.5 Probable Compliance Measurements

Probable compliance measurements are permitted by the regulation to allow the railroad to assess, in an approximate manner, whether or not specific sources within its boundaries exceed the noise level limits on receiving property that are incorporated within the regulations.

Probable compliance measurements are to be conducted in the same manner as receiving property measurements, as described in Sec. 3.4 of this handbook, with the following exceptions:

1. Measurement locations are to be on railroad property, between a particular source of interest and the receiving property line.

2. Measurement locations should not be selected such that noise barriers and other noise reduction features in the vicinity of the measurement location provide a greater shielding benefit than would be expected on receiving property.

When measurements are made in accordance with the procedures in Sec. 3.4, subject to the restrictions listed above, if measured levels are less than the limits in the regulation, there is probably compliance with the standard.

1. Enter the position (address or position number), your name, the day and date, and the type and serial number of the measurement instrumentation on the Log Sheet.
2. The Log Sheet permits tabulation of noise levels occuring over a 35 dB range. Conduct a few preliminary measurements to establish the range of expected noise levels, then label the left "Noise Level" scale to correspond to this range.
3. Enter the calibration level at the start of the measurements, and the time at which the switcher locomotive and/or load cell test stand measurements begin.
4. Using a stop watch (or watch with sweep second hand or digital seconds display), every 10 seconds measure the A-weighted sound level (fast)*.
5. Put a check mark in one of the boxes corresponding to the measured sound level.
6. After 100 sampes are obtained, determine the L_{10}, L_{90}, and L_{99} noise levels as follows. Starting with the highest level measured (the top-most check mark on the Log Sheet), count the first 10 check marks (from left to right). The noise level corresponding to the box containing the 10th check mark is the L_{10} level. The L_{90} and L_{99} levels are similarly obtained by counting to the 90th and 99th check marks.
7. If additional measurements are required, the table on the Log Sheet indicates the number of check marks to be counted to obtain the L_{10}, L_{90} and L_{99} levels, depending on the total number of samples obtained.
8. At the conclusion of the measurements enter the end time, and the calibration level.
9. Enter the meteorological data on the Log Sheet, and draw a simple sketch of the measurement site including microphone location, location of noise source(s) measured, etc.

*Specification of "fast" reflects a correction to the regulation. See footnote, p. 4.

FIG. 13a. INSTRUCTIONS FOR USE OF "LOG SHEET FOR STATIONARY SWITCHER LOCOMOTIVE AND LOAD CELL TEST STAND NOISE MEASUREMENTS."

POSITION__________ ENGR__________ TIME: BEGIN_______ END__________

DAY__________ DATE__________ CAL: BEGIN_______ END__________

MIC: TYPE_______ SN__________ DRY BULB_______ WET BULB_______

SLM: TYPE_______ SN__________ REL.HUMD._______ SKY__________

CALIB: TYPE_______ SN__________ WIND SPEED_______ DIRECTION_______

WEATHER CONDITIONS MET: Yes[ ] No[ ]

NOTES AND SKETCH: MICROPHONE POSITION MET: Yes[ ] No[ ]

TOTAL SAMPLES	L_{10}	L_{90}	L_{99}
100	10 th	90 th	99 th
150	15 th	135 th	149 th
200	20 th	180 th	198 th
250	25 th	225 th	248 th
300	30 th	270 th	297 th

Sample from top.

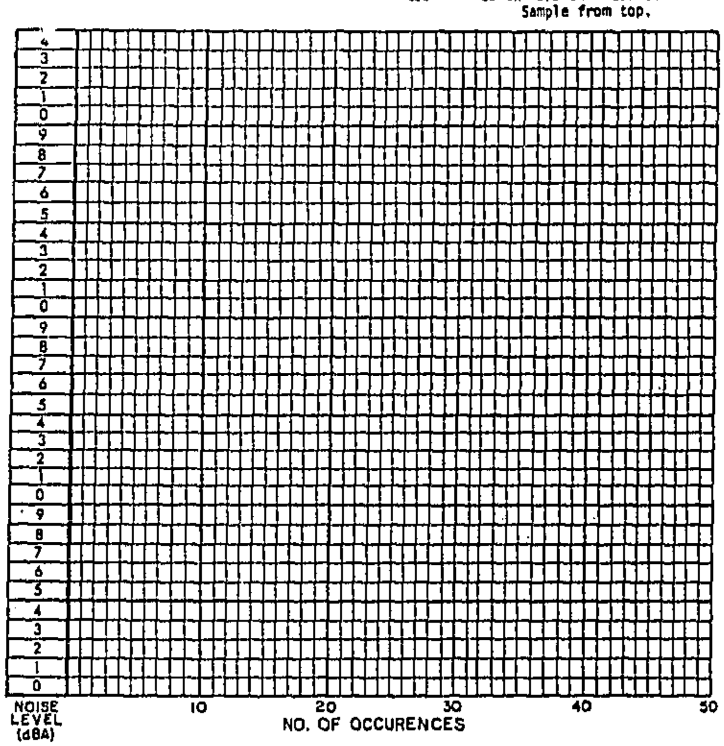


FIG. 13b. LOG SHEET FOR STATIONARY SWITCHER LOCOMOTIVE AND LOAD CELL TEST STAND NOISE MEASUREMENTS.

LOG SHEET FOR STATIONARY SWITCHER LOCOMOTIVE AND LOAD CELL TEST STAND NOISE MEASUREMENTS

POSITION C	ENGR M. SMITH	TIME: BEGIN 1600 hrs	END 1618
DAY WED	DATE 31 MAR 80	CAL: BEGIN 114.0	END 114.0
MIC: TYPE 2011	SN 123456	DRY BULB 65°	WET BULB 58°
SLM: TYPE 4120	SN 654321	REL. HUMD.	SKY SUNNY, CLEAR
CALIB: TYPE 6200	SN 246810	WIND SPEED CALM	DIRECTION

WEATHER CONDITIONS MET: Yes [✓] No [ ]
MICROPHONE POSITION MET: Yes [✓] No [ ]

NOTES AND SKETCH:

LOAD CELL MSMNTS
AT WESTERN
PROPERTY LINE
AND MAIN ST.
(SEE MAP)

TOTAL SAMPLES	L_{10}	L_{90}	L_{99}
100	10 th	90 th	99 th
150	15 th	135 th	149 th
200	20 th	180 th	198 th
250	25 th	225 th	248 th
300	30 th	270 th	297 th

Sample from top.

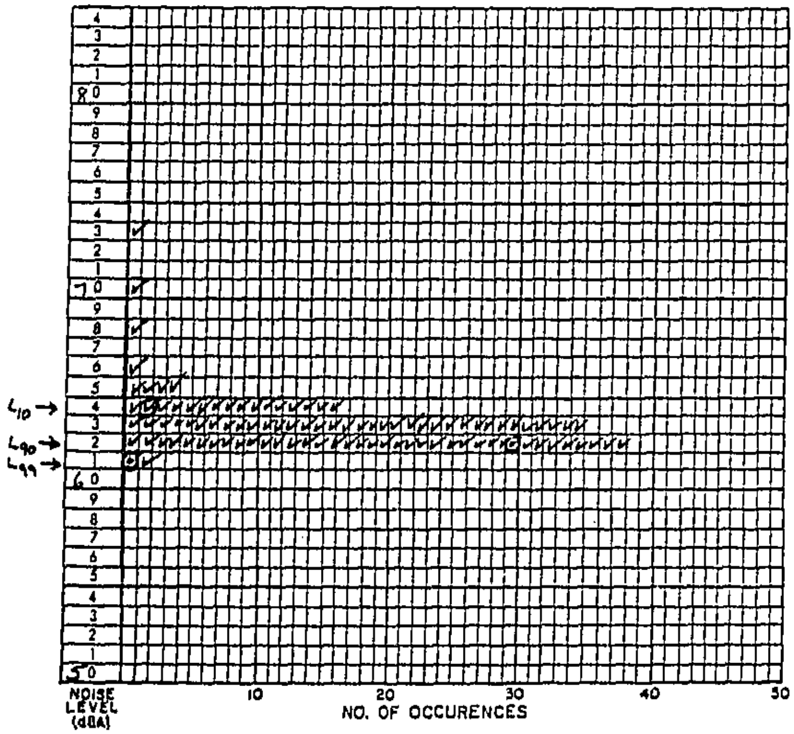


FIG. 14. EXAMPLE OF USE OF LOG SHEET.

4. MEASUREMENT HINTS AND EXAMPLES

Examples of hypothetical measurements of various rail carrier noise sources are provided in this section so that the reader may become more familiar with typical problems and situations that arise during compliance measurements in the field. The discussions below include examples of measurements of

- Stationary sources at 30 m (100 ft)
- Moving sources at 30 m (100 ft)
- Retarder and car-coupling noise at receiving property
- Stationary locomotives and locomotive load cell test stands at receiving property.

4.1 Stationary Source Measurements at 30 m (100 ft)

Stationary rail carrier noise sources that are measured at 30 m (100 ft) include stationary locomotives, stationary switcher locomotives, and locomotive load cell test stands. Measurement of these noise sources at 30 m (100 ft) involves observing the sound level meter for 30 sec during the operation of the noise source, noting the maximum level observed, and checking that this level exceeds the background level by at least 10 dB. The primary problems associated with this type of measurement involve unusual changes in noise level during the measurement period by the source being measured or by other sources.

For example, if a car coupling occurs during the measurement of an idling locomotive, causing the meter needle to jump, the data taken are invalid, and a new 30-sec period must be measured. If the locomotive is shut off in the middle of the test, the observer must wait until it is turned back on and running for a full 30-sec period before the measurements are complete. A noticeable change in noise level by the source during the test may indicate that a new test is required, but this is true only if there has been a change in throttle setting from idle to another setting since different standards apply to the different settings.

To determine which setting is being used during the measurement period, obtain assistance from railroad personnel. It may also be necessary to seek their help in determining the date of manufacture of the locomotive so that the appropriate standard may be applied. The following example illustrates some of these points.

Example

A measurement is to be made of idling locomotives that are parked for extended periods of time adjacent to a residential community. A main street nearby produces a background level (averaging about 65 dB) during the daytime that is quite noticeable from the locomotive measurement position. When an idling locomotive is measured, the maximum needle reading is 74 dB. In this case, the 10 dB-above-backbround criterion is not met, and therefore the measurements must be declared invalid.

Nighttime background levels are generally lower than daytime levels, so the measurements are taken again at 9 p.m. The background levels before and after the idling measurements are about 50 dB, and during the idling measurements, a level of 74 dB is again reached. A check of the noise standards for this source (Table 1) reveals the locomotive is in violation, irrespective of its date of manufacture. During the above measurements, a stationary runup that exceeds 95 dB for about 10 sec is observed. This level exceeds the standard for throttle settings other than idle (Table 1), but the time period is too short to allow a finding of noncompliance. Further, the idling measurements must be begun again in order to obtain an uninterrupted 30-sec reading.

4.2 Moving Source Measurements at 30 m (100 ft)

Moving sources of rail carrier noise that are measured at 30 m (100 ft) include moving locomotives, moving switcher locomotives, and moving rail cars. Measurement of the two types of locomotives involves noting the maximum noise level of the passby and checking that this level exceeds the background level by at least 10 dB. Measurement of rail car noise involves waiting until the closest locomotive on the train is at least 150 m (500 ft) away or at least 10 rail cars have passed, noting the maximum rail car noise level, and checking that this level exceeds the background level by at least 10 dB. Problems associated with this type of measurement include finding allowable measurement locations and making sure that other noises do not influence locomotive or rail car noise measurements.

The measurement location should be selected so that the effect of the track does not unduly influence the vehicle passby noise. If a bridge or trestle is observed to rattle as the train goes by, the measurement site should be changed. If the radius of curvature of the track is less than 873 m (2865 ft), the wheel-rail interaction will generate too much noise, and the site should be changed. Sometimes a rail car brake will be on too tightly, generating brake squeals. If these occur during the measurement period, the noise levels that they generate should be ignored.

When measuring rail cars alone, be careful to observe whether or not there are locomotives attached to the end of the train. Such a situation would invalidate rail car noise readings made of any of the 10 cars immediately preceding them in the train. The following example illustrates these points.

Example

A routine check of noise from a feeder rail line is to be made in preparation for new housing development near the track. If the trains do not meet the noise standards, there will be some public pressure to treat the noisy vehicles or move the track. A measurement site is selected 2.5 m (8 ft) below an elevated portion of straight track, which is within the standard requirements. A bridge is located 300 m (1000 ft) down the track, but no additional noise levels are observed to emanate from it as the trains pass by.

The first train measured is pulled by four locomotives. These register a maximum of 85 dB on the sound level meter (fast response), which is within the standard. After waiting for 10 cars to pass, the maximum for the remaining cars is found to be 90 dB. This level exceeds the standard for vehicles traveling less than 75 kph (45 mph), but is within the standard for faster speeds. To determine the approximate train speed, a count may be taken of the number of rail cars in the train (N) and the number of seconds it takes them to pass (S). Assuming an average length of 15 m (45 ft) per car, if N divided by S is less than 1.4, the train is traveling less than 75 kph (45 mph); if it is greater than 1.4, the train is traveling faster than this speed.

4.3 Retarder and Car-Coupling Measurements on Receiving Property

Retarder and car-coupling noise measurements are obtained at any receiving property location that meets the site requirements of the standard. The measurements involve reading at least 30 consecutive retarder or car-couplings events (whichever is to be measured), taking their adjusted energy average over a 1 to 4 hr period, and continuously checking that in each case they exceed the background noise level by at least 10 dB. With this type of measurement, some factors to be considered are

- Making sure the readings are consecutive (not interrupted)
- Setting the meter range correctly
- Adjusting for measurements closer than 30 m (100 ft) to the track (for car-coupling measurements)
- Adjusting for readings made with a Type 2 sound level meter.

If an interruption is made in the readings for whatever reason, the readings must be started again. It will be somewhat difficult to anticipate the maximum needle excursion for each coupling or retarder event, therefore a sound level meter with a wide dB range in its window is highly recommended. If a noise event exceeds the range of the meter, it indicates that a higher meter range is required, and a new group of 30 readings must be begun. On the other hand, the meter range must not be set so high that it is not possible to determine whether the events exceed the background level by at least 10 dB. Obviously, some experimenting and adjusting will be required here before a valid set of measurements can be acquired.

If measurements are to be taken less than 30 m (100 ft) from a track where couplings are taking place, the events on this track must be ignored. To determine on which track the events are occurring, it will be helpful either to have an assistant watch the tracks, or to use a sound level meter with a "maximum-hold" feature. This feature will hold the maximum reading of an event until the origin of the noise source can be ascertained. It is also useful for retarder and car-coupling measurements because the meter needle may swing to its maximum position very quickly; the maximum-hold feature permits an accurate reading of the noise level even after the event has occurred.

When using a Type 2 sound level meter, remember to subtract 4 dB from the average value found for retarder events and 2 dB from the car-coupling average, to take into account the wider tolerance limits of this type of meter. In order to avoid confusion, it is better to note the actual readings during the compliance measurements and to perform the subtraction later. The following example illustrates some of these points.

Example

A measurement is to be taken of car couplings at a residential position located 40 m (130 ft) from the nearest track. It is found that there is an air conditioner unit that produces noise within 10 dB of the coupling impacts, so a new site is chosen, also outside the railroad right-of-way, but only 25 m (82 ft) from the nearest track. During the measurements, the couplings on this nearest track are ignored. After 4 hr, only 25 events are recorded, so the entire sequence must be started over. This time a large train is being assembled, so a large number of couplings take place. Over 40 events are recorded in only 1 hr on tracks other than the excluded track. All 40 of these events are used to determine the adjusted average.

4.4 Stationary Switcher Locomotives and Locomotive Load Cell Test Stand Measurements on Receiving Property

The procedures involved in measuring switcher locomotives and locomotive load cell test stands on receiving property require many steps. After a suitable measurement site is selected and the noise sources under test are operating, readings are taken every 10 sec until at least 100 values are compiled.* After the readings are tabulated, various noise level and noise source criteria are checked, the L_{90} is found, and compliance with the standard is determined. If the L_{90} standard is exceeded, a new set of measurements is made at 30 m (100 ft), or if no suitable site is found for test stand measurements, a new set is made more than 120 m (400 ft) from the test stand on receiving property. Finally, these noise levels indicate whether the noise emission standards have been violated.

Potential problems with this type of measurement include exceeding the steady-state and background noise criteria and interrupting the 100 consecutive readings for various reasons. If, during the measurements, a passing sound source causes a number of readings to be much higher than the steady-state sound

*Ten-second intervals can readily be determined using a stop-watch, or a watch with sweep second hand or digital indicator for seconds. Alternately, time signals (beeps) can be recorded on a cassette recorder and played back through earphones.

from the switcher locomotives or load cell test stands, the steady-state criteria will not be met, and the measurements should be begun again.

If this change in noise level is due to observed changes in test stand operations and the change is greater than 10 dB, measure the new steady-state level by beginning a new set of 100 readings. It is essential to note the background noise level before and after the steady-state measurements. Both must be at least 5 dB below the computed L_{90} for the measurements to be valid.

If switcher locomotives and locomotive load cell test stands are both in operation at any time during the measurements, subtract 3 dB from L_{90} before checking for compliance. The following example illustrates some of these points.

Example

A locomotive load cell test stand is located near a neighborhood park. The measurement personnel arrive at the park and find that the test stand is not operating. They take 100 readings at 10 sec apart in order to define the ambient conditions. The 90th loudest level is found to be 52 dB. The next day they are informed that the test stand is operating, so measurements are made at about the same time of day as the previous background measurements. After about 50 readings, averaging about 56 dB, a switcher locomotive moves onto a nearby track and sits in an idling mode. Subsequent readings are increased by 3 dB due to this action, so an additional set of 100 measurements are attempted under this condition. But after only 25 of these readings, the test stand throttle setting is changed, which increases the level in the park by 11 dB. A full set of 100 readings are finally taken under these stable conditions. In this example, the L_{90} for the locomotive test stand is 70 dB, and is validated. Do *not* subtract 3 dB from this level due to the presence of both the switcher and the test stand, because the test stand noise clearly dominates (it is over 10 dB higher than previously existing levels). Although the original readings did not exceed the background by more than 4 dB, the final 100 measurements exceeded it by 18 dB, therefore 70 dB is the validated L_{90}.

This level exceeds the 65-dB standard, so the next step is to measure the L_{max} at 30 m (100 ft). A maximum value of 76 dB is found at 30 m (100 ft) from the test stand. This level is less than the standard of 78 dB.

APPENDIX A

SAMPLE LOG SHEETS AND CALCULATION SHEETS

LOG SHEET FOR SOURCE NOISE
MEASUREMENTS AT 30 METERS (100 ft)

POSITION__________ ENGR__________ TIME: BEGIN ______ END__________

DAY__________ DATE__________ CAL: BEGIN ______ END__________

MIC: TYPE________ SN__________ DRY BULB________ WET BULB________

SLM: TYPE________ SN__________ REL.HUMD.________ SKY________

CALIB: TYPE________ SN__________ WIND SPEED________ DIRECTION________

NOTES AND SKETCH:

WEATHER CONDITIONS MET: Yes[ ] No[ ]

MICROPHONE POSITION MET: Yes[ ] No[ ]

Time	Event No.	Source	Serial No.	L_{Max}	Fast/ Slow	COMMENTS

LOG SHEET FOR RETARDER AND CAR-COUPLING
NOISE MEASUREMENTS

POSITION________ ENGR________ TIME: BEGIN ______ END________

DAY________ DATE________ CAL: BEGIN ______ END________

MIC: TYPE________ SN________ DRY BULB________ WET BULB________

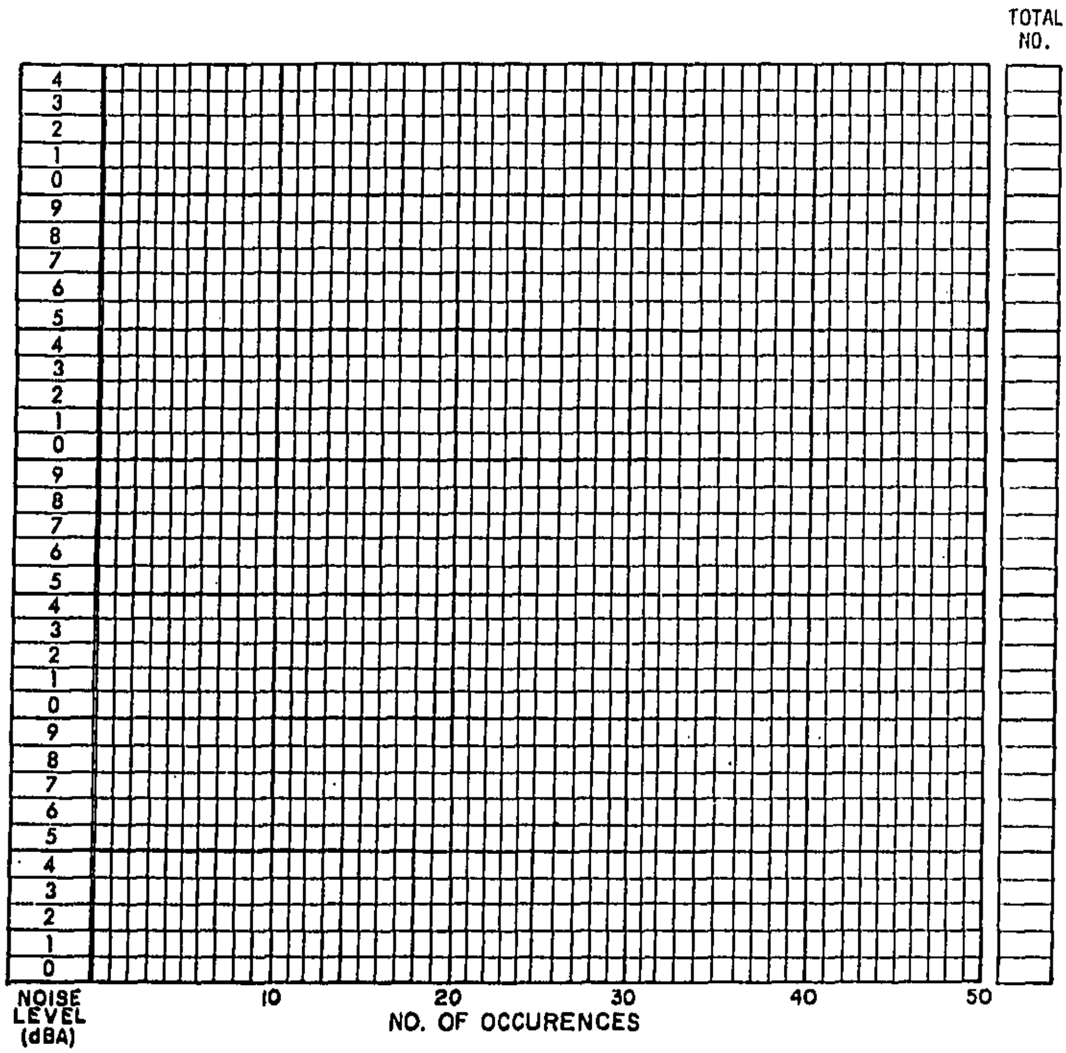
SLM: TYPE________ SN________ REL.HUMD.________ SKY________

CALIB: TYPE________ SN________ WIND SPEED________ DIRECTION________

WEATHER CONDITIONS MET: Yes[ ] No[ ]

NOTES AND SKETCH:

MICROPHONE POSITION MET: Yes[ ] No[ ]



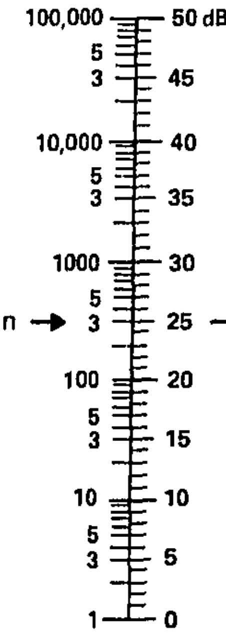
ADJUSTED AVERAGE MAX LEVEL CALCULATION SHEET
FOR RETARDER AND CAR COUPLING SOUNDS

POSITION__________ ENGR__________ TIME: BEGIN______ END__________

DAY______________ DATE__________ MEASUREMENT DURATION, T______ min.

Noise Level, dB	Total No.				Relative Energy
4		x	2½	=	000
3		x	2	=	000
2		x	1½	=	000
1		x	1¼	=	000
0		x	1	=	000
9		x	8	=	00
8		x	6½	=	00
7		x	5	=	00
6		x	4	=	00
5		x	3	=	00
4		x	2½	=	00
3		x	2	=	00
2		x	1½	=	00
1		x	1¼	=	00
0		x	1	=	00
9		x	8	=	0
8		x	6½	=	0
7		x	5	=	0
6		x	4	=	0
5		x	3	=	0
4		x	2½	=	0
3		x	2	=	0
2		x	1½	=	0
1		x	1¼	=	0
0		x	1	=	0
9		x	8	=	
8		x	6½	=	
7		x	5	=	
6		x	4	=	
5		x	3	=	
4		x	2½	=	
3		x	2	=	
2		x	1½	=	
1		x	1¼	=	
0 (Baseline Level)		x	1	=	
n =			Sum =		
n ÷ T =			Sum ÷ n =		

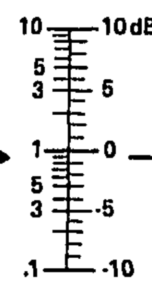
Sum ÷ n →



$L_{ave\ max}$ = Baseline Level + ☐

= ______ dB

n ÷ T →



$L_{adj\ ave\ max} = L_{ave\ max} +$ ☐

= ______ dB

LOG SHEET FOR STATIONARY SWITCHER LOCOMOTIVE AND
LOAD CELL TEST STAND NOISE MEASUREMENTS

POSITION____________ ENGR____________ TIME: BEGIN________ END____________

DAY____________ DATE____________ CAL: BEGIN________ END____________

MIC: TYPE________ SN____________ DRY BULB________ WET BULB________

SLM: TYPE________ SN____________ REL.HUMD.________ SKY____________

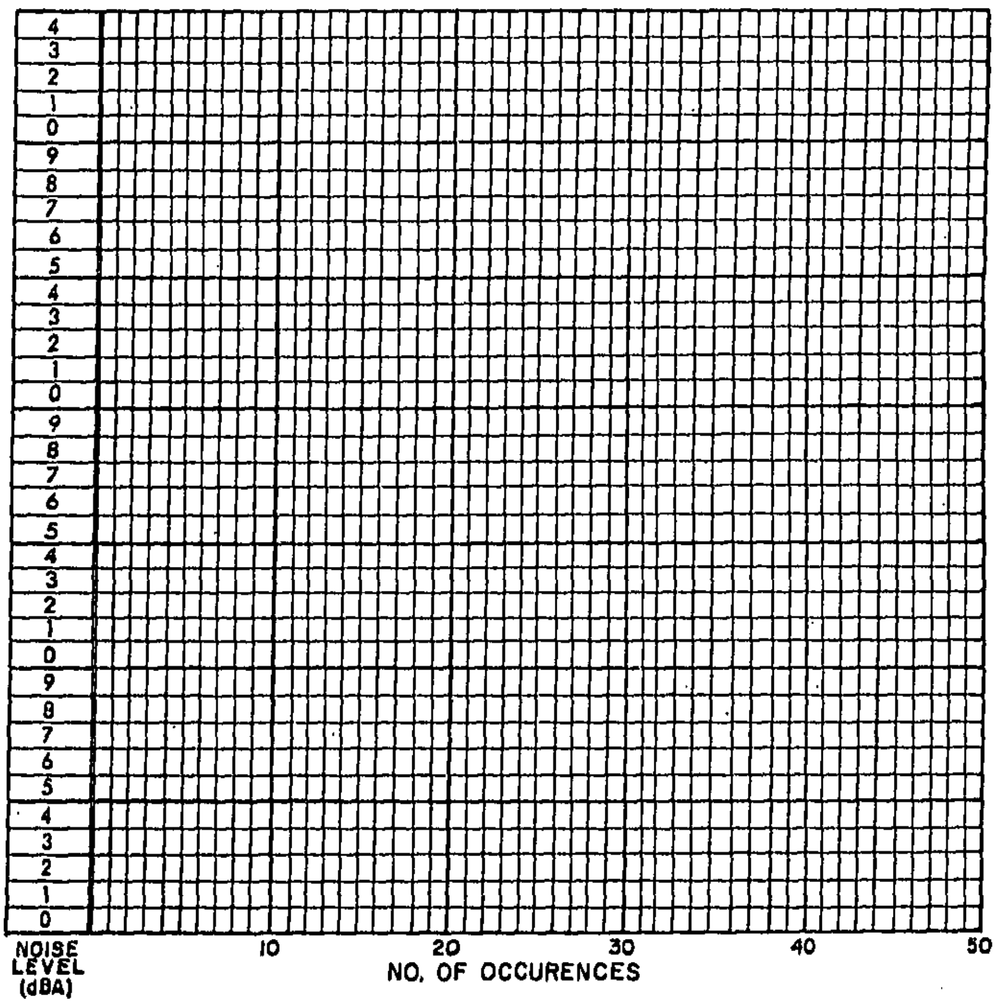
CALIB: TYPE________ SN____________ WIND SPEED________ DIRECTION________

WEATHER CONDITIONS MET: Yes[ ] No[ ]
MICROPHONE POSITION MET: Yes[ ] No[ ]

NOTES AND SKETCH:

TOTAL SAMPLES	L_{10}	L_{90}	L_{99}
100	10 th	90 th	99 th
150	15 th	135 th	149 th
200	20 th	180 th	198 th
250	25 th	225 th	248 th
300	30 th	270 th	297 th

Sample from top.



APPENDIX B: BASICS OF SOUND

B.1 Physical Nature of Sound Sources, Paths, and Receivers

Any noise problem can be viewed in terms of three inseparable aspects:

- The source of sound waves
- The path(s) they take
- The receiver(s) who hears them.

Even the definition of sound (i.e., sound is defined as the sensation produced in the organs of hearing by certain pressure variations or vibrations in the air) implies that each of these three components is important. In this section, each component will be highlighted as it relates specifically to railroad noise.

As its definition suggests, sound requires a *source* of vibrations or air pressure variations, a medium or *path* that will propagate the sound, and a *receiver* to be sensitive to those vibrations after they have traveled through the path(s) from the source(s). A source can be any vibrating object, such as a loudspeaker or a wheel on a rail. This object will invariably push and pull on the surrounding air molecules, which in turn, will do likewise to the air surrounding them. As this series of expanding and contracting layers of air propagates away from the source (in the form of waves traveling at about 338 m/sec [1128 ft/sec]), it encounters objects in its path, some of which reflect more sound energy toward receivers than would otherwise have gotten there. It should be made clear that the energy in the wave, not the air itself, propagates great distances. The vibratory motion in the air remains very small, but if the oscillations are large enough and occur within a certain range of frequencies, they are detected as sound.

Two characteristics of sound deserve discussion before specifics of receivers, paths, and railroad sources are further examined. The propagation and reception of sound depend largely on the apparent size and shape of the source as viewed from the receiver. For example, the rate at which sound energy is dissipated due to the natural spreading of waves away from the source (just as the height of water waves diminishes radially from a pebble dropped into a pond) depends on whether the source is "seen" as a *point* (e.g, a locomotive 300 m [1000 ft] away) or a *line* (e.g., 100 rail cars 30 m [100 ft] away). Because of this effect, the loudness of sound generally decreases more rapidly as we move away from point sources than as we move away from line sources.

Apart from the manner in which sound waves behave physically, they must also be considered in terms of the human sensitivity to these waves once they reach the receiver. Sound waves (the push-pull motion) produced by a vibrating source can be measured (with specially designed instruments) as slight variations in pressure. Loud and soft sounds correspond, respectively, to large and small pressure variations, but the range of pressure variations that the human ear can detect is tremendous. A very loud sound can cause one million times the pressure variations of a very quiet sound. Thus, to describe sound in terms of pressure variations would be very cumbersome. To compute a simple acoustics problem in this manner would require a vast effort just to add up all of the digits. A more compact scale is needed, therefore, to describe the size (or energy content) of a sound.

The scale that has been devised for this purpose is based upon logarithms. In acoustics, the unit of this logarithmic scale is the *decibel*, or one-tenth of a *Bel*. The *Bel* is named for Alexander Graham Bell, the famous inventor. For this reason, the abbreviation of decibel, dB, capitalizes the second letter.

The decibel scale most commonly used to measure the size of a sound is sound pressure level (SPL). The mathematical formula for the sound pressure level is

$$\text{sound pressure level (SPL)} = 20 \log \frac{P}{P_{reference}} \quad ,$$

where $P_{reference}$ refers to the standard reference pressure (corresponding approximately to the faintest audible sound), and P is the pressure of the sound in question. For those wishing a more detailed discussion of sound pressure levels and other decibel scales, refer to any basic text on acoustic measurements.

Two such texts are: *Handbook of Noise Measurements* by the General Radio Company and *Acoustic Noise Measurements* by the Bruel & Kjaer Company. At present, however, it is only important to understand that sound pressure levels are a measure of the size of a sound in terms that not only simplify calculations but also relate closely to the subjective response of loudness.

Obviously, two locomotives make more noise than one. Predicting the *actual* sound level increase, however, is perhaps not quite so obvious. For example, if two identical locomotives operate simultaneously under the same load, equidistant from the microphone, the resulting sound level will be only 3 dB higher than that for the single operating locomotive. For two sounds of different SPL, the sum of the two will always be less than 3 dB above the sound level produced by the stronger source alone. If the two sound sources produce individual levels that differ by 10 dB or more, adding the two together will produce a level not significantly different from that produced by the stronger source operating alone.

To add any two sound levels, the chart in Fig. B.1 can be used.

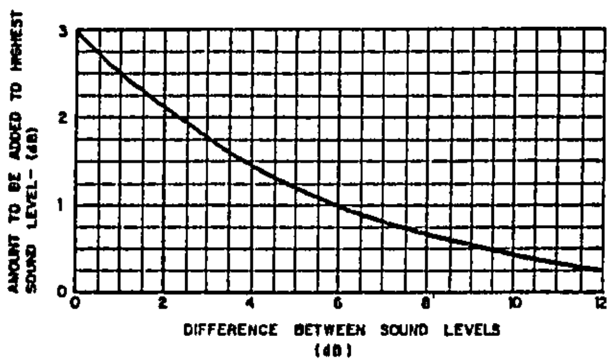


FIG. B.1. GRAPH FOR DECIBEL ADDITION.

First, find the difference between the larger and smaller sound levels. Then locate this number on the horizontal scale. Follow this point upwards to the intersection with the curved line. Note the number to the left, on the vertical scale. Add this number to the *larger* of the two sound levels. This is the combined level. For example, to add levels of 70 dB and

74 dB, the difference is 4 dB. From Fig. B.1, the amount to be added to the larger is almost 1.5 dB. Therefore, the total is about 75.5 dB. In this way, any number of sound levels can be combined in pairs, beginning with the lower and working toward the higher levels.

B.2 Sound Receiver Characteristics

B.2.1 Hearing response

Sound energy is converted into the logarithmic decibel scale not only because it is more convenient to deal with smaller numbers that represent the great range of pressures to which people are sensitive, but also because hearing sensitivity to loudness behaves "logarithmically." Figure B.2 depicts common sounds and the corresponding sound levels, showing that 0 dB represents the faintest sound that a person with excellent hearing can perceive, while a sound that causes physical pain would be at or above 120 dB.

In addition to the measured magnitude of a sound wave, the *frequency* must also be considered. The frequency is simply how frequently the sound wave vibration (the push-pull cycle) repeats (cycles) itself in a given space in one second. Some sound waves vibrate quite rapidly, others less so. Still other sound waves vibrate at many different rates simultaneously. The ear perceives the frequency of these vibrations as the "pitch" of a sound. High-pitched sounds vibrate very rapidly; low-pitched sounds vibrate at a much slower pace. The frequency at which the air particles vibrate in a sound wave is measured in units of Hertz, or Hz, named after the famous 19th century German scientist. One Hz is one cycle per second.

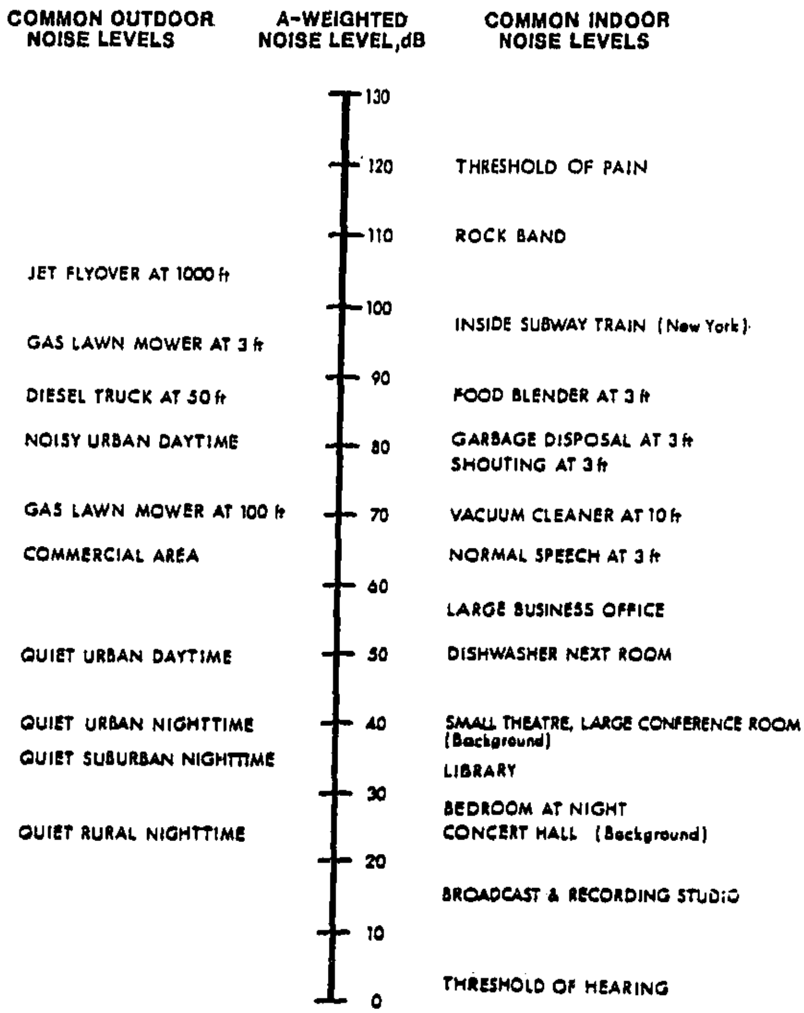


FIG. B.2. COMMON OUTDOOR AND INDOOR NOISE LEVELS.

The human ear can detect a wide range of frequencies, from about 20 to 20,000 Hz. In the low range (20 to 500 Hz) are the bass sounds — those produced in a hi-fi by the "woofer." The mid-range frequencies (500 to 2000 Hz) are where most speech occurs. The high frequencies (2000 to 20,000 Hz) are the treble sounds, produced in a hi-fi by the "tweeter." People are least sensitive to the very lowest and highest frequencies and most sensitive to the mid-range, or speech, frequencies.

B.2.2 Sound level descriptors

If two sounds of equal sound pressure level were heard, one at 63 Hz and one at 1000 Hz, the 1000 Hz sound would be judged louder than the 63 Hz sound. This characteristic, peculiar to human hearing, must be accounted for when sound is measured if the measurement value is to relate to people's sense of loudness. The sound-measuring instrument used for railroad noise enforcement electronically modifies the sound so that it corresponds to the sound the ear detects.

The electronic filter used in sound-measuring instruments to approximate the frequency response of the human ear is called the A-scale, or A-weighting, filter. In imitation of human hearing sensitivity, a sound-measurement instrument equipped with an A-weighting filter is less sensitive to sounds of low or very high frequencies than to sounds of mid-range frequencies. Thus, by first filtering a sound through an A-scale device, a measurement is obtained that corresponds approximately to how people would rate the sound. These measurements are called *A-weighted sound levels* and are expressed in decibels on the A-scale as "A-weighted sound levels of X dB." The A-weighted decibel scale has been widely accepted as the proper measure of railroad noise. In fact, the levels shown in Fig. B.2 are really typical indoor and outdoor A-weighted sound levels (L_A), not unweighted or *overall* dB.

In order for any measured noise level to have meaning, some mention should be included (either stated or implied) regarding the time-varying nature of the sound. For this purpose, "descriptors" are used that employ not only the A-weighted sound levels but also a measure of the time during which a specific event occurs.

One of the simpler descriptors that states the highest sound level measured, or expected in a given environment over a specified period of time (or for a given event), is the "maximum A-weighted level" L_{max}. Normally, the L_{max} will occur at the time of closest approach of a moving source; as this distance increases, the L_{max} stands out less and less above the background noise at the receiver. For close distances, the maximum noise levels are high, and the noise level changes are rapid. The significance of this fact will be pointed out later.

The energy-equivalent (or energy-average) sound level L_{eq} is becoming commonly used as a descriptor of noise that fluctuates with time. L_{eq} involves an average of the *energy* of the fluctuating sound, rather than an average of the sound *level*. For example, if a fluctuating sound is measured using A-weighting, such that half the time the level is 60 dB and half the time the level is 80 dB, the sound *level* average is 70 dB. However, the *energy* average (L_{eq}) is higher, 77 dB, because 80 dB represents so much more sound energy (100 times) than 60 dB. Therefore, the L_{eq} tends to emphasize the loudest sounds (as does people's hearing) because these sounds contain most of the sound energy.

The L_{eq} is defined as the continuous, or steady-state, A-weighted sound level that has the same sound energy as the fluctuating sound level being measured.

Because the L_{eq} does not depend on the statistical nature of the noise-time pattern, it provides an effective method for the comparison or combination of noises from sources whose time histories differ greatly. For example, without L_{eq}, the comparison of noise from a highway and a railroad would be very complex. The L_{eq} provides a straightforward comparison and total by the simple operation:

$$\left.\begin{array}{l} L_{eq}\ \text{(Railroad)} = 55\ \text{dB} \\ L_{eq}\ \text{(Highway)} = 64\ \text{dB} \end{array}\right\}\ \text{Total}\ L_{eq} = 64.5\ \text{dB.}$$

The time period over which the L_{eq} is developed may usually be taken as 1 hr, 24 hr, or a 15-hr daytime and 9-hr nighttime period. These time periods would provide a 1-hr L_{eq}, a 24-hr L_{eq}, or a daytime or nighttime L_{eq}, respectively.

As creatures of a regular work habit, people have come to expect the right to (relative) evening and nighttime quiet in the home environment. The day-night sound level (L_{dn}) has been developed to describe this quality of the habitable, 24-hr noise environment. The L_{dn} is the A-weighted noise level averaged (on an energy basis) over a 24-hr period, with appropriate weightings applied for the noise levels occurring in the nighttime periods. The L_{dn} incorporates a 10-dB adjustment for nighttime (10 p.m. to 7 a.m.) noise intrusions to account for the increased annoyance during those hours.

As a train moves, the sound level near the tracks rises and falls with time. If the sound levels near the tracks are recorded continuously before, during, and after the passby of a train, a time history of the sound similar to the one in Fig. B.3 would be obtained.

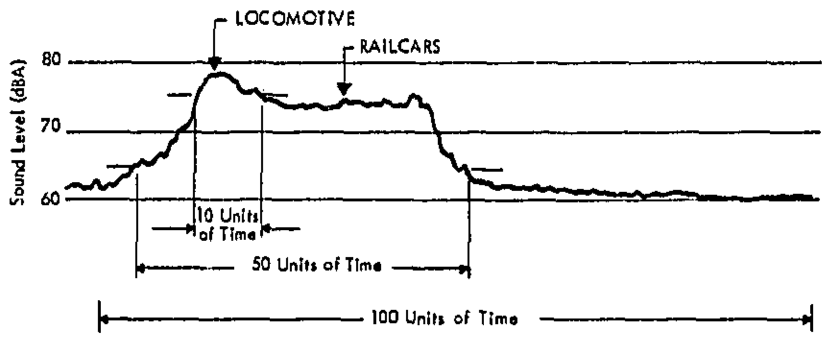


FIG. B.3. TIME HISTORY OF A TRAIN PASSBY.

This rising and falling of the sound level is mainly a distance effect. From the previous discussion on the effects of distance, it can be seen that the maximum sound level will be produced when the locomotive is closest to the measuring microphone. The sound level remains relatively constant, however, as the full train passes by the microphone.

Several other time-related descriptors have been developed to describe the fluctuating character of many noise environments. This is important because annoyance to noise is apparently based partly on its fluctuating nature.

Suppose that the length of the sample trace in Fig. B.3 is assigned an arbitrary time interval of 100 units. The length of 10 time units and 50 time units on that sample trace could be determined. By examining the upper portions of the sample trace, one can then determine the sound level that is exceeded for these 10 time units and 50 time units; these are called the 10th and 50th percentile levels, L_{10} and L_{50}, respectively, of the noise sample.

In Fig. B.3 this procedure is followed. By approximate fitting, it is found that L_{10} = 76 dB, and L_{50} = 65 dB, approximately. For this illustration, notice that the total noise level fluctuates greatly (between 61 and 78 dB - a 17-dB swing) and that the difference between the L_{10} and L_{50} values is also quite large (11 dB). Large differences, such as these, are characteristic of sparse traffic and close distance to the track.

Percentile levels can be determined for a specific event (such as the train passby in Fig. B.3) or for a specified time period (such as 10 min, 1 hr, etc.). The noise level exceeded for any desired percentage of the time can be determined, such as 1%, 90%, and 99% (L_1, L_{90}, and L_{99}, respectively).

B.2.3 Effects of sound

Since noise levels are added logarithmically, people often do not understand what a 1-dB increase in noise level means subjectively. Therefore, the following information is presented to help clarify the effects of increasing noise. Under real-life listening conditions, the following noise level changes would probably be perceived as

1 dB Not noticeable

3 dB Barely noticeable, only if the listener concentrates on the noises heard

5 dB Clearly noticeable, but not outstanding

10 dB Clearly noticeable, evaluated subjectively as halving (or doubling) in loudness

20 dB 1/4 (or 4 times) the loudness of a reference noise level.

Excessive noise can affect both animals and humans in several ways. One measureable effect of noise is hearing loss. Damage or loss of hearing relates to both the level and duration of the sound at the receiver. In general, however, the noise levels required to produce hearing loss are higher than the noise levels measured in the vicinity of railroad tracks or railyards.

Probably the most well-known effect of noise on people is the interference or "drowning out" of speech, television and radio listening, and telephone usage by loud noises. This effect has been well researched and can be quite accurately predicted based on the speaker's voice level (or television volume), distance from speaker to listener, and the sound level of the interfering noise at the receiver. Table B.1 shows maximum sound levels for reliable conversation at the distances and noise levels indicated.

Noise levels that interfere with sleep are not as well defined. This is due to the wide variation in human sensitivity to noise while sleeping and the different physiological levels of sleep. Although it is clear that sleep quality is reduced by noise events, the significance of these disturbances is still under investigation and not clearly understood.

TABLE B.1. SPEECH INTERFERENCE TABLE — AVERAGE NOISE LEVELS [db(A)] AT A RECEIVER THAT PERMIT BARELY ACCEPTABLE SPEECH INTELLIGIBILITY.

Distance, ft (m)	Voice Level			
	Normal	Raised	Very Loud	Shouting
1/2 (0.15)	81	87	93	99
1 (0.3)	75	81	87	93
2 (0.6)	69	75	81	87
4 (1.2)	63	69	75	81
6 (1.8)	60	66	72	78
8 (2.4)	57	63	69	75
10 (3.0)	55	61	67	73
12 (3.6)	53	59	65	71
16 (4.8)	51	57	63	69

Note: Values apply for average male voices (reduce values 5 dB for female voice), with speaker and listener facing each other, using unexpected word material. Values may be increased 5 dB when familiar material is spoken. Distances assume no reflecting surface to aid the speech sound.

B.3 Sound Path Characteristics

B.3.1 Attenuation of sound with distance

As indicated earlier, the natural spreading of sound waves away from a source usually causes a diminishing of the wave energy at greater distances, and the rate of this loss of energy with distance depends on whether the source is "seen" as a point or a line. This loss is called "geometrical spreading" and is usually expressed in terms of so many dB per doubling of distance. Besides being dependent on the type of source (whether it is "viewed" as being a point, such as a single locomotive at a great distance, or a line, such as a long string of nearby rail cars), the measured sound level change with distance depends on whether the intervening ground is hard or soft. Table B.2 summarizes the expected losses.

TABLE B.2. SOUND LEVEL CHANGE IN RELATION TO TYPE OF SOURCE AND GROUND.

Source Type	Ground Type	dB Loss per Doubling Distance
Point	Hard (asphalt, hardpan, concrete)	6
Point	Soft (grass, cultivated farmland, crops)	7.5
Line	Hard	3
Line	Soft	4.5

From Fig. B.4, if the A-weighted sound level of a locomotive is measured at 15 m (50 ft) and at 60 m (200 ft), the measurement value at 60 m (200 ft) – four times farther away – would be 12 dB lower than the measurement value at 15 m (50 ft), assuming hard ground.

B.3.2 Sound path obstacles

When a sound wave encounters an object of sufficient size and density, some of the energy is reflected, some is absorbed, some may still pass through, and some will "bend" around the edges of the barrier. If the obstacle is properly (or improperly) located, it can actually increase the level at the receiver due solely to reflection.

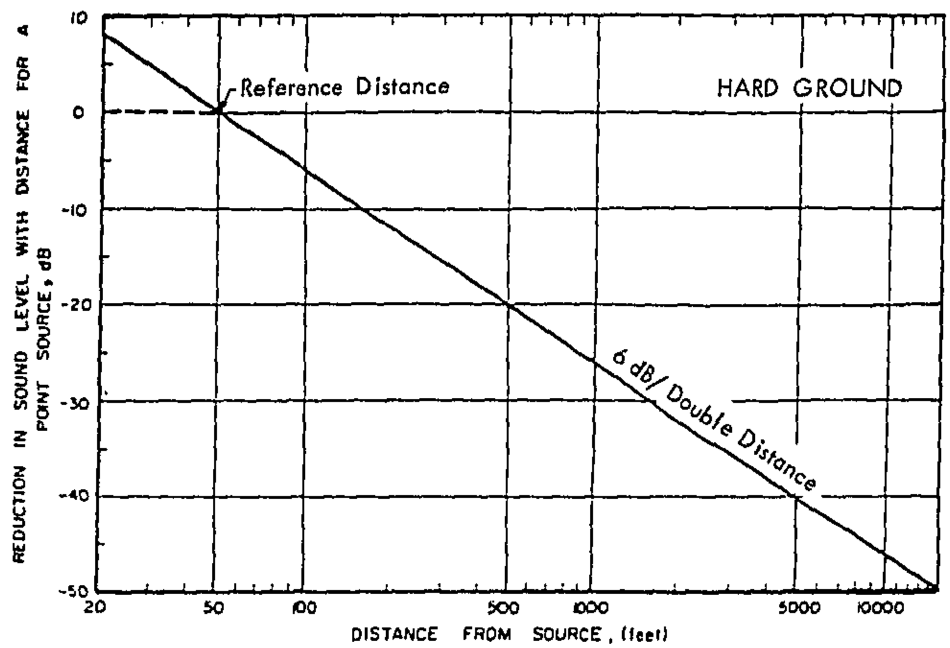


FIG. B.4. REDUCTION IN SOUND LEVEL WITH DISTANCE FOR POINT SOURCES OVER HARD GROUND.

The simplest form of sound reflection occurs when sound waves strike a large, flat, hard surface, as shown in Fig. B.5. As the waves strike the surface, they rebound. The reflected sound waves leave at an angle equal to the angle at which the incoming waves struck the surface.

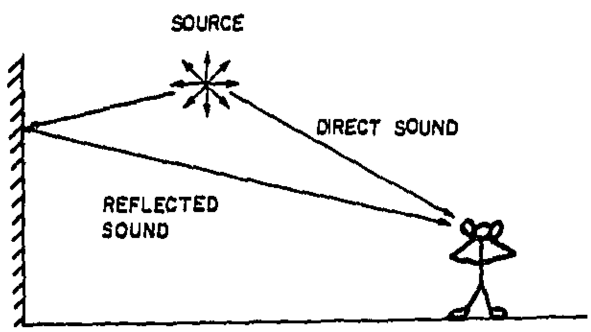


FIG. B.5. EFFECT OF A SOUND-REFLECTING SURFACE.

Typical large reflecting surfaces near railroad tracks and yards might be buildings, bridge structures, embankments, retaining walls, and parked rail cars. The presence of large reflecting surfaces can significantly change the sound level measured from rail sources. Because of this effect on measurements, the noise emission regulations include measurement site criteria regarding the presence of miscellaneous objects.

Of course, just as reflections can increase the level at a receiver, some obstacles can reduce the level at the receiver by shielding the receiver from the source. To be effective in reducing noise levels, such "barriers" must completely break the line of site from the source to the receiver.

APPENDIX C: USE OF SOUND LEVEL METERS

The most important factor in performing rail carrier noise compliance measurements is the proper use and understanding of the sound level meter. In this section, the sound level meter is described, along with the auxiliary equipment that is needed to perform the required measurements correctly. Measurement procedures that are intended to yield as consistent and accurate readings as possible are recommended. Additional equipment that can enhance the quality and quantity of data acquired is also listed.

C.1 How the Sound Level Meter Works

The chain of events from the production of a sound to the reading of its level on a meter involves many intermediate steps. First, the pressure fluctuations in the atmosphere must be converted to an electrical signal ("transduced") by a microphone. Microphones generally have 1/2-in. or 1-in. diameters and are rated as to the accuracy of their frequency response for sound impinging from all angles (random incidence).

After the signal has been transduced by the microphone, it passes through a preamplifier into a spectrum-shaping network inside the sound level meter. The spectrum weightings available on most meters are A, B, C, and linear (no weighting). The A-weighting filter adds or subtracts from the various frequency components of the signal in a way designed to mimic the response of the human ear. Therefore, the A-weighting is used for railroad noise measurement purposes.

Once filtered, the signal is fed into a second amplifier inside the meter that usually has a gain control in 10-dB steps adjustable by the operator. The proper attenuator selection must be made so that the maximum excursion of the meter needle in response to a noise falls within the range of the meter window (usually 15 to 20 dB). If the anticipated maximum level is underestimated, the needle will top out, and the true maximum will have been missed.

Before the signal reaches the meter, it may be fed to an external device such as a tape recorder or headphones. The signal passes internally through a needle response-time network, which is set to either Fast or Slow for noise compliance measurements. The Slow setting gives a continuous reading, which is an approximate average of the sound level over the previous 1 sec. The needle moves more slowly at this setting than at the Fast setting, making the reading easier. The Fast setting averages the signal over about 1/8 sec (125 msec) and causes the needle to move more rapidly.

The overall accuracy of sound level meters in transferring pressure fluctuations to meter needle readings is codified by the American National Standards Institute (ANSI). ANSI Standard S1.4-1971 classifies sound level meters according to four types: Type 1 (Precision), Type 2 (General Purpose), Type 3 (Survey), and Type F (Special Purpose). For rail carrier noise compliance measurements, Type 1 meters are preferred. Type 2 meters may also be used if certain adjustments are made to the readings (see Sec. 3.4).

C.2 Auxiliary Equipment

In addition to the sound level meter, at least four pieces of auxiliary equipment are required. A number of other pieces are also suggested for making noise measurements. The required pieces are a calibrator, windscreen, tripod, and a log sheet or annotation pad.

When the calibrator is coupled to the microphone, the calibrator produces a standardized, stable source of sound at a single frequency and at a known sound pressure level. It is good practice to calibrate the meter before and after taking each set of noise data, and to make any small adjustments in the "gain" of the sound level meter to keep it reading correctly. A "small adjustment" might be up to 1 dB. Before adjusting the gain of the sound level meter, let it warm up for at least 2 min. Let the calibrator warm up for at least 1/2 min, and check the battery level of the meter. If the needle deflection is below the appropriate lower limit line of the meter scale on battery check, new batteries should be installed in the sound level meter. The batteries of the calibrator should also be checked periodically and replaced when necessary. If, at the time of a calibration, the sound level meter appears to have shifted more than about 1 dB from its last calibration, this is a clue that something may be wrong with either the calibrator or the sound level meter. If battery replacement does not return the instrument to reasonably correct condition, refer to the *Instruction Manual* for assistance or send the meter and calibrator back to the manufacturer for a check or repair. It is useless to take questionable data.*

A windscreen is a porous sphere, often made of foam, that covers the microphone to reduce the wind turbulence without reducing the sound signal. Without a windscreen, even low-speed wind movement over the microphone produces turbulent

*At regular intervals (at least once per year), measurement equipment should be checked out to ensure that operating characteristics satisfy the requirements specified in the regulation (Sec. 201.22).

noise that may be greater in level than quiet background noise that may be measured. In high winds (greater than 12 mph) and/or in quiet backgrounds, false sound level readings may be obtained even with the windscreen in place. In this case, readings should not be taken. To listen for wind noise or other false nonacoustic signals, a set of well-fitted, high-quality, high-impedance earphones may be connected to the sound level meter when background noise levels are being taken. (Low impedance headphones load down the output of the sound level meter so that falsely low readings are obtained.)

A tripod supports the sound level meter during measurements, leaving the measurer's hands free for taking data. The microphone height should be 1.2 to 1.5 m (3.9 to 4.9 ft) above ground level.

A log sheet or annotation pad is an essential piece of measurement equipment, even if the tape recordings will be analyzed at a later time. Before taking measurements, the following information should be noted:

- Time of measurement
- Location of site
- Location of microphone
- Description of equipment
- Equipment settings
- Weather conditions (temperature, humidity, wind speed).

Additional recommended equipment includes a stopwatch, or watch with a large, readable sweep-second hand; a dry-bulb and wet-bulb anemometer for measuring humidity; a thermometer; a tape measure; a wind speed indicator; duct tape (or other strong tape) for securing microphones and cables; and extra batteries for calibrator and sound level meter.

C.3 Measurement Procedures

Briefly, a proper noise measurement procedure should follow these steps:

1. Determine appropriateness of microphone location, weather conditions, and background noise
2. Set up equipment
3. Calibrate before measurements
4. Annotate initial conditions
5. Take data
6. Calibrate after measurements
7. Annotate final conditions
8. Take down equipment
9. Analyze and document results.

The detailed procedural requirements for making rail carrier noise compliance measurements are given in Sec. 3; therefore, only general guidelines with respect to these steps are presented here.

Proper location of the microphone in an essentially non-reverberant area is necessary in order to avoid misleading readings caused by nearby reflective surfaces such as buildings and steep hills. Contrary to popular opinion, trees do not greatly influence noise propagation, unless there is a very thick stand of them. Therefore, one or two trees in the site area may be ignored, along with one or two people, signal poles, low lying boxes and equipment, etc., as long as they are no closer than a few meters from the microphone.

High humidity can affect noise measurements by causing intermittent short circuits at various points in the electrical system through condensation. Excessive wind can add to the noise level readings by generating turbulence around the microphone. At extremely low temperatures, measurements should be avoided because batteries will be sluggish or need frequent replacement and the calibrator may drift. These and other environmental conditions should be checked with respect to specifications in the equipment instruction manuals before proceeding to set up equipment.

During equipment setup, check for loose connections and proper equipment settings before calibrating. Annotate the required information on your log sheet, and proceed with the measurements. If there are drastic changes in weather conditions or a large period of time elapses between one block of data and another, calibrate again, and note the new conditions.

While making the measurements, the observer should stand to the side and to the rear of the microphone (if it is attached to the meter). This will minimize the microphone picking up reflections off the observer from the sound source.

When the data collection phase is finished, calibrate the system once more, note the time and other pertinent information, and dismantle the system. The data should be analyzed as soon as possible thereafter so that details of the measurement program are not forgotten by the attending observers.

C.4 Alternate/Additional Measurement Equipment

Some additional equipment exists that can replace and/or enhance the sound level meter.

Graphic level recorders record the time history of fluctuations in noise level on a continuously rolling drum of paper. This equipment is very useful for visualizing the attack and decay time of car-coupling noise, for instance. It is also useful for identifying other intrusive noises such as car passbys and aircraft flyovers. The observer can merely put a mark near the peak of the intrusive event indicating the source of the noise. A drawback of this equipment, however, is that the response time of the pen that draws on the paper cannot be accurately calibrated and adjusted. Therefore, except for nearly steady-state conditions, the noise level readings obtained are best restricted to illustrative purposes.

Tape recorders are the best form of noise measurement, since virtually all the noise data are collected and stored. However, only professional models may be used if the data are to be valid. Cassette recorders that cannot be calibrated and that do not have frequency response similar to Type 2 or better sound level meter specifications described in ANSI S1.4-1971 are not suitable, except for source identification or annotation. Most inexpensive cassette recorders have automatic level control during recording, and thus are useless for recording noise data.

Integrating sound level meters provide additional information that can reduce analysis time and increase accuracy. These meters, depending on the model, can average the impinging noise level over a specified period of time, provide statistical noise level information, or integrate the noise level over the time during which a specified threshold is exceeded.

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