STANDARD 806-03

SIGNATURE MEASUREMENT STANDARDS GROUP

ACOUSTIC SIGNATURE COLLECTION METHODOLOGY STANDARD

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Provides a standard procedure foer the collection of atmospheric acoustic signatures. Reviews acoustic sensor parameters, methods of deployment, instrumentation procedures, ground truth requirements, calibration procedures, and meteorological and other factors affecting sound propagation. Applies to measurements involving wheeled and tracked vehicles, air-cushioned vehicles, rotary and fixed-wing aircraft, jet noise, cruise missiles, watercraft, explosive type sources, or combinations thereof.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

The development of this standard grew out of the recognized need to establish compatible methods among all Department of Defense (DoD) test centers for the collection of acoustic signature data. In recognition of the diversity of testing situations that confront the ranges, these recommendations are formulated to allow for maximum flexibility in terms of implementation and analysis of data. The Signature Measurement Standards Group (SMSG) also recognizes the importance of capturing this knowledge for use and benefit of the next generation of testing engineers.

The *Acoustic Signature Collection Methodology Standard* captures the corporate knowledge of personnel who have many years of acoustic experience. These individuals are recognized and respected for their contributions to the discipline. It is safe to assume that 48 or more technical personnel contributed to making this document possible. Development of the standard was a team effort, which included multiple agencies from the government, military, universities, and private industry. These include, but are not limited to the following: the National Center for Physical Acoustics, University of Mississippi; the US Army National Ground Intelligence Center; the US Army Yuma Proving Ground; the 46th Test Wing (TW) Chicken Little Program Office; MITRE Corporation; Penn State University; the 46TW/TSR Eglin AFB FL; Army Research Laboratory, Adelphi, Maryland; USAF Arnold Engineering Development Center; US Army Waterways Experiment Station; US Army Aberdeen Test Center; Bishop Multisensor Corporation; and the US Army BAT Program Office.

The Chair of the Range Commanders Council, Seismic, Acoustic, and Magnetic Committee, Signature Measurement Standards Group would like to give special recognition to four individuals who made significant contributions to this project: Nino Srour from the US Army Research Laboratory, Adelphi, Maryland; Dr. James Chambers, University of Mississippi; De Loyd, US Army National Ground Intelligence; and Dr. Charles Burmaster, MITRE Corporation. The SMSG welcomes any comments, questions, corrections, or additions to this document. Please address any inquiries to:

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ACRONYMS & INITIALISMS

ac/AC	alternating current
ANSI	American National Standards Institute
CD	compact disk
CPA	closest point of approach
dB	decibel
DoD	Department of Defense
FFT	fast Fourier transform
GMT	Greenwich Mean Time (Zulu)
GPS	Global Positioning System
Hz	hertz
IEC	International Electrotechnical Commission
IRIG	Interrange Instrumentation Group
MET	meteorological
NIST	National Institute of Standards and Technology
Pa	pascal
RASS	radio acoustic sound system
RCC	Range Commanders Council
re	reference
RH	relative humidity
SAM	Seismic, Acoustic, and Magnetic Committee
SMSG	Signature Measurement Standards Group
SODAR	sonic detection and ranging

SECTION 1

INTRODUCTION

1.1 General

Man-made sound sources, including all types of machinery and human activity, have their own peculiar characteristics. Quite often, the sound is distinctive enough to allow identification and tracking of the source. However, as a sound propagates through the atmosphere, it may be affected by a variety of meteorological and atmospheric conditions. The sound received at a remote listening station can also be modified by surface conditions such as terrain and other geographical features. Line of sight is not required to receive an acoustic signal, but obstructions can influence received amplitude and frequency. In addition, characteristics of receiving, measurement, and recording systems can influence data. Careful characterization of all these factors is critical to developing accurate signature measurements. The goal of this document is to define the measurements that must be made and the data that must be recorded if measured acoustic signals are to be useful.

1.2 Scope

This document provides a standard procedure for the collection of atmospheric acoustic signatures. Acoustic sensor parameters and methods of deployment are described. In addition, instrumentation procedures, ground truth requirements, calibration procedures, meteorological and other factors affecting sound propagation are reviewed. The standard is broad enough that acoustic signature data can be analyzed and processed in numerous ways. This standard applies, but is not limited to, measurements involving wheeled and tracked vehicles, air-cushioned vehicles, rotary and fixed-wing aircraft, jet noise, cruise missiles, watercraft, and explosive type sources (i.e., plastic explosives, bombs, artillery, mortars, and missiles) or combinations of these.

When planning to capture acoustic measurements in the atmosphere, many variables must be identified, evaluated, controlled, and documented. At a minimum, these include the characteristics of the sound source, a description of the receivers and recording system, characterization of meteorological and ground conditions along the propagation path, a description of the terrain, and notes on background or nuisance sound sources.

This procedural standard does not address sporadic occurrences such as high-amplitude events in the near field, shock waves from supersonic events, infrasound, or very long-range propagation (greater than 10km or less than 10 Hz). The procedures contained here reflect technology that is in current use at the time this standard was written. New approaches and sensors should be encouraged, and this standard will be modified as these innovations are thoroughly tested.

1.3 Reference Documents

1.3.1 American National Standards Institute (2001). *Sound Level Meters.* Specification Document No.: ANSI S1.4-1983 (R2001).

1.3.2 American National Standards Institute (1999). *Template Method for Ground Impedance.* Document No.: ANSI S1.18-1999.

1.3.3 Burmaster, C.L., Donnangelo, N.C. and Hogenkamp, H.P. (Sep 2002). "Improved Acoustic Detection Using Resonant Elements," *Proceedings of the 2002 Military Sensing Symposium, Battlefield Acoustics.* John Hopkins University, MD.

1.3.4 International Electrotechnical Commission. *Electroacoustics – Sound Level Meters – Part 1: Specifications.* Document No.: IEC 61672-1 (2002-2005) [A reissued document formerly numbered 60651].

1.3.5 Kinsler, L.E., Frey, A.R., Coppens, A.B and Sanders, J.V. (2000). *Fundamentals of Acoustics, Fourth Edition.* John Wiley and Sons.

1.3.6 Ziomek, Lawrence J. (1994). Fundamentals of Acoustic Field Theory and Space-Time Signal Processing. CRC Press.

SECTION 2

ACOUSTIC SIGNATURE COLLECTION METHODOLOGY

2.1 Acoustic Sensors and Instrumentation

The simplest form of an atmospheric acoustic data collection circuit consists of an acoustic source and a collection circuit. The circuit consists of a microphone with a windscreen, a preamplifier, an amplifier, connecting cables, a recording/playback system, and a power source.

2.1.1 Acoustic Sensors

For the purpose of this document, the words *acoustic sensor* and *microphone* are synonymous. Microphones are used to convert acoustic pressure fluctuations in the atmosphere into electrical signals. A precision device of scientific grade must be used when making acoustic measurements. These devices must meet established national standards (American National Standards Institute, ANSI S1.4-1983 or International Electrotechnical Commission, IEC 60672). A current traceable calibration from the National Institute of Standards and Technology (NIST) of these sensors is required.

2.1.2 Windscreens

No outdoor measurement should be attempted without use of a windscreen. Windscreens are used to reduce the effects of pressure fluctuations carried across the sensitive area of the microphone by the ambient wind. Wind flowing across the surface of the microphone introduces low frequency noise in the microphone output signal. A windscreen can also protect the microphone from the accumulation of water vapor and dust in the work environment. While the windscreen reduces low-frequency noise, it can attenuate the acoustic signal at high frequencies. Typical loss of signal that results from using windscreens is 0 dB at 3 kHz, 0.5 dB at 5 kHz, and 2 dB at 12 kHz. Even when the signal of interest is at high frequency, wind noise in the absence of a windscreen will often saturate preamplifiers/amplifiers or the sensor. Acoustic measurements should be avoided when wind speeds exceed 7.0 meters/second (15.7 knots/hour). An 8-cm diameter windscreen should be sufficient for most data-collection exercises. If the source has significant energy below 100 Hz, or it is necessary to collect acoustic signatures when wind speeds exceed 7.0 meters/second, a larger windscreen should be used. In such conditions, it is imperative that the background noise level in the frequency range of interest be monitored in real time and the windscreen be increased in size. If that is not sufficient, measurements should be suspended.

Recent tests involving the use of aerodynamically-shaped windscreens have shown that it is possible to collect quality acoustic data in conditions that exceed the maximum wind speeds (7.0 meters/second). These applications typically involve the use of flying platforms such as remotely-controlled aircraft.

2.1.3 Preamplifier and Instrumentation Amplifier

Preamplifiers for microphones are typically placed very near the sensing element. Preamplifiers must be capable of driving a length of cable without significant loss of signal or distortion. Instrumentation amplifiers are placed in the signal path after the preamplifier and near the microphone to avoid noise amplification. Proper impedance matching should be a consideration when using amplifiers. Instrumentation amplifiers have typical gains of 20 dB and 40 dB. All amplifiers should be selected to have a frequency response similar to that of the microphone unless the amplifier is being used as a filter.

2.1.4 Dynamic Range

The dynamic range is typically specified for a microphone-preamplifier combination. The low end of the dynamic range is determined by the self-noise of the preamplifier when its input is terminated by the capacitance of the microphone. Preamplifier self-noise and microphone sensitivity limit the low end of the dynamic range. The upper end of the dynamic range is usually limited by the amplitude or the output-current level at which the preamplifier no longer amplifies linearly or the level at which the microphone begins to distort the signal. The dynamic range is expressed in dB.

2.1.5 Connecting Cables

The cables used in the data collection circuit should have low noise characteristics. The length of the cable will sometimes influence the quality of the data obtained from hardwired, data-gathering systems; therefore, all cable runs should be kept as short as possible. Instrumentation cable is shielded, twisted pair, insulated 20 AWG or larger wire. The twisting holds the lines together mechanically and aids in balancing each conductor to minimize the influence of nearby magnetic and electrostatic fields. Each sensor will have its own cable. The individual cables are bundled to create a harness.

> **NOTE**
>
> Ensure that power cables are not set alongside of the data cables.

2.1.6 Instrumentation Recorder

Instrumentation recorders typically have multiple channels. The selected recorder should have a frequency response as great as the sensor/amplifier system and have a dynamic range sufficient to capture all acoustic events with a minimum of 3dB of headroom. Digital audio recorders are often used. Special care must be taken to ensure that the frequency components of the input signal do not exceed one-half of the channel sampling rate (Nyquist frequency).

Recorders should have a current calibration, an anti-aliasing filter, and have enough bandwidth for the application of interest.

2.1.7 Power Source

The use of batteries is highly recommended when collecting acoustic signatures. It eliminates the introduction of ac-power harmonics or other noise into the data stream. All instruments (equipment and sensors) discussed in this document are operated directly from battery sources.

Some devices draw a significant amount of current over a period of a few hours. In cases of this type, the battery voltage level must be automatically recorded to ensure that the voltage levels are maintained at the proper level. Some instrumentation devices have built-in alarms that warn of low-voltage readings. Voltage levels should be checked and recorded as part of the data product.

2.2 Acoustic Sensor Orientation, Placement, and Architecture

The simplest deployment is a single microphone. Guidance for directivity can be found in the microphone calibration documents, which are typically provided by the manufacturer or calibration agencies. More often, an array of microphones will be used. This array may consist of individual or multiple, linked sensors. Arrays can be configured according to any of several geometric sensor patterns that vary with specific test requirements and may include circles, triangles, and linear designs. Acoustic arrays are typically used to provide bearing estimates to a sound source and for removing the effect of an undesired sound source. The array orientation depends on size of the geometric pattern and the operating frequency of the acoustic source under study.

2.2.1 Placement of a Single Acoustic Sensor

Care must be exercised in the placement of the microphone on the ground surface. Seismic vibrations can influence the microphone output. The noise created from this coupling is referred to as *microphonics*, which is of special concern below 100 Hz. One technique for isolating the microphone from the ground is to place the microphone on an inflated inner tube. The inner tube should not be inflated to a point of rigidity as this undermines its purpose (see Figure 2-1).

2.2.2 Sensors Placed Directly on the Ground Surface

Since microphonics is not a major problem at high frequencies, it is acceptable for the acoustic array to come into direct contact with the ground surface. For some types of microphones, microphonic noise is so low in frequency that it can be ignored below the threshold of concern. In other cases, it might be desirable to have the microphone simultaneously sense seismic vibrations. The type of microphone placement must be documented in the ground truth. An example of a placement of an array on the ground surface is shown in Figure 2-2.

Figure 2-1. Single microphone isolated from ground vibrations.

Figure 2-2. Microphones placed in direct contact with the ground surface.

2.2.3 Acoustic Arrays and their Deployment

Before acoustic array configurations are finalized, consideration should be given to spatial aliasing. An acoustic array typically contains three or more sensors deployed in some specific geometric configuration. Acoustic arrays are commonly used in the field for detecting and locating moving objects and for improving signal-to-noise ratios that will facilitate classification of moving ground and airborne systems.

2.2.3.1 Acoustic Ground Surface Array Deployment for the Detection of Aircraft. The documentation of ground truth measurements for airborne sources requires determination of the source altitude above the terrain. If this determination is to be made using acoustic sensors, a ground surface acoustic planar or volumetric array is required. For a volumetric array, one of the microphones should be elevated above the surface from ¼ to 1 wavelength.

2.2.3.2 Subsurface Acoustic Sensor Emplacement in an Air Cavity. The underground microphone is recommended for those data collection exercises where noise is a problem for surface microphones. The underground placement of acoustic devices can vary from a single microphone to an array. Geometric design varies with the applications and specific test requirements. A surface microphone should be collocated near the subsurface microphone.

The porous nature of soil enables the propagation of acoustic signals into the ground where they can be sensed with a subsurface microphone contained within a Helmholtz cavity. Isolation of the microphone from the surrounding soil can be accomplished by using a barrier (inner tube) that minimizes seismic impulse sensing while allowing acoustic noise to reach the sensor. The soil acts as a low pass filter (~1000 Hz low pass) for acoustic coupling and propagation. This characteristic can prove quite useful when it is necessary to sample noise from vehicles, but it also makes it difficult to record a true vehicle signature.

Figures 2-3 and 2-4 show two views of typical placements of an underground microphone. In the example illustrated in Figure 2-4, a subsurface microphone is placed in an air cavity. In this specific application, the design of the subsurface microphone should be such that the resonant frequency (f_o) lies inside of the frequency band of interest for the source. To calculate the resonant frequency of the Helmholtz resonator, use equation 2-1 (from Kinsler, ref. 1.3.5). For detailed instructions on performing a rough field measurement of the resonant frequency refer to “blocks of wood” method in Burmaster, et. al (ref. 1.3.3).

$$f_o = QB = \frac{c}{2\pi}\sqrt{\frac{S}{L_e V}} \qquad (2\text{-}1)$$

where:

- Q = pressure gain in the cavity at resonance
- B = half power bandwidth (Hz)
- c = sound speed of air (m/s)
- S = surface area of the neck of the Helmholtz resonator (m^2)
- L_e = effective length of the neck (m)
- V = volume of the cavity (m^3)

Figure 2-3. Placement of a subsurface microphone in a cavity (view #1).

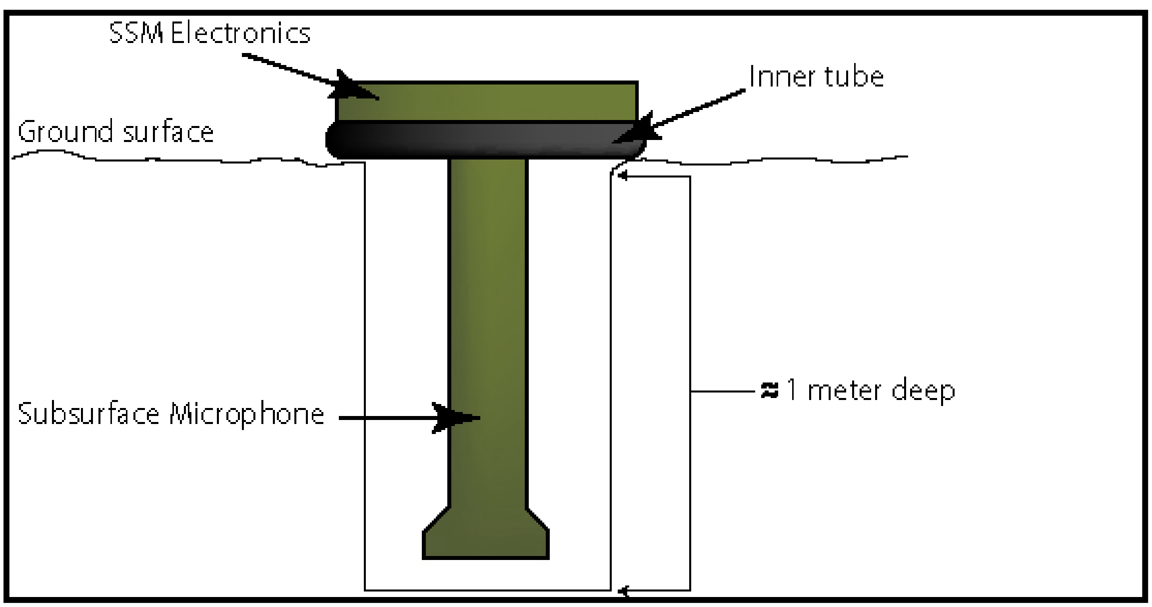

Figure 2-4. Placement of subsurface microphone in an air cavity (view #2).

2.2.3.3 Microphones Placed at the Source. It is often desirable to instrument the source with microphones. This procedure provides near-field data, which, while not easily related to the far field, can often serve as a basis for source diagnosis. The onset of the far field is a function of frequency and is calculated as shown in equation 2-2 (Ziomek, ref. 1.3.6, page 412).

$$\text{Onset of Aperture Far Field} = \frac{\pi D^2}{\lambda} \tag{2-2}$$

where:

D = largest dimension of the source
λ = wavelength

An onboard recorder is used to record the output of the microphones. It is not unusual for such a measurement to involve an array of several microphones in the interior and on the exterior of the test vehicle. Isolation of the microphones and instrumentation from vibration is especially critical in this application. Proper placement of the microphone should be no closer than one meter from the exhaust and at the highest practical point, e.g., rooftop of the vehicle (see Figure 2-5).

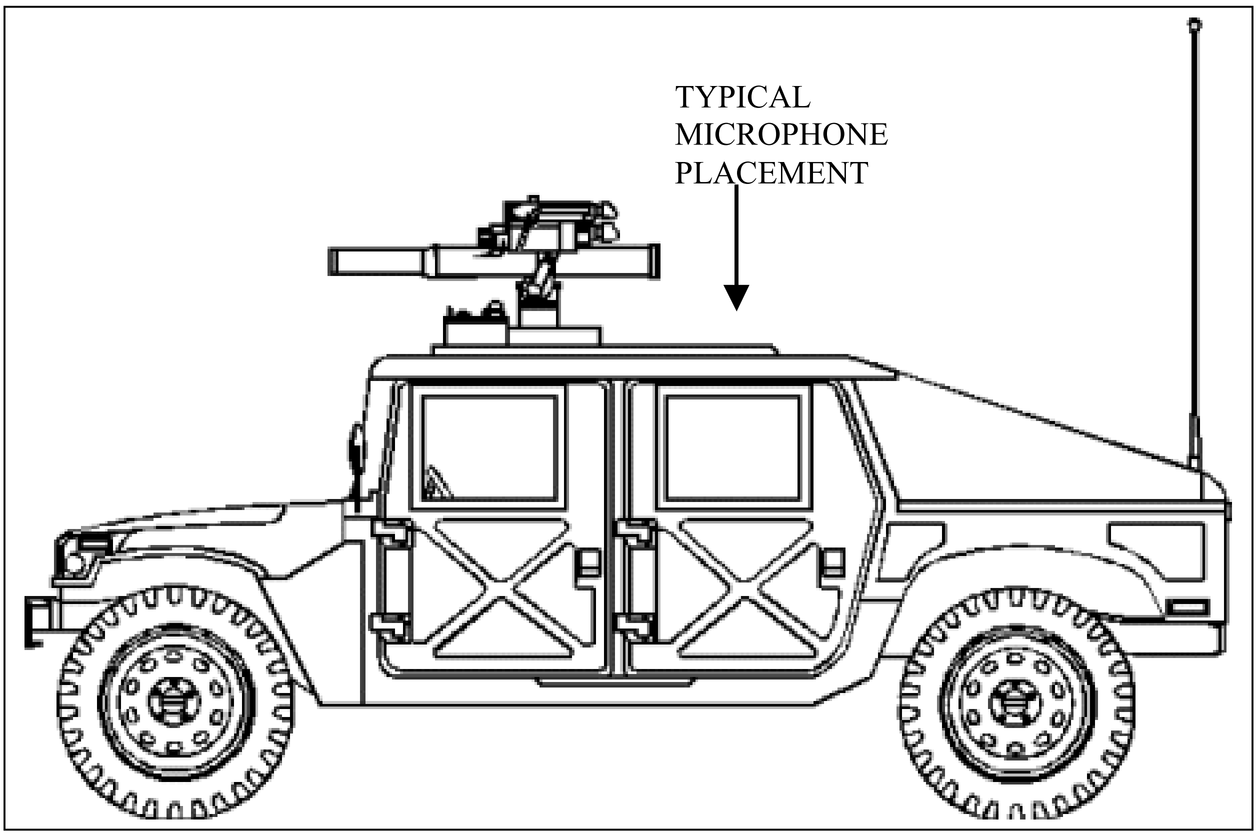

Figure 2-5. Microphone placement on the rooftop area of a vehicle.

2.2.3.4 Suspended Microphones. Suspended microphones allow for the three-dimensional characterization of the directivity of the source. The recommended arrangement consists of a line of independent microphones placed at 10-degree intervals and located in the far field. These microphones should be calibrated in the same manner as other microphones. It is necessary to survey the microphone configuration in its suspended form (see Figure 2-6).

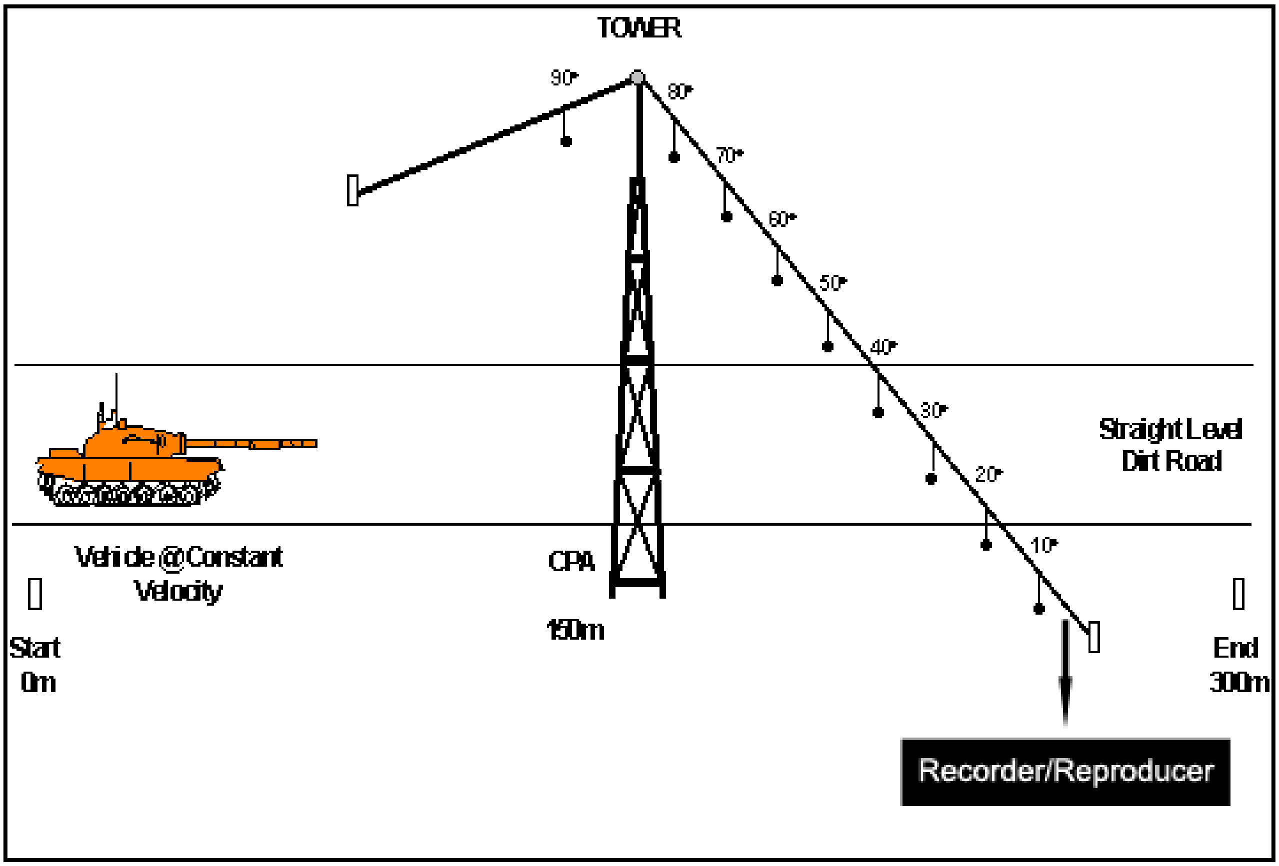

Figure 2-6. Suspended microphones intended to collect vertical acoustic signatures.

2.2.4 Microphone Parameters

2.2.4.1 Operational Characteristics. Microphones are required to meet established national standards (ANSI S1.4-1983 or IEC 60672). Operational characteristics for microphones differ from one manufacturer to the next, while standard properties such as dynamic range and frequency response are similar. Microphones are seldom limited by sensitivity. The practical limit is imposed by background noise, which will differ from site to site. When planning the experiment, close attention must be paid to the conditions under which the microphones are to be used. Different types of microphones work best in hot, cold, or dry weather environments. The microphone parameters are listed in Table 2-1. These are typically supplied with the microphone calibration certificate; which should be copied in the ground truth documentation.

TABLE 2-1. ACOUSTIC SENSOR PARAMETERS	
Parameter Name	**Recommended Units**
(a) Open circuit voltage receiving sensitivity	millivolts/pascal (mV/Pa)
(b) Polarization voltage	volts (V)
(c) Operating humidity range	percent relative humidity (% RH)
(d) Operating temperature range	Celsius (ºC)
(e) Maximum sound pressure level	decibels (dB re20μPa)
(f) Capacitance	picofarads (pF)
(g) Dimensions	inches or centimeters (in. or cm)

2.2.4.2 Microphone Parameter and Symbol Descriptions

(a) Open circuit voltage receiving sensitivity. The open circuit voltage receiving sensitivity is measured in mV/Pa. The voltage sensitivity is flat over a certain frequency response, which is set and specified by the manufacturer. The frequency response of a microphone is a measure of its relative ability to respond uniformly to all frequencies within a specific range (expressed as a lower to higher frequency limit in hertz).

(b) Polarization voltage. A voltage applied to some microphones to bias them properly. Required polarization voltages vary from 0–200 V. Some microphones do not require this voltage; they are either permanently polarized or utilize a piezoelectric or moving coil active element.

(c) Operating humidity range. The lower and upper humidity range within which the microphone can properly function and remain in calibration (expressed in terms of percent relative humidity).

(d) Operating temperature range. The minimum and maximum temperature limits within which the microphone can properly operate and remain in calibration. In some cases, corrections for temperature are required (expressed in degrees Celsius).

(e) Maximum sound pressure level. The maximum sound pressure level that can be applied to a microphone before the electrical signal is distorted by the preamplifier (in dB re20μPa).

(f) Capacitance. The effective capacitance of the microphone without the preamplifier (typically expressed in picofarads). Note that not all microphones are capacitive.

(g) Dimensions. The diameter of the microphone cartridge expressed in inches or centimeters.

2.3 Calibration

Accurate acoustic measurements require proper calibration procedures. The entire measurement system including microphones, pre-amps, amplifiers, and data recorders must be calibrated with the connecting cabling to be used in the experiment. The following are common procedures used to ensure that the acoustic measurements meet a uniform standard of quality. Microphones must be of scientific grade and have current calibration traceable to a NIST standard. The calibrated microphone must have a frequency and phase plot. These devices must meet established national standards, ANSI S1.4-1983 or IEC 60672.

NOTE

If the microphone is improperly handled (e.g. touching, dropping, or contaminating the diaphragm of the microphone), the microphone calibration will be invalidated.

2.3.1 Field Acoustic Calibration

Calibration of the acoustic system in the field typically involves placing a sound pressure level calibrator on each microphone and recording the signal produced. The sound pressure level calibrator must have current calibration documentation traceable to a NIST standard. A pistonphone is an example of a sound pressure level calibrator. Since barometric pressure does influence the pistonphone or any pressure coupler calibrator, this data should be monitored and recorded. Many pistonphone calibrators can generate several selectable tones. The calibration must be accomplished in the frequency range of interest. Calibration tones should be placed at the beginning and end of the data collection segment. Additional calibrations must be accomplished every 6 hours or less. As an example, if environmental conditions change significantly, the frequency of calibration should be adjusted accordingly. The sound pressure level of these tones is selectable with some sound level calibrators. Typical values are 94.0 dB, 104 dB, and 114 dB. The duration of the calibration signal should not be less than one minute.

NOTE

Do not hold the microphone during the calibration process.

2.3.2 Obtaining a Comparison Amplitude and Phase Calibration

When element-level microphone data is intended for use in adaptive beam forming algorithms (or use in other so-called super-resolution techniques), the field acoustic amplitude calibration alone is generally insufficient to enable good performance. Depending upon the type of microphone, the absolute phase differences between microphones across the frequency band of interest often introduce significant error in frequency domain approaches to beam forming. In such instances, it is possible to obtain a relative amplitude and phase calibration for the array elements by simultaneously subjecting a reference microphone and all of the array microphones to random white noise and comparing average phase differences using fast Fourier transforms (FFTs). All of the methods of ensonifying the reference and array microphones with white noise must eliminate resonances in the acoustic transfer duct between the white noise source and the (collocated) microphones. Frequency domain (FFT) processing is then used to compare the outputs of all the individual elements (FFT phase and amplitude responses) with those obtained simultaneously from the reference microphone. The measured phase and amplitude differences (the relative calibrations) can then be used in signal processing software to adjust all subsequent received signals prior to adaptive signal processing.

2.3.3 Background Noise Samples

Samples of background or ambient noise must be collected at least every hour and should not be less than one minute in duration. The source and characteristics of the noise should be included in ground truth comments. A real-time spectrogram is often used to identify unwanted spectral components.

Microphone sites should be selected to minimize background noise levels. When practical, the background noise level, including wind noise, should be at least 30 dB below the maximum sound level from the system undergoing tests as sampled at the closest point of approach (CPA). In some cases, the noise criteria cannot be met. In no case should measurements continue if the signal does not exceed the background and wind noise by 6 dB at the CPA.

The spectogram in Figure 2-7 shows an average background noise level between 31 and 41 dB re20μPa per hertz. An examination of the data sample shows some spectral lines of interest, which should be noted when analyzing the data. This sample shows two prominent spectral lines at 60 and 120 Hz. These were attributed to a gasoline powered electrical generator operating in the adjacent test range. A rotary-wing aircraft flying in the area on a different test created spectral lines between 60 and 120 Hz. The impulse shown was the result of a detonation event from some demolition work on the range. The spectrogram software being utilized was designed to ignore impulses when measuring the maximum and minimum levels.

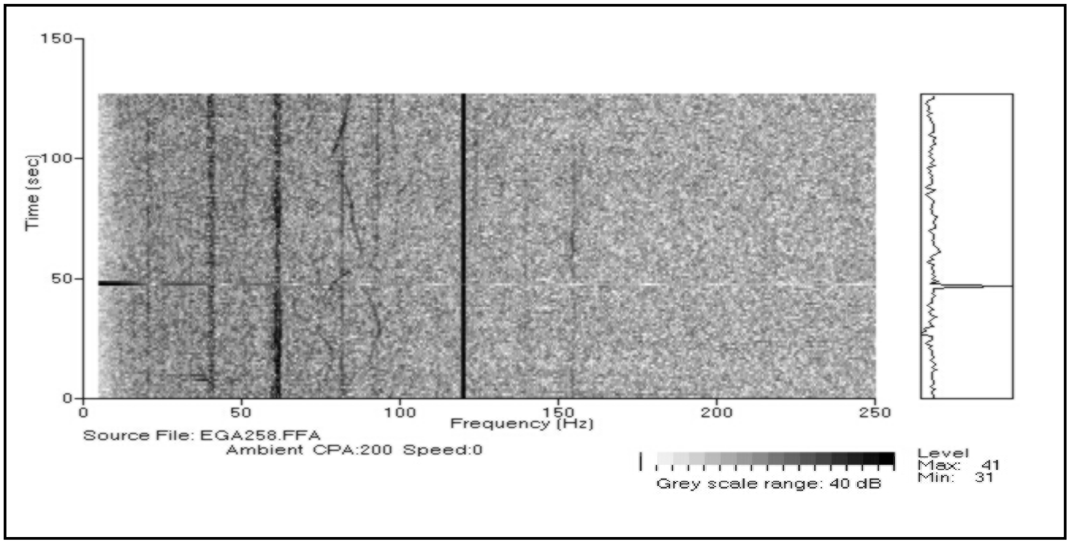

Figure 2-7. Spectrogram shows non-test-related signals in the background noise data sample.

2.3.4 Field Measurement of Frequency Response

A white noise source is used to inject a signal into the acoustic signal path in place of the microphone and preamplifier. The white noise signal travels the length of the data cable and into the recording system. The frequency bandwidth of the white noise should equal that of the microphone. This measurement will identify non-uniformity of frequency response in the system. The white noise source should have a current calibration certification traceable to NIST. Figure 2-8 shows a typical circuit used to evaluate frequency response.

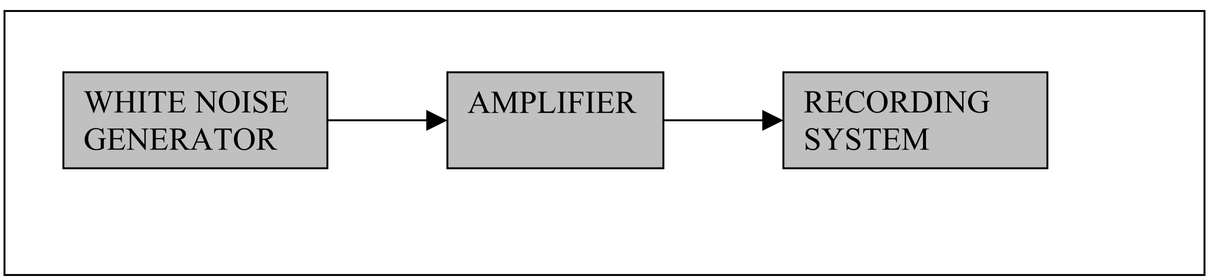

Figure 2-8. Typical circuit used to evaluate frequency response.

2.4 Survey and Positioning

Accurate location of microphones must be documented for coherent processing of acoustic data. The accuracy required depends upon the type of experiment being conducted (frequency of sound source, propagation distance, etc.). A typical measurement involves ground vehicles that emit sounds below 1 kHz. For such measurements, an accuracy of 1-5 meters (reference to CPA) for a single microphone or the center of an array is often sufficient to establish geographical location. Within an array, the three-dimensional location of individual elements relative to each other must be known to within one-tenth of the smallest wavelength (3 cm at 1 kHz, 1 cm at 3 kHz). If possible, locate the position of sensors using differential Global Positioning System (GPS); otherwise, perform a land survey.

When the measurements involve sound from moving sources, a GPS time-space-position system is installed on each source. Care must be taken to ensure proper positioning of the GPS unit and antenna on the source to prevent masking. The placement of the GPS receiver should be offset in relation to the vehicle's exhaust. When GPS is not available, or GPS is erratic, the use of manually-surveyed road markers or buoys is recommended. In this case, the source is observed and a verbal record is made of the marker numbers using a voice data recorder.

2.5 Meteorological Data

The environment has a dramatic effect on the transmission of acoustic signals through the atmosphere. The received amplitude and phase are dependent upon meteorological (MET) conditions. Transmission losses are frequency dependent, so the received signal spectrum depends upon atmospheric conditions along the propagation path. The phenomenon that most seriously affects the received signal is refraction, which results from gradients in wind or temperature and scattering by atmospheric turbulence. During the day, ground heating can result in high air temperatures near the ground level, which decrease with higher elevation. At night, this situation often reverses. The speed of sound is proportional to the square root of absolute temperature, so temperature gradients result in speed-of-sound gradients. Since refraction depends upon a gradient in the speed of sound, the temperature and wind speed (and direction) must be measured as a function of elevation. Figures 2-9 and 2-10 show examples of daytime and nighttime propagation patterns.

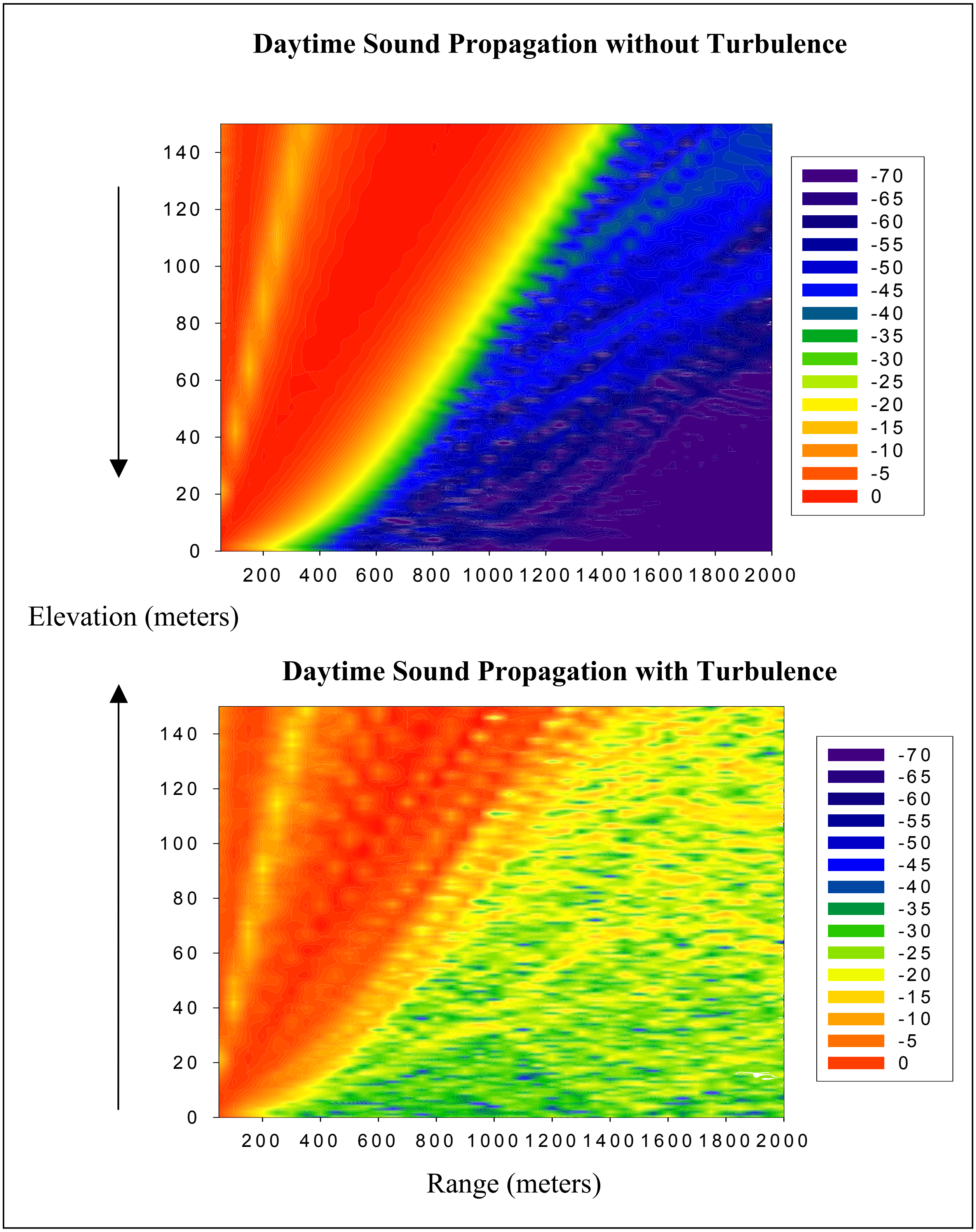

Figure 2-9. Examples of daytime sound propagation with and without turbulence.

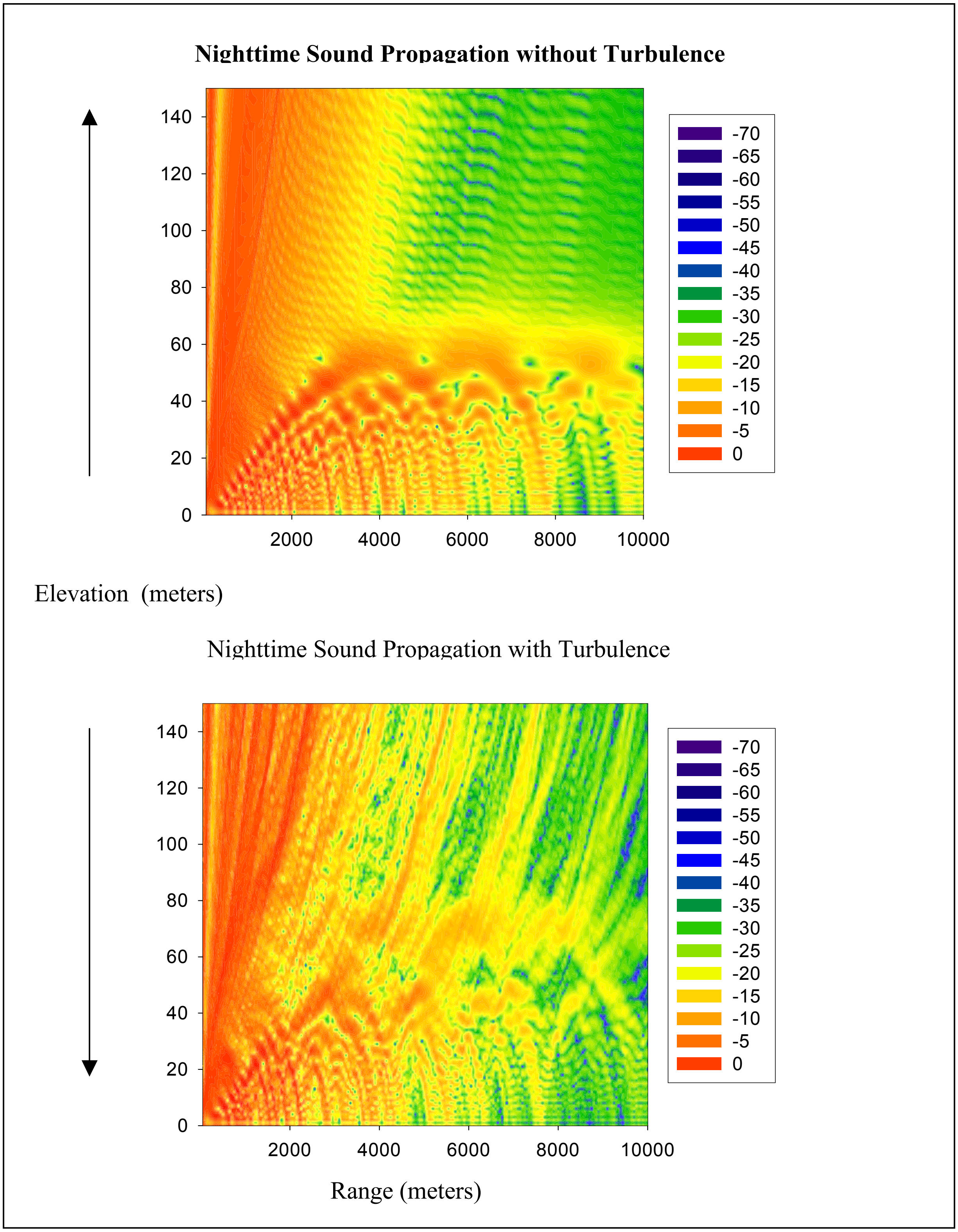

Figure 2-10. Examples of nighttime propagation with and without turbulence.

2.5.1 Capturing MET Data near the Surface

A minimal measurement system places temperature and wind sensors at different elevations on a tower. Figure 2-11 shows sensors at 1 meter, 3 meters, 5 meters, and 10 meters. Additionally, one set of MET instruments is placed on the ground surface. As a general rule, the measurements of temperature and wind should extend out to a height approximately equal to one tenth the anticipated longest propagation distance. For experiments involving propagation distances greater than 100 meters, tethersondes, radiosondes, or ground-based measurement systems (RASS or SODAR) are required.

Figure 2-11. Meteorological tower shows instrument placement.

MET measurements should be taken as near to the source and receiver as practical. Environmental conditions should be annotated (i.e. sunny, windy, cloudy, clear, overcast, etc.) in a data log or the ground truth ledger. The absence of meteorological data gathered at heights sufficient to describe propagation conditions will often make resulting acoustic data useless.

Turbulence also plays a significant role in determining received-signal phase and amplitude. In non-line-of-sight conditions or in a refractive shadow, turbulent scattering can be the dominant sound propagation mechanism (see Figure 2-9). Unfortunately, the science that would completely account for the effects of turbulent conditions is not fully developed. Measurements of turbulence are typically made using high-speed devices such as hot wire and/or sonic anemometers placed at different altitudes. Although use of these devices is preferred, they are not required.

2.5.2 Acoustic Meteorological Data Parameters

The parameters for meteorological data, which should be collected in the course of acoustic measurements, are listed in Table 2-2.

TABLE 2-2. ACOUSTIC METEOROLOGICAL PARAMETERS

Parameter	Units	Rate[1,2] & Precision
(a) Meteorological station date & time	Years, months, days, hours, minutes & seconds	None Optional
(b) Wind speed	Meters/second	Average/maximum 1/10 meter per second
(c) Wind direction	Degrees	Sample 1 degree
(d) Air temperature	Celsius	Sample 1 degree
(e) Surface air temperature	Celsius	Sample 1 degree
(f) Relative humidity	Percent	Sample 5 percent
(g) Barometric pressure	Millibars	Sample 5 millibars
(h) Sea state	Beaufort Scale	As it changes 1 unit
(i) Snow density	Kilograms/meter cubed	Periodic 1 kilogram/meter
(j) Snow moisture content	Percent	Periodic 1 percent
(k) Time since last snow fall	Hours	Periodic ½ hour
(l) Snow surface roughness	Millimeters	Periodic 1millimeter

Notes:

[1] Sample Rate: Meteorological data is typically sampled at five-second intervals to determine the maximum and minimum values and is averaged every minute. At the end of each minute, the average, maximum, and minimum values are recorded. Longer time intervals up to one minute for sampling and five minutes for averages are acceptable.

[2] Periodic Rate: When the term *periodic* appears above, measurements are made every twelve hours or after a significant change is noted by measurement personnel.

2.5.3 Acoustic Meteorological Parameter Descriptors

(a) Meteorological station date and time. Date and time the meteorological data was collected at the acoustic site. Format to be used (yyyy mon dd hh:mm) with the time noted in Zulu (GMT). The use of seconds is optional.

(b) Wind speed. Identified as the average wind speed (meters/second). Placement of the wind speed sensor (elevation) is documented. Measurement should be accurate to within 0.1 meter/second.

(c) Wind direction. Direction from which the wind is blowing measured clockwise from true north (degrees). Measurement should be accurate to within 1 degree.

(d) Air temperature. The air temperature at the meteorological station is read with a calibrated temperature sensor when the sensing element is dry (expressed in degrees Celsius). Placement is near the wind speed sensors. Suggested precision is 1 degree.

(e) Surface air temperature. The temperature of the air measured 30 centimeters above the ground surface (expressed in degrees Celsius). Suggested precision is 1 degree.

(f) Relative humidity. The ratio of the amount of water vapor actually present in the air to the greatest amount possible at the same temperature (percent). May be measured with a calibrated hygrometer or a sling hygrometer. Suggested precision 5 percent.

(g) Barometric pressure. The actual pressure of the air in the vicinity of the acoustic site (expressed in millibars). Acoustic properties of the air are not very sensitive to barometric pressure so an error of 5 millibars is acceptable.

(h) Sea state. Measurements of the sea surface using the Beaufort wind scale. Suggested precision is 1 unit.

(i) Snow density. Density near the surface of the snow within the acoustic footprint (expressed as kilograms/meter^3). Suggested precision is 0.5 kilogram/meter^3.

(j) Snow moisture content. Liquid water (moisture) content in the snow near the surface (expressed as a percent). Suggested precision is 1 percent.

(k) Time since last snowfall. Approximate time since the end of the last snowfall (expressed in hours). Suggested precision is ½ hour.

(l) Snow surface roughness. The roughness of the snow surface to a depth of 5 millimeters in a given area. Suggested precision is 1 millimeter.

2.5.4 Measurement of Meteorological Conditions in the Upper Atmosphere

Meteorological measurements can be made at higher elevations than available with towers by using an acoustic sounder, such as a radio acoustic sounding system (SODAR) or a radiosonde (RASS). Sounder measurements are a continuation of the meteorological measurements from ground-based towers. Sounders typically begin to collect data at elevations of 20-50 meters, so an overlap of data is not common. See Table 2-3 for data output available from sounders, which should be entered into documentation.

TABLE 2-3. SOUNDER PARAMETERS & UNITS

Parameter	Units
(a) Sounder time	Years, months, days, hours, minutes & seconds
(b) Wind speed	Meters per second
(c) Wind direction	Degrees
(d) Temperature	Degrees Celsius
(e) Relative humidity	Percent
(f) Barometric pressure	Millibar
(g) Height above the ground	Meters

(a) Sounder time. Date and time the meteorological data was collected. Format to be used (yyyy mon dd hh:mm:ss) with the time measured in Zulu.

(b) Wind speed. The wind speed samples from the upper atmosphere (measured in meters per second).

(c) Wind direction. Direction from which the wind is blowing measured clockwise from true north (measured in degrees).

(d) Air temperature. Temperature of the atmosphere measured at varying altitudes (measured in degrees Celsius).

(e) Relative humidity. The ratio of the amount of water vapor actually present in the air compared to the greatest amount possible at the same temperature (expressed as a percentage).

(f) Barometric pressure. The actual pressure of the air in the atmosphere (measured in millibars).

(g) Height above the ground. The height above the ground (expressed in meters).

2.6 Ground Truth Measurement Documentation

Ground truth is ancillary technical information that adds substance to the interpretation of acoustic data. Documentation is critical in this process.

2.6.1 Data Logs. The data log is a time-referenced document used to record source activity and those changes that take place during a test. These sources may be continuous or impulsive in nature. For vehicle, watercraft, and/or aircraft measurements, the following should be recorded, if applicable:

- The type of source
- Speed
- Engine rpm as a function of time
- Gear
- Direction of travel
- Transmission low range
- Countermeasures
- Vehicle configuration (missile empty/full, combat loaded, hatches open/closed)

Similar data for other test targets should be noted. Changes in amplification and anti-aliasing filter bandwidth range, sensor replacements, data channel assignments, identification of other noise sources, and other unusual events that take place during the test should all be written down or placed on the recorder voice channel.

2.6.2 Data Contamination from Human Sources. All non-essential individuals will leave the test area when the data collection begins. Remaining personnel will refrain from speaking or making noises when working around the data collection acoustic sensors.

2.6.3 Voice Channel. Voice is used to provide a real-time narration of all events that take place at the test site during the test. It is critical for later interpretation of the data. A channel on the data recorder is used for transferring the narration to another appropriate medium such as a CD.

2.6.4 Instrumentation Description. Specifications for all instrumentation should be included in the log. When the manual for an individual piece of equipment is quite long, a copy of the specifications, type, and location of manual will be sufficient. The log should include calibration certificates and sensitivities where appropriate. Items for which there is no manual (such as windscreens) should be described in detail including manufacturer. (Refer to paragraph 2.1 for further detail on instrumentation.)

2.6.5 Sensor Orientation and Placement. Placement and location of sensors (x, y, & z), number of sensors, sensor gains, beam pattern, range to target, etc.

2.6.6 Ground Vehicle Test. This type of test involves the use of ground vehicles, wheeled, track, and air-cushion type. Inputs for the data log include, but are not limited to, vehicular runs, type of vehicle, Interrange Instrumentation Group (IRIG) time, vehicle speed and rpm, vehicle gear, transmission range, direction of travel, changes in instrumentation amplification, sensor placement, sensor gains, data channel assignments, differential GPS data, other noise sources, observable environmental changes, and unusual events that take place during the test.

2.6.7 Aircraft Test. Inputs include but are not limited to the vehicular run, flight profile, type of aircraft, IRIG time, changes in instrumentation amplification, sensor placement, sensor gains, data channel assignments, noise sources, differential GPS data, and unusual events that take place during the test.

2.6.8 Photos and Drawings. These are used in technical reports and for reconstruction of the experimental layout. If practical, these photos and drawings should be provided in electronic form.

2.6.9 Operator Interview. Interviews with the vehicle operator/aircraft pilot can provide details about the operation of the vehicle. Annotate gear changes, e.g., in what gear did activities start and finish.

2.6.10 Listing of Test Team. A listing of the test team members should be prepared so that information can be exchanged more readily at a later date.

2.6.11 Differential GPS. Documentation of GPS configurations is needed for the purpose of archiving acoustic data. The reference point and accuracy of the location should be documented.

2.7 Site Description and Ground Cover Characterization

A description of the test site should include length and width of the test track, composition of the track, size and type of vegetation or ground cover, type of soil, type of snow, position of sensors in relation to test track, natural barriers, etc.

2.7.1 Ground Surface and Soil Properties

The soil and ground cover, whether grass, cropland, rocks, or snow can have a dramatic effect on acoustic propagation. Thermal conduction and viscosity of ground and ground covers can modify signals as they reflect off and through those mediums. While the actual acoustic wave/soil interaction is quite complex, for the purposes of analyzing acoustic propagation, one can treat the reflection from the ground as a reflection from an impedance surface in a manner similar to that found in electric circuits. Values for the impedance of various types of ground and ground surfaces have been determined empirically based on the flow resistivity, which is the resistance to the passage of air through a material. Nominal values for the flow resistivity of various surfaces are listed in Table 2-4. It is the flow resistivity, rather than the actual impedance, which is often requested in acoustic propagation models.

TABLE 2-4. FLOW RESISTIVITY	
Ground Surface	**Flow Resistivity** (cgs rayls)*
Dry snow, new fallen 0.1m over 0.4 m older snow	10-30
Sugar snow	25-50
Forest	20-80
Grass, rough pasture, airport, public buildings, etc	150-300
Roadside dirt, ill defined small rocks up to 0.1 m mesh	300-800
Sandy silt, hard packed by vehicles	800-2500
"Clean" limestone chips, thick layer (0.01 to 0.025 m mesh)	1500-4000
Old dirt roadway, fine stones (0.05 mesh) interstices filled	2000-4000
Earth, exposed and rain packed	4000-8000
Quarry dust, fine, very hard packed by vehicles	5000-20 000
Asphalt, sealed by dust and light use	30 000
Upper limit set by thermal conduction and viscous boundary layer	200 000-1 000 000

*(1 cgs rayl = 1000 Pa s/m^2)

Refer to ANSI S1.18-1999 American National Standard, *Template Method for Ground Impedance,* to accomplish more accurate measurements.

2.7.2 Characteristics of Snow

As an example, snow is one type of ground surface over and through which sound propagates. In addition to flow resistivity, other properties should be evaluated, including the following:

(a) Snow density. Density near the surface of the snow within the acoustic footprint is expressed as kilograms/meter^3.

(b) Snow moisture content. Liquid water (moisture) content in the snow near the surface (expressed as a percent).

(c) Time since last snowfall. Approximate time since the end of the last snowfall (expressed in hours).

(d) Snow surface roughness. The roughness of the snow surface to a depth of 5 millimeters in a given area.