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Infrasound Sensor Evaluation Definition of Terms

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Introduction

Infrasound sensors installed at International Monitoring System (IMS) stations must meet a minimum set of requirements defined by the Preparatory Commission (PrepCom) for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), with further refinement by the Provisional Technical Secretariat (PTS). These requirements specify the performance characteristics that a sensor must possess, such as noise, pass-band, sensitivity, and dynamic range. The terms used to describe many of the requirements do not have clear definitions that are commonly agreed upon across the monitoring community. Differences in basic definitions between those who set requirements and the sensor manufacturers, evaluators, and end users can be critical in determining whether or not a specific sensor is acceptable. Defining mutually agreed upon definitions for how an infrasound sensor's performance is to be evaluated will be beneficial to the entire monitoring community. An initial set of definitions is proposed for consideration.

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I.2. Minimum Requirements for Infrasound **Station Specifications**

Characteristics	Minimum Requirements
Sensor type	Microbarometer
Number of sensors	Four element array[a]
Geometry	Triangle with a component at the centre
Spacing	Triangle basis: 1 to 3 km[b]
Station location accuracy	≤100 m
Relative sensor location	≤1 m
Measured parameter	Absolute[c] or differential pressure
Passband	0.02 to 4 Hz
Sensor response	Flat to pressure over the passband
Sensor noise	≤18 dB below minimum acoustic noise[d]
Calibration	≤5% in absolute amplitude[e]
State of health	Status data transmitted to the International Data Centre
Sampling rate	≥10 samples per second
Resolution	≥1 count per 1 mPa
Dynamic range	≥108 dB
Timing accuracy	≤1 ms[f]
Standard temperature range	−10°C to +45°C[g]
Buffer at the station or National Data Centre	≥7 days
Data format	Group of Scientific Experts format
Data frame length	≤30 s
Data transmission	Continuous
Data availability	≥98%
Timely data availability	≥97%
Mission capable array	≥3 elements operational
Acoustic filtering	Noise reduction pipes (site dependent)
Auxiliary data	Meteorological data[h]

[a] In the case of noisy sites or when increased capability is required, the number of components could be increased.
[b] 3 km is the recommended spacing.
[c] Used for daily state of health.
[d] Minimum noise level at 1 Hz: ~5 mPa.
[e] Periodicity: once per year (minimum).
[f] Better than or equal to 1 ms.
[g] Temperature range to be adapted for some specific sites.
[h] Once per minute.

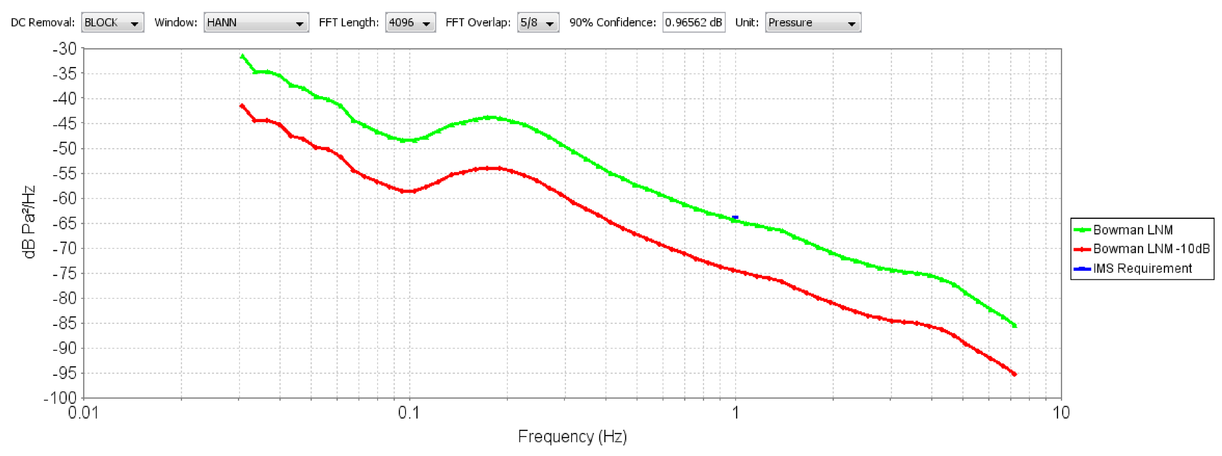
Sensor Noise

Sensor noise is taken to be random deviations in the sensor output signal that are uncorrelated with the phenomena that the sensor is intended to be measuring. IMS requirements specify a maximum infrasound sensor noise at just a single frequency, 1 Hz. A more complete requirement would be to specify the maximum sensor noise level across the application passband of 0.02 to 4 Hz, relative to some noise model (i.e. 10 dB below a noise model, such as the Bowman Low Noise Model).

Sensor Noise may be evaluated in different ways:

- Isolated from input pressure measurements using port caps on the sensor or an isolation chamber.
- Incoherent noise analysis from 2 or 3 co-located sensors measuring a common coherent signal.

Noise levels are analyzed as power spectral density (Pa^2/Hz) across frequency and generally interpreted relative to some model.



Data is collected from the sensor over a time period to have a sufficiently small confidence interval and frequency resolution. At a 20 Hz sampling rate, a minimum of a 4096 point FFT window would provide sufficient low frequency resolution to measure down to 0.02 Hz with a frequency resolution of 4.88 mHz. With a 5/8 overlap in the FFT windows to compute the power spectra, at least 3 hours of data will be required to have a 90% confidence interval of less than 1 dB. An 8196 point FFT window, having improvements in frequency resolution, would require at least 6 hours of data to have a similar confidence interval.

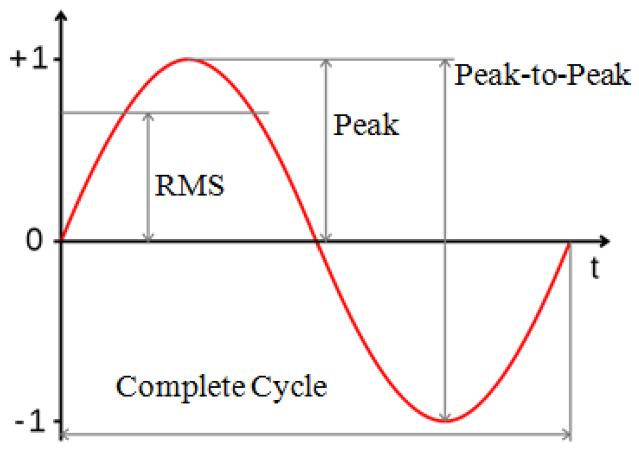
Dynamic Range

Dynamic range is the ratio between the largest and smallest signals that may be observed on the output of a sensor. IMS requirements specify that an infrasound station shall have at least 108 dB of dynamic range. For the purpose of sensor evaluation, it is assumed that the sensor must meet this 108 dB requirement. It is expressed in decibels as:

$$10 \cdot \log_{10}\left(\frac{Largest\ Signal\ Amplitude}{Smallest\ Signal\ Amplitude}\right)^2$$

The smallest observable signal is bounded by the sensor noise. Therefore, the measurement of sensor noise shall be used as the smallest signal. The sensor noise must be converted from a power spectra across a passband to a time-domain amplitude, expressed in root-mean-squared (RMS) units, where dF is the frequency resolution and P[k] is the noise power spectra:

$$Pa_{rms} = \sqrt{dF \sum_{k=n}^{m} |P[k]|}$$



Selecting a signal to represent the largest signal amplitude may be subject to interpretation. Generally, the signal will have an amplitude equal to the clip level of the sensor. We have chosen to define the largest signal as the RMS value of a full-scale sinusoid. The advantages of using the RMS of a sinusoid are:

- A sinusoid is a mathematically simple definition without any discontinuities.
- Sinusoids can be generated with relative ease by signal generators and acoustic sources for validating sensor performance including the clip level.
- Nonlinearities in the sensor output are easily visible as distortion across the sinusoid.
- Approximates the impulsive characteristics of transient signals that would be expected to cause a sensor to clip.
- Using the RMS of both the largest and smallest signals ensures the units are consistent and the dynamic range is dimensionless.

Calibration

A sensors calibration refers to the correctness of its sensitivity (i.e. mV/Pa or mV/Pa/s). The IMS requirements state that the calibration must vary by less then 5% in amplitude, to be evaluated at least once per year. There is no requirement for the phase response, although 5 degrees is the amount typically used. The requirements do not state whether the calibration is at 1 Hz or across the entire passband.

The deviation in the sensors calibrated sensitivity is assumed to be relative to either the sensors nominal sensitivity or its measured sensitivity prior to deployment.

Routine calibration of an infrasound sensor typically is performed in the field with either a portable calibrated pressure generator or relative to a calibrated reference sensor.

Clip

There is no IMS requirement for the minimum level at which a sensor will clip (the maximum signal that the sensor can record). There are requirements for the maximum self-noise and minimum dynamic range, but these requirements don't strictly enforce a desired clip level.

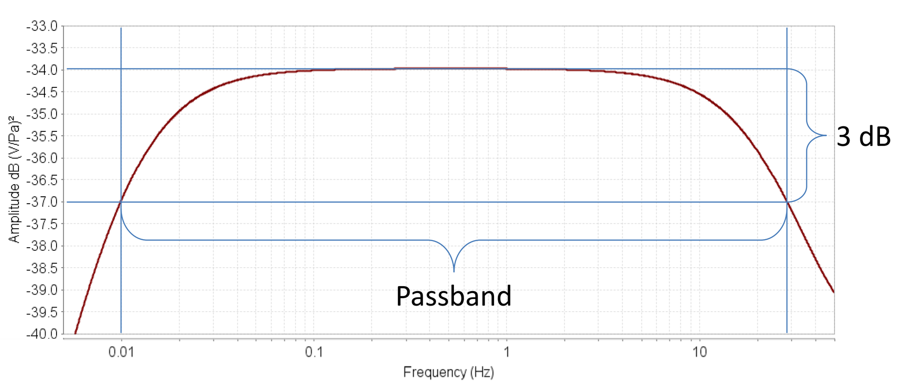
If the intent of the 108 dB dynamic range requirement is to establish a minimum clip level, then 108 dB above the minimum noise level of 18 dB below 5 mPa at 1 Hz would correspond to a clip level of approximately 160 Pa.

Clip levels can be evaluated by generating a tone and then adjusting the amplitude until clip is observed. Note that the clip level should only be maintained for a few cycles of the tone so as not to risk damaging the sensor.

Passband

The passband of a sensor is the frequency range over which the sensor is able to measure with a nominally constant sensitivity. The upper and lower frequency bounds of the passband are defined as the points at which the sensors amplitude response is 3 dB below, or half, the nominal sensitivity. Note that the response and the 3 dB limits are expressed in units of power, which is the square of amplitude.

The passband bounds may be determined by generating input tones with a constant amplitude across a range of frequencies and identifying the frequencies at which the sensor output power is reduced by half.



Alternatively, the passband may be evaluated by generating a bandwidth limited white signal that is inputted to the sensor. The input signal is presumed to have a flat spectra covering at least the sensor passband. The output of the sensor under test is then compared to the output of a calibrated reference sensor with known response characteristics. The passband limits can then be observed directly from the spectra of the sensor output.

Sensor Response

The requirement for sensor response is that the sensor output will be flat to pressure over its passband. However, there is no specification for the degree of flatness. In addition, the requirement seems to apply only to the amplitude response with no mention of the phase.

We typically evaluate the sensor response by verifying that the sensor under test does not deviate from its predicted response across the passband by more than 5% in amplitude and 5 degrees in phase. Note that the predicted response includes the individually evaluated sensitivity at 1 Hz as well as the 3 dB roll off present at the edges of the passband.

The sensor response may be measured by generating a bandwidth limited white signal that is inputted to the sensor. The input signal is presumed to have a flat spectra across at least the sensor passband. The output of the sensor under test is then compared to the output of a calibrated reference sensor with known response characteristics.

The outputs of both the sensor under test and reference sensor are corrected for their respective responses and then compared using coherence analysis to determine the relative amplitude and phase between them.

Traceability

Traceability is a critical requirement for any sensor evaluation that is to be performed.

Test configurations and conditions should be fully documented and the test environment properly controlled to ensure the repeatability of results.

Wherever possible, all equipment should have current calibrations that provide traceability to a standards laboratory.

Resolution

The requirement for resolution is that there is > 1 count per 1 mPa. This requirement is a system level specification that includes both the sensor's sensitivity and the digitizer's bitweight.

For a digitizer with a 40 Vpp range and 24-bits of resolution, the bitweight would be approximately 2.38 uV/count. Using this bitweight, the sensor sensitivity would only need to be > 2.38 mV/Pa. The sensor sensitivity may be evaluated using a tone, typically at 1 Hz, across a range of pressure amplitudes relative to a calibrated reference sensor. Both the sensor under test and the reference sensor are isolated from background noise.

Note that stated minimum sensitivity value may vary depending upon the chosen digitizer or application.

References

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