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Acoustic Positioning Systems

Acoustic interference

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1 ACOUSTIC INTERFERENCE

1.1 Introduction

Acoustic interference can be a problem for operations when several acoustic systems and/or many transponders are in use or deployed within reach of each other. The interference can cause both erroneous measurements and loss of position. The reason for this is the relative small bandwidth that is in use on hydro acoustic systems, causing all to operate very close in frequency. Various types of systems will have different qualities for suppressing interference.

By good knowledge of systems involved and good planning acoustic interference for offshore operations can be minimized.

Acoustic interference arises when more than one underwater acoustic system is active simultaneously within range of each other. The equipment can be installed on one common vessel or on several vessels operating in the same area.

1.2 Definition

Acoustic interference in this paper is defined as disturbance from signals generated by various types of systems using sound in water to measure or communicate.

Disturbance from propellers, thrusters or drilling is defined as noise and is not discussed here.

Reflected signals from own equipment is defined as multipath and is not discussed here.

If the acoustic interference is caused by other systems on one vessel or systems on other vessels we consider that as *inter system interference*. On the other hand if the interference is caused by conflicting transponders on one system it is considered as *intra system interference*.

1.3 Interference on acoustic signals

The acoustic interference appears when two signals overlap each other partly or fully in time. The result is that these two signals will be mixed in the water and the receivers.

1.3.1 Signal overlapping

Illustrations of overlapping signals are given below. The delay corresponds to an overlap of approximately 50 % of the signals.

Time delay	Phase difference relative to carrier (25 kHz)
5.0033 ms	30 °

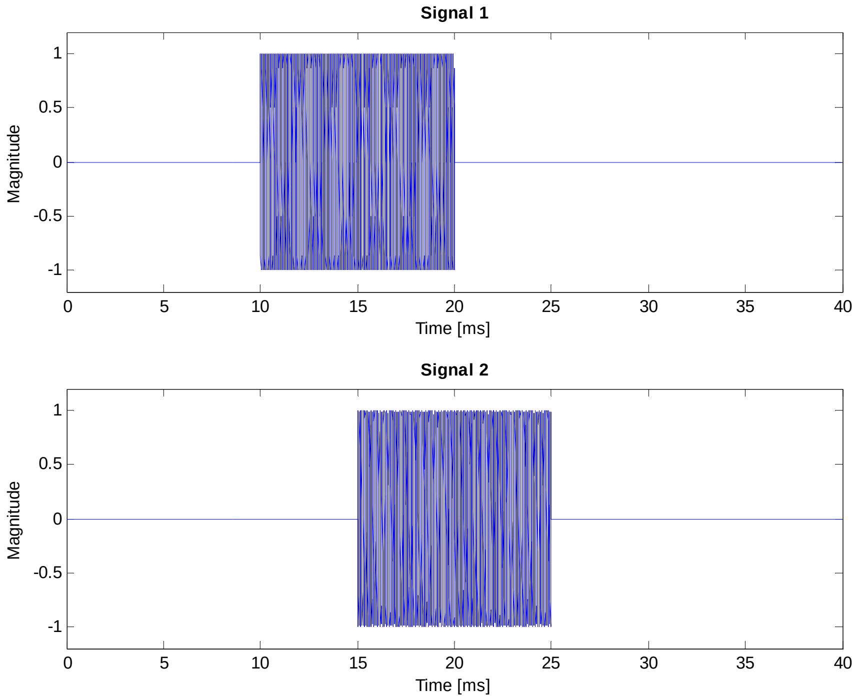
The illustrations thereby are of two interfering signals transmitted from two different sources traveled trough a direct path added in a receiver. Both signals have a carrier of 25 kHz. The interfering signals have equal magnitude.

Two signal forms are illustrated (only signal forms of the same type overlap):

Signal form	Bandwidth	Pulse length
Continuous Wave (CW)	100 Hz	10 ms
Direct Sequence Spread Spectrum (DSSS)	3.1 kHz	10 ms

Figures of the signal before and after signal processing are given for each signal form.

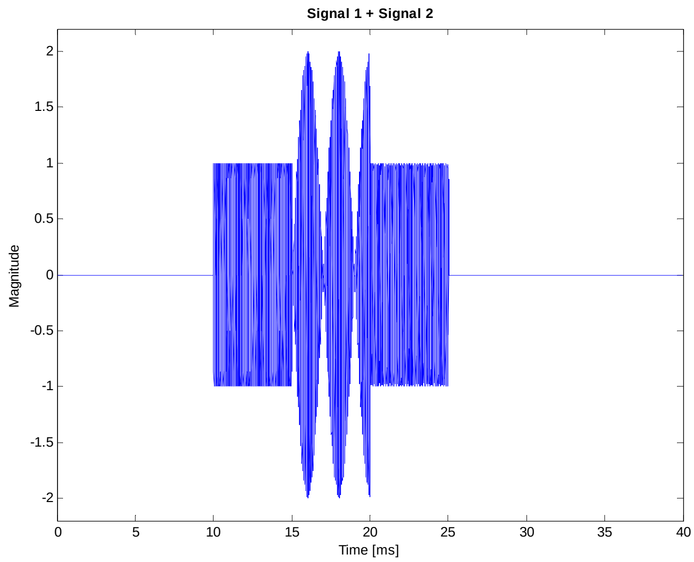
Below is a figure illustrating two signals before being added by the receiver. The example is of two CWs 30° out of phase, but the shape is the same for all DSSS as well.



Two interfering signals 50% overlap

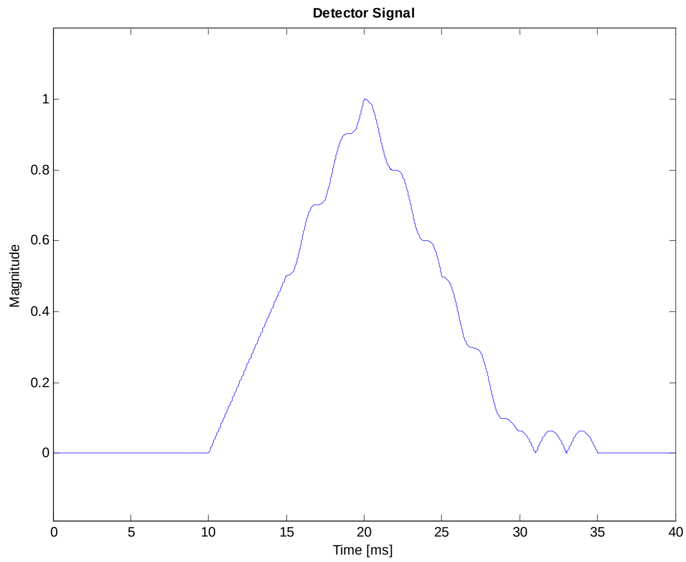
CW

In the case below the reference signal has a frequency of 25kHz while the interfering signal has a frequency of 25.5kHz. Below is a figure illustrating the two CW signals after being added by the receiver.



Two interfering CW signals 50% overlap

Below is a figure illustrating the input to the detector for two CW signals after being added by the receiver.

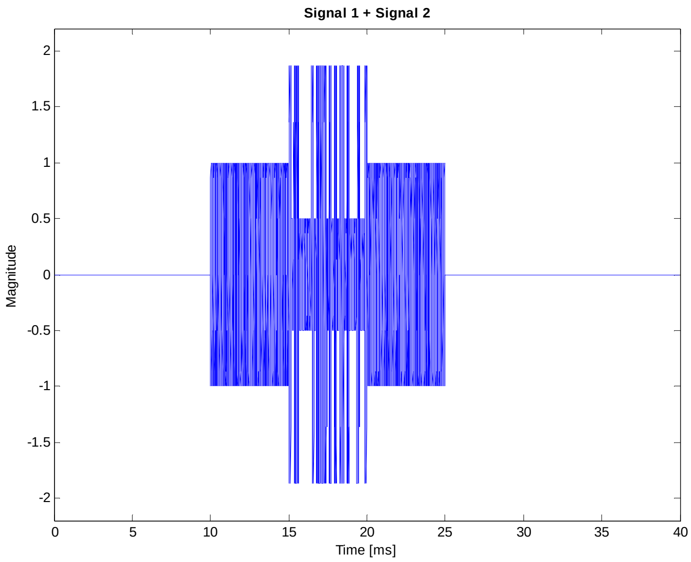


Detector input CW

We see that the overlapped pulse causes interference on the output signal (from 5ms into the pulse). However it is still possible to have a good and reliable detection of the Signal1 pulse.

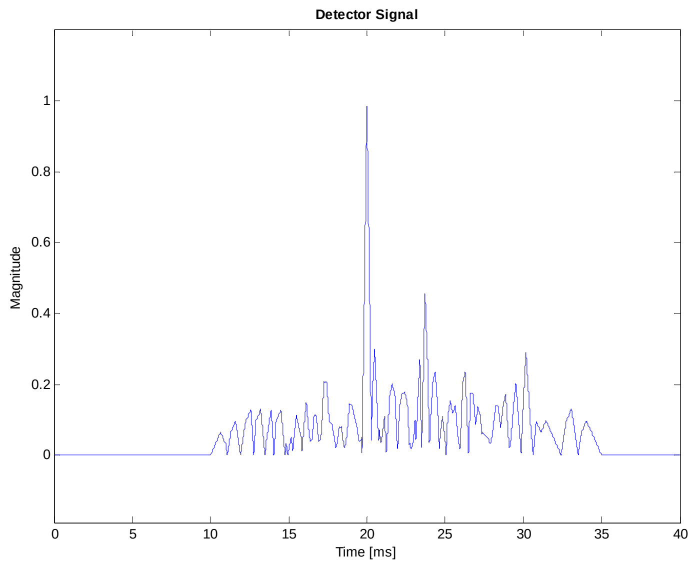
DSSS

Below is a figure illustrating two DSSS signals after being added by the receiver.



Two interfering DSSS signals 50% overlap

Below is a figure illustrating the input to the detector for two DSSS signals after being added by the receiver.



Detector input DSSS

We see that the overlapped pulse causes a peak at approximately 4ms after the first main peak. This peak is damped to 40% (-8dB) of the main peak. A detector can perform reliable and accurate in this situation. The overlapping signal causes generally higher side lobes.

1.3.2 Intra system interference

Many drilling units are equipped with two acoustic positioning systems both working with one transponder each in SSBL mode. Working with 5 LBL transponders each is an other case. A third scenario is one system doing positioning and one system doing BOP telemetry control. Onboard one vessel, interference is normally handled by use of different transponder channels to avoid same frequencies or channels being used simultaneously. The HiPAP operator station automatically gives warning on possible interference situations.

Due to different channels or frequencies and that the signal strength is more or less equal, the return signals does not normally causes problems for the acoustic system. In case of a transmit pulse overlaps a reply pulse the situation is more critical.

As an example we have looked at one scenario where one system is doing positioning and one system is sending a telemetry command at 1500m water depth.

A possible loss of telemetry messages or positioning replies can happen if one system happens to transmit at the same time as the reception of the reply occurs (pulse overlap). The signal strength of the transmit pulse is very strong compared to the return signal from 3000m.

The telemetry message is typically 28 pulses within 4 sec., each pulse is 10ms. The navigation pulses is typically 4 pulses within 4 sec., each pulse is 10ms.

With a pulse overlap of 50% the probability for this to happen at 1500m water depth is 56%.

This situation can cause a position jump or loss of the position or a loss of telemetry message. The position jump will be rejected by the DP system.

However, if a pulse overlap appear, the interference is much reduced due to the different frequency band (- 36dB), narrow beam transmitter beam (-25dB), narrow receiver beam (-25dB) and the transmission loss from the distance between transducers at 20m will be 26dB. All together the transmit pulses from the other system is reduced by 112dB. Compared to the signal from the transponder which is damped 87dB at 3000m we have a margin of 25dB.

The damping of out of band frequencies allows telemetry operation and positioning to operate simultaneously with a minimum of interference.

1.3.3 Inter system interference

During multi vessel operations within a limited area the possibility for acoustic interference increases. Similar scenarios as with intra interference may appear, but now the distance to the other transmitting unit is greater and thereby the signal level quite decreased.

However there is a possibility that identical channels are used by the systems. Loss due to different frequency band, are then not to be accounted for and the effect can be severe; locking on wrong position.

Another factor important factor is that the different vessels can be equipped with equipment from various manufacturers. The systems may have different properties with respect to acoustic interference. The actual transmit and receive protocol are different and does not easy fit together. The operators for such operations need to plan the operation in advance to reduce the interference.

One vessel can operate with a CW system and one with a DSSS system. The CW pulses will be seen as narrow band noise by the DSSS system, and a DSSS signal will be seen as broad band noise by the CW system. Both systems should manage this interference.

1.4 Consequences – reduced performance

Acoustic interference can reduce the performance of any acoustic system. For DP vessels, acoustic positioning systems along with acoustic telemetry are highly used.

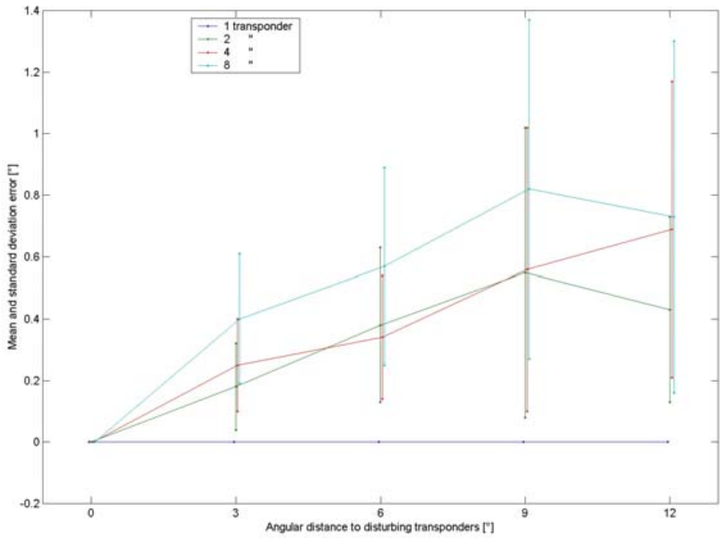
Reduced performance can be:

- Total loss of signal – no position
- Total unstable position – large position jumps
- Reduced accuracy – standard deviation increased
- Lock on wrong transponder – erroneous position

1.4.1 Impact on directional measurement

SSBL or USBL systems derive the position from range and angular measurement. The position accuracy is proportional to the accuracy of the directional measurement.

A directional error of 0.5 degrees corresponds to 17.5m at 2000 meters of water depth.



The figure above shows an example of the increased standard deviation on angular measurement when the system receives multi replies simultaneously. The replies have different channels. We see that the standard deviation increases as a function of number of simultaneous replies and the angular distance between the transponders. At an angular distance from 9° and further we see an improvement in standard deviation due to the fact that the narrow receive beam (±5°) do suppress the other replies.

1.4.2 Consequences for DP operation

Above four situations were mentioned as possible outcome of a acoustic interference problem:

A. Total loss of signal – no position

B. Total unstable position – large position jumps

C. Reduced accuracy – standard deviation increased

D. Lock on wrong transponder – erroneous position

The behaviour of the DP system heavily depends on the number of reference selected and accepted.

Single reference systems

If the acoustic positioning system is the only selected or accepted system situation A and B will cause an alarm on the DP system and the reference system will be rejected.

In situation C the DP system will be unstable and possible with high thrust usage.

In situation D it is more difficult to predict the behaviour; if the locking on wrong position causes a relative small position jump the DP will start to re-position. If the position jump is big the DP will reject the position reference system and no reference system is available. The DP system will eventually go into a “position dropout” situation similar to case A and B.

Multi reference systems

If the acoustic position reference system is used together with DGPS and/or other reference system, the DP will weight the different systems and can decide which system that is not reliable and reject it. However, loosing the acoustic position reference can cause the operation to stop due to class regulations.

2 REDUCING ACOUSTIC INTERFERENCE

There are some actions that can be taken to reduce acoustic interference.

1. Directivity on transmission and reception
2. High channel separation
3. Reduce number of transponders being used
4. Reduce interrogation rate

Directivity on transmission and reception is addressed by using narrow pointing beams to focus on the signal source.

Reducing number of transponders being used can be more challenging. In some LBL operations using the MULBL system will solve the problem. Also using the HAIN system will allow SSBL mode operation which requires fewer transponders compared to LBL.

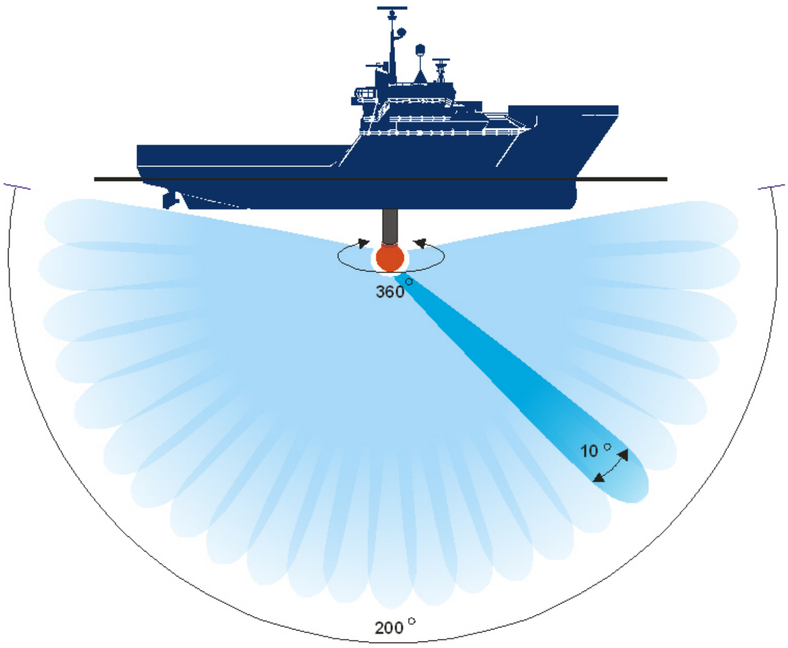
Reducing interrogation rate gives more time for other acoustic systems, but lower position update rate is not wanted. Using the HAIN system can improve that.

The two first points above are a challenge for the designers of the acoustic systems, the two last points are important for operators planning the operation.

2.1 Narrow pointing beams

To reduce the interference from a transmit pulse the onboard system can be designed to transmit in a directional beam. In this way energy is only transmitted in the direction of the transponder and interference to other systems will be reduced. On a HiPAP system with ±5° beam the energy is reduced by approximately 25 dB relative to an omnidirectional transducer.

In the same way focusing the receiver to point toward the transponder reduce interference from other systems. A HiPAP system with ±5° beam will reduce sensitivity to other directions about 25dB.



Narrow pointing transmitter and receiver beams.

2.2 Filtering and channel seperation

Bandpass filtering letting through energy only within the defined bandwidth of the system is effective stopping inter system interference from systems operating in a different frequency band. Bandpass filters are implemented both in hardware and software.

Within the defined bandwidth, the suppression between channels is a result of the inherent properties of the signal and the way it is processed in the receiver. The method of processing the signals differ between different systems and is not treated here. Any suppression measures given in the following are based on typical methods of signal processing.

Inherent properties of the signal waveforms are anyway the most important factor in establishing the channel suppression. Common signals used in positioning systems are the Continuous Wave (CW) signal and recently the Direct Sequence Spread Spectrum (DSSS) Signal.

The signal suppression of CW signals depends on the frequency separation between two neighboring channels. In standard navigation the frequency separation in Kongsberg HPR systems are 500 Hz resulting in a channel suppression of 36 dB. Kongsberg HPR Telemetery channels frequency separation is 250 Hz resulting in a channel suppression of 32 dB. The channel suppression is decreased as the signals are closer in frequency.

DSSS signals are phase shift keyed wideband signals having several channels overlapping in frequency. Here the concept of channels is more an abstract term as what really separates the channels from each other is the pattern of phase shifts and not the frequency only. The suppression between DSSS signals depends on the length of the phase shift pattern within the signal. Typical suppressions for DSSS signals suitable for positioning systems are between 16 dB and 29 dB increasing with phase shift pattern length.

2.3 Multi-User LBL positioning

Several individual vessels and ROV units can now position themselves using the same seabed transponder array. The system and principle has the following main advantages:

- Provides high position accuracy (comparable to standard LBL).
- A small number of transponders serve all vessels and ROVs.
- Secures high position update rate (down to approx. 2 seconds), which is essential in DP operations.
- Avoids transponder frequency overlap when vessels are working in the same area.
- Passive system - all vessels are ”listening” only.

A transponder array is deployed and calibrated by use of subsea baseline measurements. One transponder is used as the Master in the positioning phase. The other transponders are called the Slaves.

The Master transponder acts as a beacon. It starts a positioning sequence by doing the steps described below. This is done regularly with an interval set by telemetry from one of the vessels.

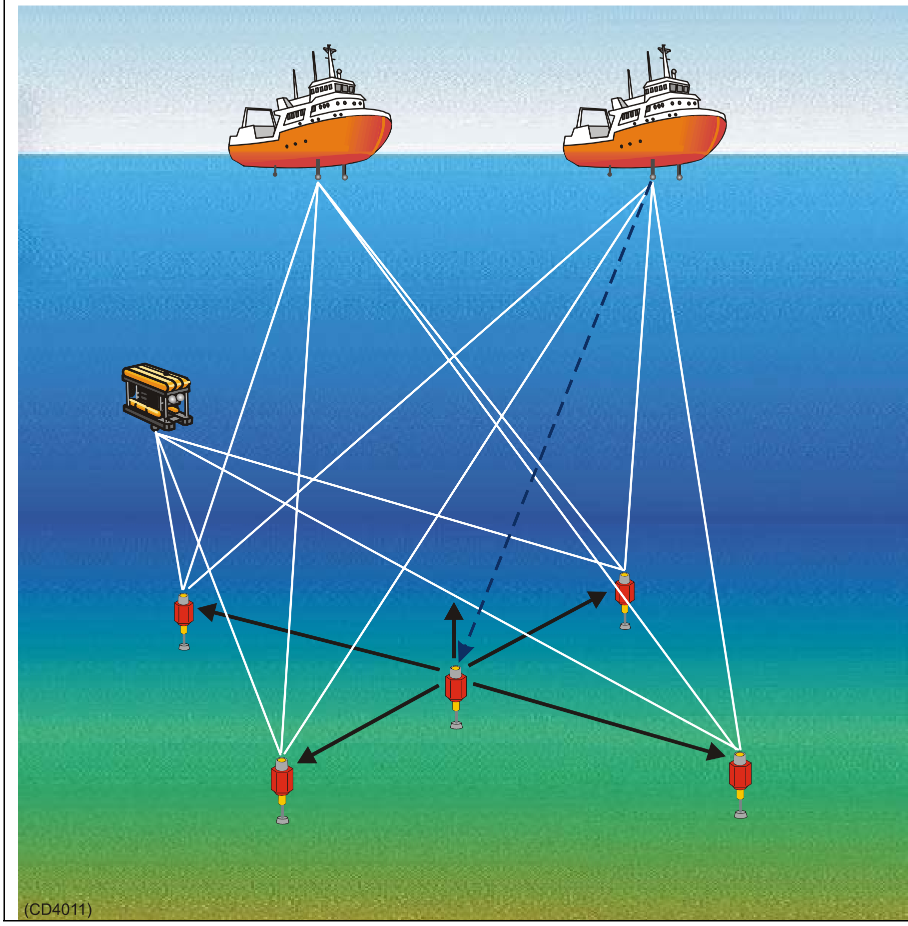
1 The Master interrogates the Slaves.

2 The Master transmits its individual transponder channel to be received by the vessels/ROVs positioning in the array.

3 Each Slave transponder receives the interrogation from the Master and transmits its individual reply channels after a turnaround delay.

A MULBL system positioning in the array, listens for the individual channels transmitted by the master beacon, and by the Slave transponders. When they are received, the system uses its knowledge about their positions in the TP array to calculate the differences in range to the transponders in the TP array. The time difference between the Master interrogation and the start of the reception of the pulses at the system is unknown. It has to be calculated together with the position of the vessel or ROV.

All vessels to use the MULBL array need the coordinates of the transponders and the channel numbers, which will be distributed on a file.



Multi user operation

2.4 HAIN POSITION REFERENCE

The HAIN system for vessel positioning is an aided Inertial Navigation System. The position drift that is inherent in the inertial navigation systems, is limited by the acoustic position measurements relative to transponder(s) on the seabed.

The system can be used with both Super Short Base Line (SSBL) and Long Base Line (LBL) position input.

The HAIN provides an improved position of the vessel that both has increased accuracy and higher update rate than the original position from the acoustic measurements. This extends operational water depth and reduced battery consumption. Position output during acoustic dropout will be maintained.

2.4.1 System description

The HAIN position reference system provides:

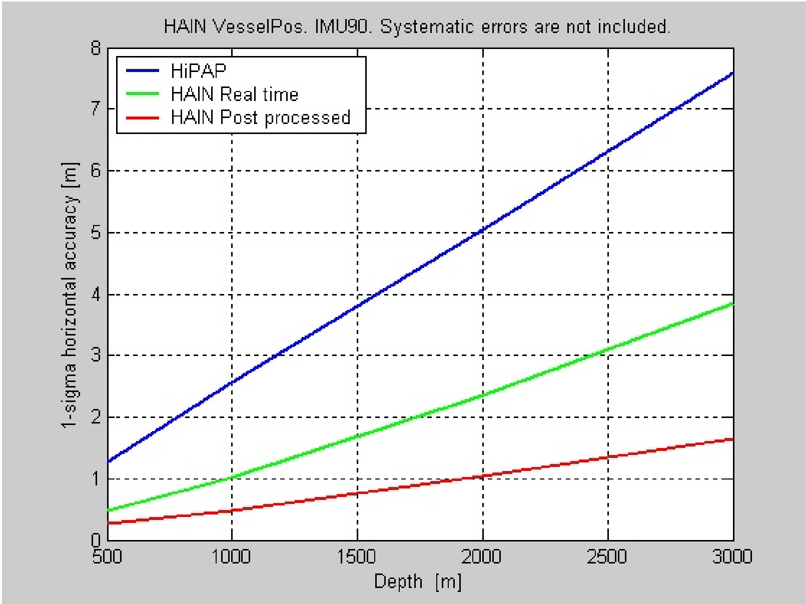
- • **Improved acoustic position accuracy**
  - \- The HAIN system will typically improve the accuracy some 2-3 times.
    Example: If the ”ping to ping” deviation is 6 meters, the HAIN will reduce this to approximately 2 meters.
- • **Higher position update rate**
  - \- The HAIN calculates a new position every 1 second regardless of water depth.
- • **Extends operational depth capabilities**
  - \- Since both the accuracy and the position update rate are improved, the HAIN allows operation in deeper waters.
- • **Longer transponder-battery lifetime**
  - \- The HAIN position update rate allows slowing down the acoustic update frequency. This will result in less ”ping” per hour, and thereby longer battery duration.
- • **Position update during acoustic drop-out**
  - \- The HAIN gives continuity in position output even though the acoustic position should fail to operate in periods of limited time.

The figure below shows the HAIN Position reference system used with a HiPAP system.

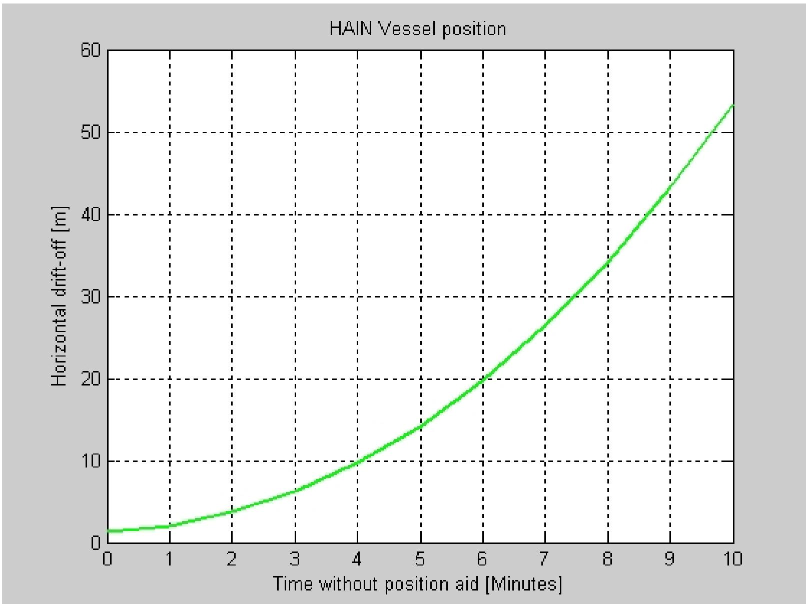
The HAIN Positioning reference system can be used on any vessel equipped with acoustic positioning system.

2.4.2 Accuracy

HAIN combines the acoustic measurements and the readings from the IMU in an optimum way. The navigation equations update the vessel position, velocity, heading and attitude almost continuously based on the readings from the IMU. The Kalman filter corrects these values when new acoustic positions are available. This result in improved position accuracy compared to the acoustic measurements, as illustrated in figure below.



HAIN Position Reference Accuracy figures – HiPAP SSBL aided



HAIN Position Reference Accuracy figures during position dropout.