Session Index

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SENSORS

ACOUSTIC POSITIONING SYSTEMS
"A PRACTICAL OVERVIEW OF CURRENT SYSTEMS"

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Abstract.

Acoustic (Hydroacoustic) position reference systems are used extensively within the Dynamic Positioning (DP) community. A clear understanding of the capabilities and limitations of these systems is required by all involved in the procurement, engineering and operation of DP vessels. The increase in the number of DP vessels working in close proximity and the increased water depths are just two of the factors driving the development of acoustic positioning systems.

There are existing commercial sources that provide acoustic positioning systems with varying levels of capability as a Dynamic Positioning (DP) position reference sensor (PRS). Systems are currently available to provide a position reference to 12,000 feet of seawater (fsw) or 3,700m with an absolute accuracy of 3-5m and a relative accuracy of <2m. Also available from these and other sources are shorter range, higher resolution acoustic positioning systems. This paper discusses how these systems are configured and what capabilities they have. A definition of conventional systems and frequency bands is included. In addition to system types, some of the more common problems associated with acoustic positioning systems and some solutions to these problems are outlined. The paper concludes that although some systems, or components readily exist to provide reliable and repeatable position references, greater understanding during the specification and preliminary engineering stage of a DP vessel design and specification is required to achieve desired operational capabilities.

I. Introduction

The goal of this paper is to outline what acoustic positioning capability exists at this time and to also discuss the advantages and limitations of these systems. Conventional systems and their modes of operation are described to ensure a clear understanding of current terminology and present capability. Some of the recent advances in acoustic positioning are also described.

II. Types of Acoustic Positioning Systems

The distance between acoustic baselines is generally used to define an acoustic positioning system – that is the distance between the active sensing elements. Three primary types of acoustic positioning systems are usually defined in this way.

Table 1. Baseline Lengths

Type of Acoustic Positioning System	Baseline Length
Ultrashort Baseline	<10cm (4")
Short Baseline	20m to 50m (60' to 160')

Long Baseline	100m to 6,000m+ (350' to 20,000')

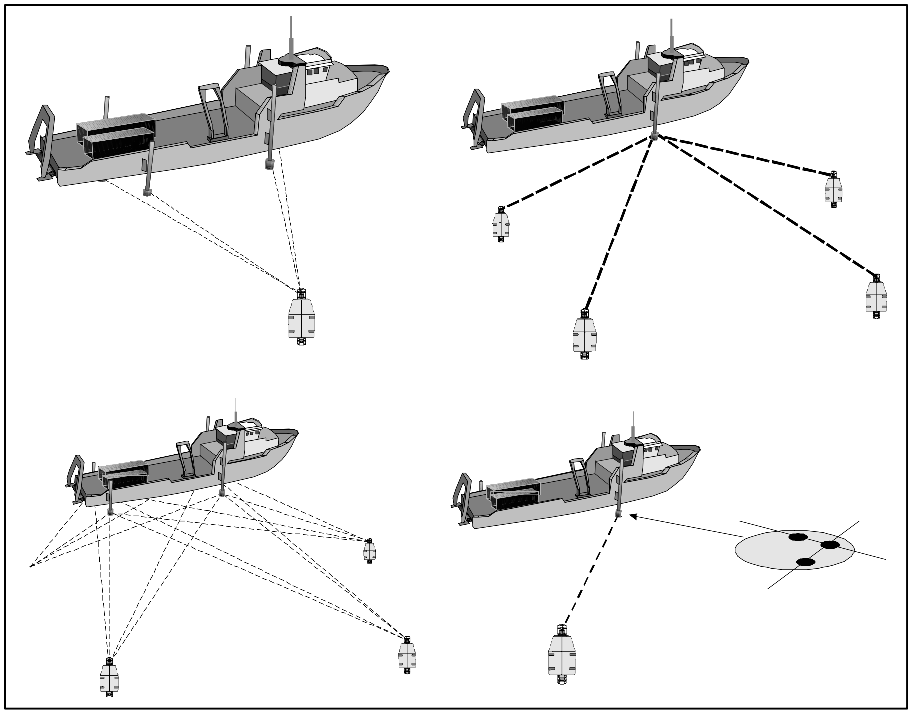

Fig.1 Primary Types of Acoustic Positioning Systems

A. Ultra Short or Super Short Baseline (USBL or SSBL)

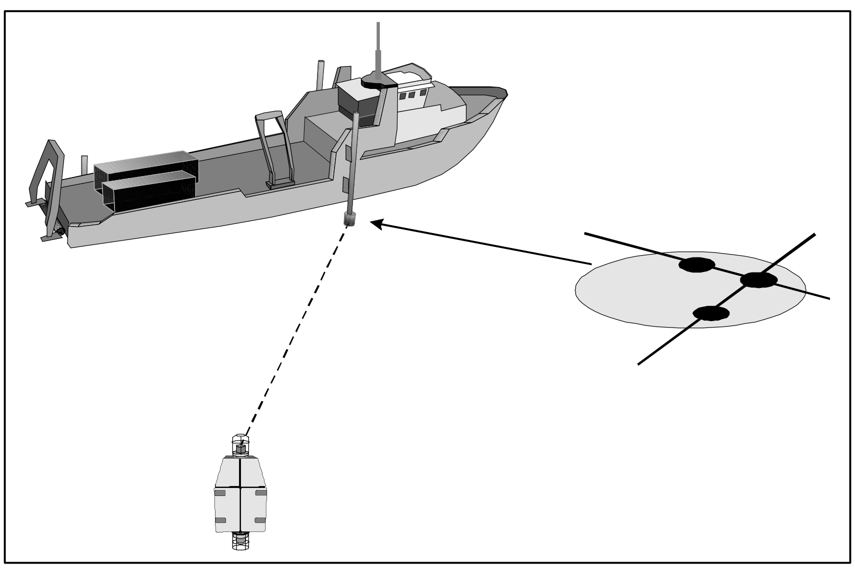

Fig. 2 Ultra Short Baseline

This system measures phase comparison on an arriving “ping” between individual elements within a multi-element (≥3) transducer. This phase comparison is used to determine the bearing from the USBL transceiver to a beacon.
If a time of flight interrogation technique is used (Transponder or Responder), a range to that beacon will also be available from the USBL system. An USBL system can work in pinger, responder, or transponder mode. Any range and bearing (position) derived from a USBL system is with respect to the transceiver mounted to the vessel and as such a USBL system needs a Vertical Reference Unit (VRU), a Gyro, and possibly a surface navigation system to provide a position that is seafloor (earth) referenced.

The advantages of Ultra Short Baseline (USBL) positioning systems are:

- Low system complexity makes USBL an easy tool to use.
- Ship based system – no need to deploy a transponder array on the seafloor.
- Only a single transceiver at the surface – one pole/deployment machine.
- Good range accuracy with time of flight systems.

The disadvantages of Ultra Short Baseline (USBL) positioning systems are:

- Detailed calibration of system required - usually not rigorously completed.
- Absolute position accuracy depends on additional sensors - ship's gyro and vertical reference unit.
- Minimal redundancy – only a few commercial systems offer an over-determined solution.
- Large transceiver/transducer gate valve or pole required with a high degree of repeatability of alignment.

B. Short Baseline (SBL)

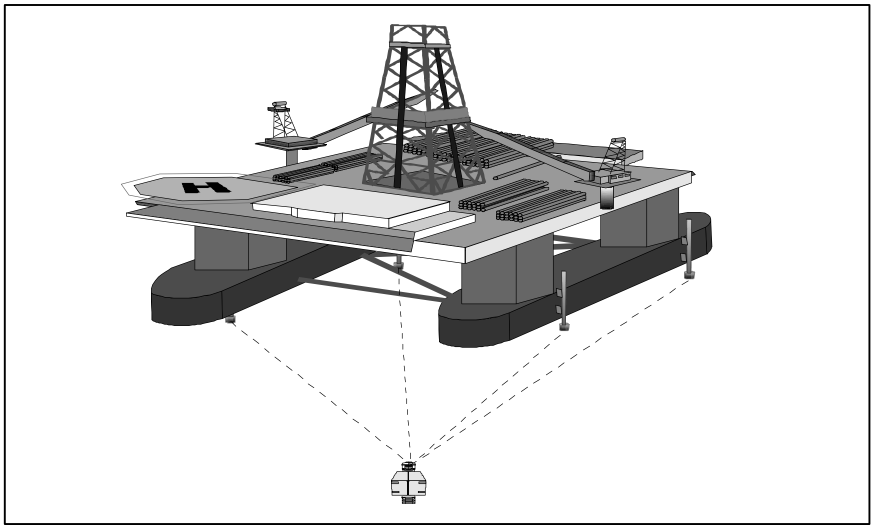

Fig. 3 Short Baseline

Short baseline systems derive a bearing to a beacon from multiple (≥3) surface mounted transceivers. This bearing is derived from the detection of the relative “time of arrival” as a ping passes each of the transceivers. If a time of flight interrogation technique is used (Transponder or Responder) a range to that beacon will also be available from

the SBL system. A SBL system can work in pinger, responder or transponder mode. Any range and bearing (position) derived from a SBL system is with respect to the transceivers mounted on the vessel and as such a SBL system needs a Vertical Reference Unit (VRU), a Gyro, and possibly a surface navigation system to provide a position that is seafloor (earth) referenced.
The advantages of Short Baseline (SBL) positioning systems are:

- Low system complexity makes SBL an easy tool to use.
- Good update rate when used with a pinger
- Good range accuracy with time of flight system.
- Spatial redundancy built in.
- Ship based system – no need to deploy transponders on the seafloor.
- Small transducers/gate values.

The disadvantages of Short Baseline (SBL) positioning systems are:

- System needs large baselines for accuracy in deep water (>30m).
- Very good dry dock/structure calibration required.
- Detailed offshore calibration of system required - usually not rigorously completed.
- Absolute position accuracy depends on additional sensors - ship's gyro and vertical reference unit.
- >3 transceiver deployment poles/machines needed.

C. Long Baseline (LBL)

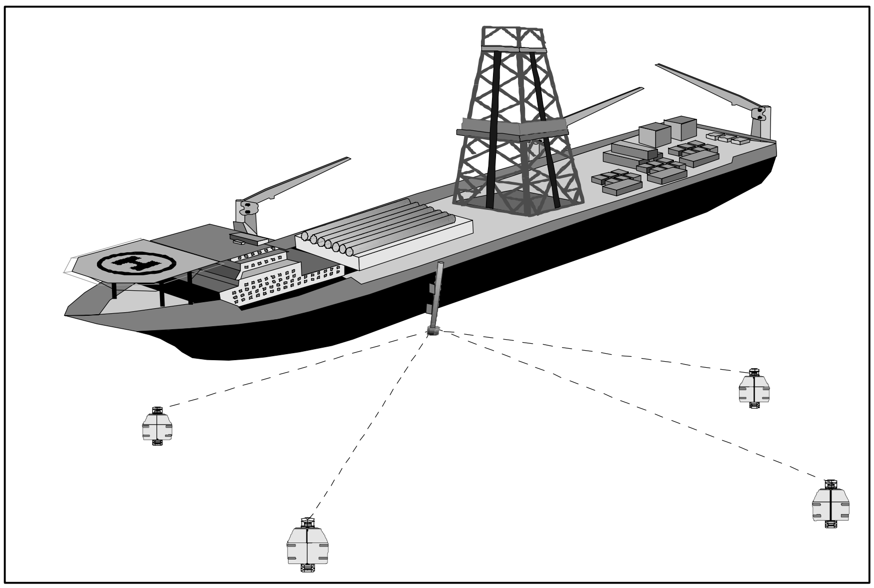

Fig. 4 Long Baseline

Long Baseline systems derive a position with respect to a seafloor deployed array (grid) of transponders. The position is generated from using 3 or more time of flight ranges to/from the seafloor stations (“range/range”). A LBL system can work in responder or transponder mode. Any range/range position derived from a LBL system is with respect to relative or absolute seafloor coordinates. As such a LBL system does not require a VRU or GYRO.

The advantages of Long Baseline (LBL) positioning systems are:

- Very good position accuracy independent of water depth.
- Observation redundancy.

- Can provide high relative accuracy positioning over large areas.
- Does not need a VRU or Gyro
- Small transducer – only one deployment machine/pole.

The disadvantages of Long Baseline (LBL) positioning systems are:

- Complex system requiring expert operators.
- Large arrays of expensive equipment.
- Operational time consumed for deployment/recovery.
- Conventional systems require comprehensive calibration at each deployment.

D. Combined Systems

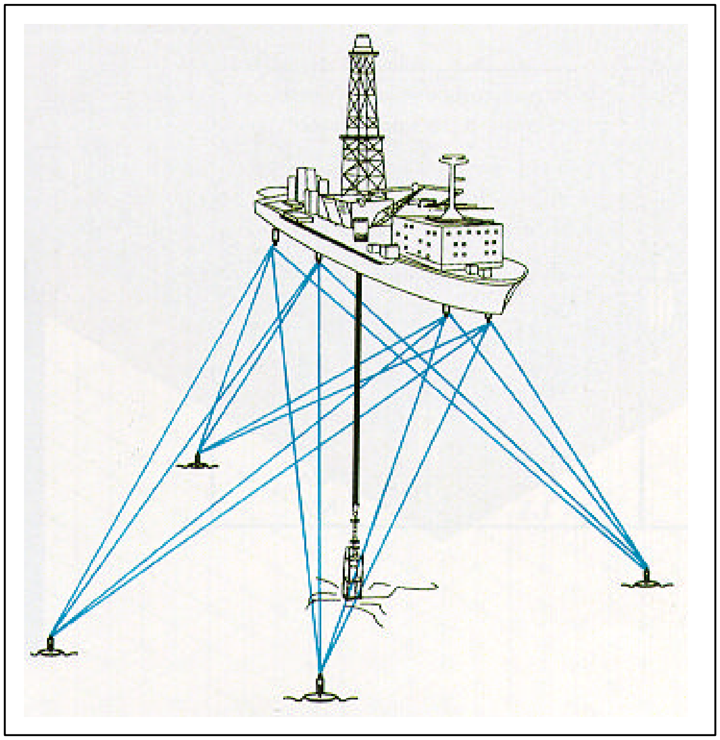

Fig. 5 Combined Systems

These systems combine the benefits from all of the above systems and provide very reliable and redundant positions. With these benefits come more complex systems. Combined systems come in many varieties:

Long and Ultrashort Baseline	(L/USBL)
Long and Short Baseline	(L/SBL)
Short and Ultrashort Baseline	(S/USBL)
Long, Short, Ultrashort Baseline	(L/S/USBL)

Multi-user systems

Multi-user systems are going to be required where more than a single vessel is working within close proximity. An example of this will be during a field development a drilling, construction, pipelay and ROV support vessel will all be required to hold station with a DP system in very close proximity. The current acoustic positioning systems cannot provide sufficient channels within the standard bandwidth available to allow all vessels to position without interference between systems.

Several methods are operational or under development to overcome this problem:

Single “master” seafloor beacon interrogation systems
Master surface vessel with radio telemetry synchronization to all other vessels
More channels within same band through signal processing techniques
Use of different frequency bands for construction and DP operations

Acoustic pollution is a significant issue West of Shetland, Brazil and is becoming an issue in the Gulf of Mexico.

III. Frequency Bands Used for Acoustic Positioning Systems

Table 2. Frequency Bands and Maximum Range

	Frequency Range	Maximum range*
Low Frequency (LF)	8 kHz to 16 kHz	>10km
Medium Frequency (MF)	18 kHz to 36 kHz	2km to 3.5km
High Frequency (HF)	30 kHz o 60 kHz	1,500m
Extra High Frequency (EHF)	50 kHz to 110 kHz	<1,000m
Very High Frequency (VHF)	200 kHz to 300 kHz	<100m

*This assumes in band noise on the surface vessel, at the transceiver, to be less than 95 dB and the source level of the beacon to be >195 dB re 1µPa @ 1m.

Usually the selection of the frequency band is related to the required accuracy specified for the vessel and maximum water depth. Water depth becomes a concern when we cannot “talk” to the equipment from the surface. As a guide, the frequency bands can be used to the following water depths if communications to the surface are required:

LF	Operational to full ocean depth
MF	Problems beyond 3,500m
EHF	Problems beyond 800m to 1,000m
VHF	Problems beyond 100m

Even at the above depths in the case of MF equipment, some special transducers may be required to work between the seafloor and the surface if the vessel is very noisy. Also the pressure rating (mechanical design) of the housing and transducer may not be to the required depth. In some instances you may also have a piece of equipment mechanically rated to a depth that will not acoustically work to that depth. An example is Sonardyne’s 2,500m rated omni-directional transponder (Compatt) in the MF band. If this is deployed in 2,500m of water under a noisy DP vessel, the source remaining at the surface, after transmission loss from the seabed, is probably not enough for the surface equipment to detect and provide a position.

If positioning accuracy is the primary reason for the selection of a particular frequency band, then other limitations (cannot communicate to the surface) have to be considered.

Acoustic positioning systems are available in all of the above frequency bands. The majority of full ocean depth systems are in the LF band. The majority of LBL and USBL systems used in Dynamic Positioning applications, site survey and construction work are in the Medium Frequency band. Metrology and engineering measurements are usually made in the EHF band. Imetrix makes a LBL system in the VHF band primarily for positional control of robotics.

IV. Components of an acoustic positioning system

The elements of acoustic positioning systems are referred with a wise range of terms. Often these terms are confusing and not necessarialy correct. To try and provide a definition of some of the terms used a description of the elements of acoustic positioning systems is outlined below.

A basic acoustic positioning system:

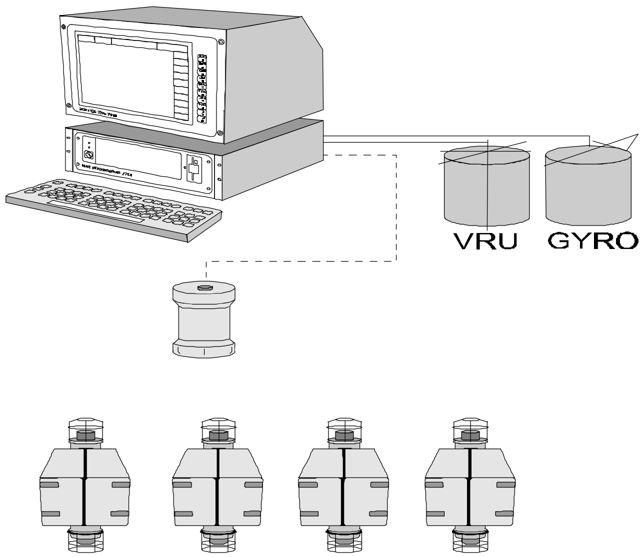

Fig. 6 Components of a Acoustic Positioning System

Display.

Monitor, Visual Display Unit (VDU), Display. The system display of menus and positioning information providing an interface to the acoustic positioning system for the user or DPO.

Processor

Processor, Central Processing Unit (CPU), computer. The central processor processes raw range data and sends graphical commands to the display. The processor also probably handles the scheduling of the interrogations into the water and the scheduling of the interfaces with other sensors and equipment. It is the processor that collects data from the Vertical Reference Unit and the Gyro for the acoustic positioning system. It is the processor that provides data out to the DP desk.

Transceiver

Transceiver, transducer and with older SBL systems Hydrophone. A transceiver takes serial data and power from the processor and transmitts and receives acoustic range and telemetry data through the water column. The transceiver is on the end of a deployment stem. Be it a deployment machine or an over the side pole, or a minim moon pool. Transceivers can be range range devices (LBL transceivers – RovNav). Multiple range range transceivers at the surface is a Short Baseline system. Transceivers can be range and bearing devices (USBL). Modern processors can have various different transceivers connected and operational at the same time.

Hydrophone

A hydrophone is a listening (receiving) only transducer or array of transducers. The units through the hull were hydrophones in a pinger based system. SBL and USBL systems can be pinger based.
Beacons

Pinger, Transponder, Responder.

A “Pinger” is a free running device that constantly transmits at a known repetition rate, on a known frequency for a predetermined pulse length. Pingers can be used with conventional SBL and USBL systems.

A “Transponder” responds to an acoustic interrogation with an acoustic reply. Transponders can be used with any of the types of acoustic positioning systems (LBL, USBL, SBL).

“Intelligent Transponders” are units that have intelligence within them from a microprocessor. These units have telemetry links to the surface and allow many of their parameters to be modified or monitored acoustically through this link. A Sonardyne name for an intelligent transponder is a “ Sonatech have a unit called a “Sonarmark”.

A “Responder” is an acoustic device that is electrically triggered to reply acoustically. Small combined Transponder//Responder units are often used on ROV’s or Towfish with USBL systems. The primary advantage is the ability to electrically trigger a response from a noisy ROV rather than acoustically interrogate a transponder on the ROV. Many manufacturers sell combined small transponder/responder units.

“Transducer” is usually used when referring to the acoustical element that actually converts Volts into an acoustic ping or vice versa. All acoustic transducers have to be mounted so that they have “line of sight” (acoustic sight) with the other transducers within the acoustic positioning system. All transceivers and transponders will have an acoustic transducer associated with it.

Pressure transducers are also used within acoustic positioning systems to provide a depth measurement from the pressure of the head of water above a unit.

V. Positioning Accuracy

Accuracy or repeatability is often misquoted when discussed with regard to positioning systems. To clarify this confusion some definitions are listed below:

A. Definitions of Accuracy.

A.1. Absolute Accuracy

This is often called predictability or geodetic accuracy and it is the measure of accuracy with which a system or procedure can determine a position with respect to a well-defined reference system or coordinates (e.g. a geodetic datum or grid coordinates mathematically related to the geodetic datum).
The absolute accuracy of any acoustic positioning system will always be affected by the surface reference positioning system **-** (D)GPS or other surface navigation system.

A.2. Repeatable Accuracy

Repeatability is the accuracy with which a surveyor or navigator can return to a position whose coordinates have been derived previously from the **same** system.

A.3. Relative Accuracy

This is the accuracy with which one object can be positioned relative to other objects usually (but not always) using the same system, at the same time. This is usually the accuracy that is required of a LBL or USBL system. Acoustic positioning systems (particularly LBL) provide very good relative accuracy independent of water depth.

A.4. Precision

This is the degree of refinement of a value while accuracy is the degree of conformance with the correct value.

A.5. Resolution

Resolving power is the measure of the degree of performance capability that a positioning system can achieve. This can be clock resolution or filter width in an acoustic positioning system.

B. Long Baseline Positioning Accuracy.

The accuracy of a conventional LBL system is independent of water depth but very dependent upon frequency.

Table 3. Long Baseline Positioning Accuracy Versus Frequency

	Frequency Range	Typical relative, static accuracy*
Low Frequency	8 kHz to 16 kHz	2m to 5m
Medium Frequency	18 kHz to 36 kHz	0.25m to 1m
High Frequency	30 kHz o 60 kHz	0.15m to 0.25m
Extra High Frequency	50 kHz to 110 kHz	<0.05m
Very High Frequency(?)	200 kHz to 300 kHz	<0.01m

*This definition requires clarification as often a static sampled (multiple acoustic observations in the same place) accuracy is quoted as being achievable for a dynamic moving objects (single position update per location with up to 3 or 4 second epochs) This is rarely the case.

C. Ultra Short Baseline and Short Baseline Positioning Accuracy

The accuracy or repeatability of USBL or SBL acoustic positioning systems are quoted as a percentage of slant range. The greater the depth - the greater the slant range - the less repeatable the position.

The diagram below shows the repeatability as a percentage of slant range of two Kongsberg Simrad USBL systems and a Sonardyne USBL system versus SNR in channel.

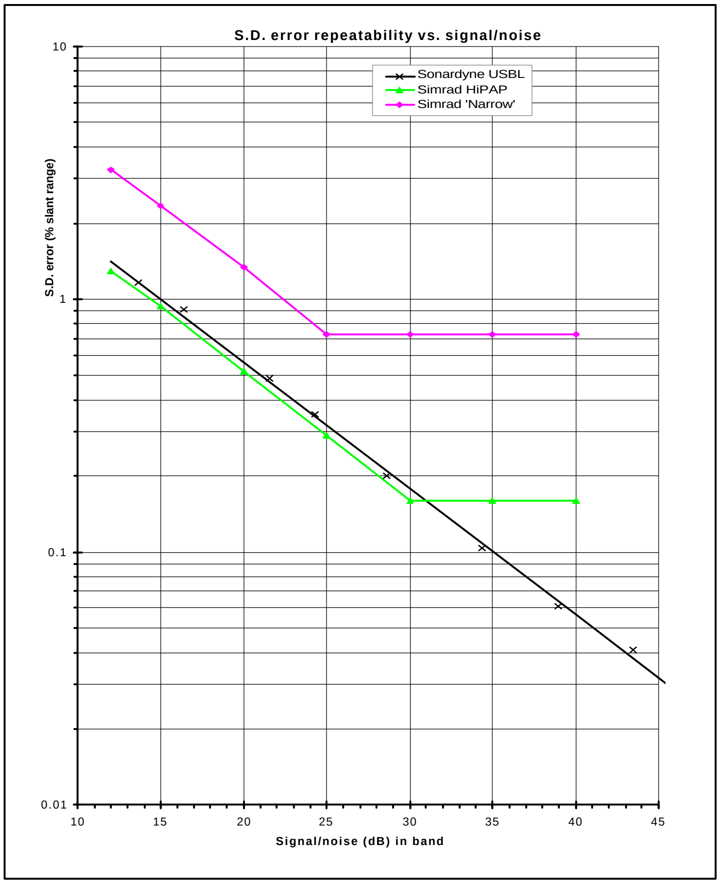

Fig. 7 USBL Repeatability Versus SNR

C.1. USBL or SBL System Accuracy

As mentioned above an USBL or SBL system requires additional sensors to derive anything but a relative position. To provide some simple guidelines to estimate the combined system accuracy, the accuracy can be described by the statistically un-correlated summation of the individual elements of the system.

USBL or SBL System accuracy can be defined as:

$$\sqrt{\{Acoustics^2 + Gyro^2 + VRU^2 + Surface\ Navigation^2\}}$$

Acoustic element is quoted percentage of slant range at applicable SNR in meters
Gyro element is quoted error (degrees) in Gyro over horizontal offset in meters
VRU element is quoted error (degrees) in VRU over vertical offset in meters
Surface navigation element is quoted accuracy of surface navigation system in meters

Note: all quoted accuracy figures need to be of the same dimensional probability.

VI. Listing of Commercial Sources of Acoustic Positioning Systems

A. USBL Manufacturers

Kongsberg Simrad	HPR300, HPR410, HiPAP
Nautronix	ATSII
ORE	LXT, Trackpoint II Plus
Sonardyne	USBL

B. SBL Manufacturers

MORS(Oceano)	
Nautronix(Honeywell)	RS5D
Sonardyne	SBL

C. LBL Manufacturers

Benthos	
Desert Star	
Edgetech (EG&G)	
Imetrix	
Kongsberg Simrad	408
MORS(Oceano)	
Nautronix(Honeywell)	906, 916
ORCA	GIB
Sonardyne	PAN, Compatt etc.
Sonatech	

D. Integrated System Manufacturers

Kongsberg Simrad
Nautronix (Honeywell)
Sonardyne

VII. Problems Associated with Acoustic Positioning Systems

To try and reduce frustrations and concerns associated with the use of acoustic positioning systems some of the more common issues are discussed below:

Cost
Noise
Line of Sight
System Complexity

A. Cost

Many potential system users look at individual component costs rather than the lifetime cost or loss of opportunity when sourcing acoustic positioning capability. Acoustic positioning hardware is (should be) designed to last many years and should be capitalized over multiple projects.

- A capital purchase saving of $200,000 can be lost with one day of down time for a DP drilling vessel due to malfunction of an acoustic position reference system. These rigs are designed for a 15 to 20 year operational life.

- The costs of the acoustic positioning system compared to the overall operational goals must be understood when cutting corners.

B. Noise Considerations

The basic signal processing technique used in most conventional tone burst matched filter acoustic positioning systems utilizes a wide-band filter, hard-limiting amplifier, and narrow-band filters, followed by detection and validation circuits. The tighter the narrow-band, the more channels can be squeezed in - the larger the pulse lengths are required. A longer pulse length reduces battery powered transponder life. The range timing resolution of this type of detector under low noise conditions is ultimately limited by the rise time of the narrow band filter. Noise causes increased timing jitter, as it affects detection of the leading rise time of the envelope and will eventually prevent the reception of an interrogation or reply signal.

The more noise at the receiver – the less accurate an acoustic positioning will be.

There are five main classifications of acoustic "noise" and they vary in their characteristics and levels of destruction:

Ambient Noise (*NA*):

This is generated by external factors such as waves, wind, rain, general traffic and sea life etc.
Generally these levels are low in the 10 kHz to 100kHz band, less than 40 dB re 1 µPa in a 1 Hz bandwidth. However, heavy rain can increase the noise level by 15 dB to 25 dB at 10 kHz.

The noise level in shallow water for a given sea state is about 9 dB above the deep water case. This can increase by approximately 25 dB in typical offshore oil field environments.

Self Noise (*NS*):

This includes noise, which is entirely generated as part of the offshore operation and includes propulsion, machinery, hydrodynamic (flow), and circuit noise:

Propulsion Noise

This noise is principally caused by the cavitation of a surface vessel's, ROV or AUV's propeller. Propulsion noise is very commonly found offshore. Variable pitch propellers are generally more noisy than fixed pitch propellers. The noise spectrum level normally increases with frequency to peak between 100 Hz to 1,000 Hz and then decreases at about 6 dB/octave. This source of noise is thus more critical for LF systems than equipment operating in the higher bands. Propeller noise also increases with speed and it is important to position transducers as far away as possible from these noise sources.

The acoustic noise associated with a conventional survey vessel has been measured to be in the region of 120dB re 1 µ Pa across the frequency band used for positioning. Thus for a hull transducer mounted 5m from the main noise source, with a directivity of 15 dB between the signals returning from the seabed transponders and the noise from the vessel thrusters, the effective wide band self noise level at the transducer is:

$$NS = 120 - [20 \log_{10} 5] - 15 = 91 \text{ dB}$$

If a minimum wide band signal to noise detection threshold of 6 dB is assumed, it can be shown that under these conditions the maximum positioning range at MF will only exceed 3,000 m with a beacon of source level >195 dB re 1 µPa @ 1 m..

Machinery Noise

This is noise associated with generators, winches, etc.... on the surface vessel, or with the hydraulic system on ROV's or AUV's. It is difficult to quantify these noise sources without detailed tank testing. Experience has shown that acoustic noise associated with the hydraulic system on ROV's (pumps, pressure release valves etc....) is frequently the limiting factor in the performance of acoustic positioning systems. In some instances it can completely interrupt operations.

An example can be illustrated with noise data collected on a Hydra ROV noise study. This test was to confirm actual noise levels and to establish their effect on range measurement jitter using equipment operating in the MF band. The (wide band) noise level in the same horizontal plane as the hydraulic pumps at a distance of 2 m was typically in excess of 140 dB re 1ìPa. This was higher than expected and would severely limit the LBL range capability. This noise was related to the hydraulic power pack and bypass relief valve and the level decreased when the thrusters were running. The syntactic buoyancy material on the Hydra attenuated this noise level in excess of 20 dB, and successful acoustic range measurements were shown to be possible with an omni-directional transducer raised up on an extension ram above the syntactic foam.

Flow Noise

This is created by any turbulent boundary layer. Generally, unless excitation and radiation of sound occurs from structures within the surface vessel, this is not a major noise source for acoustic positioning systems. However, it can critically affect towed transducers or externally mounted transducers operated at high speeds with poor hydrodynamic characteristics. Most acoustic manufacturers now offer some form of hydrodynamic towed body, which permits LBL operations at survey speeds up to 6 - 8 knots.

Reverberation (*NR*)

Reverberation arises as a direct consequence of using an acoustic positioning system. Reverberation can be subdivided into four major classifications:

- Volume reverberation - Scattering by particle matter, both animate and inanimate.
- Sea surface reverberation - scattering off the surface.
- Sea bottom reverberation - scattering off bottom layers.
- Structure reverberation - scattering off man-made structures.

The latter three types are the most dangerous, as "multipath echoes" can be highly coherent and cause total destructive interference with the "direct" path signal from an interrogator or transponder.

Structure Reverberation

This is an area of concern when installing components of acoustic positioning systems, specifically mounting of transducers. Coherent strong multipath signals are often associated with bad mounting practice and can cause destructive interference of the direct signal. This is particularly the case with large smooth surfaces such as foam packs and vessel hulls where signals will be reflected with very little energy loss. The consequences of this reverberation can be minimized by correct choice of mounting location, frequency band (higher the better) and geometry.

The relationship between the above noise elements, the beacon source level and the signal to noise ratio at the surface can be described as follows:

Signal to Noise ratio (*SNR*) = $E - N$

Where $E = SL - TL$

$N = 20 \, Log_{10} \, NT$

And $NT = \sqrt{(NA^2 + NS^2 + NR^2)}$

E is the received signal sound pressure in dB re 1 µPa
N is the total "in band" noise level in dB re1 µPa
SL is the source level in dB re 1 µPa @ 1 m
TL is the one way transmission loss in dB
NT is the total noise pressure level in µPa
NA is the ambient noise pressure level in µPa
NS is the self noise pressure level in µPa
NR is the reverberant noise pressure level in µPa

C. Line of Sight

The two primary factors that reduce the performance of acoustic positioning systems are noise as described above and lack of a "line of sight" between acoustic units. An acoustic receiver has to acoustically "see" the signal it is to detect. Variations in topography and water column will impact the line of sight between a transmitter and a receiver.

Placing beacons onto a Riser or BOP stack such that when deployed they are hidden from the surface transducer, due to the rotation of the stack, is a common example of the lack of line of sight.

Another example that causes problems for construction users of long baseline systems is the topography of the seabed. LBL array deployments have to be well planned in areas that have significant variations in seabed topography. Using longer deployment strops will help, as will bringing transponders closer into the work area. Longer strops reduces the accuracy of the system. Bringing the array closer in requires more beacons, more calibration, recovery and deployment time if not well planned.

A bathymetry map with some resolution that covers the proposed area of work area is a very valuable asset.

Ray bending - shadow zones

Variations in the velocity profile are primarily driven by pressure as water depth increases beyond 1,500m. Temperature and salinity remain fairly constant below this depth. Below this region (1,000m to 1,500m) transmitted energy will be refracted upwards. This leads to an effect known as a shadow zone. Within the shadow zone an acoustic range cannot be measured as the interrogation signal is refracted above the array transponders and is never "seen" at the transponder. This will not be an issue when trying to position from the surface to the seafloor. But for accurate LBL array calibrations over long distances (Construction rather than a DP LBL array) shadow zones and their affects have to be understood.

To ensure that arrays are deployed and will remain in "sight" ray tracing software and applicable velocity profiles are required. The transponder array design needs to be completed only after the ray tracing plots have been reviewed. Strop lengths in excess of several hundred meters are often used to overcome the problem of positioning a vehicle at the seafloor with an LBL array over large areas.

VII.D. System Complexity

Many deep water systems specifically LBL or combined system (L/USBL) can seem complex to novice users. The primary solution to this problem is good training, equipment familiarization, and solid operational procedures. Arriving on the job site is no time to discover lack of knowledge or that the batteries need to be changed in the transponders.

Conclusion

System and component advances are needed and are presently under development to provide better solutions for multiple users and deeper water operations from more powerful, noisier vessels. Very capable acoustic positioning systems are presently available for DP operations to deep water depths today. A clear understanding during the procurement, engineering and operational stage is required by all involved to ensure that these systems are implimented correctly and provide the required results.

Abreviations

CIF	Common Interrogation Frequency
dB	Decibel
EHF	Extra High Frequency
GPS	Global Positioning System
HF	High Frequency
Hz	Hertz, measure of frequency
LBL	Long Baseline
LF	Low Frequency
LOP	Line of Position
MF	Medium Frequency
PAN	Programmable Acoustic Navigator
Ms	millisecond
SBL	Short Baseline
SL	Signal/Source Level
SNR	Signal to Noise Ratio
SPL	Sound Pressure Level
SSBL	Super Short Baseline
SVP	Sound Velocity Profile
TL	Transmission Loss
USBL	Ultra Short Baseline
VHF	Very High Frequency
Vp	Speed of Sound in Water