DYNAMIC POSITIONING CONFERENCE
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Acoustics

Acoustics – Digital, Spread Spectrum, DSP, Wideband… What does this mean for Real World DP operations?

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Abstract:

Acoustic technology has progressed significantly over the last 5 years with the advent of low power, digital signal processing systems. Developments in the field have enabled complex signaling techniques to be integrated into acoustic positioning and subsea control systems. As a result of this, acoustic system manufacturers have had to re-examine their approach to offshore positioning and subsea control. This has resulted in the introduction of several terms – Digital Acoustics, Spread Spectrum, DSP, Wideband and others.

This paper attempts to provide some clarity to the user and specifier of these systems. It outlines available technology and how this can be applied to current Dynamic Positioning and Control applications. Sonardyne has extensive experience in the development, deployment and operation of these systems offshore, most recently, incorporating said spread spectrum technology. This experience has been invaluable in the delivery of a positioning system that is now providing positioning and control solutions for numerous offshore applications.

As with any system offshore it is essential that it provide reliability, redundancy and repeatability. The operational scenario for an acoustic positioning reference for DP remains one of the most challenging anywhere. This paper examines the implementation and performance of these new technologies in this environment, drawing on Sonardyne's real world experience.

Acknoweldgements

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Introduction:

Acoustic positioning techniques have long been used as position reference systems for Dynamically Positioned vessels. Until recently, acoustic positioning sensors were used as backup for more mainstream DP position reference systems such as DGPS. The role of acoustics was as a secondary reference system. During periods of high levels of sun spot activity throughout 2000, DGPS reliability was degraded and the reliance on acoustic position reference systems increased.

In addition to issues related to DGPS, operations have moved to deeper and deeper waters and development times associated with deepwater fields have decreased. This has resulted in the deployment of greater numbers of dynamically positioned vessels into small field development areas.

These factors have placed increasing demands on acoustic systems. This has been the subject of previous papers published at this conference in 2002, titled “Flexible Acoustic Positioning System Architecture.”

The following paper outlines the development of new acoustic signaling techniques and their application to Dynamic Positioning Operations. The paper is intended to further the reader’s understanding of some of the terms used by manufacturers as well as some of the issues which need to be considered when evaluating such systems for DP operations.

What is Digital Signal Processing?

Digital Signal Processing is simply the means of generating and processing complex wideband or spread spectrum acoustic signals.-Signals are synthesized in a Digital Digital Processor and converted into analogue form prior to transmission as acoustic signals through the water. Conversely at the receiver acoustic signals are converted to an analogue voltage and then into digital form prior to processing in a Digital Signal Processor

These devices have been available for a number of years, but until recently were very power hungry, making them unsuitable for long term battery powered applications such as underwater transponders etc.

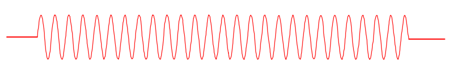
The rapid expansion of mobile phone industry in recent years has led to the development of low power, low cost DSP devices. This has enabled these signal techniques to be adopted in acoustic transponder based systems, giving rise to the reality of digital wideband acoustic positioning and data transfer.

Signal Types

Tone Signals

Existing tone based systems use acoustic pulses of a single frequency and non modulated. A minimum difference in that frequency is required to produce a number of interrogation and reply channels.

- These frequencies must be far enough apart to avoid interference between channels (false detections)
- This results in small numbers of channels being available within an acoustic spectrum.
- In crowded areas, the Campos Basin for example, acoustic interference between rigs is a real problem.

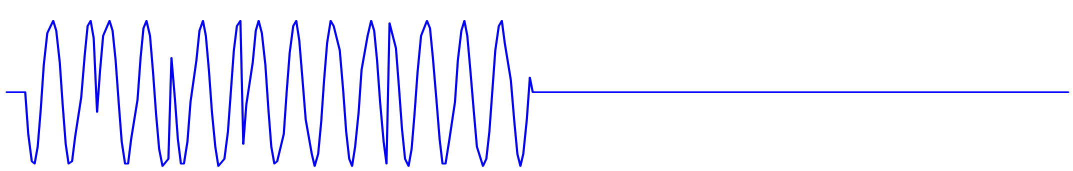


Transmitted Acoustic Tone Pulse

Wideband Signals

Digital Wideband/Spread Spectrum signals use: phase modulation to ‘write’ channel information or data onto an acoustic pulse.

This is known as Phase Shift Keying (PSK)



- The number and position of the phase changes within the pulse defines its channel identity or code.
- Once within the digital domain the wave form is represented as a binary number.
- Many channels can now be defined using different codes on a single frequency.
- By using different frequencies and codes it is now possible to produce hundreds of truly independent and robust acoustic channels rather than the handful available with tone based systems.

<u>Signal Detection</u>

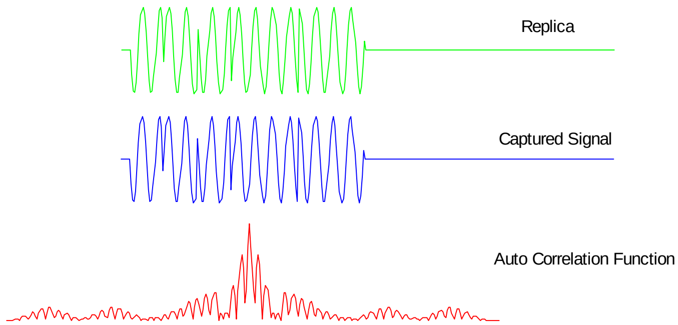
Apart from the dramatic increase in the number of available channels, the other major benefits of digital spread spectrum arise from the manner in which the signals are detected and decoded, giving greatly improved performance in noise and multi-path conditions.

This is known as Correlation Processing:

- A replica of the signal is stored in the receiver.
    - For multiple PSK codes, replicas of every code in use are stored in the receiver.
- Each signal received is correlated against every stored replica, to find the correct ‘match’.

The correlation process consists of the following stages and is shown graphically below.

- The received waveform is sampled at each increment of a high speed clock and stored as a time series of samples. Each sample is a binary number corresponding to the amplitude of the waveform at that instant.
- The stored replica waveforms are stored in the same format.
- The captured waveform is then compared with the first stored replica.
- This is done by ‘moving ‘ the captured signal past the stored replica, by one clock interval at a time. and comparing the two at each step. A ‘score’ is awarded for the number of points of similarity between the two.
- The captured waveform is then advanced by one clock interval and the process repeated, for the entire length of the captured signal.
- The ‘score’ at each stage will be low as there will be few points where the captured waveform matches the replica.
- As the time increments advance, and the two waveforms approach alignment, the correlation ‘score’ will rapidly increase, reaching a peak as the two waveforms are exactly aligned in time.
- The correlation ‘score’ will then rapidly diminish as the captured signal is further advanced past the point where it is in exact alignment with the replica.
- The time history of these correlation ‘scores’ is known as the Auto-correlation Function and gives:
    1. A very accurate time of arrival, denoted by the sharp correlation peak.
    2. Accurate confirmation of which coded signal has been received, as the sharp correlation peak will only occur when the incoming signal is compared with a matching replica. It will not give a strong correlation peak against non-matching replicas.
- The incoming signal is correlated against each of the stored replicas in turn. to determine which code it corresponds to.



What is Wideband and Spread Spectrum?

Wideband and Spread Spectrum are essentially two ways of describing the same thing. Spread Spectrum is better used to describe the communications part of a system when the bandwidth in Hertz significantly exceeds to number of bits of information transferred per second but in recent times has become a synonym for any system utilizing complex signals. Wideband is a more suitable generic name for the implementation of complex signals to determine range and therefore, position.

In a tone based (or narrow band) system, the bandwidth that the acoustic pulse occupies is the inverse of the pulse length e.g. a 4ms pulse occupies a bandwidth of approx 250 Hz. The pulse bandwidth defines the minimum channel separation required to avoid cross-channel interference.

This in turn places a limit on how many individual channels can be accommodated within a given acoustic operating band.

If too many users are operating in close proximity they will inevitably start to interfere with one another as there will be some multiple usage of the limited channels available.

The effect modulating the phase (and/or frequency) of the signal pulse is that because it is no longer a simple sine wave but a much more complex waveform, the pulse will occupy a much wider bandwidth than would a corresponding tone signal. A typical wideband ranging pulse would typically have a bandwidth of several kHz, as opposed to a few hundred Hz for a tone signal.

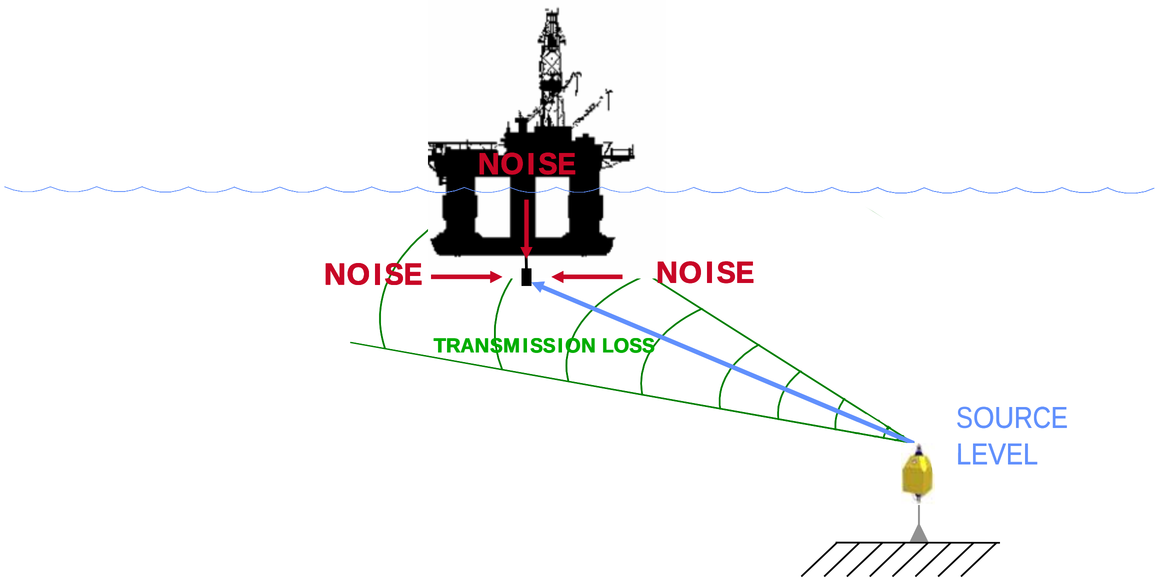
This is not a limitation to the number of channels as we are no longer relying on frequency separation to distinguish between channels. This is now achieved by correlation processing so many different codes within the same bandwidth can be detected and decoded.

As the effect of this type of signal modulation is to widen the acoustic bandwidth that the pulse occupies, it is variously referred to as wideband or spread spectrum.

What does this mean for Real World DP Operations

A DP operation presents many challenges for an acoustic positioning system as follows:

1) Noise
Acoustic in band noise generated by thruster cavitation will increase noise levels at the surface receiver. This will make reception of acoustic signals more difficult. This relates back to the sonar equation as below.



SNR = SL-TL-N

Where SNR = Signal to Noise Ratio i.e. amount of acoustic signal detectable above noise.
SL = Source Level of Transponder
TL = Transmission Loss
N = Noise

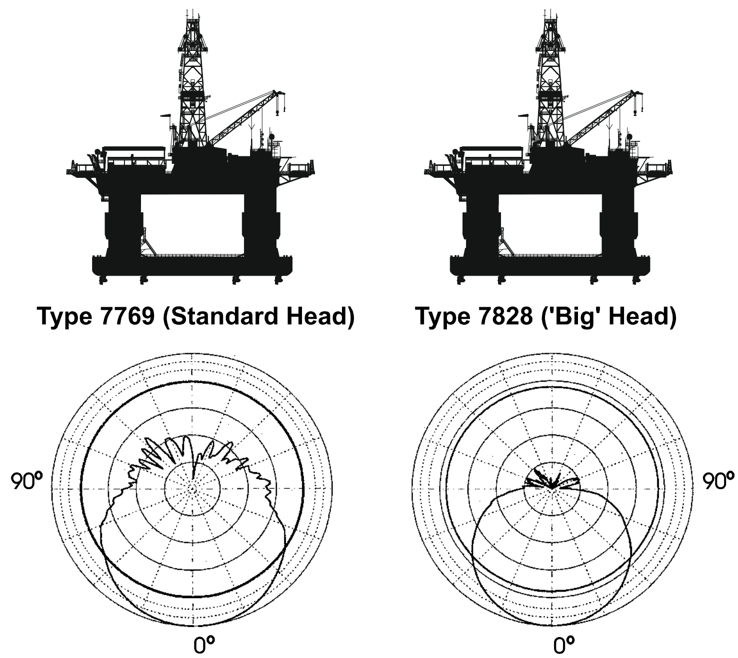
Hence if the DP vessel generates significant in band acoustic noise, the acoustic system must be optimized to ensure that the signal from the reference transponder can be received. The reference transponder can be up to 7,000m from the receiver in some cases.

Current analogue systems have relied on the ability to increase acoustic output levels from reference transponders or enhancements to the surface transceiver to reduce the impact of noise. Enhancements to the surface transceiver have been as follows:

Surface transceivers have used beam steering algorithms to electrically focus sectors of the transceiver on the incoming acoustic signal.

Modify mechanical design of transceiver to ensure that receive beam pattern is less sensitive in the location of noise sources. An example is shown in the diagram over the page where the Sonardyne Big Head USBL transceiver design is less sensitive above the horizontal.

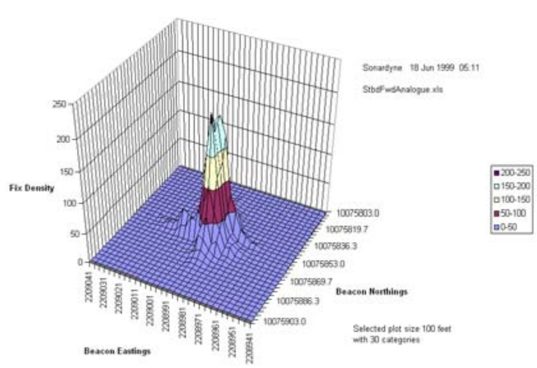
USBL Transducer Array Polar Plot (Element A)

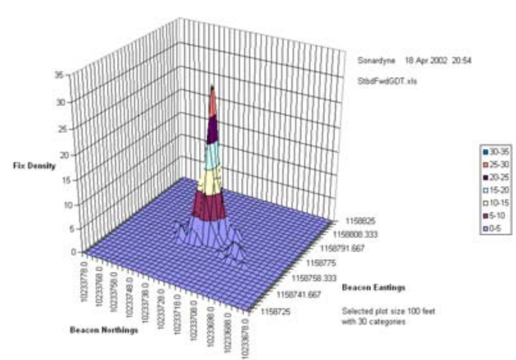


Digital Signal Processing of Wideband Signals offer advantages in a high noise environment for the following reasons:

Precision of Ranging

For a given signal to noise ratio the ranging precision of a wideband system is typically ten time greater than a comparative narrowband system





Analogue Transceiver *Digital Transceiver*

The position plots above show the results of a spin over a seabed transponder and the resulting transponder positional plot. The first plot was undertaken using an analogue head on a DP drilling vessel. The second plot was recorded some time later from the same location when the previous analogue head was replaced with a digital unit for evaluation purposes. Although both plots look similar, the plot from the digital transceiver is more defined with less scatter. This reflects the processing gain from using a digital rather than an analogue unit.

Ability To Detect Transponder Signal Against A Background Of Noise

The receipt of an acoustic signal and the subsequent resolution of position rely on the following stages:

Detection – this requires the signal energy to be higher than the noise energy in a signal duration by a defined “Detection Threshold”. The threshold may be varied to obtain the optimum trade between probability of detection and the probability of a false detection.

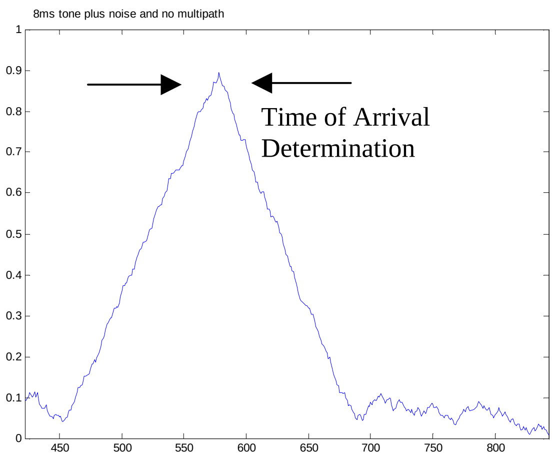
Once the decision of signal presence is made then the signal is processed for ‘Parameter Estimation’. The time of arrival of the signal is estimated for range determination and in the case of a USBL system the signals from multiple receive elements are processed to estimate the direction of arrival. In principle other parameters can be estimated such as the “Doppler Shift” of the signal which can give information such as the relative velocity between the transponder and the vessel.

For a given signal to noise ratio the use of a wideband signal does not provide any advantages in the detection phase. The incoming signal must still have sufficient energy to exceed the noise level by the Detection Threshold. If in a narrowband system the detection threshold cannot be achieved and the power of the beacon cannot be increased the only option is to increase the signal duration. This will as a consequence decreases the bandwidth. In a wideband system it is possible to increase or preserve the bandwidth AND increase the signal duration to improve the signal to noise ratio.

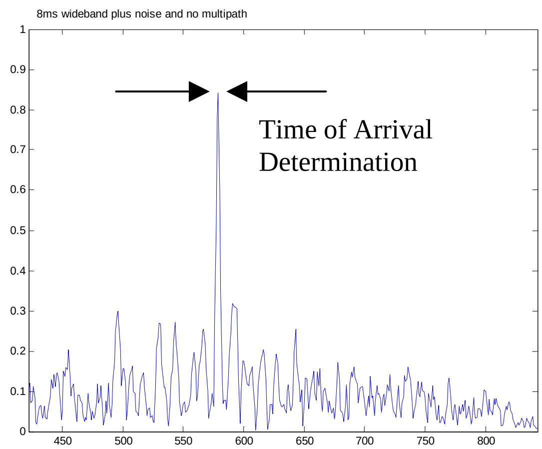
Wideband also offers extremely significant advantages in the parameter estimation phase. The peak of the wideband filter output is easier to identify, since it offers a clear measurement point. While a tone signal may still be detected, the determination of time of arrival may be difficult in a high noise environment.

The graphs below illustrate that a tone signal, although detected, does not have as clear a point at which to measure the time of arrival when compared to the Wideband signal.

8ms Tone in the presence of Noise



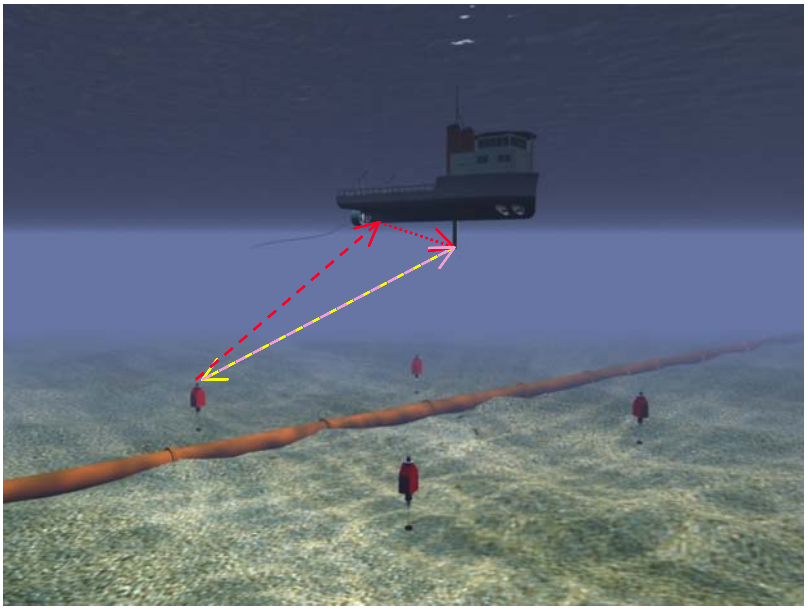
8ms Wideband Signal in the Presence of Noise



2) Multipath

Multipath is a common phenomenon in acoustic positioning and occurs when an incoming signal is received after it has been reflected from another surface.

This is shown in the diagram below, where a signal is reflected from the vessel hull before receipt. The signal could also be reflected from other reflectors, such as subsea structures, the sea surface or the seabed. In vessel operations however, the most likely reflector will be the vessel hull.



In tone systems, multipath will manifest itself in a couple of ways:

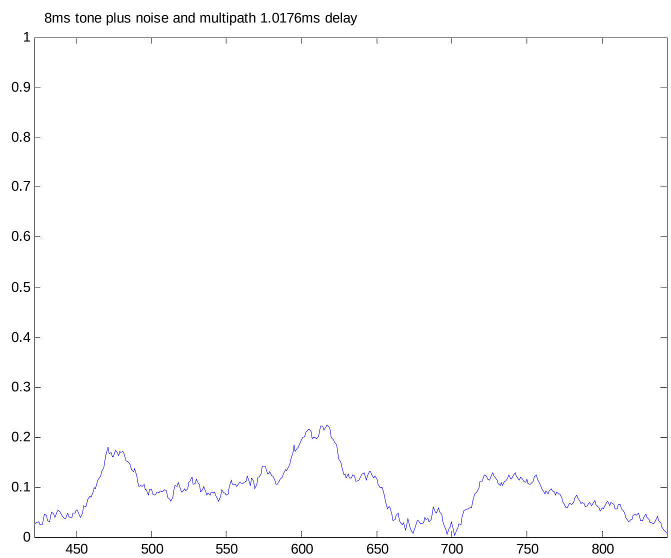
If the reflected path is sufficiently longer than the direct path, the user will see two received signals, separated by time. In this case, the later signal will be rejected through software gating. This is unlikely to occur in vessel operations, unless the signal has been reflected from seabed to sea surface and is therefore significantly later in arrival than the real transmission. This can happen in areas where the seabed is hard and the sea is very calm. Under these circumstances, both seabed and sea surface are good reflectors.

When the reflected path is not sufficiently longer than the direct path, which is usually the case on a vessel. The most likely effect of this is that the two incoming pulses will overlap. If the receiver cannot separate all of the incoming pulse, it is possible that neither signal will be detected and validated. In this case, a position dropout will occur.

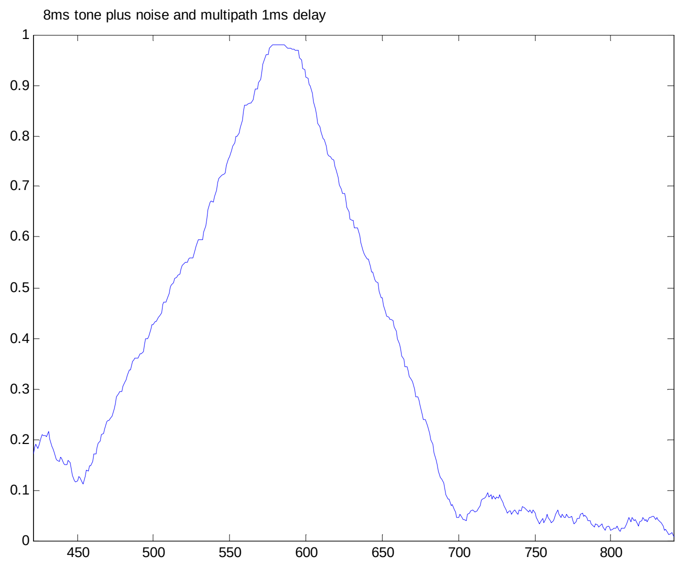
Wideband systems are more tolerant of multipath conditions, since the measurement point is more clearly defined. This allows different signal paths as close as 0.25 milli seconds to be received. The receiver can still distinguish between the different signals and the software will ensure that the correct path is selected.

The following diagrams demonstrate this. Each diagram shows the output from a correlation filter from a receiver which is receiving tone and wideband signals in an environment where noise and multipath are present.

Output from filter for Tone Signal.

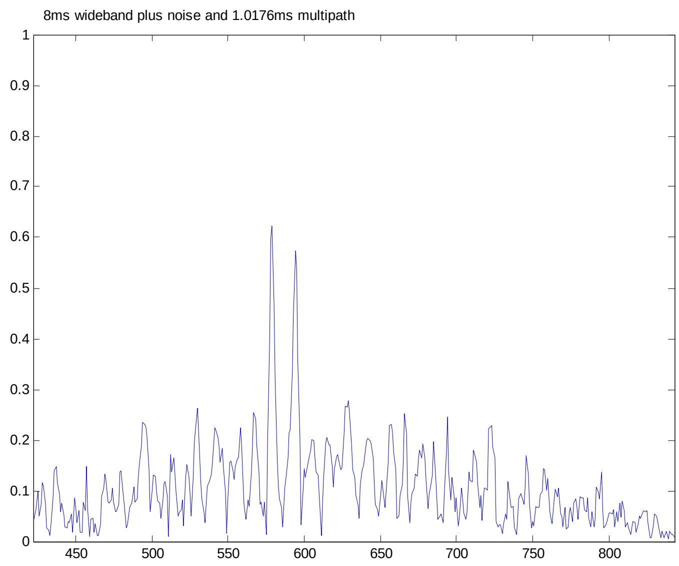


The diagram above illustrates the case where multi-path interference of a narrowband signal has resulted in signal destruction. In this case the signal would not have been detected. In the diagram below signals from two paths have combined (constructive interference). The filter output is flat topped and the time of arrival is ill-defined. It is very difficult resolve the direction of arrival of both paths.



Output from Filter for Wideband Signal

The output from the wideband filter below shows very clearly a direct and a reflected path. This will allow the system to recognize the reflected signal and reject it. It is easy to estimate the direction of arrival of both signals.



3) Battery Life

All subsea transponders rely on internal batteries for power. As detailed above, one of the main requirements for acoustic systems operating in a DP environment is to overcome vessel generated noise. The traditional way this is achieved is by increasing the output source level of the transponder. Most DP vessels operate with transponders with source levels in the region of 192 – 202dB. Most transponders allow the operator to vary the output source level during operations and this allows the selection of the lowest possible output power level to be used.

The use of wideband signals as detailed above allows better performance at lower signal to noise ratios. This also allows the user to operate positioning transponders with lower source levels and thus extend battery life. For mobile operations from a monohull vessel, the issue of battery life may seem unimportant. On a large DP drilling vessel however, it is desirable to have seabed units which will last as long as possible allowing the vessel to minimize disruption to operations through transponder battery replacement. Current battery life for a transponder in a typical DP operation would be in the region of 9 months. Wideband signals should allow this to be extended to more than 12 months.

4) Interference

Most DP vessels operate in areas where there are also other DP vessels. The picture below shows a typical operational scenario during a construction project offshore West Africa.

Analogue acoustic systems have relied on separation of discrete analogue tones in order to avoid interference. The growth in use of acoustics as a DP position reference has made it more and more difficult to provide sufficient channels for all vessels to continue operations without some level of interference.

The issue of frequency management is particularly bad in congested areas and has required many vessel operators and their clients to plan operations carefully in order that each vessel can work with minimal interference.

The introduction of wideband signals allows many more channels to be introduced into systems through the use of coded signals which are transmitted on analogue tone carriers. In a wideband system, the analogue carriers can now overlap or even be identical, as long as the code is different. Sonardyne's analogue systems allow up to 15 channels to be used. Sonardyne's new system using wideband signaling offers up to 448 unique channels. This clearly removes any concerns over frequency management or acoustic pollution allowing multiple vessels to operate in close proximity without interference.

5) Update Rate

Any position reference sensor for station keeping must provide a highly repeatable solution. A DP model also needs frequent updates of data with minimal variance between positions. Transmissions of acoustic signals through water are limited in speed by through water sound velocity. The introduction of a wideband signal will not change this – the signal will continue to travel at the same speed.

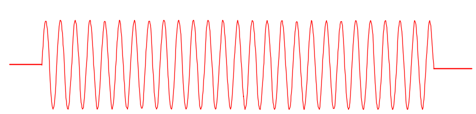
Digital processing allows a more flexible approach than possible with analogue processors. An example is the use of ping stacking, where digital transceivers can be used to stack interrogations in the water column to transponders which can in turn respond. Whilst this technique may seem to be a replica of pinger based acoustic systems which have been in existence for a long time, the technique allows the operator to maintain control over the acoustic transmissions from the subsea transponder. This is particularly important in order that battery life and acoustic traffic can be controlled without recovering units.

6) Repeatability

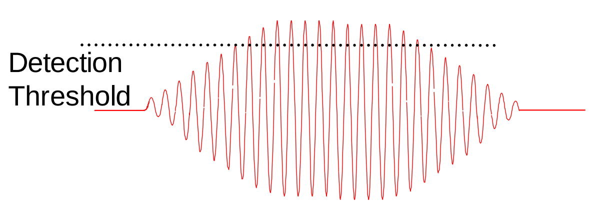
Wideband signals allow more precise measurements to be made from the acoustic signal. In order to explain this statement, a comparison between analogue measurements and wideband measurements is made in the following paragraphs:

Analogue Signal Measurement

On receipt, analogue signals are first filtered to remove any noise. The filter outputs a ramped output as shown below.



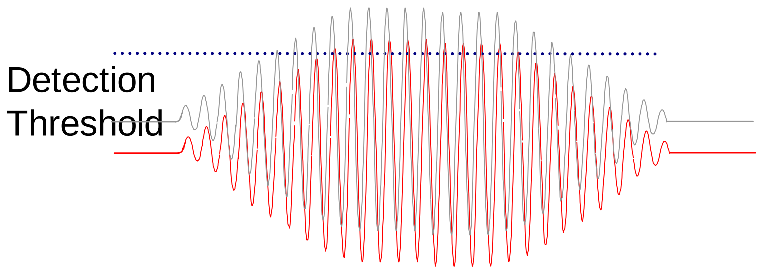
Transmitted Acoustic Pulse



Received & Filtered Pulse

An analogue signal is received when the signal level exceeds a detection threshold in the receiver. As the incoming pulse exceeds this detection threshold, it is then validated and the measurement point is determined. This is shown in the diagram above.

Noise can affect the measurement of arrival time, since this can increase or decrease the remaining analogue signal and effectively move the measurement point. This is shown in the diagram below.

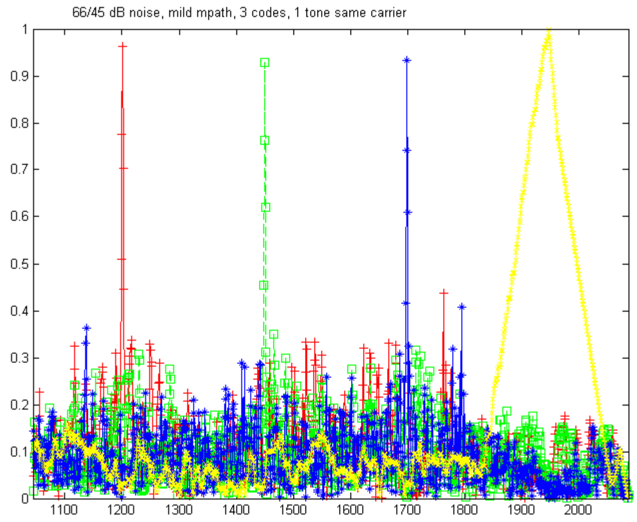


Received & Filtered Pulse

As can be seen in the diagram above, if there is a higher level of signal remaining at the receiver, as represented by the grey line, the measurement point will be slightly different.

In circumstances where the noise level is high, the remaining signal from the transponder will decrease. This will degrade the repeatability of the resulting position since the measurement point will be more difficult to determine on each pulse and in some cases, it may not be possible to detect the incoming signal and a position update may not be possible. This scenario will have been experienced by most DP operators, when the vessel is in situations where thruster use increases, perhaps during periods of bad weather, or when another DP vessel is alongside, adding to in water acoustic noise.

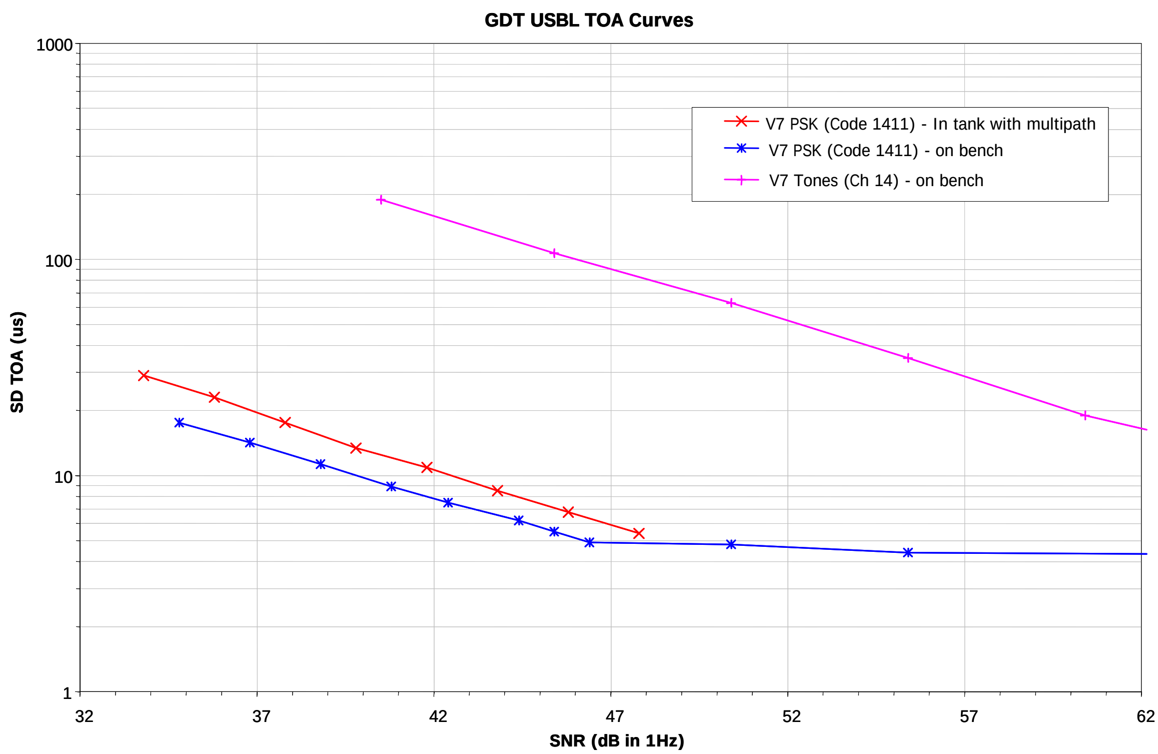
With a digital signal, the measurement point is greatly improved, since the surface receiver is matching a replica of the transmitted signal. Only when there is an exact match will the correlation function output a spike. An example of the output from a typical correlation filter from receipt of a wideband signal is shown below:



As can be seen from the filter output shown above, the measurement point for the wideband signals (red, green and blue) is a clearly defined point and far easier to process than the tone shown in yellow.

An important point to note from the graph above is that the receiver is receiving a tone signal and three wideband signals (using the same carrier tone) simultaneously without any problem.

The improvement in detection timing for wideband signals is significant. This is shown in the graph below:



The graph above, shows available Signal to Noise ration on the X axis and Time of Arrival Standard Deviations in micro seconds on the Y axis. The pink line shows performance based on the receipt of analogue tones on the bench. It is clear that the standard deviation of time of arrival measurements decreases considerably as signal to noise ratio increases. That is, the more signal we have remaining on receipt, the smaller the spread will be on our time of arrival measurement i.e. the position will be more repeatable.

The blue line shows performance of wideband signals on the bench and the red line shows performance of wideband signals in a reverberant test tank.

The graph shows that there is a marked improvement with time of arrival measurements from analogue tones to wideband signals. In terms of Signal to Noise Ratio, there is a 20dB improvement from tone to wideband.

So what does this mean?

The improved time of arrival measurement capability means that we can improve positional repeatability. Alternatively, we can maintain current positional repeatability with lower available signal to noise ratio, that is, we can reduce the output source level of the transponder or tolerate greater levels of vessel noise. In essence, we can use transponders more efficiently while also improving system performance in the presence of noise.

CONCLUSION

There are clearly benefits to DP operations to have wideband acoustics and significant improvements in performance and robustness can be achieved. There are also improvements which can be made to existing systems through the addition of digital receivers which will also improve performance, while allowing vessels to gradually migrate to digital technology.

Wideband acoustic systems continue to operate in the same environment that analogue systems have always operated in. Wideband signals offer us some processing gains whereby we can better manage the issues, as described above. However, the issue of sound velocity remains.

Sound velocity constrains the speed of transmission of acoustic signals and also causes refraction of acoustic signals. Each signal is refracted according to Snell's law as it passes through different layers of seawater with different densities. In DP applications, sound velocity has been less of an issue since the position reference transponders are usually installed directly beneath the DP vessel. Hence the travel path of the acoustic signal is perpendicular to the water density change interfaces or layers. It is in situations where the path of the signal is traveling from a location with a greater horizontal offset that sound velocity becomes a problem and needs to be modeled to ensure that signal refraction is understood and corrections applied.

The use of a wideband signal will improve the performance of an acoustic positioning system for DP. Perhaps the main benefit to a DP vessel operator and a DP vessel client is that the system will extend the operational envelope from current systems. That is, the system will allow performance in environments where noise levels are higher, or in areas where there is a high level of acoustic communication in the water already. This in itself should allow the vessel operator to reduce the amount of time spent on downtime due to unusable acoustic position inputs.

Although not covered in this paper in any detail, wideband also offers opportunities for improved acoustic telemetry which could be beneficial for ancillary operations from the DP vessel. Wideband technology can be used to provide fast subsea communications at rates up to 10kbps. This has implications for applications where umbilicals are currently deployed to control subsea systems. The introduction of subsea power generation systems and more efficient battery packs makes the removal of umbilicals a more realistic option.

Further information on any topic covered in the paper is available by contacting the author.