White paper

Multiplying the Effectiveness of Helicopter ASW Sensors

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Abstract

The introduction of low frequency active dipping sonar systems has enabled ASW helicopters to achieve significantly increased detection range. As a result a single helicopter, rather than a pair of helicopters, is adequate for both search and attack operations. However, modern threats comprising small diesel submarines operating in littoral waters, in adverse acoustic conditions, remain a challenge. This paper shows how recent developments in sonobuoys combined with a low frequency active dipping sonar system can have a force multiplier effect, providing significantly improved performance as well as improving the helicopter's tactical freedom. The paper quantifies performance improvements, based on simulation, for a specific combination of dipping sonar and expendable active sources and passive receivers, for an illustrative barrier scenario.

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This paper has been jointly prepared by Ultra Sonar and Communication Systems (Greenford, UK), L3 Ocean Systems (Sylmar, California)

Background

The ASW helicopter, equipped with dipping sonar, has been a formidable opponent to the submarine for many decades, especially in a layered defence posture with other platforms such as MPA and ASW frigates. In the past, the most pressing threat has been from nuclear submarines in deep water, where active sonar detection ranges have allowed these aircraft to operate effectively for much of the time in favourable acoustic propagation conditions. The benefits of dipping sonar were considerably improved with the advent of low frequency systems, taking advantage of the significantly increased ranges that could be achieved at much lower frequencies. The HELRAS sonar, fitted to the EH101 helicopter, represents state of the art.

The move to littoral operations and the increasing threat from the smaller diesel submarine, or SSK, is, however, tipping the balance back in favour of the submarine. The SSK, especially when able to remain submerged using Air Independent Propulsion (AIP), is a much smaller, stealthier, and therefore more dangerous opponent. More importantly, sonar conditions in many parts of the world are far worse inshore than in deep water. Local knowledge, and a familiarity with operating in littoral waters, will give the submarine commander a decisive edge when conducting both defensive and offensive operations. At the same time, reports emerged of submarine fitted systems for launching anti-helicopter missiles, making helicopters potentially more vulnerable in the dip. Whilst this does not presently appear to be much of a challenge, it could become so if helicopters presented themselves as a target.

At the same time, defence costs continue to rise inexorably. The world's larger navies are continually looking for ways to reduce the cost of operations, while more nations are concerned with an emerging local SSK threat and want a defensive capability at low cost. It is clear that, if the individual helicopter were made more capable, then it could offer increased search rates and the prospect of operating as a self-contained unit, rather than in the cold war tactic of operating in pairs.

So, although the dipping sonar still represents a powerful sensor system in its own right, changing circumstances merit re-visiting the benefits of complementary solutions to fill emergent gaps in capability. Modern sonobuoy systems, such as the General Dynamics

Canada Conduction-cooled VME Acoustic Processor/Receiver (CVAR), when operated in conjunction with LFA Dipping Sonars, appear to provide significant tactical advantages.

Maritime Patrol Aircraft (MPA) and some ASW helicopters have used sonobuoys for many years, but submarine quieting programs have now made passive search more challenging without external cueing, eg fixed or towed arrays, and even these are reducing in capability. Consequently, modern sonobuoys are evolving to counter the changing threat and sustain the MPA's capability. Passive buoys remain effective for target classification through signature analysis, and for short range tracking of fast targets. Medium frequency active sonobuoys are also still effective for short-range, target relocation and attack tracking. However, it is the development of low frequency active sonobuoys, when used multistatically with the latest standards of passive sonobuoys, which offer the greatest promise. More importantly, as these buoys operate in the same acoustic spectrum as dipping sonars such as HELRAS, there is significant potential for them to be used together and to offer improvements in system performance, and therefore platform capability.

Multistatics

Figure 1 illustrates the migration from monostatic to multistatic sonar. The simple monostatic case is well understood, and is the basis for most sonar. Bistatic operation, say, between a helicopter and its mother ship's towed array, or between 2 helicopters or 2 ships, offers some increase in coverage. However, it is the use of multistatics that provides substantial and, in some cases, unexpected benefits.

Low frequency multistatic active technology has been under development for at least 10 years and has concentrated on developing suitable high power projectors that could be deployed remotely. As typical source frequencies could be detected on existing passive systems, eg towed arrays and sonobuoys, it made sense to concentrate on the projector. Although research continues, presently large, expendable sources, operating at very high power, and deployed from ships or submarines, are not the way forward. Instead, airborne sensors, such as the LF dipping sonar with its high power, precisely defined ping shape and sequence, and multiple dip depth capability; or air-launched, A-size sonobuoys, either explosive or electro-acoustic, have emerged as suitable candidates. Typical systems include HELRAS and FLASH ADS, and the USN SSQ-110 series impulsive buoys, or the Thales RASSPUTIN and Ultra Electronics' SSQ 926 ALFEA electro-acoustic buoys.

For the sonobuoys, there are pro's and con's to each. Explosive buoys provide only a few pings per buoy, which presents a problem in terms of classifying and tracking a target, but they offer long ranges because the source level is relatively high. If built in quantity, these buoys can be economic to develop, although in practice the usage rates will tend to be low, due to safety and environmental considerations, and so the cost advantage may not be realised. Conversely, electro-acoustic buoys provide a lower source level, but with a precisely defined ping shape and sequence, which can be detected in a matched filter. Also, with sufficient battery life, they can be set to ping automatically for hours.

Deploying multistatic systems on aircraft solves another problem of the technology: the need to know where and when the ping originated, and to be able to monitor multiple receivers, typically in real time, for tactical systems. The command and control problem is greatly simplified in the case of airborne, compared to surface ship, multistatics because all transmitters and receivers are under the direct control of the aircraft. There is no need for tactical data links or for encoding timing or location information into ping waveforms. Furthermore, for typical line-of-sight radio telemetry links, an aircraft operating at altitude can receive from a far wider area than a ship, and can react far more quickly to any detection.

Persistence on patrol remains a problem, but for searching large areas of ocean, or even littoral coastline, the aircraft is far more effective.

Figure 1 also shows a key feature affecting multistatic operations: aspect dependency.

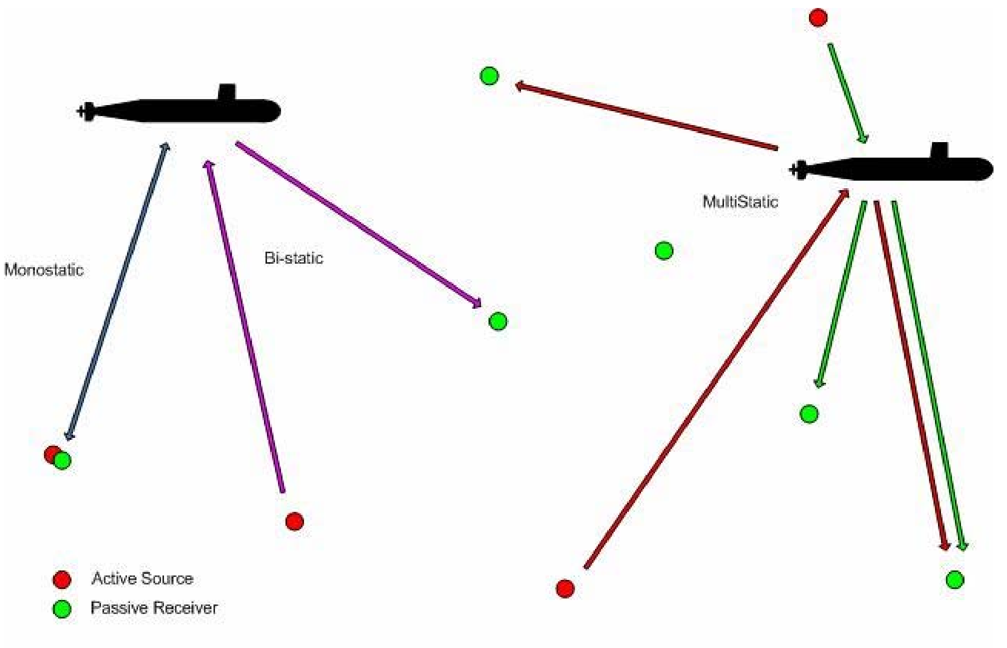


Figure 1. Sonar Source/Receiver Combinations

Sonar returns vary significantly with target aspect, with variations due to glint angle being as much as 20dB. There is little that the monostatic sonar designer could do about aspect dependency, which submarine commanders have traditionally exploited; 'turn tail-on to the source and change depth' is in every tactics manual. Although turning tail presents more Doppler and more detectability with CW. There is a trade-off between increasing Doppler and decreasing target strength. For multistatics, though, it is a positive advantage. The submariner does not know where the sonobuoys (both source and receiver) are, so turning tail-on to one source, could actually increase his risk of detection from other source/receiver combinations. Figure 2 shows, for a generalised target shape, the typical effect of aspect dependency in a multistatic system, where α is the incident angle and β is the reflected angle. The monostatic case is merely one example, where α and β are coincident. The plot shows, for given combinations of α and β, the areas of maximum signal excess.

In conditions with well-developed layers, combining variable depth sonar (eg a helicopter-based dipper) with sonobuoys produces some very interesting phenomena. In a typical dip sequence, the VDS would be deployed to multiple depths, to search in the different layers. This would increase the overall probability of detection in a given water column, but takes time, especially with the longer ranges expected of low frequency active. Dip sequences could take 15 to 20 minutes to complete. However, energy leakage from, say, to a surface duct could illuminate a shallow target multistatically such that it could be detected on a shallow sonobuoy, whereas it may not have been detected by the VDS below the layer.

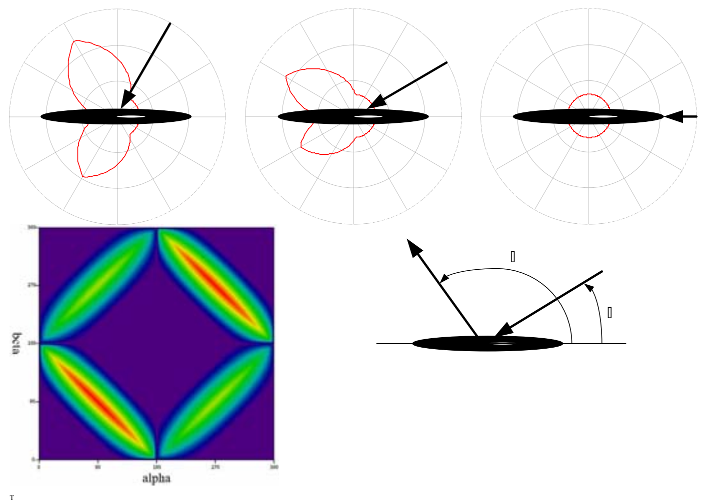


Figure 2. The Effects of Glint Angle

Figure 3 below illustrates a series of signal excess plots of dipper and sonobuoys against shallow or deep targets. The axes are in 10km units. Figure 3.a shows signal excess against a deep target with a deep dipper. Should the target come shallow, then the deep dipper coverage reduces to almost nothing (3.b). The addition of a shallow Barra sonobuoy, however, markedly changes the shallow target detection case (3.c). Of course, the dipper and the Barra would need to be monitored both monostatically and multistatically at the same time.

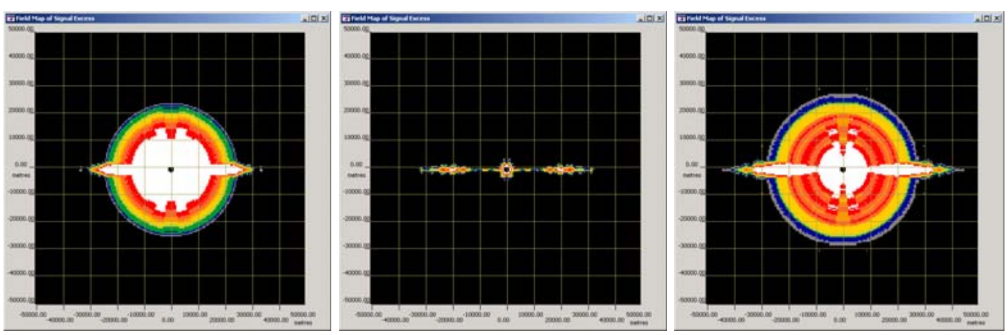


Figure 3.a Figure 3.b Figure 3.c

Figure 3. MultiStatic Cross Layer detections

Earlier Work

At UDT 2001, L-3 Communications, Ocean Systems (L-3OS) presented a Poster Paper addressing the benefits of combining dipping sonar, hull-mounted sonar and towed arrays[i]. Using a helicopter-based VDS close to a ship gave significant benefits across the water column:

- Covert receiving platforms.
- Extended coverage of the water column.
- Extended coverage area in adverse littoral environments.

- Improved performance in areas containing islands.
- Increased probability of detection in overlap areas.
- Increased responsiveness to changing tactical situations.
- Confusion of adversary resulting from more complicated, multi-sonar configurations.
- Cost-effective approach to increased performance by augmenting existing systems.

Figure 4 shows typical results for a Mediterranean environment, illustrating the concept

Then, at UDT Malmo in 2003, a further paper[ii] was presented which first suggested combining passive sonobuoys bistatically with dipping sonar. For that paper, the chosen scenario was a barrier operation across a choke point with varying sonar conditions. The study showed that, by combining the two sensors, significant gains in coverage could be achieved, although for this particular case, a third party, eg MPA or UAV, was required to either monitor or relay the passive buoy's multistatic data, as the helicopter in the dip would have limited RF reception range on the buoys. Figure 5 shows the Sound Velocity Profiles (SVP) at each dip position, the active range of the day prediction and the signal excess expected from the combined sonar system. The calculations would allow a single helicopter to provide a 90% Detection Probability (P_D) against a 4 kt target across a barrier frontage of some 350km. Without sonobuoys, 2 helicopters would be needed. The synergy of combining these two sensors was, in this case, some 60% greater than the performance of the systems alone.

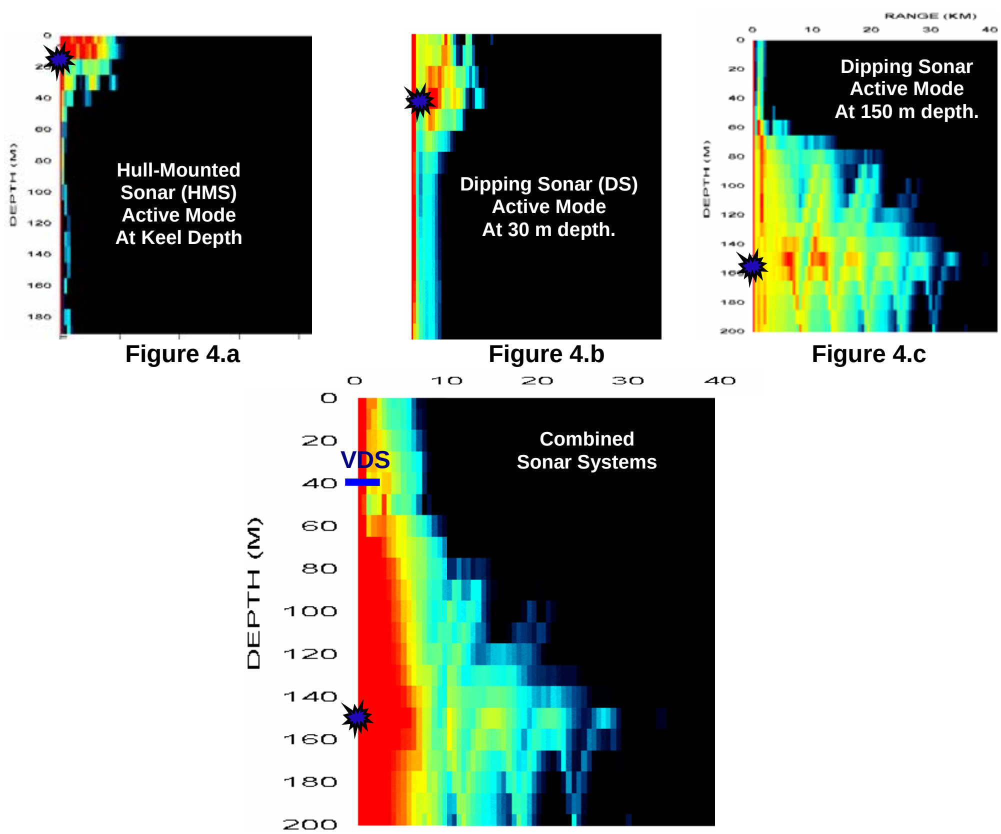
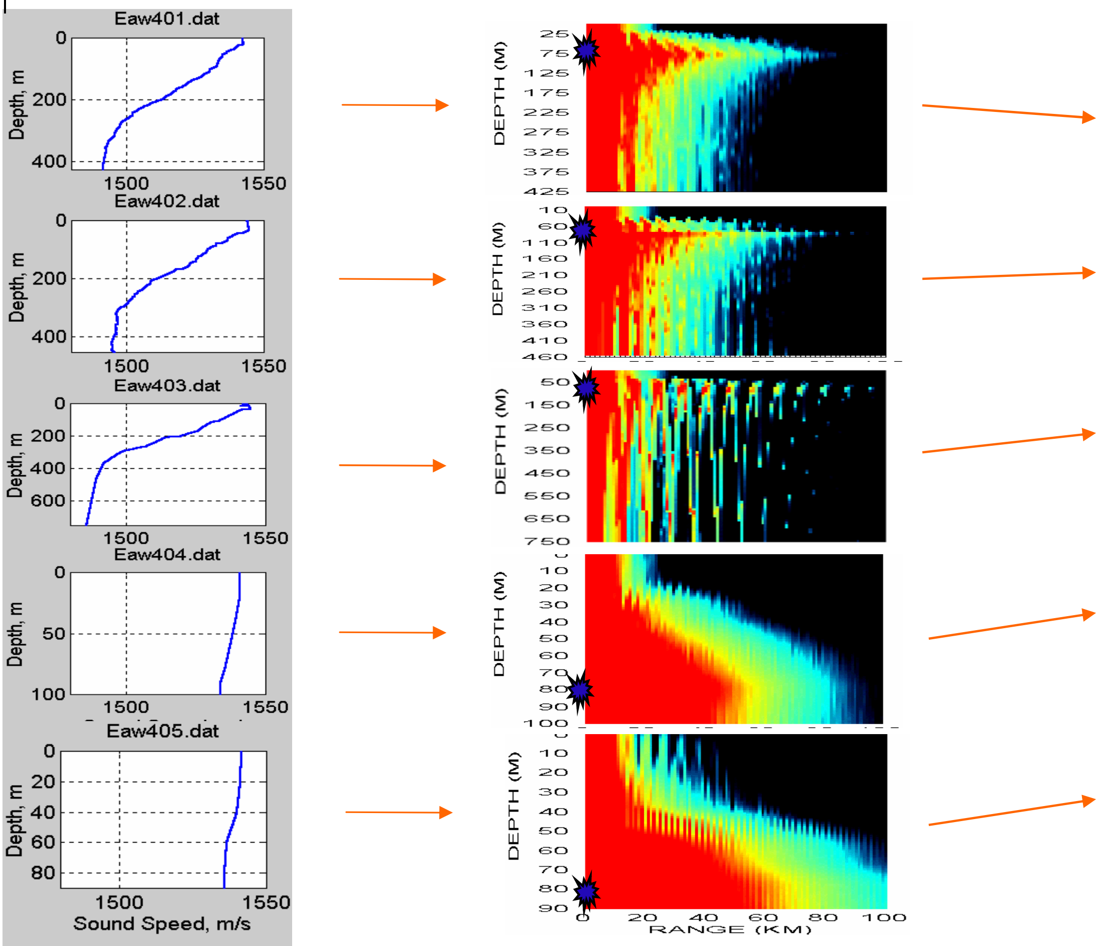


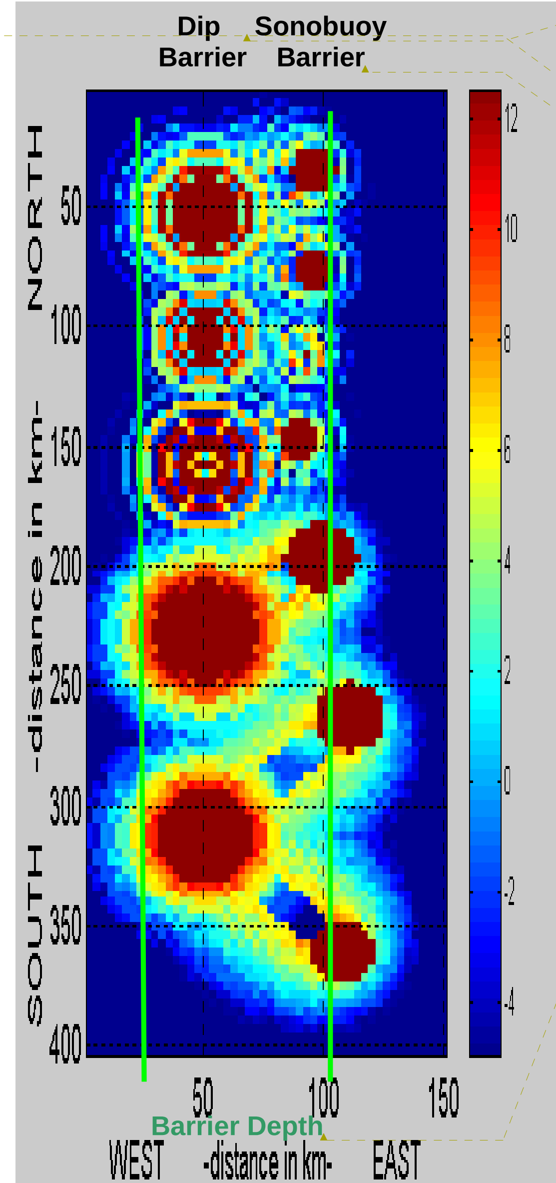
Figure 4.a **Figure 4.b** **Figure 4.c**

Figure 4.d

Figure 4. Combining Sonar Sensor Coverage

Figure 5. Active Dipping Sonar combined with Passive Sonobuoys - Coverage: 28200 km^2





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Sonobuoys in Helicopter operations

The 2003 L-3OS paper hinted at the potential synergy and prompted further study into using sonobuoys with dipping sonar.

Information from passive sonobuoys, when used as receivers in multistatic systems, is telemetered to the aircraft using VHF radio. So, when the helicopter is in the dip, they can only be monitored when they are within the RF horizon, typically 15-20 km from normal helicopter dipping heights. However, under poor acoustic conditions, when the RF range is comparable to acoustic ranges, then sonobuoys could be used to extend the search area. They have a much longer life (currently 6 to 12 hours, but potentially up to 48 hours life) than the helicopter mission time and, in the littorals, could be anchored in a barrier field, to support continuing operations in, for example, a choke point. Typically, as a helicopter dips through an area of operations, it would process data from the dipper and those buoys within RF range, multistatically, to achieve greater search coverage.

Low frequency, expendable active sonobuoys, operating at similar frequencies to dipping sonars but with a lower source level, offer a different and entirely new capability. As an expendable, they are not attractive for protracted helicopter operations, and in these circumstances the sensor of choice would be the dipper. However, there are a number of situations where they would complement the dipping sonar.

- They do not need to be in continuous RF coverage from the helicopter as they can be set to ping continuously to a fixed sequence over the buoy's life (at least 6 hours).
- They could be deployed to supplement a passive sonobuoy field, and/or to be monitored multistatically by the helicopter using its dipping sonar. The buoys could, for example, be deployed on a shallow ridge and project into deeper water. The helicopter could then operate passively up threat, disguising its position from the submarine while at the same time monitoring a passive barrier multi-statically.
- Should the helicopter gain dipper contact at long range, an active/passive pair of buoys could be deployed on breaking dip or en route to continue tracking the target as the helicopter transits to the next dip position.
- They could be used for a number of tactical gambits. They could deter a submarine (the submariner would not know if a helicopter was present or not). They could drive it in a particular direction, eg into a passive barrier or toward the helicopter. They could also be used as an attack sonar, giving the helicopter freedom to manoeuvre for an attack and avoiding any counter-detection or counter-attack zone for as long as possible.
- Finally, it is worth noting that the medium frequency monostatic active sonobuoys DICASS and CAMBS also offer this tactical freedom, whether processed multistatically or not. Processing of these buoys is typically included in a modern sonobuoy processing suite, and Common Acoustic Processors, such as the General Dynamics Canada CVAR, capable of handling both sonobuoys and a dipping sonar in a single LRU are becoming increasingly sophisticated.

The Littoral Environment

Both dipping sonar and multistatic sonobuoy systems provide an effective area search capability on their own, in many conditions. However, both are vulnerable to the difficult sonar conditions found inshore: shallow water, multiple layering, sharp thermoclines, reverberation, and potentially high noise levels; all of which compound the problem of finding a very small target.

To better understand the issues surrounding the use of using these sensors together, a typical shallow-water environment was selected for modelling purposes. The Sound Velocity Profile (SVP) of the selected area is at Figure 6 and, although this specific instance is in the Southwest Pacific, it is typical of many similar areas. It shows a very shallow surface heating layer, above a shallow mixed layer and a sharp negative gradient to the bottom, in this case, at only 80m.

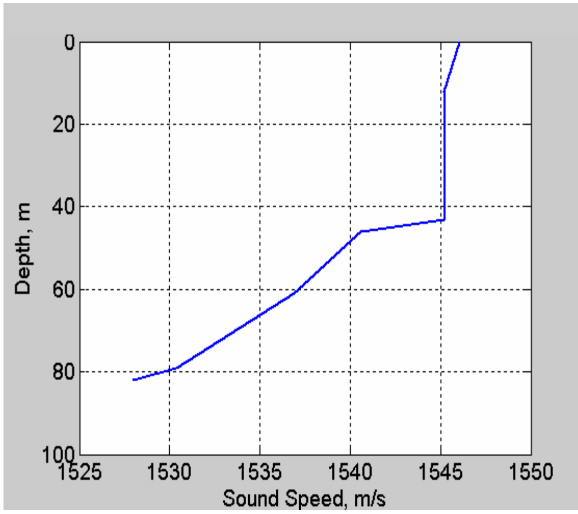

Figure 6. Sound Velocity Profile

The chosen scenario was to provide a barrier surrounding a sensitive area (eg an Amphibious Operating Area) protecting against an SSK attempting to penetrate the defences at 5 - 8kts. The water conditions were assumed to be uniformly poor throughout although, in reality, conditions would, of course, vary along the barrier's length. A 90% P_D was required and the objective was to explore the utility of a single helicopter equipped with a modern dipper, eg HELRAS, and modern sonobuoys, eg SSQ 926 ALFEA and SSQ 981E Barra. Sortie length was assumed to be about 4 hours including 1 hour of transit.

Three tactical cases were considered**:**

- Case 1: Helicopter flies a monostatic dip cycle at low altitude.
- Case 2: The helicopter deploys a sparse passive sonobuoy barrier 20km up-threat at the start of the mission and then enters a low altitude dip cycle. The passive sonobuoys within RF range are monitored multistatically during each dip sequence. An extension of this tactic would be to deploy a second sonobuoy barrier the same distance down-threat and dip in between the 2 barriers.

Case 3: The helicopter deploys a barrier of passive buoys 20 km up-threat, plus a further barrier of LF active sonobuoys pinging autonomously a further 15km up threat, and/or on the barrier ends. The helicopter monitors LF active buoys whilst in the dip, (acoustically) and in transit between dips (via RF).

Figure 7 illustrates the scenario.

Typical coverage simulations show that, although it takes time to deploy these buoys, the barrier depth gain from a single row of passive buoys is around 30%, and from 2 rows of buoys is around 60%, see Figure 8. The increases will have a proportionate effect on swept width, and the overall effect on sortie time can be contained by deploying the buoys en-route to the search start point.

In the scenario modelled, SSQ 926 ALFEA, combined with SSQ 981E Barra, gave about a 45% increase in barrier depth. In all cases, the length of the barrier was determined by the spacing between dips to ensure a high P_D, and varied from around 70 nm for very short detection ranges

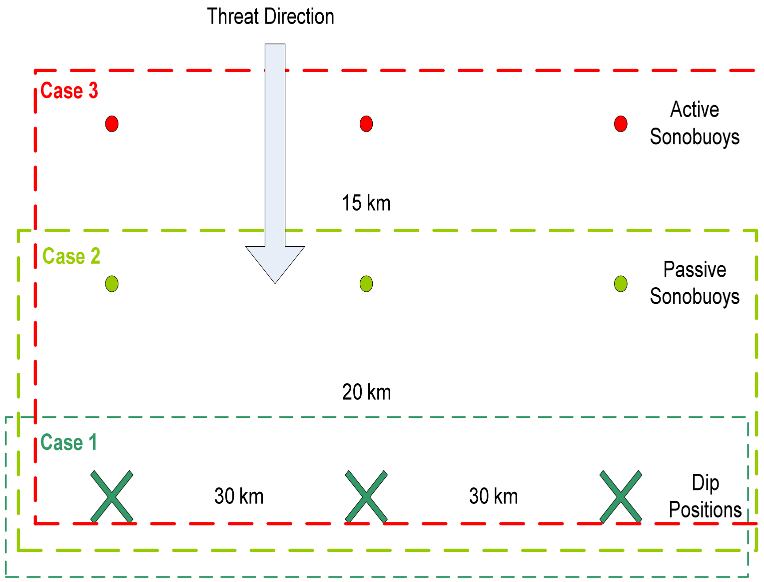

Figure 7. Combined Sonobuoy/ADS Barrier

to 150-180nm for detection ranges of around 20nm. Associated with this was a very high swept width, the key benefit of which was that, even for a submarine transiting at 8 kts, the helicopter could assure barrier security with one pass along the barrier; there would be no need to cycle along the barrier multiple times. In some cases, the helicopter could even return to its mother ship, refuel and return to the barrier for a second

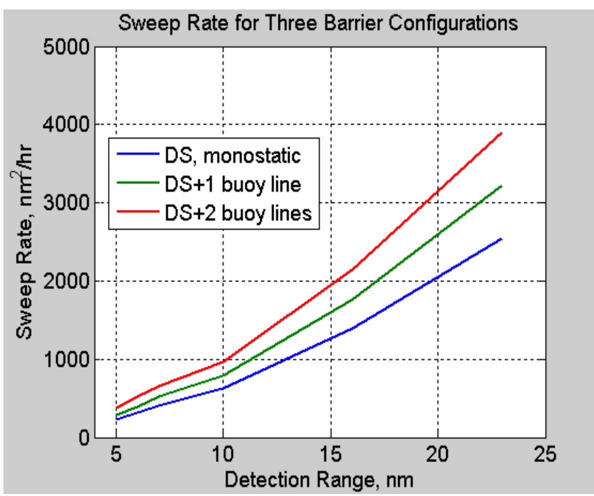

Figure 8. Detection Range v Swept Width

pass without compromising security. In this latter case, barrier security could be maintained ad infinitum, provided there were enough crews to fly the missions. Gaps in coverage could be secured whilst the helicopter was on deck by using deployed ALFEA buoys bistatically with the ship's towed array, there would be no need for an RF telemetry link from the ship to the buoy.

One other surprising aspect emerged from these studies, and that was the time in the dip to take full advantage of the VDS at varying depths, given the very long ranges expected. Halving the dip cycle time nearly doubled the barrier length and so there may be merit, under some conditions, in deliberately exploiting cross-layer propagation to extend barrier frontage.

Figure 9, to the same scale as Figure 3, illustrates the typical coverage patterns that might be expected at each dip position along the barrier.

Shallow Target, Shallow Sensors

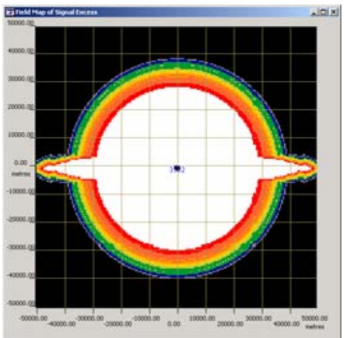

Figure 9.a. ADS alone

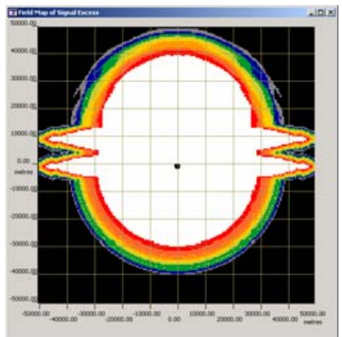

Figure 9.b. Plus Barra

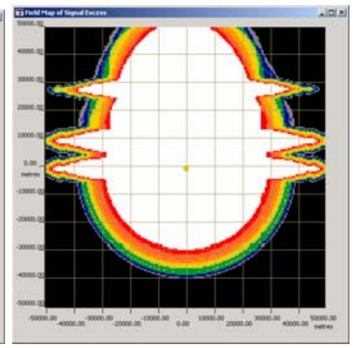

Figure 9.c Plus Barra/ALFEA

Deep Target, Deep Sensors

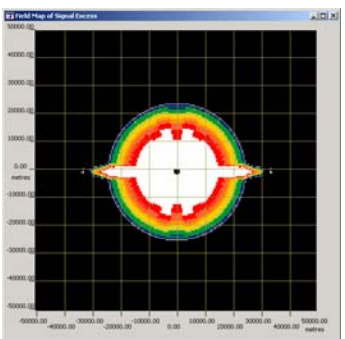

Figure 9.d ADS alone

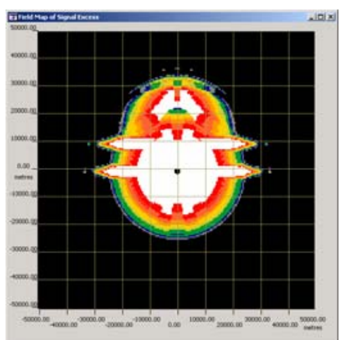

Figure 9.e. Plus Barra

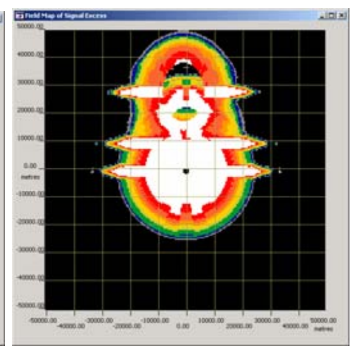

Figure 9.f. Plus Barra/ALFEA

Deep Target, Shallow ADS, Deep Sonobuoys

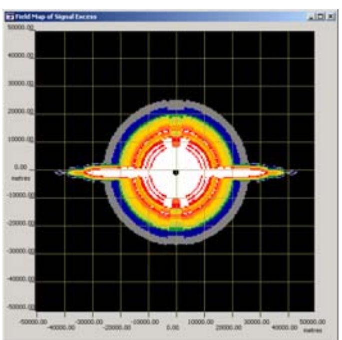

Figure 9.g ADS alone

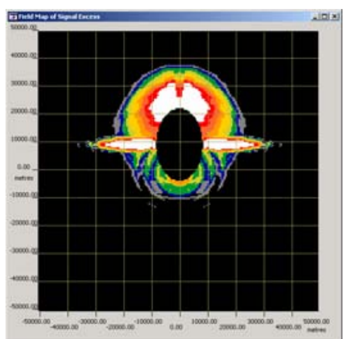

Figure 9.h ADS TX plus Barra

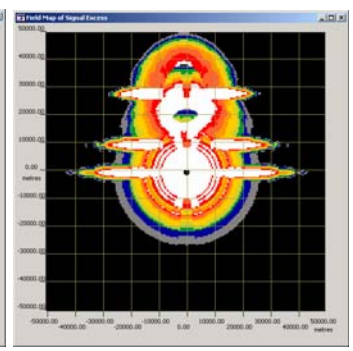

Figure 9.i. Plus Barra/ALFEA

Figure 9. Typical Coverage Calculations.

Total barrier coverage is given in Figure 10.

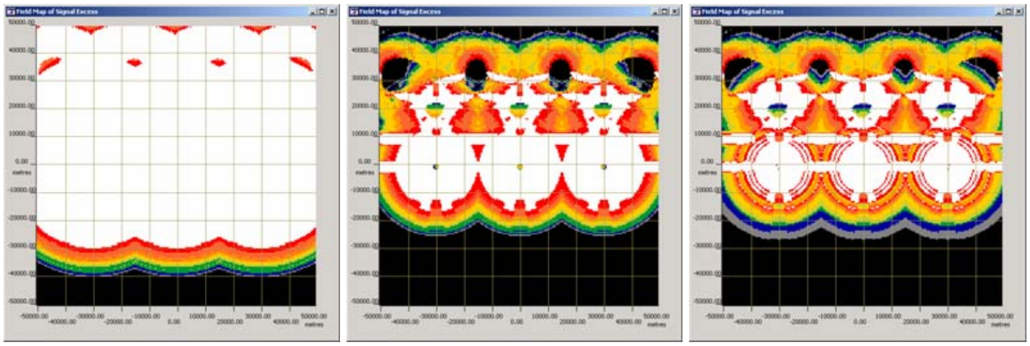

Figure 10.a. Shallow **Figure 10.b. Deep** **Figure 10.c. Cross-layer**

Figure 10. Typical Barrier Coverage

Multiplying Effectiveness

In selecting ASW systems for the future, navies will need to consider the specific threat and, through modelling, judge the level of capability they need for their particular circumstances and environmental conditions. The shift to littoral operations against ever more stealthy submarines is simply yet another step along the path of conflict between the submarine and its hunter.

Calculating coverage patterns can be complex, and relies on a good understanding of the local propagation conditions. The parameters that can be varied to optimise performance include: dipping sonar operating depth, sonobuoy operating depth, acoustic wave train characteristics, geometric relations between sensors, helicopter hover height, helicopter transit speeds and heights, active source levels, and ping repetition rates. There are doubtless many others. The analysis conducted here represents very simple operational cases and obviously warrants further investigation.

Inshore, the lone helicopter, using low frequency dipping sonar in conjunction with a range of sonobuoys, could now provide an effective search against one of the most difficult threats yet deployed: the SSK with AIP. It is the addition of sonobuoys to the mix that brings the flexibility which, in turn, offers the following added benefits:

- Passive signature classification of high speed targets.
- Passive tracking of fast manoeuvring targets with or without countermeasures.
- Maintaining contact during transit to next dip position.
- Tactical freedom to manoeuvre for active re-location, tracking and attack.
- Shepherding the target.
- Cross-layer and mixed depth detection.
- Supplementing dipper area search in poor sonar conditions.
- Covert or disguised operations.
- Facing an anti-helicopter missile threat.

All of this can be achieved in a single LRU that could provide the complete functionality needed for both types of sensor.

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[i] Dipping Sonar, Hull-Mounted Sonar, Towed Arrays: Performance in Realistic Operational Environments Dated October 2001. Joseph E Whalen. L-3 Communications Ocean Systems.
[ii] Effectiveness of Dipping Sonar and Sonobuoy Multi-Static Systems in Establishing and Maintaining Littoral Barriers. Joseph E Whalen, Donald A Frederick, and Michael Ogle. L-3 Communications Ocean Systems.