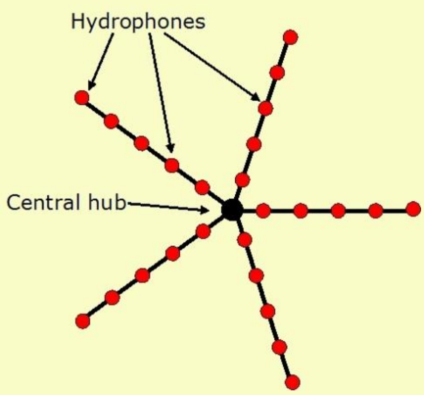
Barra Sonobuoy Design

What shape should the array of hydrophones take?

A larger array provides better angular resolution and allows the sonobuoy system to better distinguish between two acoustic "contacts" (ships or submarines) in the same general direction, but the array has to be practicable to construct and to deploy in the ocean. For construction reasons, it was decided to use arms set out radially from a central hub.

How many arms should there be?



An even number of arms (say, 4) would not give a good directional pattern; the polar diagram of an array of 5 arms is better than that of one with 3 arms; an array with 7 arms would be more difficult to construct and more expensive to manufacture. Eventually a decision was taken to have 5 arms.

Fortuitously, an odd number of arms provides hydrodynamic stability: if the surface buoy is dragged by the wind, as happens in practice, one arm of an array with an odd number of arms will always point upstream. If there had been an even number of arms, the array would have rotated unstably.

How large should the array be and how many hydrophones should it have?

The more hydrophones used and the larger the array, the better in general will be the performance of the system. But more hydrophones means more complexity, lower reliability and higher cost. Signal processing studies against the known characteristics of potential submarines showed that an array with a diameter of about 5m would be needed. It was found that a suitable compromise between performance and cost was to put 5 hydrophones on each arm of the array, so that the total number of hydrophones was 25.

How can the sonobuoy be packaged?

Barra had to be compatibility with sonobuoy equipment in use in allied forces, so it had to fit a cylinder 5 inches in diameter and 3 feet long (124mm dia, 914mm long) and weigh no more than 17.5kg.

Barra canister and cut-away
Full image

Arm collapsed
Full image

Arm extended
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Fitting all components into such a small volume was a major challenge.

One of the major challenges was the deployment of the array; several techniques were considered. The radial arms could be coiled up, rather like a tape measure, and when extended the tape would curl into a full circle, but this was found to be difficult to manufacture. Independently, Canadian defence scientists experimented with long plastic balloons pumped full of water. Eventually the DSTO mechanical engineers opted for telescopic radial arms.

The vision for the sonobuoy anticipated at least some of the dramatic advances in microcircuitry. When the sonobuoy was conceived, integrated circuits were only in development in laboratories but the sonobuoy inventors anticipated their arrival in time to allow electronic components to be made small enough.

Loading a sonobuoy into aircraft

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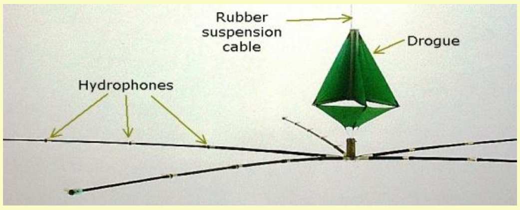
A great deal of effort was expended by DSTO in designing the assembly to demonstrate that it was possible to package the hundreds of components and to deploy them reliably. Industry then made significant modifications to make production more economical, and incorporated high standards in manufacturing and testing to allow the required operational reliability to be attained.

The sea is full of "ambient noise" that interferes with the detection of submarines, from many sources: there is the familiar sound of breaking waves and rain; marine life makes a wide variety of sounds. Ships, even at a great distance, add to the background noise, particularly at the lower frequencies, because low-frequency noise can propagate with relatively little loss for great distances. Then there is unwanted noise generated by the sonobuoy system itself ("self-noise").

How to suppress all this noise?

Noise can be reduced significantly by appropriate signal processing. Read more about signal processing

Any movement of the array can create unwanted "flow noise" and cause other problems as well. If the array moves up or down, the resultant pressure changes – although small – can produce noise and adversely affect the digitisation of signals. The surface buoy is moved by wind and waves, sometimes violently.



Barra array and drogue deployed in air

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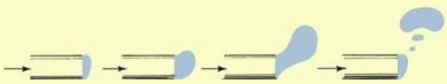

Formation of a bubble

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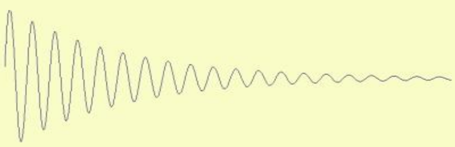

The sudden collapse of the bubble produces a tiny ringing sound

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To isolate the hydrophone(s) from the movement of the surface buoy, sonobuoys commonly use compliant (rubber) suspension cables that contain the necessary electrical conductors. To increase further the degree of isolation, Barra uses a drogue to anchor the array to the water at depth. The large effective mass of the array, the drogue and the compliant cable together provide the desired isolation.

There are, however, problems with rubber cables: these have a tendency to elongate ("creep") after some time, changing the depth of the array. In addition the elastic properties can change with time.

In exploring the options for the compliant cable, a very soft steel spring (similar to the toy called "Slinky") was tested. This had very desirable elastic properties that did not change with time. However, the final decision, based on cost, manufacture and packaging, was to use an appropriate rubber cable.

Sonobuoys commonly use silver chloride batteries with seawater as the electrolyte. (The advantage is that the electrolyte does not have to be packaged into the sonobuoy, so there is a saving in weight.) However, seawater batteries generate tiny bubbles of hydrogen. It was found that the bubbles created noise which, although of low level, was loud enough to interfere with the very sensitive hydrophones nearby. Care had to be taken in the design to ensure that bubble noise did not degrade performance.

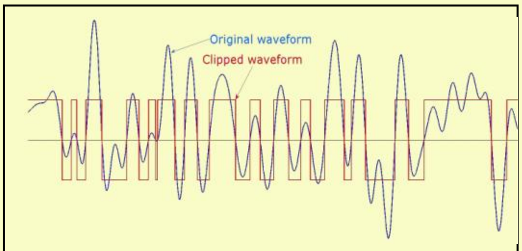
When deployed, the array will point in some random direction, so a compass is needed to show its orientation. How accurate does the compass have to be?

Operational Research studies were conducted to understand better what the system specifications should be. Computers were used to model engagements between aircraft and submarine. It was found – as was expected – that the probability of successfully countering the submarine improved with accuracy of location.

At the frequencies of interest, a 5-m array of hydrophones can determine the direction of sound to a high accuracy, so a similar compass accuracy was specified to match the inherent accuracy of the array. (Note that the compass had to fit into a diameter less than 5 inches, survive deployment shocks, operate over most latitudes, and cost very little.)

This accuracy was better by far than anything that had been achieved to date, and Barra is still the most accurate sonobuoy available.

The RAAF and RAN specified that radio signals transmitted from the sonobuoy to the aircraft had to fit into the existing radio frequency channel allocation. A (then) standard sonobuoy, with a single hydrophone, could readily transmit its signals within this channel, but on the face of it, 25 hydrophones would require 25 "standard" channels of radio frequency – far too much. How can all the information from the 25 hydrophones be transmitted without using too much bandwidth.



Illustrating infinite clipping

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There are many advantages in converting signals to digital format (as a series of bits) before transmission to the aircraft. Digitisation is common today – for example with .mp3 and CD recording – but at the time of Barra development it was far from routine. The more bits are used, the more faithfully does the digitised data represent the original signal, but the greater the bandwidth required.

Using a small number of bits to represent hydrophone outputs incurs a loss in performance. A trade-off is thus involved between sonar performance and bandwidth.

After studies that suggested that the performance loss would be minimal, it was decided to digitise using only a single bit – in what is called "infinite clipping". This allowed the signals from all 25 hydrophones to be transmitted to the aircraft in a manner compatible with the international standards, and using only twice the radio frequency allocation of the standard sonobuoy.

A source of concern was interference in the aircraft receivers from sonobuoys. If the aircraft drops two sonobuoys that happen to use adjacent radio frequency channels, and is flying close to one sonobuoy and far from the second, there is the possibility that the strong radio frequency signal received from the nearby sonobuoy will spill over into the channel used by the distant sonobuoy. How can this problem be avoided?

The possibility of this occurring was recognised by experienced system engineers. The decision needed was whether appropriate filters should be incorporated in the sonobuoys or whether the aircraft receivers should be designed to cope with this situation. Because of the cost of putting filters in all sonobuoys, it was decided at a system level that the aircraft receivers would be designed to take this matter into account.

As in any advanced development of this kind, many unexpected faults were revealed and cured. How were these addressed?

The original design for by DSTO used telescopic arms that were extended by gas pressure. The arms, hinged at their bases to the top of the array body, were initially clustered tightly around the body and held in place by the buoy canister. On entering the water, this assembly was ejected from the canister and the compressed arms rose quickly to the horizontal. They then were extended to approximately 2.5m length by pressure from gas canisters in the arm. This deployment system was thoroughly tested at the facility at Kilsby's Hole, Mt. Gambier, during the 1960s and early '70s, and subsequently at sea in the Jervis Bay area against Oberon class submarines.

The company contracted to manufacture the sonobuoy (AWADI) decided that the DSTO design would be too costly for production manufacture and opted for a different approach. They calculated that the buoyancy of the surface float, pulling against the mass of the array, would exert enough force to extend the telescopic arms and lock the arms with taper locks. This concept was also tested thoroughly at the Kilsby's Hole facility.

Some major problems emerged during development testing:

a. The locking of the arm joints was found to be unreliable. Various taper angles were investigated, but the problem was eventually found to be the entrapment of a film of water between the taper surfaces during deployment. This was solved by introducing a perforation of the outer taper surface to let the trapped film escape.
b. When deployed in the sea with a significant shear current, the array assembly would sometimes invert under the sideways force of the current – a problem not associated with the original inherently stable DSTO design. This was solved by the introduction of deployable weights to help speed up the extension process and to keep it more vertical, and stronger springs to flick the arms quickly out into a stable 'shuttlecock' configuration.
c. It was found during later sea trials that, when sonobuoys were dropped from altitudes above 20,000 feet, that sonobuoys were disappearing. A significant test series was initiated, eventually with a Macchi jet aircraft following the ejected buoy down and marking its splash point with a dye marker, to allow subsequent recovery by divers. It was found that the problem was caused by the mechanism for releasing the sonobuoys from the aircraft. Modifications to the mechanism cured the problem.

Sonobuoys have to undergo severe conditions: after storage for up to 5 years, they are dropped from an aircraft at altitudes up to 10,000 feet. Temperatures in the aircraft at altitude can be as low as -54°C. The Barra sonobuoy has to survive impact into the water, even into heavy seas, and work for up to 4 hours.

The complexity of the Barra sonobuoy far exceeds that of any previous sonobuoy. How to achieve a highly reliable product, yet maintain or reduce overall cost?

Test facility at Kilsby's Hole, South Australia
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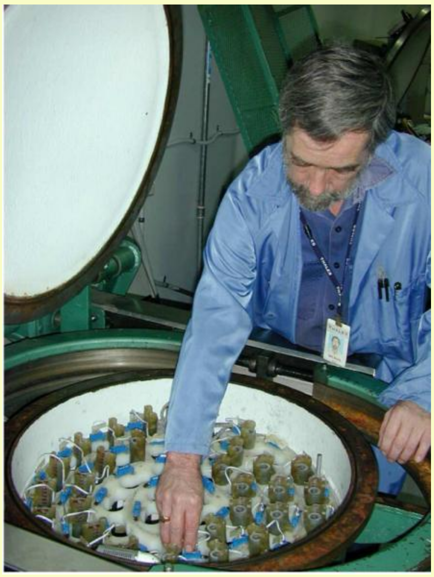
To ensure that the sonobuoy could survive the impact into the water, an elaborate test facility was constructed in a deep, fresh water hole in the south-east of South Australia, chosen because of the remarkable clarity of the water. It was comprised of a powerful pneumatic gun to project test sonobuoys into the water, and a large tube floating vertically in the water down which observers could climb to observe and film the deployment of the sonobuoy. A systematic series of tests was conducted with sonobuoys fired in at various angles and speeds. a



Pressure testing hydrophones
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To meet the high reliability targets in production, engineers used design tools such as reliability modelling, reliability apportionment, reliability prediction, stress analysis, failure mode and fault tree analysis.

Final packaging
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Over the years, this has been achieved in the Barra sonobuoy through the design of simplified mechanical systems, the use of high strength plastics, and highly integrated electronic sub-systems.

Sonobuoy Test Range Facility Jervis Bay, NSW
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During the prototype testing and production development phases, reliability growth testing and environmental stress testing were performed. Throughout sonobuoy manufacturing, components are tested comprehensively, high standards are maintained, production processes are monitored for quality and reliability, and regular Production Reliability Acceptance Testing is performed. A dedicated Sonobuoy Test Range near Jervis Bay, NSW is maintained and used to verify acceptable quality and demonstrate the reliability of the Barra Sonobuoy.

After manufacture, samples of sonobuoys are dropped into the ocean to demonstrate the reliability of production batches.