Indicator Loops and Anti-submarine Harbour Defence in Australia in WWII

By Richard Walding

Methods of detecting submarines have been many and varied but one which rose to prominence in World War Two was based on sensing the magnetic field of a vessel as it passed over conducting cables laid on the seabed. Such 'indicator loop' technology was founded on the work of the scientist Michael Faraday in the 1800s but developments by the British Admiralty before and during the Second World War saw it reach its zenith and then disappear almost as soon as the war finished. Indicator loops have been classified as secret all of their working life and only a small number of men – and women – knew of their existence. This article surveys the history of its development particularly as an outgrowth of controlled mining and focuses on the Royal Australian Navy's Operation 'Robert and Arthur' in Moreton Bay as a case study in its deployment. An examination is made of the different backgrounds of several men and how this may have shaped their personalities before coming together for two years at Bribie Island. Comment is made on how social needs drove the science and technology behind this anti-submarine technology.

'Indicator loops' are long lengths of cables laid in precise patterns on the seabed and forms part of he underwater defences of a harbour, anchorage or other locality. The presence of steel-hulled vessels – both surface craft and submarines – is indicated by the swing of a galvanometer needle at a nearby shore station. Anti-submarine vessels are stationed nearby to attack submarines detected by the loops.

Australia's use of indicator loop technology has largely passed unnoticed. This is not only because the need for it dissipated after World War 2 but its confidential classification ensured access for 30 to 50 years afterwards was restricted. Loop technology was developed by the Royal Navy from the early 1900s and arrived in Australia from England in the late 1930s just prior to World War 2 but disappeared completely within a year of the war ending. Its demise was not only in Australian ports but complete throughout the ports of Australia's allies – Britain, USA, Canada, South Africa and New Zealand for example.

As the militarization of Germany proceeded during the 1930s Their Lordships of the Admiralty had recommended to the Australian Naval Board that three harbours were suitable for defending with indicator loops, namely Sydney, Fremantle and Darwin.[1] A semicircle of five loops was laid outside Sydney Heads in May 1939 followed by two loops at Darwin in 1939, and in February 1940, three loops off Fremantle. This was to be the extent of loop-laying until the entry of Japan into the war at the end of 1941.

By mid-1942 loops were being readied for installation in Moreton Bay[2] for the protection of the Port of Brisbane soon to become the biggest US submarine base in the Pacific Ocean. Soon after this loops were laid in Broken Bay (16 km North of Sydney), Port Moresby, Port Kembla (Wooloongong) and Port Stephens (Newcastle). Loop stations approved for Port Phillip (Melbourne) and Jervis Bay (170 km South of Sydney) never eventuated.

Indicator loops may have been secret for the whole fifty years of their life but there were two famous penetrations of loop defended harbours in World War Two, namely, the sinking of the HMS *Royal Oak* in the Royal Navy's fleet base at Scapa Flow in the Orkney Islands North of Scotland and, closer to home, the midget submarine attack in Sydney Harbour.

In the first case German U-Boat U-47 skirted round the defences and thus rendered the defences useless. In the second case midget submarines were detected although interpretation of the results was somewhat slow and confused. A more comprehensive description and analysis of these penetrations is made later. However, it is fair to say that indicator loops provided sufficient deterrence that the enemy generally avoided attempts to penetrate allied harbours preferring to attack at sea. Not that the enemy was aware of the exact nature or location of indicator loops but they did know there were systems of passive harbour defences (booms, nets, blockships, controlled mines) at important ports which was enough to make them very wary anyway. The question of whether indicator loops were ultimately effective will be discussed once some background is provided.

Indicator loop technology had its genesis in efforts to detect and destroy shipping using underwater mines – particularly controlled mines detonated from shore. An appreciation of loop technology requires an understanding of the limitations of early submarine detection methods. Many different techniques for the detection of submarines have been developed, used and sometimes discarded in the century just passed. As well as time-honoured visual sightings, they include: radar, Asdic (sonar), electromagnetic radiation emissions, heat sensing, exhaust analysis, magnetic sensing, sea lions and pelicans. Before the main theme of this article is developed the last two should be explained.

In 1942 Churchill recalled the research undertaken by the Admiralty in 1917 which promoted the use of trained sea lions – known for their ability to detect underwater sounds – but the Royal Navy wondered how and when they should be released.[3] When they did, the sea lions chased everything but submarines and stuffed themselves so full of fish that they stopped chasing anything. And the pelicans: the Navy was asked to consider training pelicans to land on German periscopes which would make them stand out and easy to bomb. Admiral Duff was to later call these proposals ‘childish’.[4] Nevertheless underwater sound detection and magnetic detection seemed the most promising avenues of research. The history of antisubmarine underwater sound detection has been well covered elsewhere[5]

Two methods relying on magnetic properties are magnetic anomaly detection (MAD) and indicator loops. Any steel vessel – magnetised or not – will cause a variation in the earth’s magnetic field and a sensitive magnetometer can detect this anomaly. The prospector’s metal detector works on this principle. The MAD system uses such a magnetometer dragged on a cable behind a slow moving aircraft and will detect a change in the noise of earth’s magnetic field as it passes over steel objects up to 500 m below.

They are used today but because of their severe limitations, they are not considered an initial detection sensor. The Royal Navy started experiments on MAD in 1939 and in 1944 the US Navy sunk German U-boat *U-761* off Gibraltar with the aid of MAD. The Japanese Navy first employed an MAD instrument in antisubmarine warfare during the middle of 1944. It was planned to use MAD equipped aircraft to sweep heavily travelled convoy routes, but lack of aircraft and equipment prevented this.[6]

However, of major interest in this article are the ‘indicator loops’ which rose from obscurity in the early 1900s to a peak in World War 2 promptly dying as more sophisticated techniques such as MAD and sonar took over. However, a study of indicator loop technology gives a good insight into how science and technology are driven for social needs and how the allied navies responded to the German and Japanese submarine threat.

But there are remnants of loop technology still in existence. These help provide an important understanding of how harbour defence policy was made, how the technology was implemented and how the day-to-day running of a ‘loop control station’ worked. For example, on the beach at Bribie Island, 100 km North of Brisbane, there is a 1942 loop control station. Attempts are being made to conserve the 10 m square concrete hut but time, tides, vandals and amateur conservators are having some negative impacts. Also on the beach are some steel ‘loop’ cables slowly rusting away and when prized open they reveal silk tape with the inscription “Edison Swan – Gloucestershire 1942”. How steel cables lain on the seabed can detect submarines is a mystery to most people and is most often confused in popular reports with metal detector technology – which it surely isn’t. To understand how the technology works and it’s role in defending allied harbours in two World Wars before ending up as so much useless scrap and land fill, it is important to appreciate its early history and technical detail.

The Controlled Mine

Indicator loops have an early history that owes much to the even earlier history of mine warfare. Ever since the development of the submarine in the mid-1800s ways to detect and destroy such ships has occupied the minds of military thinkers. The first floating mine was designed and used during the American Revolution. In 1776 David Bushnell invented the "Bushnell's Keg." This primitive mine was composed of a watertight keg filled with black powder and a flintlock detonator which was suspended from a float. These kegs were placed in the Delaware River so that, it was hoped, they would float into British ships downriver.[7] From this simple start grew the notion of controlled minefields to be detonated electrically from a shore station. Robert Fulton tried to do this in the US in the War of 1812 but underwater cables were in their infancy and earth leakage of current was insurmountable. The Royal Navy’s first interest in mines (or ‘torpedos’ as they were first known) was in 1838 when Royal Engineer Officer C. Pasley (later General Sir C. Pasley) successfully demolished the wreck of the HMS *Royal George* by electrically detonating submerged charges from shore, thus marking the beginning of submarine mining.[8]

Problems with controlled minefields and underwater telegraph cables lead to improvements in cable technology. For example, by 1842, Samuel Morse had solved the insulation problem in the cables he developed for underwater telegraphy and Samuel Colt – of Colt revolver fame – was able to impress U.S. President John Tyler by sinking a schooner on the Potomac River by sending an electric current through wires to ignite the black powder in a mine tethered near the ship.

The Royal Navy warmed to idea of using mines to defend harbours following Pasley's demonstration and the early success in the American Civil War. The Admiralty sponsored further research at the School of Military Engineering in Chatham, England and in 1863 a study was launched to report on the uses of "Floating Obstructions and Submarine Explosive Machines in the Defence of Channels".[9] Five years later the Admiralty decided that the defence of harbours and ports with submarine mines was quite feasible. The Queen's Regulations for 1879 make the first mention of "Leading Torpedo Man" a position which, in reality, required the practical expertise of an electrician as well as that of a seaman gunner-torpedoman.[10]

In the case of Australian ports, controlled minefields made their first appearance in the late 1800s - for example, Port Phillip and Fort Lytton (Brisbane) had them in the 1880s when every other country seemed to be an enemy of Britain. The system developed by the Admiralty had control cables leading from the mines to a master switch inside a concealed observation station on shore. The position of each mine was plotted on a master chart and the minefields were monitored from the observation station where ranges and bearings of attacking ships could be taken. In the event of an assault on a defended anchorage or port, the movements of the enemy ships were plotted and when they moved into the minefield a selected group of mines was detonated.[11]

However, the advent of the submarine meant that visual observation from the shore station would be impossible if the submarine was submerged. This is where science, technology and societal needs converge to produce the next major step in anti-submarine warfare – the submarine-detecting 'indicator loop'.

One of the earliest harbours to be defended with this loop technology was the Royal Navy's Grand Fleet anchorage at Scapa Flow in the Orkney Islands to the North of Scotland. In 1918, a German submarine, *UB-116*, was detected in the loop minefield and destroyed.[12] However, to understand its evolution, it is necessary to review a history of scientific development stretching back to the discovery of the relationship between electricity and magnetism in the mid 1800s.

Navigating magnetically

More than 2000 years ago the Greeks were aware that a certain type of rock attracted pieces of iron. They called it *lodestone* because it also pointed at the Lodestar (North Star). The Chinese sculptured spoons from similar rock to use for direction-finding. There are written references to the use of magnets for navigation dating from the 12th century. In 1213 James Goldman described the scene off the coast of France on the 29 May where the British fleet was fogbound: "They have a new device they call a compass. I stood watching while they made one. It requires a lodestone and a saucer filled with water and an iron needle and a piece of straw. They touch the needle to the stone, then thrust it through the centre of the straw and float it. As if moved by unseen hands, the needle turns. It points North. Why it does no one knows".[13]

On May 30th, King John's fleet won a total victory against the French King Phillip's fleet which was three times larger thus preventing the French invading England. From then on, the Earth's magnetism became an essential component of navigation. However, none of these uses or developments could be called 'science'. Most were fortuitous accidents from which of detailed observations were made. There was little attempt to find out about the nature or origins of magnetism. That is, they were not 'science'.

Faraday's discoveries

British experimentalist Michael Faraday was born in 1791 and rose to become one of the greatest scientists of the 19th century.[14] In 1831 he attempted to discover just how an induced current was produced from a magnet and coil of wire. He was aware from Charles Wheatstone's experiments that a sound can cause nearby objects to resonate with the same frequency. Faraday's research into electricity was guided by the belief that electricity is only one of the many manifestations of the unified forces of nature, which included heat, light, magnetism, and chemical affinity. Although this idea was erroneous, it led him into the field of electromagnetism, which was still in its infancy. In 1785, Charles Coulomb had been the first to demonstrate the manner in which electric charges repel one another, and it was not until 1820 that Hans Øersted and Andre Ampere discovered that an electric current produces a magnetic field. Faraday's ideas about conservation of energy led him to believe that since an electric current could cause a magnetic field, a magnetic field should be able to produce an electric current. He demonstrated this principle of induction in 1831. When a magnet passes over a conductor such as a copper wire, an electric current is produced by a process known as 'electromagnetic induction'. Faraday investigated the phenomena and encapsulated the relationships between magnetism and electricity as Faraday's Law: principally that the induced voltage (EMF) is proportional to the rate of change of magnetic flux. A more appropriate way of saying this is the EMF is proportional to the strength of the magnetic field (B) of the ship, the length (L) of the conductor in the field and the speed (v) at which the field is cut by the wire.

A ship's magnetization

Steel ships, like iron and steel generally, will become magnetized when placed in a magnetic field. Depending on their reactions to the field, the iron and steel can be divided into two main types. Soft iron will acquire magnetism readily and will lose it when removed from the field. This type is called induced or temporary magnetism. Wrought iron is, in general, of this type. Hard iron is gradually magnetised and remains so when removed form the field. It is said to receive permanent magnetism. Cobalt and tungsten steel are of this type. When a ship is being built and fitted out, the vibrations from rivetting, drilling, hammering and welding causes it to become magnetized.[15] A simple experiment shows this: if an unmagnetised steel rod is pointed south and hit with a hammer several times, it will become magnetised. If the rod is pointed east-west the effect is almost unnoticeable. Although the earth's magnetic field is not strong, a ship's hull contains so much steel that it acquires a measurable permanent magnetic field during construction and riveted ships more so than welded. However, the orientation of the magnetic field in the ship's hull is not simple.

The Earth's magnetic field 'dips' down towards the ground in the northern and southern hemispheres. It is parallel to the ground only at the equator (dip angle 0°); at the poles it is vertical (dip angle of 90°). The dip angle varies with the latitude, so in England, with a dip of 68° the field line would make an angle of 68° to the ground and pointing down. The usual convention is to show the direction of magnetic field lines going from the Earth's South Pole to North Pole.[16] A steel rod, if held horizontally there and hit with a hammer, would tend to acquire a north pole largely on the underside of the rod and south would be largely on the top. In the shipbuilding centres of Australia, the dip angle is also about 68° but as Australia is in the southern hemisphere, the field is still 68° to the ground but pointing up. A horizontal steel rod struck in Australia would have its underside magnetised south and the top side would be largely north. Japan, being closer to the equator has a dip angle of about 50°. Ships constructed in the northern hemisphere thus acquire a magnetic polarity but with their keel (the underside) being the north pole. For example, British, American, Japanese and German ships are said to be "north-down". Australian ships conversely are said to be "south-down". Once the ships are launched, the hard iron retains this magnetic polarity permanently.

But magnetisation is not just due to construction vibration – there are many other ways a ship can be affected. The inclusion of guns, turrets and heavy steel fittings will have an impact but once it sets sail, the magnetism will alter again when it feels the vibration of her machinery and meets heavy seas. Changes will also occur if the ship has been heading the same direction for a long time; lightning strikes, magnetic storms, heavy gun firing, moving guns and turrets from their normal positions, loading and unloading cargo or even just a list on the ship.

The other form of magnetism is called temporary or induced. This is the sort any iron object such as a ship will develop when placed in a magnetic field such as the Earth's. The temporary magnetism varies with the direction the ship is heading. The nett affect of both categories of magnetism is that ships all acquire their own particular magnetic field – sometimes called their ‘magnetic signature’. If a ‘north-down’ ship is heading north in northern waters then the induced magnetism reinforces the permanent magnetism to produce a strong (north-down) signature. However, if it is heading south in northern waters the induced magnetism acts to weaken the permanent magnetism. It is weakened even further if it is heading south in southern waters. A corollary exists with ‘south-down’ ships. The important point is that signatures are rather complex entities and their measurement and interpretation is fraught with difficulties. As far as indicator loops and magnetic mines are concerned it is only a ship’s vertical magnetization (up, down) that is of interest. Ships also have both fore-aft and athwartships magnetization but this is of little consequence in the loop and mine situation. It is however of considerable interest when one is ‘correcting’ the compass.

The Navy also became involved in research as to how a ship’s magnetization could be camouflaged or removed so as to reduce it’s detection by the enemy. There are two ways to reduce a ship’s magetisation and hence camouflage it against magnetic detection. Vessels can have on-board “degaussing” coils which are supplied with a direct current to generate their own magnetic fields designed to oppose the ship’s induced magnetisation. Degaussing coils have been used on military and civilian ships for the best part of the last century; those added to the Queen Elizabeth added 84 tonnes to her weight. During travel, operators anticipate the induced magnetic field about a vessel and adjust the current to actively oppose that field, dependent on the orientation of the vessel. As coils cannot be permanently placed around a submarine, degaussing is hence not an option.

However permanent magnetisation is difficult, if not impossible, to anticipate with degaussing coils. Consequently the permanent magnetisation of naval vessels can be deleted in a procedure known as deperming. A deperm treatment involves wrapping a copper cable longitudinally around the vessel and “flashing” currents of up to 6000A through that cable. This is essentially a very large solenoid with the vessel as the core. At the same time, the vessel is berthed inside a second coil that is used to apply an appropriate vertical field to reduce vertical magnetisation and hence camouflage the ship from magnetic mines. However, deperming can be time consuming (up to several days) and sometimes the resultant magnetisation from an initial deperm is unacceptable and the process has to be repeated. Ultimately, with a combination of degaussing and deperming a ship's magnetisation can be reduced to almost zero for quite some time. Ships would routinely come to port to have the degaussing coils checked and also have a deperm. During the course of WW2 for example, 417 degaussing tests and 334 deperms were carried out by the Garden Island depot and Cockatoo Dockyard in Sydney Harbour.[17] The degaussing range was located off Bradley's Head and consisted of a single loop on the seabed. A ship would be instructed to 'run the range' and its magnetic signature would be measured. This would enable CSIR scientists to compute the positioning of the DG coils and the current required for efficient degaussing. A similar range was located in the mouth of the Brisbane River. Deperming in Brisbane was undertaken down near the submarine depot at Newfarm.

Research on ships' magnetism began in earnest at the outbreak of WW1. Although the Admiralty had established an Experimental Works of its own in the 1870s, the Navy possessed no central research establishment.[18] However, the outbreak of WW1 gave a powerful stimulus to naval research and development particularly regarding the new threat to British naval supremacy posed by the submarine. On the 5 July 1915, the Admiralty established the Board of Invention and Research (BIR) "for the purpose of securing for the Admiralty, during the continuance of war, expert assistance in organizing and encouraging scientific effort in relation to the requirements of the Naval Service".[19] It consisted of a central committee under the Admiral of the Fleet, Lord Fisher, a panel of scientists including the leading lights from the world of physics such as J.J. Thompson (discoverer of the electron), Ernest Rutherford (discoverer of the proton) and Sir William Crookes (discoverer of cathode rays), and a Naval Secretariat.[20] Almost as soon as it was established the committee asked one of its members, the physicist and electrical engineer William Duddell FRS, to report on "the general question of detecting submarines by electrical and electromagnetic means" which he did on 9 September 1915. Duddell reviewed the literature on the magnetization of ships and whether such magnetization could be detected externally and concluded that "it seems, improbable that any of this stray field would extend outside the iron shell of the vessel"[21] and hence the idea of detecting submarines by virtue of their magnetic field was not possible. Not to be deterred, fellow committee member William H. Bragg (also FRS) investigated further and ended up making a significant advance in submarine detection.

Bragg Loop

William Henry Bragg was born at Westward, Cumberland on July 2, 1862. He studied physics in the Cavendish Laboratory during part of 1885 and at the end of the year was elected to the Professorship of Mathematics and Physics in the University of

Adelaide, then Professor of Physics at Leeds (1909-1915), University College London (1915-1925), and then Professor of Chemistry in the Royal Institution. The work of Bragg (and his Australian-born son Lawrence) on X-ray diffraction in crystals in 1913-1914 earned them jointly the Nobel Prize in 1915.[22]

During the First World War, William H. Bragg was appointed to the BIR[23] and was put in charge of research on the location of submarines by the detection and measurement of underwater sounds and electromagnetic induction. At that time, his son Lawrence was a captain in the Army Sound-Ranging Corps in France and explained to his father during a periodic visit to London how enemy guns could be ranged using microphones. The Admiralty showed great interest in this as it paralleled their research into sound detection of submarines using Asdics.[24] At the BIR W. H. Bragg developed the 'Bragg Loop' to use in conjunction with a controlled minefield.

The essential feature of such a system was a single loop of steel-armoured electric cable of the sort used for underwater telegraphy laid on the sea floor enclosing an area measuring about 600 yards by 25 yards. On the principle of an electric dynamo, a steel ship crossing the loop would induce a small voltage, the size of which would be increased by use of multi-cored cable. The current was carried to a control station on shore where it was amplified using a mirror galvanometer. The deflection was further magnified by a small lamp shining on the mirror causing a small light spot to move across a transparent screen thereby indicating the passage of a ship. In the simplest case, the light spot would start at the centre, move to the right, move left past the centre and back to the centre again. The mine control personnel would call this the galvanometer 'swing'.[25]

A row of mines was laid down the centre of the loop, the mooring consisting of twin-core cable. The sinkers of the mines were connected by a similar cable, the cores of which would be led ashore through a tail cable and connected to a firing generator in the control station from which different groups of mines could be detonated electronically.[26] The defence of a harbour would normally consist of several of these mine loops, while on the seaward side a 'guard loop' without mines would be placed. If a swing was detected on the guard loop, the operator would close the control switch to start the 300V generator and then switch "Mines to Active". If a swing was detected on the mine loop after a swing on a guard loop it meant that a submarine had passed over the loops. The operator would then fire the mines as the galvanometer spot crossed its zero after its first displacement.[27] The US company Western Electric also developed a similar system to the Bragg Loop in WW1.[28]

Many references may be found in the Admiralty archives to indicator 'nets' as an anti-submarine device. They are entirely different to indicator 'loops'. When Their Lordships of the Admiralty discuss indicator nets at Scapa Flow they are referring to antisubmarine boom nets that have carbide lamps attached so that when a submarine strikes the net the lamp lights and indicates its position.[29]

A few examples of the loop controlled minefield show that it did have success in WW1. This is important in the development of the indicator loop as it showed detection using the principles of magnetic induction was possible. In November 1914, the first loop controlled minefield was laid at Blyth by HMS *Vernon*. It was followed by others at the mouths of the Tyne, the Tate, the Wear and Hooten Head in England.[30] In 1915, a Directorate of Controlled Mining was formed with old hands from the days of 1903.[31] In 1917 more loop controlled minefields were laid in the Dover Strait. Later, in 1918, shore controlled loops and hydrophones were laid at the Folkestone and Cape Griz Nez Gates which went 3 to 4 miles offshore. The last loop controlled mines were laid there on 11 August 1918. These soon achieved success when U-Boat *UB-109* was sunk with only 9 survivors.[32]

By 1 October 1918 the war was ending. The Battle of Amiens in France had been disastrous for Germany prompting the Kaiser to remark on 11th August "the war must end".[33] Admiral Scheer had realized this three weeks earlier and recalled the U-Boat fleet, now rendered impotent by the lowered quality of the crews, back to their naval base at Flanders. The German cabinet had also agreed to US President Wilson's condition for an armistice that U-Boats were not to sink passenger ships at sea. Scheer wrote "cabinet had thrown in the sponge".[34] One of the Flanders commanders Lieutenant Emsmann was ordered[35] to make one last desperate attempt to cripple the Grand Fleet in the North Sea. The U-Boats waited outside Scapa Flow hoping to catch the fleet unawares as it was lured south by other U-Boat activity. However the submarines were sighted off the Orkneys on the afternoon of 28 October 1918 and the harbour defences were alerted. HE (hydrophone effect) was heard and Emsmann's *UB-116* was tracked through the Hoxa Boom into Scapa Flow – home of the Royal Navy Grand Fleet. When the galvanometer spot indicated she was over the mine loop, the mines were fired and she sunk with no survivors. This was the last submarine to be sunk in WW1. After the armistice, a diver went down and found the body of Emsmann with his confidential log book clasped in his hand. He died while trying to destroy it.[36]

Training

Aware that training of mine personnel was a critical factor in its success, their lordships initiated a training scheme for antisubmarine officers and midshipmen a few months before the armistice – mostly involving the new 'Asdic' echo ranging and location equipment.[37] After the war, antisubmarine training continued at HMS *Vernon* – the home of the Torpedo Branch. In 1923, two RAN officers – Commander James

Esdaile and Lieutenant Commander H. G. K. Melville – completed the A/S Course at Greenwich with flying colours, coming first and second respectively in their class[38]. Further training for RAN officers and ratings would wait until the mid 1930s.

Inter-war loop development

At war's end nobody knew what the policy of the Admiralty would be in the peace that followed. It seemed likely that defence spending would be reduced and that the small scientific research groups co-ordinated by the BIR would be disbanded, allowing temporary scientists to return to universities, teaching or back to industry.[39] In Britain, as in France and the United States, government funds were withdrawn or the scientific studies were allowed to run down but spite of the depression taking hold during the 1920s, research into passive harbour defences did continue.[40] The single Bragg Loop suffered from a major design problem: background magnetic disturbances such as lightning ('terrestrials') or the fields emitted by nearby electrical machinery such as trams or underwater telegraphic cables ('industrials') produced spurious swings (perturbations or 'perts') on the galvanometer. A loop pattern was required that nullified changes in background magnetic fields and this brought about the first of the true 'indicator loops'. The Board of Invention and Research was dissolved in January 1918 and a Director of Experiments and Research (DER) was appointed to co-ordinate the various experimental stations. As far as loop research is concerned, the establishment of the Underwater Detection Establishment (UDE) at the shore station HMS *Osprey* (Portland Naval Base) in 1927 was of great importance. Here, research into hydrophones, Asdic and indicator loops was undertaken. This was confirmed by the Admiralty that year when they wrote to the dominions, including the Australian Naval Board, promoting indicator loops as 'a desirable element in Coastal Defences (of harbours)'.[41]

The indicator loop developed by UDE envisaged a pattern of three parallel cables spaced about 200 metres apart (or about the length of the ship they are trying to detect). Earliest trials of this three-legged indicator loop design were undertaken by the Chief Scientists from HMS *Osprey* and HMS *Vernon* on behalf of the UDE. The chosen site was Valletta Harbour in Malta and trials lasting six months began in September 1929. The aim was two-fold: to establish whether Malta was suitable for mine, guard or indicator loops; and to obtain scientific data for advancing the development of indicator loops.[42] The report made several recommendations regarding the size of loops, means of reducing perturbations, the optimum type of cable to use and the likelihood of success in detecting submarines at various depths.

The most appropriate loop arrangement was the 'three-legged loop' as shown in Figure 1. The loop cable consisted of a single core of seven strand copper wire and was typically 5000 yards (1800 m) long and 200 plus 200 yards (180 m) wide. The centre leg joined the top cable in a waterproof junction box. In the lower junction box, the centre leg and the outer and inner legs were joined to the 'tail' to shore. The tail was usually four-core, seven-strand, the spare strands being used for doubling-up the copper wires to reduce resistance. The right ‘inner leg’ conductor was connected to a ‘box, balancing’ (in Navy parlance) which was just a 40 Ω variable resistor used to equalize the resistance of both half-loops before being joined to the ‘outer leg’. This box was located inside the Loop Control Hut on shore.

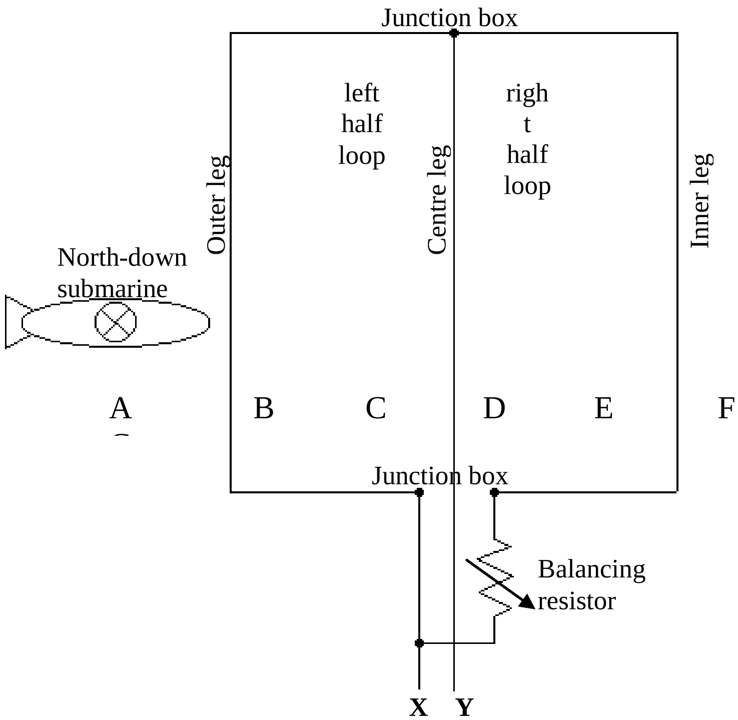

Figure 1: ‘North-down’ submarine approaching a three-legged indicator loop.

In the case of a north-down submarine (German, Italian, Japanese), the magnetic field points down towards the ocean floor and the direction of the current in the loop can be determined if the direction of the vessel is known. The figure above depicts a submarine moving over a loop, as viewed from above. The submarine's magnetic field is shown as a circle with a cross inside – this indicates a field pointing away from the viewer (down to the ocean floor). The 'outer' leg is to the seaward side of the harbour and the 'inner' towards the port. For a boat making an inward crossing, the 'outer' leg would be crossed first.

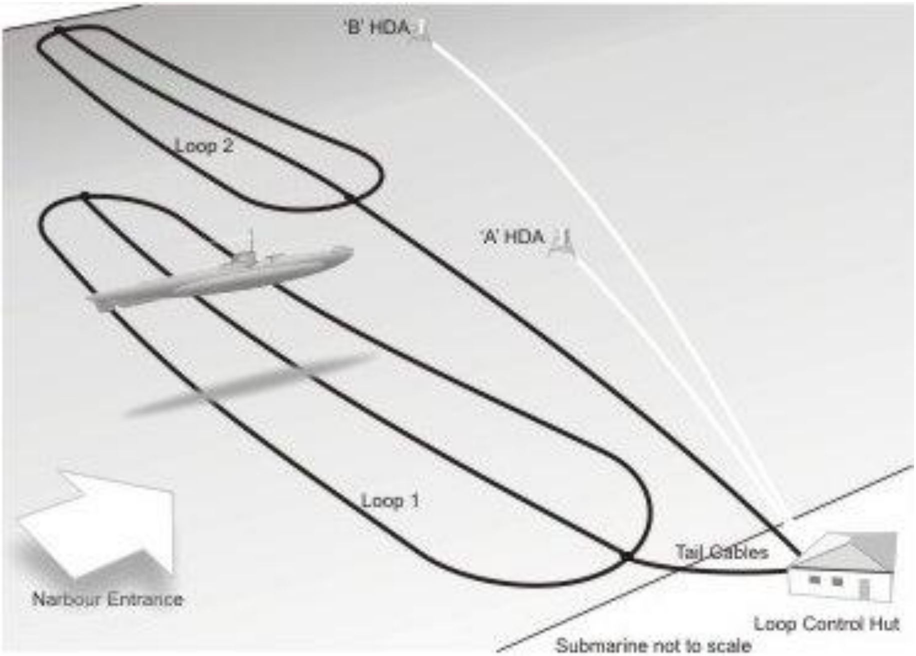

Figure 2:

Imagine a 250 ton un-degaussed north-down U-boat making an inward crossing (approaching a loop from the left) at 10 knots. U-boats would link a magnetic flux of 40 000 Maxwell[43] with a loop 10 fathoms (20 m) below it. At position *A*, no flux would cut the conductors so there would be no change in flux and the galvanometer would read zero. As the U-boat approached the outer leg (at *B*) the flux would begin to cut this cable and an anti-clockwise current would be produced. Terminal *X* would become positive with respect to *Y*. By the time the boat reached the centre of the left loop the change in magnetic flux would be negligible as all the boat's flux would be within the loop. So at point *C*, the induced current would be zero and the voltage on *X* would be zero. At point *D*, the U-boat is crossing the centre leg and induces a clockwise current in the left loop and an anticlockwise current in the right loop. This makes *X* doubly negative with respect to *Y*. Upon reaching the centre of the right half loop (*E*), all the field is within this half loop so the change in flux is again zero and hence *X* reads zero volts. As the boat begins its exit over the outer leg (*F*) a clockwise current is induced and *X* becomes positive again. At position *G* the magnetic field of the submarine can no longer be detected and the voltage reduced to zero again. The final signature looks like two wave crests with a doubly deep trough in between. For the same boat making an outward crossing, the deflections of the galvanometer would be opposite but the sizes would be more-or-less the same.

Sometimes three-core cables were used for standard loops and when connected in series within each half-loop, three times the current was developed.

Developments in the 1930s

By 1931 indicator loops had proved themselves with friendly ships but performance in war was uncertain. Although it was the Admiralty Lordships' clear intention to extensively use indicator loops for the defence of harbours at home and abroad, and it was their policy to lay them in peacetime because of the time required for such operations, no large laying program was even contemplated.[44] As Churchill was later to say "As long as the British Navy was undefeated, and as long as we held Singapore, no invasion of Australia or New Zealand by Japan was deemed possible".[45] The Royal Australian Navy seemed to concur. In 1935 the Navy Board undertook hydrographic surveys of selected harbours and on 4 May 1936 sought Admiralty advice on the suitability of installing indicator loops for fixed defences. The Admiralty replied on 10 May 1937 advising that they saw "no objection to the proposed indicator loops areas at Darwin, Sydney and Fremantle."[46] They further advised that there appeared to be no firm in Australia with the equipment necessary for making cables or the specialized electrical equipment and that all should be made in England. Later events would prove them very wrong. One of the major advances made in England during the 1930s was the development of an 'integrator' to replace the galvanometer. Scientists at HMS *Osprey* refined the moving coil galvanometer into a fluxmeter especially designed for measuring magnetic fields. Unlike the galvanometer whose deflection depended on both the strength of the magnetic field and the rate at which the ship's field cut the loop, the integrator's deflection depended solely on the total amount of flux cut and was independent of the rate of cutting. The special design meant that it was very accurate even when the flux change was very slow, for example, even when a vessel crossed at 1 knot. The integrator was sensitive enough to show deflection from currents as small as thousandths of a microampere.[47] About 250 integrators were made before and during the war, mostly by Muirhead and Co. and Evershed and Vignoles Pty Ltd in London.

The estimated cost for the three loop stations was £42,500 ($2.7 million in 2005 dollars). At a conference on 8 August 1937, the Chief of Naval Staff confirmed that the Naval Board would erect loop control huts in peacetime and lay 'light' cable by power boat for testing and training purposes and that heavy armoured cable would be laid at the outbreak of hostilities. It further indicated that a suitable site for an A/S school should be selected. Commander John Esdaile – a graduate of the HMS *Osprey* 1924 antisubmarine course – recommended that a four-day A/S training program for RANR ratings on loops, and three weeks for Asdic (sonar) training, would be sufficient. *Asdic* stood for "Anti-Submarine Detection" and the suffix "ic" was added to make it a noun. Churchill's comment that it stood for "Allied (or Anti) Submarine Detection Investigation Committee" appear to be without foundation – no such committee ever existed.[48] Churchill later said "The Asdics did not conquer the U-Boat; but without Asdics the U-Boat would not have been conquered".[49] The final recommendation was to appoint an officer "of some standing with high A/S qualifications" for detailed planning.[50] At its meeting on 22nd September 1937, the Naval Board approved sending Lieutenant George Knox RAN to *Osprey* for A/S officer training in January 1938 at a cost of £160.[51] While Knox was at *Osprey*, Winston Churchill, as former First Lord of the Admiralty, inspected the school on 15 June 1938 accompanied by the First Sea Lord Admiral Dudley Pound and given an Asdic demonstration the following day. Upon his return in August 1938 Knox was to become almost indispensable in antisubmarine harbour defence in Australia.[52]

Back in Australia, a site for the antisubmarine school had been selected – within the existing Royal Australian Naval Reserve depot at Edgecliff – and was to have instruction similar to that of HMS *Osprey*. The school, under the command of the very popular Acting Commander Harvey Mansfield 'Sinbad' Newcomb RN, began its first class for officers on 20 February 1939. As with the RN A/S School at HMS *Osprey*, the commander was also responsible for proposals to lay indicator loops (with the approval of the Navy Board) and organize and arrange local production of A/S equipment. By the onset of the war in September 1939, 66 officers and 32 ratings had been trained at HMAS *Rushcutter*.[53] The appointment of Engineering Lieutenant Raymond Allsop in July 1940 and Engineering Sub-Lieutenant James Gell Elder on 20 January 1942 was quite inspired. Allsop was chief electrician with radio 2SB Sydney and inventor of Raycophone projection equipment[54] installed in 500 picture theatres by 1938; and Elder was an engineer from Amalgamated Wireless Australasia (AWA). Their contributions to improved design and local production was immense.[55]

During this time the Admiralty had also been considering its loop program. By 1938 indicator loops had been laid at Portland, the Firth of Forth and Singapore and over the course of the following two years loops were added to Portsmouth, Plymouth, Oban Bay (Scotland), May Island (Firth of Forth), Penang and Hong Kong. Planned loops for Belfast and Malta never eventuated; neither did they at Berehaven (Bere Island) and Queenstown (Cobh) because southern Ireland chose to remain neutral much to Churchill's disgust. In May 1939 the first Australian loops were laid off Sydney Heads in a semicircle from the Curl Curl Surf Club to just south of the Dover Heights Fire Command Building (close to the Bondi sewer outlet). These were the 'Outer Loops' – numbered 1 to 5 - laid to the prevailing 'wide loop' pattern with 200 yards between legs and a length of about 2000 yards each. An "Inner Loop" (No. 11) was laid between South and North Heads but with a closer leg spacing of 100 yards.[56] As well as indicator loops, the Admiralty's policy was to lay Harbour Defence Asdics (HDAs) as a further form of harbour defence.[57] The HDA was a version of the ship-borne Asdic for use in defending harbours against submarine incursion. A transducer, transmitter and receiver were enclosed in a metal dome which was suspended beneath a metal tripod (the dan buoy) placed on the ocean floor and controlled by cables from the loop control station. The HDA is mentioned here as it is always used as an addition to indicator loop defences.

RAN Training Begins

Approval had also been given for RAN ratings to undergo Submarine Detector (SD) and Higher Submarine Detector (HSD) training at HMS *Osprey* at Portland. The first group of Australian ratings was aboard HMAS *Yarra* when ordered to Portland. One of the ratings was AB Douglas Haig. After the course he joined HMAS *Perth* which departed Portsmouth for New York on 26 July 1939. Haig arrived at New York on the 4th August 1939. It was a stifling day with 80 degree heat. The ship berthed at Pier 53 opposite 14th Street at 8.30am. That day, being the Queen's birthday, the ship was dressed overall. Several clubs were opened to the crew and admission to Radio City Music Hall was free. On the 9th August, an open day was held onboard for locals and over 450 people visited the ship. Friday 11th August was Australia Day at the New York World Fair and a contingent from the ship was present at the official ceremony outside the Australian Pavilion. All seemed to be quite rosy and Haig was enjoying himself. But this was soon to be shattered. He brought home clippings from the New York Times. The headlines on September 1st read "German troops invade Poland, Danzig joined Germany". On September 2 the clipping said: "Twenty-one years after the close of the last war, Europe is again at the beginning of a new one, a war that threatens to be longer and far deadlier than that which began in 1914. For the moment only Germany and Poland are engaged. Last midnight France and Great Britain had not yet intervened by force of arms as their engagements to Poland pledge them to do. Within a few days, they will be fighting, too. It is only a short time before a great part of Europe will be involved". His last clipping was from September 3rd: "Great Britain declared a state of war existed with Germany". Aboard HMAS *Perth* that night Haig was told to return forthwith to Australia and he just had enough time to visit the World Fair the next day. He saw the two special clear perspex television sets made for display at the Fair, so as to remove all doubts from the mind of the public that TV images were authentic. The images were authentic – of the build up to the war – and it was time for him to go. The eight submarine detectors were told to make their separate ways back on different ships as they were too valuable to risk being torpedoed on the one ship. Haig went North into Canada, across to San Francisco by Canadian Pacific Railroad and then sailed back to Australia aboard the *Niagara*. He was not allowed to wear any identification that he was an A/S specialist; a torpedoman's badge would have to do.

Six weeks after the start of the war Scapa Flow was under attack again. On October 14, 1939, a German U-Boat *U-47* under the command of Lieutenant Prien, torpedoed HMS *Royal Oak* with the loss of 786 officers and men and escaped quietly to the open sea. Scapa Flow was defended by indicator loops in Hoxa Sound (the eastern, or tradesman's entrance) and Hoy Sound (the southern entrance), 27 controlled mine and guard loops and eight blockships as well as an extensive series of boom defences.[58] *U 47* had avoided all of these defences and negotiated a small gap in the swirling waters of Holm Sound, the eastern approach to Scapa Flow. The Royal Navy had thought these waters were too rough for penetration by a U-Boat so the small gaps were considered unimportant. A blockship arrived plugged the gap 24 hours later.[59] The navy was learning salient lessons in just how determined sub-mariners would prove to be.

Development of indicator loop technology was the sole prerogative of Britain. The US paid little attention to it between the wars. Formal arrangements for the exchange of technical information between the US and UK were made in 1936 with the London Naval Treaty and the first exchange occurred in 1938 concerning minesweeping techniques. A major milestone was marked with the 1940 'London Mission' of the British Admiralty Delegation to Washington and fruitful exchanges occurred thereafter.[60] The major focus of this article is the RAN's use of loops and accordingly no further discussion of the very significant US deployment of indicator loops is warranted.

In Australia, the Navy installed two loops at Darwin in 1939, and in February 1940, three loops off Fremantle. This was to be the extent of loop-laying until the entry of Japan into the war at the end of 1941. In the meantime the Naval Board also planned loops at Jervis Bay, Port Kembla, Port Stephens, Broken Bay, Moreton Bay, Port Phillip and Port Moresby. The speed of the Japanese southward thrust and the arrival of US forces in Australia were soon to change these plans with Jervis Bay and Botany Bay being cancelled while the existing loop layouts were to be repaired, relaid, relocated or reinforced with additional loops. In May 1942, a sixth outer loop was added to the Port Jackson (Sydney) defences and another loop (No. 12) was placed further in the harbour.[61] No. 12 loop had a similar leg spacing to the No.11 loop of between 110 and 160 yards. This proved to be a fortuitous decision.

With the arrival of the first US convoy on 20 December, 1941, the loop laying program became a joint concern of both the Department of the Navy and US General Douglas MacArthur as Commander of South West Pacific. Partly because of its closeness to the war zone and large dry dock for US ship repairs, the defence of Brisbane's harbour became a high priority and was now planned for an August 1942 completion date.[62] This was about to be realised as Operation *Robert and Arthur*.

Operation Robert and Arthur - Moreton Bay

Under the code name *Operation Robert and Arthur*, the Navy was to lay four indicator loops in an 18 km line from Bribie Island at Woorim to Comboyuro Point on Moreton Island. This was *Operation Robert*. *Operation Arthur* consisted of four HDAs (Harbour Defence Asdics) approximately two miles south of the loop system. The cable was to come from Sydney stores which were imported from London. Three loops were to be monitored from the Bribie side at the RAN No. 4 naval station and one from RAN No. 7 station (at Bulwer on Moreton Island).

Bribie Island is a 20 km long sand island about 50 km north of Brisbane. It is separated from the mainland by the narrow Pumicestone Passage. To the east, 18 km across Moreton Bay, is Moreton Island. Bribie Island was home to the Joondoobarrie aboriginal clan for at least 2000 years before the present. They first came to the attention of Europeans in 1799 when Matthew Flinders sailed up Pumicestone Passage and landed on a sandy southern shore he called Skirmish Point. White development followed and the 200 or so Joondoobarrie were soon disposessed of their land, eventually being relocated to a 50 acre reserve at Dunwich on nearby Stradbroke Island by 1891.[63] The influx of visitors began in the early 1900s and Bribie became a favourite holiday destination particularly after the steamship *Koopa* began weekly visits from Brisbane. At the start of WW2 the Army made the island a restricted zone and just about all civilians had to leave. The *Koopa* was requisitioned for military use. Those civilians that remained included the postmistress, policeman, hotel owners, guest house proprietors, nightsoil man, the shopkeeper, Bowling Club manager, three young female shop assistants, a one-armed man, an aboriginal woman, families of the aforementioned, and several retired couples some of whom let out their houses to service wives. In total there were about 100 civilians.[64]

One of the first stages in loop defences is to have an accurate hydrographic survey of the area. From Flinders onward, the Royal Navy had prepared detailed hydrographic charts of Moreton Bay and the Admiralty advised *Rushcutter* of the most appropriate location of the planned loops. The techniques for making accurate measurements in harbours have concerned hydrographers for a long time. The techniques (apart from the echo sounder after WW1) had not changed since the early 1800s.[65] Lieutenant George Knox and his assistant Ordinary Seaman David Bishop were to use the same procedures in marking out the positions of the loops in Moreton Bay.

George Knox arrived at Moreton Bay in May 1942. He was assigned young rating David Bishop who was posted to HMAS *Tamworth* still being built at Maryborough but not yet ready for sea. Bishop had just left Sydney the same day as the midgets arrived.

The two men stayed at Shirley's Guest House at Woorim. It was Bishop's task to mark out the three survey points along the beach. Using a tractor on loan from the Main Roads Department, he snigged trees out of the scrub and tied them together into a tripod about 24' high. To this he added a 16' length of bamboo with a yellow and red flag on top. "You could see the flag from Moreton Island" he said.[66]

These were the triangulation stations Ash, Elm and Fir and were a known distance apart (about 2 km). Lines of sight joining the stations formed a series of triangles covering the loop area in the bay. It was typical to give stations 3-letter names and survey ships could be easily identified by lengths of bamboo poles on the upper deck. During WW2, there were 18 ships engaged in survey duties around Australia. The cables were laid by HMAS *Bangalow* which stayed about 150' off shore and a little barge pulled cable on to the deck and then to shore.

The tail cables were pulled up to the control hut with a tractor and placed in trenches in the sand about 2' deep. In some places they were weighted with 3 to 5 cwt 'pigs' of iron as sinkers. Bishop recalled "George Knox was a terrific little bloke; he was good to work with. He was good to us and we were good to him. We'd get up at 3 am sometimes to work the tides and the days were long. But we thought we were doing a good job. It was very important to keep the subs out of Brisbane. I never regretted it one bit". Bishop was only young. He was asked by the army to drag the 6" guns across the island to Fort Bribie. They gave him three bottles of beer from the sergeants' mess for his effort.

The cable used for loops and tails was of two types. The loop cable was known as "single core lead loaded cable - Admiralty Pattern 1989" and made in England by W. T. Henley's Telegraph Works Co. Ltd. It consisted of a single core of 7 strands of 0.029" tinned copper wire covered with three layers of india rubber then a layer of waterproof tape and wound with jute yarn. This was then covered with hessian tape and spirally wound with a soft lead alloy wire. The lead was covered with more waterproof tape, a tarred jute serving, two more layers of hessian tape, 22 steel armour wires (each about 2 mm diameter) covered in lead. The outer covering was a braiding of dressed hemp yarn wrapped over hot pitch and resin, and finally a preservative coating. The overall diameter was 1.3" or about 33 mm. It weighed 6.09 tons per 2000 yard mile in air (6.8 lb per yard). The cost in 1938 was £180 per 1000 yards. The ‘tail’ cable was Admiralty Pattern 7048 which was a 4 core, 7 strand cable made by Edison Swan Cables Ltd, Lydbrook, Gloucestershire in 1940 for their parent company Siemens Electric Lamps and Supplies Ltd. This cable had 3 cores in white rubber and one in black rubber laid up together with centre divider of black rubber, square in section. The cores were insulated with a rubber sheath and armoured with 20 galvanised steel wires, finally braided with hemp yarns and compounded with preservative. It weighed 3.1 tons per mile in air, about half that of the loop cable. The Navy paid £144 per 1000 yards for this type of cable in 1938. The extra weight of the lead-loaded cable was to make it less buoyant in water and to help prevent it moving in the currents.

On 18th July 1942, cableship HMAS *Bangalow* left Sydney and laid 93000 yards of lead-loaded loop cable and 64000 yards of tail cable at Bribie between 1st August and 24th October. Construction of the loop hut, power huts and accomodation was undertaken by the Civil Constructional Corps, a group set up by the Allied Works Council – and completed by 30th September for a cost of £1000 and £2100 respectively. Bishop left on October 3rd and missed the completion of the loop laying. Operation Arthur commenced in November with the HDA Dan Buoys being positioned on the 1st and the cables laid by the 17th. The HDA cable was Admiralty Pattern 660 which was a 7 core, 7 strand, 0.029". The 7 cores were each insulated with india-rubber and wound in silk and separated by jute beddings. This was wrapped in more silk and tarred jute braid and protected by 15 steel armour wires (30 mm diameter) and two layers of tarred hemp braid wound in opposite directions. It was made in England by Hoopers in 1941.

Figure 3: Loop Control Hut, Bribie Island 2004.

Facilities and Accommodation

The loop station consisted of a number of buildings located at the end of North Street, Woorim. The architect's plans didn't survive contact with the Civil Constructional Corps which altered the designs to suit the changed staffing. The main building was a 30' x 30' seven-room loop control hut located in the dunes with a clear view to Caloundra Port War Signal Station and the whole of Moreton Bay. It was of all-concrete construction with walls, floor and roof made out of 12" thick reinforced concrete and cost £1000 ($2000 then, or $55000 today). Accommodation consisted of several weatherboard huts on stumps with asbestos-cement skillion roofs and lined in parts with three-ply sheeting. These included a 69' x 18' ratings recreation and mess hut with an attached 18' x 18' kitchen and galley, 46' x 18' ratings sleeping quarters, 69' x 18' officers' quarters, mess, showers and latrines with an 18' x 14' kitchen annex, and a 10' x 15' store. There was also an 18' x 23' concrete and galvanized iron ratings' ablutions block and two 16' x 12' power huts made out of 12" concrete.[67]

Personnel

To run the station (which also consisted of the naval stations RAN4 and RAN9), the RAN had decided on "1 Lieutenant Commander as Extended Defence Officer (XDO), 4 Lieutenants or Sub-Lieutenants, 1 Petty Officer, 3 Leading Seamen, 16 Able Bodied Seamen (AB), and 1 Engineer Artificer".[68] Rather than describe the appointees in detail, it will suffice to focus on a few officers and ratings to give an overview of the types of tasks and interactions involved.

The first staff to arrive was the five officers. The senior officers were Lieutenant Laurie Harvey (XDO) and Lieutenant Syd Sharp (Deputy XDO and Officer in Charge of RAN4). Harvey and Sharp were two of the 12 officers to undertake the first antisubmarine officers' class (Class "A") at HMAS *Rushcutter,* beginning on 20 February 1939 and passing out 28 days later. They had both served together at Darwin and were selected by the new Brisbane NOIC 52 year old Captain Ernest Penry Thomas for further service in Brisbane. Thomas came to Australia as the Commander (second in command) of HMAS *Canberra* and was NOIC Northern Territory (at Darwin) from 1 January 1940 to 21 February 1942 surviving the Japanese air raids beginning on 19 February 1942. Harvey was born in Cowra in 1903 and joined the RAN as a 14 year-old 'boy – second class' towards the end of WW1. His was to be the typical route for a permanent officer including Naval College and stints on HMA ships *Australia* and *Sydney* but was discharged in Sydney in 1928 at the rank of PO. Minor breaches of discipline hampered his progress. During the inter-war years Harvey was the Senior Electrical Engineer with the St. George City Council in Sydney and then upon re-enlisting at the start of WW2, he was appointed Sub-Lieutenant. and then Lieutenant (RANVR) in 1940.[69] Sharp, on the other hand, had a shorter route to officer class – via a scheme for keen yachtsmen.

Most yacht clubs were circularized by the RAN in June 1938 for men with yachting experience to apply if they so wished to join the RANVR and be considered for the rank of Sub-Lieutenant. Syd Sharp was a keen yachtsman in the 1930s sailing around Sydney Harbour as a crewman on the *Wanderer*.[70] He had competed in many ocean races and joined the Royal Motor Yacht Club Younger Set (for "social reasons"). Sharp – a member of the Army militia – applied for enlistment in the navy in August 1938 and after an interview by nine permanent service officers, an IQ test and a medical he was accepted. The arrangement under which he enlisted soon evolved into the 'Yachtsman's Scheme'. Following the Fall of France and the Dunkirk evacuation, the Admiralty called for suitable sea-minded volunteers from all the Dominions to serve with the Royal Navy. The Yachtsmen's Scheme, as it was termed, was gazetted by the RAN in June 1940 and subsequently over 500 Australian volunteers were selected and drafted to the U.K.

These wartime recruits were divided into two age groups. Those over thirty were required to pass the navigation tests for a Yachtmaster Certificate and, with A-class entries, were granted commissions before they left Australia. Syd Sharp did not leave Australia, however. Upon acceptance, he undertook a 28 day short A/S Officers' Course at HMAS *Rushcutter* and was soon a watchkeeper at Sydney's South Head

Loop Station and Port War Signal Station at Watson's Bay. Here he soon learnt lessons in dealing with others in his command under the tutelage of the ancient Lieutenant Commander Hoskings RN followed by the affable Lieutenant Commander Horace Thompson on 20 May 1940.

Sharp endured the remonstrations of Thompson to "Sit down subbie – drink!" and befriended his scotch-imbibing superior. Sharp also learnt an early lesson about the contagious effect of thwarted ambition as he witnessed Thompson's hostility over the promotion of Farncomb and Collins even though he (Thompson) passed out ahead of them at RAN College. Thompson was to resign in 1943 a bitterly disappointed man.

In January 1941 Sharp was sent to HMAS *Melville* (Darwin) as a watchkeeper but NOIC Northern Territory Captain Thomas had different plans. Thomas sent him out on the HMA ships *Tolga* and *Terka* for a few months to gain valuable minesweeping experience. Watchkeeping at East Point Loop Station in Darwin began peacefully in July 1941 but as Sharp recalled "on the morning of 19 February 1942, I'd just finished my breakfast and I saw a heck of a number of planes. My first thought was 'Thank goodness, the Yanks have come to help us out'. I didn't think so five minutes later. That morning 242 Japanese planes dropped 683 bombs on Darwin, sinking eight ships, destroying 23 aircraft and killing 450 people. I lost several friends. We were left to scrounge for food, trap wild geese and catch fish with traps of purloined wire netting. That's how we survived for the best part of three months."[71] Captain Thomas was transferred to Brisbane days after the first bombing. He was told of the Japanese air armada spotted over Bathurst Island beforehand and was apparently convinced that Darwin was about to have "visitors" but neglected to disperse the fleet lying at anchor or de-congest the bottleneck at the wharf. His indecision was noted at the subsequent Royal Commission but Thomas's two-year posting to Darwin had come to an end anyway.[72] Sharp continued loop watchkeeping duties at East Point until 14 August 1942 enduring the air raids on a deserted Darwin for much of that time.

Harvey, Sharp and three other officers arrived at Toorbul Point combined operations training centre in late September 1942 in a car provided by the Navy. As their driver left they realized that they had no way of getting across Pumicestone Passage to the RAN4 Naval Station. Lieutenant Commander Jack Band, officer in charge of commando training organized a barge to ferry them across. This took them to the almost-deserted township of Bongaree but they had to get to the naval station 10 km across the island – and it was already late in the evening. Bribie's policeman, Constable Lawrence Ryan took them over the bumpy unsealed sand track to the Ocean Beach Guest House where they spent the night as guests of Bribie legends Mr and Mrs Bill Shirley. The next morning the five officers walked (yes) a mile north up North Street and found the concrete loop control hut was finished and that Lieutenant Knox was about to connect the cables and get the loop equipment working properly before departing. However, the accommodation was not finished and there were no ratings to be seen. The officers were to spend the next few weeks at the Guest House until the Civil Constructional Corps finished the wardroom behind the loop hut.

Next to arrive were the ratings – 10 of them. Unlike the officers, most had already seen the hardships and terror of the war. They reported to HMAS *Moreton* in Brisbane and made their way to RAN4 by a very circuitous route. They arrived in Caboolture by train and took a bus to Caloundra being greeted by an aboriginal woman who said 'you poor boys' when they said they wanted to get to Woorim. At this foreboding comment they made it back to Caboolture and then to HMAS Moreton to hang their hammocks for another night. Woorim was 20 km across the Caloundra Passage by a non-existent barge and 19 km down the beach. That night they were all after the so-and-so who said to go to Caloundra. The following morning – 2 October 1942 – the 10 ratings caught a launch to Bribie Island and were greeted by five officers, as one rating said, 'who were waiting for someone to boss around'. The ratings slung their hammocks under a vacated and requisitioned house in North Street awaiting operations to begin at RAN4.

Many of the ratings had survived sinkings of HMA ships and were hardened to the situation dealt them. Ron Smith and Vic Young were best mates – 'oppos' – who undertook A/S training at *Rushcutter* together and had just spent four months together on HMAS *Canberra* and survived its sinking. After jumping overboard, they were both picked up by the US Destroyer *Patterson*, kitted out with Marine uniforms and were sent to Sydney for Survivors Leave. Two weeks later they were on Bribie Island lying in hammocks under a fisherman's house, listening to his records, reading his novels and swimming in the beautiful clear warm waters of Bribie Island.

Amongst the ratings was Bill Cooper who did the A/S course at *Rushcutter* in October 1940 followed by further Asdic training at HMS *Osprey* at Dunoon in Scotland. Before arriving at Bribie Island Cooper spent six months aboard the fleet sweeper HMS *Harrier* working the Russian convoys in the freezing waters of Murmansk. It was a deadly routine: go to sea out for three days, pick up an incoming convoy and escort it in to port; take on fuel, water and ammunition and go out again to pick up survivors of torpedoed ships; escort a convoy out on the way home for England, stay with them for three days then return to Murmansk. This went on for six months. He was transferred to HMAS *Nepal* but severe jaundice saw him end up at Bribie.

Other ratings to arrive at Bribie included Doug Haig who was introduced earlier. He'd been transferred off HMAS *Yarra* before it was sunk with the loss of 138 of his shipmates. Haig caught malaria and was given six moths to recuperate – at Bribie. There was also Vic English – a survivor from the minesweeper HMAS *Whyalla* who came to Bribie with a piece of shrapnel still in his shoulder (and still in him when he died); Arthur 'Shorty' Waddell RN - a survivor off the HMS *Repulse* sunk off Singapore, Ken Watson, one of the few survivors off HMAS *Parramatta*, and Frank Cross – survivor off HMAS *Nestor*. But not all ratings were 'survivors'; some had serious medical conditions and some were just mentally fatigued. Others though had not left Australia. Nevertheless it would be wrong to assume that there would be any significant differences between the 'old salts' that had been to sea and those that hadn't. To a man, they said RAN 4 was a 'Happy Ship".

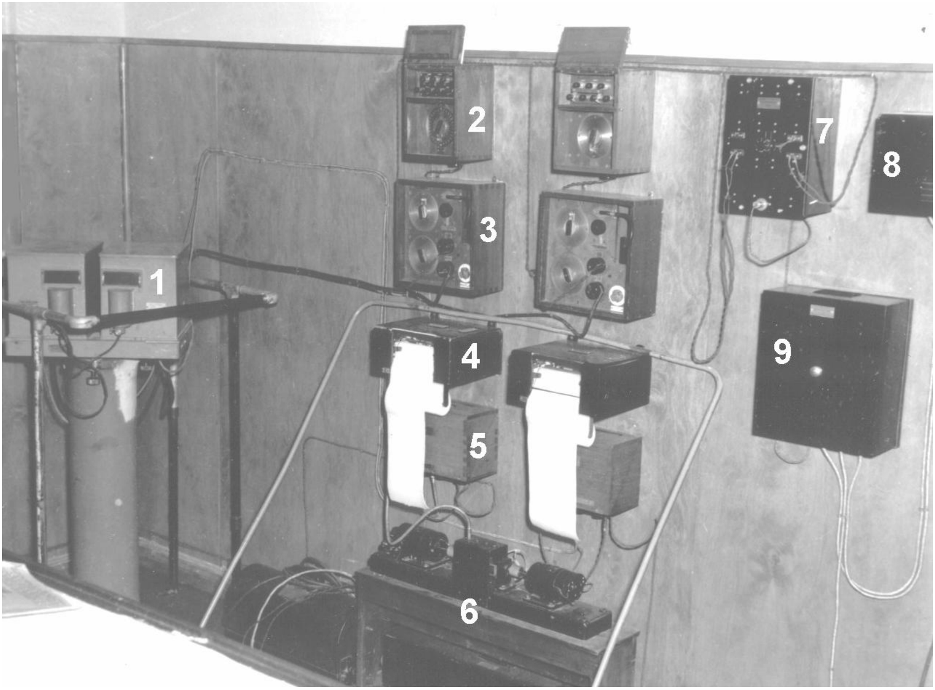

Figure 4: Set up of equipment in Loop Control Hut. The tails from the loop cables entered the hut and were connected to the Box Balancing (No. 2 on the photo below). This was connected to the Box Adjusting (No. 3) followed by the Integrator (inside No. 1). Light from the Integrator shone on to Photo Electric Cells (inside No. 1) whose signal was fed into the Amplifier (no. 5) and on to the Recorder (No. 4). The Recorder was driven by a motor (No. 6). Morse code signals picked up by the loop cables were amplified by the Loop Indicating Signal Apparatus (LISA) (No. 9) and were fed into the LISA Loudspeaker (No. 8) to be heard. Power for the equipment came from the Input Transformer Box (7).

The Loop Control Hut

Upon entering the hut from the rear, there was a central corridor with workshop to the right which was the responsibility of the Engineer Artificer. Ratings unfairly called this the ‘Bludger’s Retreat’. Next on the right was the I/L (Indicator Loop) Room. The tail cable of each loop came up the beach in a deep trench and was led into the loop room through the concrete floor. The tail cables were connected to a ‘box balancing’ to equalize the resistance of each half of the loop, then to a ‘box, adjusting’ to zero the integrator, and then to the integrator mounted on a table resting on a concrete pillar. A beam of light is reflected from the integrator mirror, on to two photo-electric cells mounted on a table, and which control the balance of a wireless valve bridge. Any out-of-balance bridge current is recorded on a moving chart by a synthetic silk thread recorder driven by a driving unit consisting of a motor and flexible shafting. The chart recorders were fixed to the ocean side wall. Two ratings were always on duty in the loop room and sat on wooden chairs facing the recorders which were fixed at eye level. For hours at a time they stared at the 6” wide roll of paper advancing at a half-inch per minute and matched the signatures to the vessels expected. Much song-singing occurred and with cups of ‘kai’ (cocoa) supplied by off-duty ratings, life wasn’t too bad at Bribie Island.

Beside this room – on the ocean side of the hut – was the HDA Room in which ratings manned the Harbour Defence Asdic if a positive contact was made by an unknown ship. This room also contained the phone and switchboard with links to the Wardroom, Skirmish Heavy Battery and the Port War Signal Station at Caloundra. Also along the front was the Binocular Room in which the one officer on watch was stationed. On the left as you entered the hut were the toilets; one for the ratings, and one with a better quality porcelain toilet pan for the officers. Between the toilets and the Binocular Room was the Wireless Telegraphy (W/T) Room. In here was an AWA 3BZ Teleradio on the frequency of the Harbour Defence Motor Launch (HDML) attached to the station.

There were four people – three ratings and one officer – on each watch. One had to have W/T experience and two needed to have ‘submarine detector’ (SD) experience. Two ratings sat on chairs in front of the loop recorders and one manned the W/T room. The officer kept constant lookout in the Binocular Room. As ships entered and departed port, the information was phoned through by PWSS to the watchkeepers and the ships’ signatures on the paper charts were matched to the ship crossing the loop. If there was ever a signature (also called a ‘ping’ – to use Asdic parlance) that was unaccounted for the PWSS and the HDML were alerted. The controlled mining stations at Tangalooma (RAN2) and Cowan Cowan (RAN3) on Moreton Island would await deflections on their guard loop galvanometers and be prepared to detonate the mines if necessary.

During the watches, ratings and officers rarely spoke to each other. The ratings would sometimes sing to alleviate the boredom but there was little if any conversation with the officer. “We had nothing in common” one rating recalled. Asked if they treated watchkeeping lightly, to a man, all regarded it as very important and could not recall anyone sleeping or truanting from their station. “We had the ships to protect” was a common response.

Watchkeeping continued for two years interspersed with swimming, fishing, shooting and practical jokes involving wallabies, snakes, pigs and goannas. But concerns of isolation and leave were constant companions. The oral histories of these men makes fascinating reading but that needs to be left to a subsequent report.[73] The station closed in October 1944 as the threat of Japanese raids diminished markedly. Before departure, the replacement Extended Defence Officer privately sold off the remaining petrol, oil, wire, water tanks, oil drums, concrete washtubs, V-belts, rope, white ant exterminator, tarpaulins and copper tubing as he said it would have been left to rot .[74] The navy thought otherwise and XDO Lieutenant Horace ‘Tommy’ Thompson was Court Martialled, found guilty and his appointment terminated on 7 November 1944, thus ending an eventful few years for the former merchant seaman. He was soon to become Harbour Master at Townsville.

Service Rendered by Indicator Loop Stations

In view of the huge expenditure on buildings, equipment, staff and training an examination of the service rendered by indicator loops in Australia is warranted. Three incidents will serve to show the use and limitations of loops in wartime. The first concerns a suspected penetration of Darwin harbour in December 1941, the second – a penetration of Sydney Harbour by Japanese submarines in 1942, and lastly – a suspected loop crossing in Moreton Bay.

The Admiralty had advised the Navy Board of the desirability of defending Port Darwin with loops as early as 1938. With the outbreak of war two loops were installed in late 1941 between East Point and ‘Midway’ – a rocky outcrop on the western side of the harbour midway between West Point and Charles Point under the control of the shore station HMAS *Melville*. In early December 1941 the NOIC Northern Territory, Captain E. P. Thomas was alerted to minelaying operations by four Japanese submarines north of Australia so a registration on the Port Darwin loops on 1 January 1942 came as no surprise. The HMAS *Melville* War Diary records “a registration on underwater indicator loops indicated a Japanese submarine entered

Darwin Harbour on a reconnaissance mission of shipping in the port".[75] Post-war analysis showed it to be a false alarm as the four submarines I-121 to I-124 did not reach Australian waters until later in January 1942. Nevertheless, it had the effect of alerting the harbour defences of the port. The payoff came on 24 January 1942 when I-124 was depth-charged and sunk – the first submarine to be sunk in Australian waters; just two months into the Pacific war. It was only a few weeks later than Darwin was bombed.

In the early months of 1942 – the Navy Board was well aware of likely further attacks on Australian ports and shipping.[76] Top of the list were Darwin, Port Moresby, Brisbane and Sydney. In May 1942 the Battle of the Coral Sea thwarted Japan's plans to seize control of Port Moresby and although undefended by indicator loops at the time, they were in place within a year.

The Midget Sub Attack in Sydney Harbour

Sydney Harbour was to be Japan's next target in Australia. The Commodore-in-Charge Sydney, Rear Admiral Muirhead-Gould (RN) was alerted to a threat by information that a submarine (I-26) was heading his way after undertaking reconnaissance in New Zealand. No special precautions were taken. On Sunday 31 May 1942, three Japanese midget submarines entered Port Jackson after being detached from their large mother submarines off Sydney Heads. Much has been written about this attack and only a brief recount will be made of events concerning loop crossings and not of the whole attack. Sydney Harbour was the first Australian port to be defended by indicator loops. The loop defence initially laid down in May 1939 prior to the war consisted of five outer loops in a defensive semi-circle from Curl Curl to Bondi and a shorter 'inner' loop (called No. 11) between the outer heads running north-east between Inner South Head and Outer North Head. The performance of the loops was monitored at the Watson Bay loop control station (HMAS *Watson*) which was under the supervision of the shore station HMAS *Rushcutter*. Modifications and repairs were constant. It was unlikely that a loop would function for more than six months without some deterioration of the cable insulation either from kinking or anchors being dragged over them.

Not long after, Loop 5 was shortened and a sixth loop added but then all loops were relaid beginning in early November 1941 as they were too taut.[77] In January 1942 a Number 12 loop was added running east-west between the inner heads (from Middle Head to Lady Bay) but again there were more problems; Loops 2 and 11 were out of action for a while due to heavy weather. By the time the five Japanese I-Class submarines arrived with their three midgets, all loops were working satisfactorily except for two outer loops (Nos. 3 and 5).

The midget submarines entered the heads individually. The first to enter was Lieutenant Chuman who passed over the faulty outer loops and then at 6.33 pm over No. 11 loop without being detected. No signatures were obtained on the outer loop system or Number 11 loop. Chuman crossed the No. 12 loop at 8.01 pm and a signature was recorded but went unrecognized at the time. However, four minutes later he became entangled in the steel mesh of the anti-torpedo boom thus ending his foray into the harbour. A self-demolition charge destroyed the midget and its two occupants.

A second midget submarine under the command of Lieutenant Ban crossed No. 11 loop undetected and then gave a signature on the No. 12 loop at 9.48 pm but again this went unrecognised. After waiting until 12.29 am that night (Monday 1 June), Ban fired torpedoes at the cruiser USS *Chicago* narrowly missing her and striking the ex-Manly ferry HMAS *Kuttabul* with the loss of 21 lives. Another signature was recorded on the No. 12 loop at 1.58 am – probably Ban making an outward crossing and escape to sea.[78] Finally, the third midget, commanded by Lieutenant Matsuo, entered the harbour and a crossing on the No. 12 loop was registered at 2.56 am – and this time recognized as such - only to be crippled by depth charges. Matsuo and his Petty Officer chose to commit suicide.

Effectiveness of Loop Technology

The navy asked if all the loops were working and if so why signatures were not immediately recognized as submarine crossings. An understanding of the loop layout and factors affecting their performance is necessary. Number 12 loop between Inner South Head and Middle Head in an average depth of 6 fathoms gave four signatures thus indicating up to four submarines.[79] Some accounts of the raid imply that the loop watchkeepers failed in their duty to notice the crossings or that HMAS *Rushcutter* was some how negligent in allowing the outer loops to reach a state of disrepair.[80] It is true that Acting Commander Newcomb was not satisfied that an efficient indicator loop watchkeeping scheme was being carried at the Watson Bay loop station and on 20 January 1942 advised Commodore-in-Charge Muirhead Gould of this.[81] It is also true that watchkeeping was improved as a result and no further changes were necessary. It is unfair and overly dramatic to assert that the state of loop preparedness was still woeful four months later as there is no evidence of this either in the archives or by interviews with *Rushcutter* officers.[82] The NOIC Sydney passed on technical data regarding the signatures to the Admiralty on 7 June 1942 but the implicated signature recordings are unavailable for further post-mortem.[83] Admiralty policy was to destroy loop recordings two weeks after being assessed (in peace time) or four weeks during wartime.

Indicator loops were originally designed with a leg spacing of 200 yards as a result of optimisation during the Malta loop trials of 1930. These and subsequent trials were based on the threat of a German U-Boat entering a harbour. In September 1939 Germany had only 56 U-Boats in commission and the 22 ocean-going type (Type VIIA) were 64 m long. The Type VIIB used by Lieutenant Commander Gunther Prien's *U-47* to enter Scapa Flow was slightly longer at 66 m. Subsequent models such as the Type IXB as used mainly in the Indian Ocean reached 76 m.[84] Japanese submarines varied between 61 m for the coastal attack submarines up to 122 m for the ocean-going attack submarines.[85] The Ko-Hyoteki 'Midget' submarines were only 24 m long.[86] The fact that the Port Jackson Outer Loops had Nos. 5 and 6 out of service on the night of the midget attack was of little consequence as the midgets were too short to have been detected anyway. Loop 11 and 12 had closer spacing but Loop 11 did not detect any submarines. The most likely cause was its location in 15 fathoms of water. The signal is attenuated with depth and the signal on No. 11 would be hardly noticeable above the background noise with a midget at this depth. The correspondence between the Navy Board and the Admiralty at the time makes it clear that the depth was a significant factor in the failure of Loop No. 11 to record the presence of a submarine.[87] However, this doesn't explain the fact that three crossings of the No. 12 loop were registered on the chart recorder but went unrecognized by the submarine detector (SD) ratings or officer on duty at the time. In his official report three weeks later, Rear Admiral Muirhead-Gould asserted: "…the loop system fully justified itself, though, naturally I must deplore the fact that the human element failed".[88] Commander Newcomb was also to comment that the loop station personnel were "lacking in concentration, caused by the long hours they were forced to spend looking at a stylograph needle which constantly fluctuated with frequent shipping traffic".[89] Not that the navy was unaware of the problem; coastwatchers in Britain had been keeping a continuous watch on the German warships *Scharnhorst* and *Gneisenau* at Brest for almost a year but their dash up the Channel in early 1942 went unnoticed. One might argue that Francis Bacon's comment in his *Of Delayes* (1625) is pertinent: 'Nay, it were better, to meet some Dangers haIfe way, though they come nothing neare, then to keepe too long a watch, upon their Approaches; For if a Man watch too long, it is odds he will fall asleepe'.[90]

A third and final suspected loop crossing occurred a year later in Moreton Bay. Immediately after the hospital ship *Centaur* was sunk by Japanese submarine I-177 20 miles off Stradbroke Island on 14 May 1943 with the loss of several hundred lives, there was a warning from NOIC Brisbane to be extra vigilant as enemy submarines were known to be operating in the area. The watchkeepers were not aware of the sinking until it was made public in Wednesday's *Courier Mail* several days afterwards. An unidentified crossing was detected on the No. 1 loop at 2005 hrs on May 18 1943 and graded as a possible crossing by a midget submarine proving yet again Bacon's collorary: 'On the other side, to be deceived, with too long shadowes, as some have been, when the Moone was low, and shone on their Enemies backe) and so to shoot off before the time'. Combined A/S and air searches were maintained for three days but without result.[91] RAN7 ratings found debris from the ship washed up on the shore on Moreton Island.

All loop cables in Australia were lifted by June 1945 although in the case of Moreton Bay only about 50% of the cable could be recovered as it kept breaking. This ended all loop activity by the RN and dominion navies and research was all but abandoned after the war. Sonar and MAD became the technologies of interest thereafter. It is worth speculating on whether indicator loops made any contribution to harbour defence in either war. Certainly not in the same was as Asdics; as Churchill was famously quoted before as saying that 'Asdics did not conquer the U-Boat; but without Asdics the U-Boat would not have been conquered'.[92] It appears that Germany and Japan were not aware of indicator loop deployment by the allies. Certainly they were aware that harbours were defended by nets, booms, mines and probably even controlled mines using guard loops, but the evidence points to them being unaware of indicator loop technology.[93]

Despite indicator loops only detecting a few enemy submarines during the war they inspired far more purposeful observation by watchkeepers than would have been otherwise. Loop and Asdic research and training went hand-in-hand as the same organisation was involved in both cases. Furthermore, local production of A/S equipment was suggested by the Admiralty because of difficulties in producing enough equipment in England. Under the control of Engineering Lieutenant Raymond Allsop, some 170 manufacturers in New South Wales were contracted to produce Asdic, loop and radar equipment in some cases of superior design to the British product. Over 360 specifications and 5600 individual drawings were prepared in the process and the technological spin-off for Australian manufacturing industry was substantial.[94] In contrast, the Japanese Army and Navy both deliberately spurned scientists, whose knowledge, laboratories and research equipment might have contributed so much toward a more successful prosecution of the war. Scientists recognized this and felt deeply injured over the lack of confidence in their ability and loyalty and so little organized research was carried on during the war.[95] By such policy Japan failed, in general, to realize those tremendous and permanent scientific advances that the allies gained from huge wartime expenditures on research.

The loops may be dead but their offspring – tape recorders, VCRs and disk drives – are still alive; well until something better than electromagnetic induction comes along.

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NOTES

[1] ADM 1/9848. Maintenance of Indicator Loops and Harbour Defence Asdic Cables, 1938. Citation of letter from Admiralty dated 10 May 1937 No. MO 3331/36.

[2] AWM 78, Item 442/1, 442/2. HMAS Rushcutter – War Diary. Details of all loop projects are to be found in this document.

[3] Board of Invention and Research, *Report on the behaviour of sea-lions towards subaqueous sounds* (PRO ADM 218/20, 1917).

[4] A. J. Marder, *Dreadnaught to Scapa Flow*, Volume 4 (1965), 78

[5] Willem Hackmann, *Seek and Strike*. (HMSO, London) is a most comprehensive review of Asdic technology.

[6] United States Strategic Bombing Survey, Pacific Naval Analysis Division Interrogations of Japanese Officials,OPNAV-P-03-100. Interrogation Nav No. 48, USSBS No. 200 Japanese Airborne Magnetic Detector, Tokyo October 1945.

[7] Paul Kemp, *Underwater Warriors* (London: Cassell, 1996), 11.

[8] Royal Navy (http://www.royal-navy.mod.uk/static/pages/8082.html). Accessed 5 April 2005).

[9] Colonel W.F.D. Jervois, *Memorandum on Torpedo Defence C.B.* (Public Record Office. WO33 46 X/L 04435). Dated 5th April 1873.

[10] Queen's Regulations and Admiralty Instructions for 1879 (London: HMSO, 1879).

[11] David Spethman & R. G. Miller, *Fortress Brisbane*. Royal Australian Artillery Historical Society (Brisbane, 1999), 7.

[12] John Terraine, *Business in Great Waters* (London: Cooper, 1989), 139.

[13] Wallace Campbell, *Earth magnetism: a guided tour through magnetic fields* (San Diego: Harcourt/Academic Press, 2001).

[14] L. Pearce Williams, Michael Faraday (NY: Basic Books, 1970).

[15] Admiralty *Navigation Manual, Vol 1, 1938* (London: HMSO, 1938), 221.

[16] Magnetic field lines show the direction that an isolated north pole would move if placed in the field. The North Pole of the Earth is actually a magnetic south pole. The N-pole of a compass was originally called the 'north-seeking pole' but any object with the same polarity as this is simply called 'north pole'.

[17] AWM 78 Item 453/1. Dept of Engineer Managers Depot War Diary.
[18] National Archives, London. Naval Research & Development leaflet (www. http://www.catalogue.nationalarchives.gov.uk/RdLeaflet.asp?sLeafletID=325). Last accessed 18 June 2005.
[19] ADM 116/1430. Report of the Board of Invention and Research,
[20] Navy List April 1916 (London: HMSO, 1916).
[21] William Duddell, *Report on the general question of detecting submarines by electrical and electromagnetic means, 9 September 1915* (PRO – ADM218/8), 3.
[22] *Who's Who* (London: OUP, 1940).
[23] Navy List, HMSO, 1916.
[24] Willem Hackmann, *Seek and Strike*. (HMSO, London), 76. This knowledge was invaluable in the sound detection of submarines.
[25] ADM 186/550, *CB Handbook of Controlled Mining*, 1938.
[26] J. S. Cowie (Captain, RN), *Mines, Minelayers and Minelaying* (London: Oxford University Press, 1949), 102
[27] ADM CB Handbook of Controlled Mining, 1938.
[28] Dwight R. Messimer, *Find and Destroy: Antisubmarine Warfare in World War 1* (Annapolis, Md.: Naval Institute Press, 2001).
[29] Arthur J. Marder, *Dreadnaught to Scapa Flow, The Royal Navy in the Fisher Era, 1904 – 1919, Volume 2* (London: Oxford University Press), 351.
[30] E. N. Poland (Rear Admiral), *The Torpedomen. HMS Vernon's Story 1887-1986* (Privately published, 1996).
[31] John Beattie, *A Memoir of Controlled Mining Technology* (Pers. comm. 2001).
[32] Kemp, *Underwater Warriors*.
[33] Terraine, *Business in Great Waters*, 136.
[34] Terraine, *Business in Great Waters*, 137.
[35] Lowell Thomas, *Raiders of the Deep* (London: Heinemann, 1929), 252, says "decided"; Terraine, *Business in Great Waters*, 139, says "ordered".
[36] Thomas, *Raiders of the Deep,* 252.
[37] Hackmann, *Seek and Strike*, 89.
[38] NAA Melbourne, "A/S Training in the RAN", dated 22 Jan 1924, in G. R. Worledge, *Contact! HMAS Rushcutter and Australia's Submarine Hunters* (Sydney: Antisubmarine Officers' Association), 2.
[39] Hackmann, *Seek and Strike*, 89.
[40] Hackmann, *Seek and Strike*, 95.
[41] ADM letter June 1927 in Worledge, *Contact!*, 3. Also ADM 1/9848 *Maintenance of Indicator Loop and HDA Cables*. Dated 4 Feb 1938.
[42] ADM259/647 *Malta Loop Trials 1929-1930.*
[43] This corresponds to a magnetic flux of 40 milliweber (mWb) in SI Units. Imperial quantities are used as in the original documents.
[44] ADM 1/9848, *Maintenance of Indicator Loop and HDA Cables*. Refers to letter from Admiralty of 15 June 1934.
[45] Winston S. Churchill, *The Second World War, Vol. 1. The Gathering Storm* (London: Cassell, 1948), 326.
[46] NAA MP1049/5, Item 1855/3/77. Dated 10 May 1937.

[47] National Archives, London. ADM 186/520. Confidential Book 1835 (3), Indicator Loops Use of the Integrator.
[48] Hackmann, *Seek and Strike*, 5
[49] Churchill, *The Gathering Storm*, 128.
[50] NAA, MP1049/5, Item 1855/3/77. Dated 9 September 1937, page 2.
[51] NAA, A2585 Item 1936/1938. *Naval Board Minutes*, Wed 22nd September 1937.
[52] NAA, MP1587/1, Item 355K. Dated 13 July 1942.
[53] Worledge, *Contact!*, 24.
[54] Bernard Harte, *When Radio was the Cat's Whiskers* (Sydney: Rosenberg, 2002), 123.
[55] Ron Bagley (Cmr, Instructor Rushcutter A/S School). Pers. corresp. February 2005.
[56] AWM 246. Maps 9/1 to 9/10.
[57] ADM 1/9848. *Maintenance of Submarine Cables in use by the Naval Service*. Dated 27 July 1939.
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[59] Churchill, *The Gathering Storm*, 385.
[60] Hackmann, *Seek and Strike*, 5.
[61] AWM 246. Maps 9/1 to 9/10.
[62] NAA, MP1049/5. Item 1855/3/278. *Indicator Loop Projects Laying Programme*. Dated 14 July 1942.
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[66] Interview with David Bishop 20-9-03.
[67] NAA, BP129/1, Item 60/1/1367. A series of indicative dyelines that were altered during construction to suit changing requirements.
[68] NAA, MP1185/8, Item 1932/2/31. *Indicator Loops at Moreton Bay*. Letter dated 3 July 1942.
[69] NAA, Canberra. Naval Service Record. Lawrence William Harvey. DOB 27 June 1903.
[70] Sydney F. Sharp (Lt.). Personal correspondence, 2001 -2005.
[71] Brisbane *Sunday Mail*, February 17, 2003, 42.
[72] Richard Connaughton, *Shrouded Secrets* (London: Brassey's, 1994), 51.
[73] The author has collected numerous hours of interviews with the ratings and officers of the Moreton Bay naval stations. A series of questionnaires and surveys makes up an oral history being used to further understand the importance of these harbour defences in WW2.
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[75] AWM 70, 400. HMAS *Melville*, War Diary 1942.
[76] Indications of Imminent Move by Japan against Australian Territory. Assessment by Director COIC, 25 April 1942. In Jenkins, Battle Surface, 166.
[77] AWM 246. Item 9/19. Sydney: Approaches to Port Jackson. Tracing showing the position of the Indicator Loops Trail Cables laid May and June 1939 (oversize chart).

[78] The day after the midget attack, Gould had a visiting American electrical expert, Professor L. A. Rumbaugh, analyse the loop recordings and they came to the conclusion that this crossing was Lt. Ban making his escape. Refer: Curruthers, 1982, 120.
[79] NAA, MP1587/1. Item 355K. Indicator Loop Equipment. Letter from NOC Sydney to ACNB and Admiralty dated 3 June 1942.
[80] Steven Carruthers, *Australia Under Siege* (Sydney: Solus Books, 1982), 133.
[81] NAA, SP338/1, Item 284/7. Sydney Indicator Loop - Watchkeeping Scheme. Dated 20 January 1942.
[82] Personal interviews, 1999 – 2005, Lt. Cmr. Ron Bagley, HM A/S School Rushcutters Bay; Lt. Syd Sharp, HMAS Watson.
[83] Not located in NAA or AWM files. Spurious hand-drawn copies in Carruthers, 1982, 15. Lt G. R. Worledge (XDO Watson's Bay Loop Station, 1943-1944, and OIC Rushcutter A/S Materials Section, 1944-1946) says that he was told in 1944 that the signature recordings "would never be found".
[84] Robert Jackson & Steve Crawford, *Fighting Ships of the World* (London: Amber Books, 2004.
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[86] Kemp, *Underwater Warriors,* 75
[87] NAA, MP1587/1. Item 355K, Indicator Loop Equipment. Letter from NOC Sydney to ACNB and Admiralty dated 3 June 1942.
[88] NAA, SP338/1, Item 201/37. Japanese Midget Submarine Attack on Sydney Harbour, May 31st June 1st 1942.
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[90] Francis Bacon. *Essay 21, On Delayes*, 1625. http://www.library.utoronto.ca/utel.
[91] AWM 78, Item 398/1, *RAN Brisbane Command War Diary*, Quarter Ending 30 June 1943, page 6.
[92] Churchill, *The Gathering Storm*,128.
[93] NAA, Melbourne. MP1587/1. Item 283M. *Japanese evaluation of US anti-submarine harbor defenses*. Dated 15 December 1945.
[94] Worledge, *Contact!* 15. Also personal communication with Lt G. R. Worledge, April 2005.
[95] US Naval Technical Mission to Japan. On line: http://www.ibiblio.org/hyperwar/USN/rep/NTM/NTM.html. Last accessed 20 June 2005.