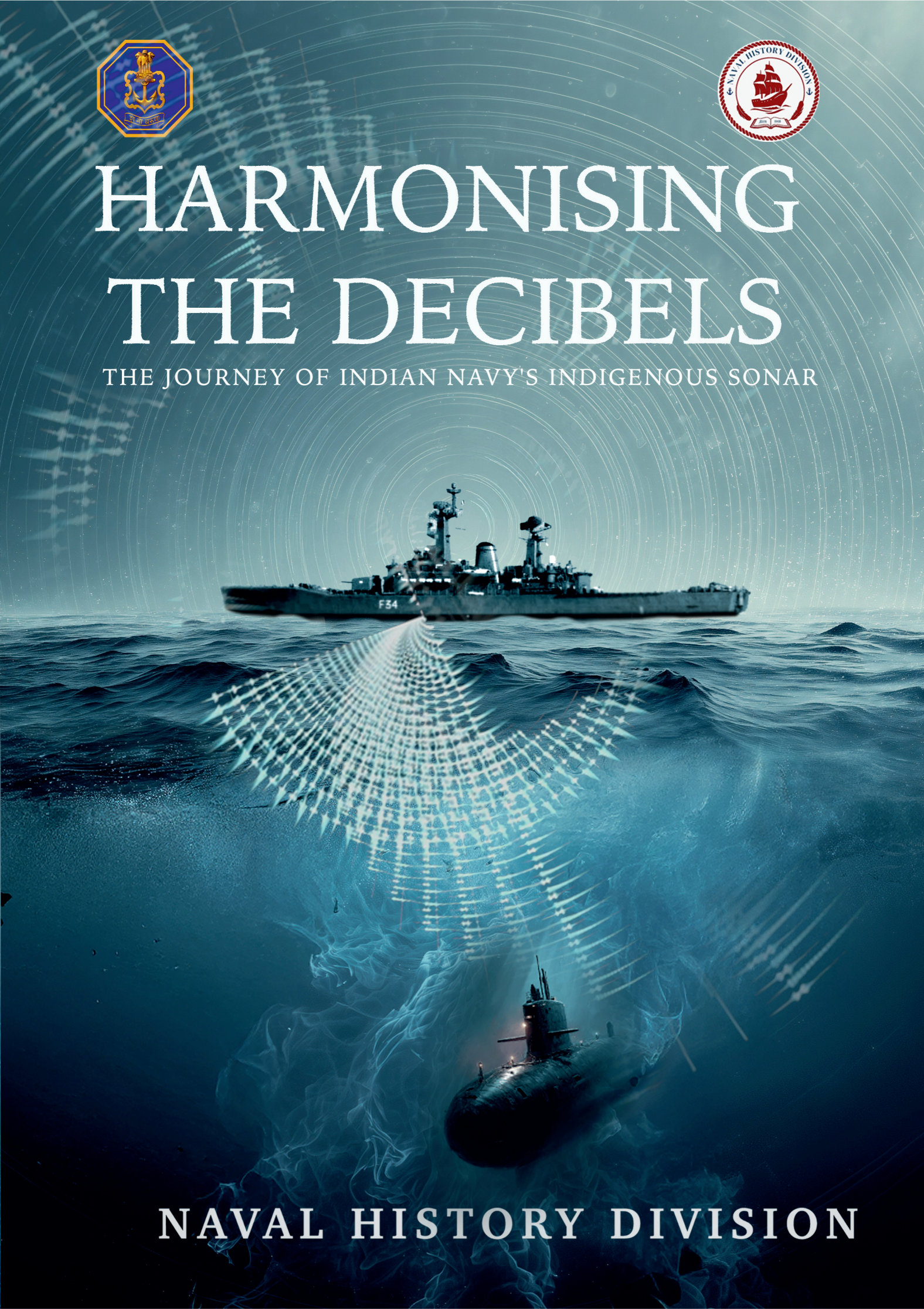
HARMONISING THE DECIBELS

THE JOURNEY OF INDIAN NAVY'S INDIGENOUS SONAR



NAVAL HISTORY DIVISION

About the Book

"Harmonising The Decibels" meticulously chronicles the development of sonar systems from the 1960s to the 1990s, showcasing a transformative era in naval technology. It depicts how the Indian Navy's fleet, initially equipped with a variety of international sonar systems, faced significant challenges in Anti-Submarine Warfare (ASW) that spurred a drive for indigenous innovation. Highlighting the contributions of pivotal figures such as Lt VK Jain and Lt Cdr Arogyaswami Paulraj, the document captures the evolution of sonar technology, from the early enhancements of the Sonar 170B to the groundbreaking development of the Advanced Panoramic Sonar Hull-mounted (APSOH) and Hull-Mounted Variable Depth Sonar (HUMVAD). The text offers an insightful exploration of the technical advancements and the strategic importance of these innovations in strengthening India's naval capabalities.

The document stands out for its detailed examination of the Indian Navy's journey towards self-reliance in sonar technology, emphasizing both the successes and challenges encountered along the way. The loss of INS Khukri and the subsequent acceleration in sonar development underscore the critical need for effective ASW systems. Through a blend of technical analysis and historical context, the document provides a comprehensive overview of how India's indigenous sonar solutions evolved to meet the country's maritime security needs. This review highlights the document as an essential resource for those interested in naval technology and defense innovation, offering a compelling narrative of how a nation transformed its approach to underwater detection and Warfare.

The document is structured into ten chapters. The key highlights of each chapter are outlined below.

Chapter 1 explores India's early dependence on foreign sonar systems and the determination to develop indigenous alternatives, marking the beginning of a quest for self-reliance.

Chapter 2 highlights the evolution of sonar technology in the Indian Navy, from initial evaluations to successful indigenization and future innovation plans.

Chapter 3 focuses on the key personnel behind the success of the Advanced Panoramic Sonar Hull-mounted (APSOH) project, whose expertise laid the groundwork for future advancements.

Chapter 4 chronicles the challenging journey from APSOII's first prototype to its successful trials and installation, underscoring the resilience of the teams involved.

Chapter 5 discusses the development of simulators and training programs for APSOH, which are now shaping future projects.

Chapter 6 details the role of the Naval Physical & Oceanographic Laboratory (NPOL) and its collaborations with agencies like BEL and Keltron in advancing India's sonar capabilities.

Chapter 7 builds on APSOH's success by exploring the critical need for indigenized sonar systems in submarines, and the innovative contributions in this area.

Chapter 8 honors Commodore Dr. Paulraj, whose visionary contributions have significantly shaped India's naval defense and sonar technology.

Chapter 9 and 10 acknowledges the distinguished individuals and agencies who played key roles in the development and success of India's sonar systems, celebrating their invaluable contributions to national defense.

Disclaimer: The contents of the book are anecdotal and based on interviews. The contents of the book should not be taken as official history.

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The Team also acknowledges the contribution of large number of individuals and units who have given access to their photo banks.

FOREWORD

1. Few topics in Indian Navy's rich history capture the complexity of design and development of a novel technology on the one hand, and the indomitable spirit and passion of the personnel involved in it, on the other, as this book does. 'Harmonising Decibels' presents a comprehensive chronicle of the development of the Navy's first indigenous sonar, from conceptual sketch to full realisation. The book provides deep insight into the collaborative effort of the Indian Navy and the Naval Physical and Oceanographic Laboratory that resulted in this remarkable achievement.

2. Well curated through personal accounts and anecdotes, the book dives deep into the engineering challenges encountered during the development of sonar APSOH and those that manifested in its integration and full operational exploitation. It reveals the immense impact the sonar had on the Indian Navy's anti-submarine capabilities and vividly reflects the stellar role of Cmde Arogyaswami Paul Raj (Retd) and his team in providing the nation this niche technology. The book also celebrates the achievement-studded inspiring journey of Cmde Paul Raj as an inventor, visionary and professional naval officer.

3. The book will hopefully inspire future generations of naval personnel to build upon the triumphs and challenges of the past and continue exploring and expanding the boundaries of technology in service of the Navy and the nation.

(Krishna Swaminathan)
Vice Admiral
VCNS

ACKNOWLEDGEMENT

The team of Authors for *'Harmonising the Decibels - The Journey of Indian Navy's Indigenous Sonar'* comprised Capt Vikas Sood, Cdr Nitin Kukreti and Lt Cdr Nagarjun NN from Anti-Submarine Warfare School, Kochi accompanied by Cdr Udit Gill and Lt Cdr SN Avinash from INS Valsura, Jamnagar and INS Satavahana, Visakhapatnam respectively.

The team compiled the story of the APSOH journey, the collaboration from design to development between the Indian Navy and NPOL, followed by production with M/s BEL, fitment on INS Himgiri by M/s MDL, and culminating in successful sea trials. APSOH was the first sonar of the Indian Navy, completely 'Made in India'. We express our deepest gratitude to Vice Admiral SCS Bangara (Retd) for his invaluable mentoring and continued support, which were instrumental in shaping this document.

The team was indeed fortunate to receive insightful input from Cmde (Dr) A Paulraj (Retd), Admiral VS Shekhawat (Retd), Dr Anant Narayanan, Dr Vijayan Pillai, Capt S. Prabhalla (Retd), Cdr Mohan Phillip (Retd) and many more. Their valuable personal experiences helped in the creation of chronological events and comprehensive narratives from the 1970s to the 1990s.

In addition, we would also like to acknowledge the support provided by NPOL, Kochi, and M/s BEL, Bengaluru in providing their perspective.

Finally, we would also like to thank the Indian Navy for providing the directions to archive the APSOH journey, without which realisation of the document would not have been possible.

HARMONISING

THE DECIBELS

Whispers Beneath The Waves

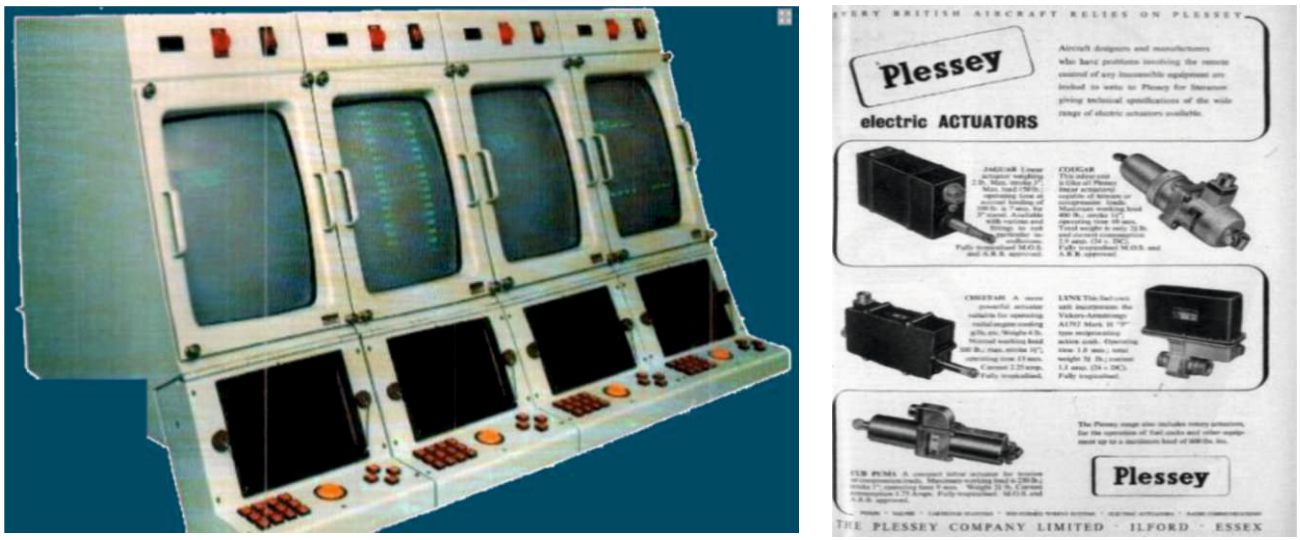
CHAPTER 1

Chapter - 1

Whispers Beneath the Waves

In the comprehensive narrative of India's defence research and development, considerable attention has been directed toward the achievements of missile and space programs. However, the origins of India's indigenous sonar capabilities have not received prominence. India, today stands tall as a pioneer in sonar's indigenous development, which has been armed on most of her warships. The path to this accomplishment was arduous and forged in fire, leaving this tale unknown. This book seeks to uncover the fascinating story of how a nation dependent on foreign suppliers and with limited technical knowledge took its formative steps toward mastering the complex underwater sensor technology.

In 1947, India emerged from the umbra of colonial rule and marked the beginning of a unique chapter as the Royal Navy transitioned into the Indian Navy. During this period, the warships and sonar systems were inherited from the British and India relied on companies like Graseby, Plessey, and Marconi for equipment and expertise.

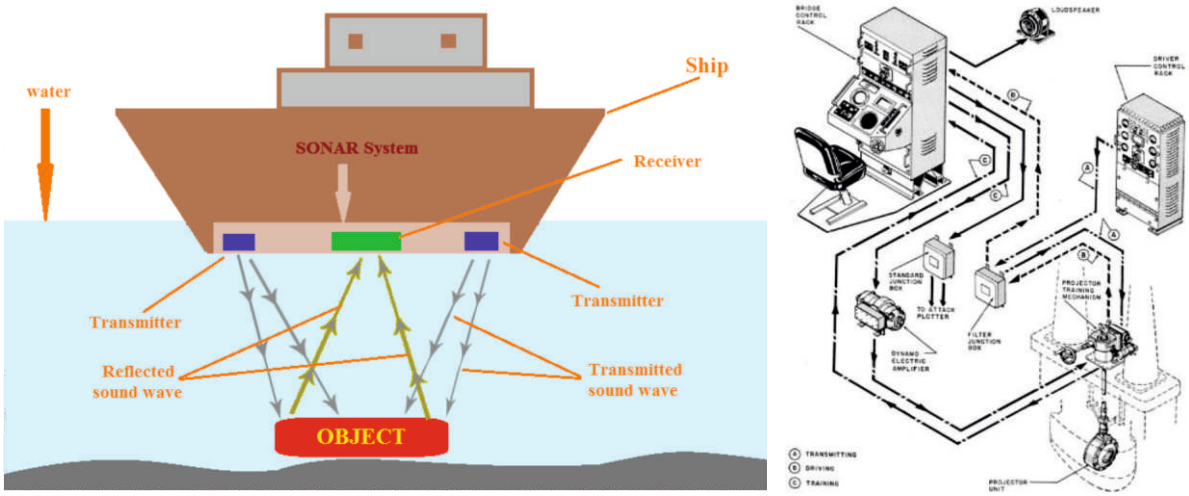


Equipment Manufactured by Graseby and Plessey in the 19th Century

The nineteenth century was dominated by the West in most domanins including that of sonar technology. Graseby, an electronics company was established in 1944 in South-West London. It assembled refurbished naval sonar equipment. Plessey was a British electronics company during the early 19th century, specialising in the manufacturing of defence and telecommunication products and expanded post-World War II through the acquisition of smaller companies, including those, overseas. Marconi was a British telecommunications and

engineering company operational. Its capability existed in Wireless Telegraph & Signal processing founded by the Italian inventor Guglielmo Marconi in 1897.

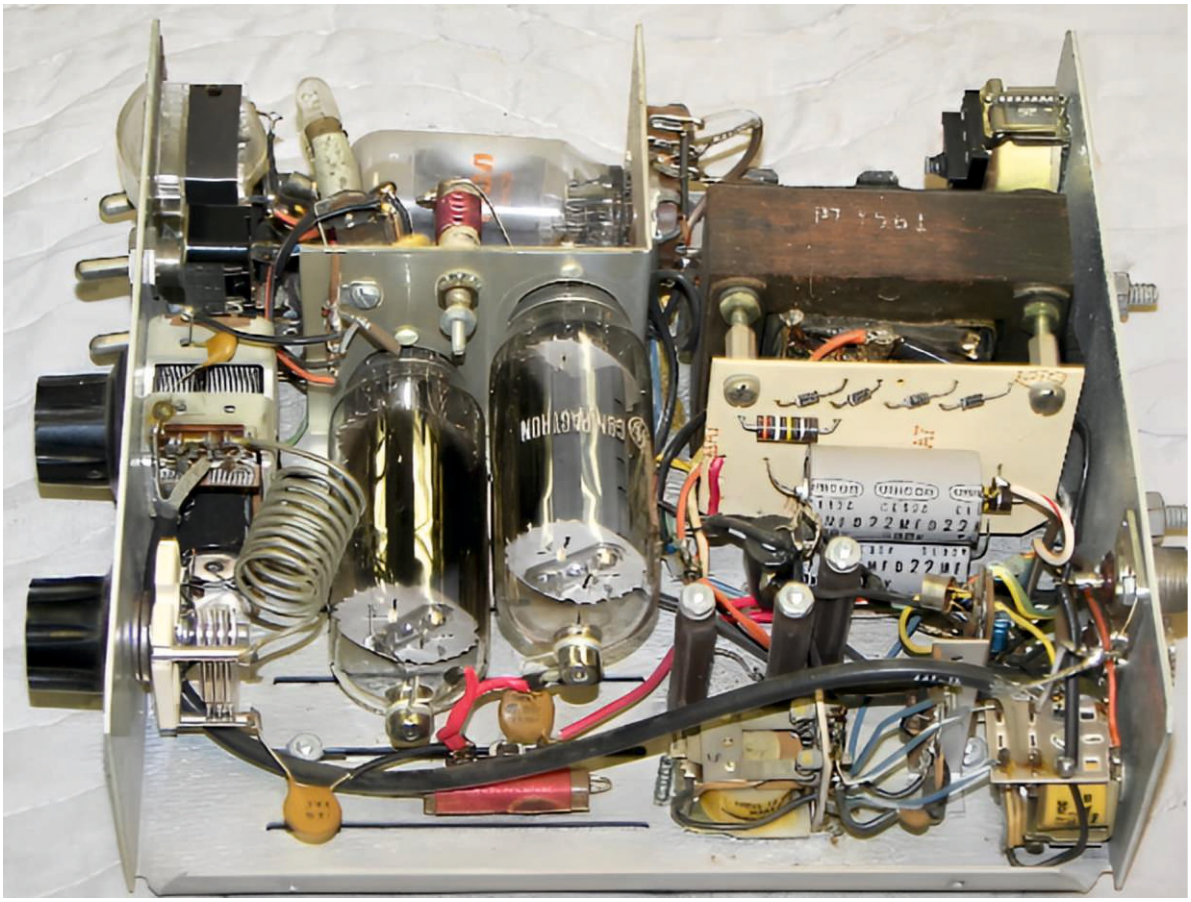
India faced a major challenge, in the backdrop of the Cold War as sonar technology was a closely guarded secret amongst a handful of nations. Apart from managing the fleet of second-hand warships, at the heart of this conundrum was also the puzzle of understanding the intricacies of sonar technology; the underwater equivalent of radar. A basic sonar system is best explained by the dual components of its systems the Wet End comprising the Acoustic Transducers beneath the hull; and the Dry End, which includes the Processing and Display system within the ship's compartments.[1]



Basic Functional Diagrams of Sonar System

In the 1960s and early 1970s, the sonars employed vacuum tube high-frequency amplifiers along with low-pass filters. These systems were crucial for detecting submarines and aiding in safe navigation but also prone to frequent damage in the precarious marine environment. The high voltage required for these tubes typically ranged from 600 to 1100 volts DC and was generated through an inverter using Germanium switching transistors. The switching frequency varied based on the type of power transformer used: which was 60-120 Hz for laminated core transformers and 1-3 kHz for toroidal core transformers.

[1] Qihu Li, Digital Sonar Design in Underwater Acoustics, London, Springer, 2012, p. 518



Vacuum Tube HF Linear Amplifiers

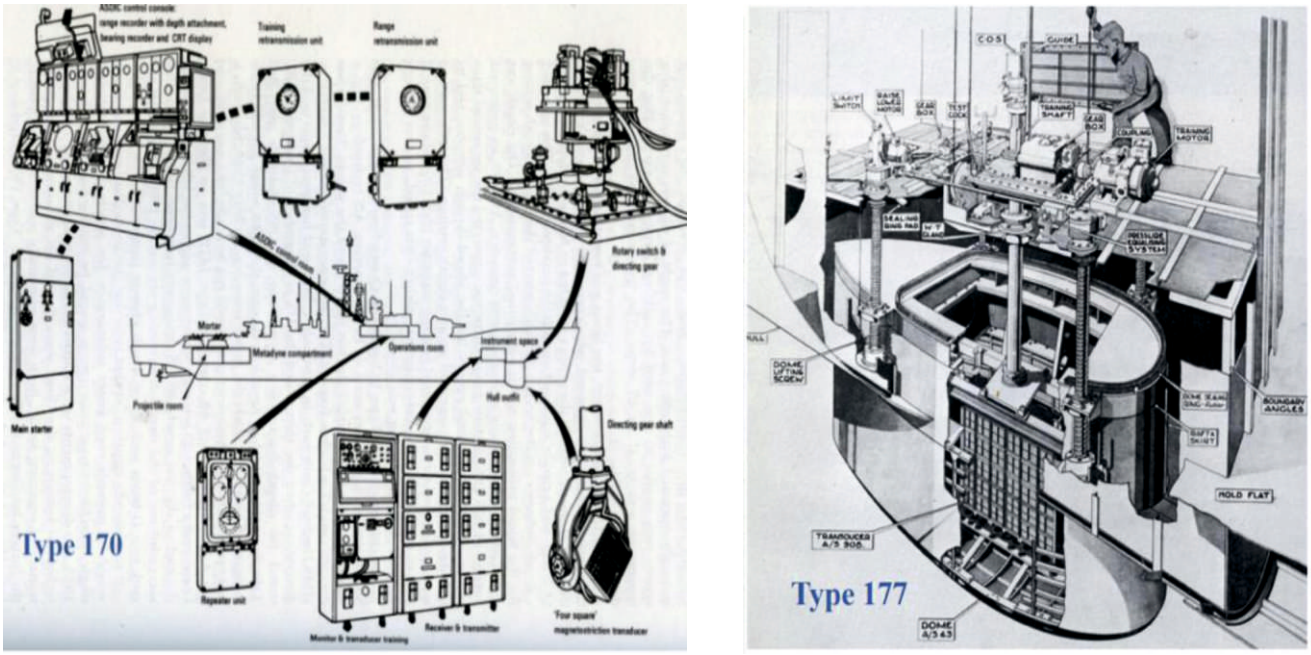
After a brief overview of the background, let us now embark on a journey through time, exploring the inception of India's Indigenous sonar program, from the initial dependence on non-native companies to the emergent steps toward indigenous development. This book brings to light the persistent efforts, teamwork, and technological breakthroughs that helped India become self-sufficient in sonar technology. This lesser-known narrative is not just an indicator of India's technological prowess, but a testament to the nation's resilience and commitment to securing its maritime borders. It is a journey filled with challenges, triumphs and the relentless pursuit of listening to 'The Whispers Beneath the Waves', an untold story that merits attention.

DID YOU KNOW?

APSOH was the first indigenous Panoramic Sonar covering 360-degree azimuth in a single transmission cycle

India Crafts its Own Sonar

The late sixties marked a critical juncture for the Indian Navy, as it sought to evaluate the performance of the foreign sonars deployed in its warships. In an attempt to enhance the capabilities, Mod-kits were experimentally integrated into the 170B[2] sonar fitted on the Khukri and Talwar Class, and 184SS sonar systems, were scheduled to be fitted on the Leander and Godavari Class. However, the outcome of these modifications proved to be a divulgence especially in light of the events during the 1971 war with Pakistan



Sonar Type 170 and Type 177[3]

The Indian Navy confronted a humbling reality in the wake of the 1971 war, when INS Khukri, equipped with 170B Sonar and retro-fitted with an indigenous mod-kit, succumbed to a torpedo attack from an undetected submarine off Diu on the Western Coast.[4] This loss

[2] Sonar on Khukri Type 170 was narrow beam attack sonar usually associated with Mortar MK 10. Types 174/177 were medium range search sonars and Type 162 was a bottom classification sonar like a depth sounder that gave an image of a submarine.

[3] Cross-over to science of underwater acoustics, *https://acoustics.ac.uk/wp-content/uploads/2018/08/D1_WHackmann_History.pdf* accessed on 12 February 24.

[4] Vice Admiral GM Hiranandani (Retd), *Transition to Triumph*, Naval Headquarters, New Delhi, 2000, p.178.

[5] Nilgiri class or Leander class frigates were designed and built by Mazagon Dock Limited in Mumbai. Six ships were built between 1972–81. These were the first major warships to be built in India in collaboration with Yarrow Shipbuilders of United Kingdom.

emphasized the urgency for an advanced sonar system, particularly for the Leander[5] class of ships, which were slated for induction from 1972 onwards. The mod-kit developed by BARC and Lt VK Jain in 1971 was later upgraded by the then Lt A Paulraj at IIT Delhi in 1972.

INS Khukri[6], (Late) Capt MN Mulla, MVC

The unfortunate Khukri incident provided the imperativeness in the development of India's naval defence capabilities, focusing on sonar technology, and steering efforts towards innovation and self-sufficiency. As a result, India commenced the journey of research and development, leading to the creation of its first indigenous sonar system, the Advanced Panoramic Sonar Hull-mounted (APSOH). This advancement has since then, played a pivotal role in shaping the future of India's naval capabilities.

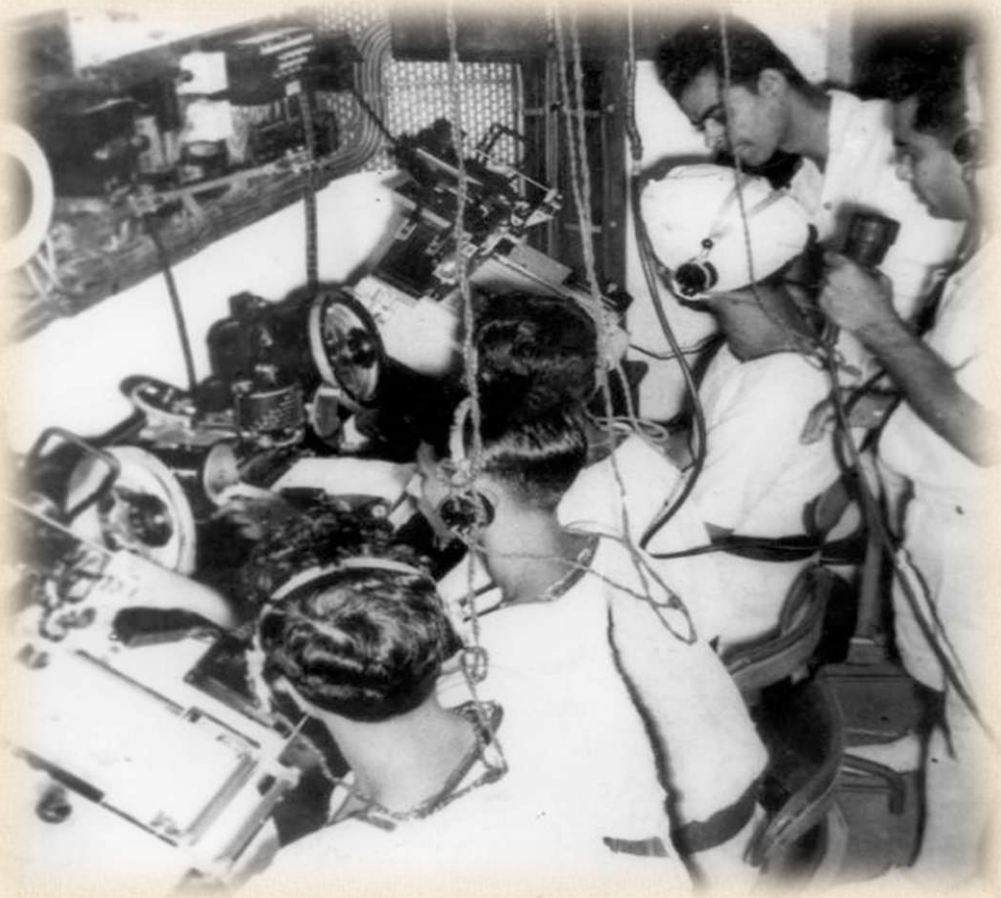
DID YOU KNOW?

Transmission waves of Sonar are Sound Waves that travel at 1496 meters per second in water, which is four times faster than it travels in Air.

[6] INS Khukri was a Type 14 (Blackwood-class) frigate of the Indian Navy. She was sunk off the coast of Diu, Gujarat, India by the Pakistan Navy Daphné-class submarine Hangor on 9 December 1971 during the Indo-Pakistan War of 1971. This was the first warship sunk in action by a submarine since World War II. Photo Courtesy: Naval History Division.

Tale Of Sonar Triumph

CHAPTER 2



Chapter - 2

Tale of Sonar Triumph

The Early 1960 - The Underwater Sensor Arsenal

During the 1960s, the Indian Navy's fleet comprised of various classes of ships and submarines, each equipped with specific sonar systems tailored for Anti-Submarine Warfare (ASW) operations. The Brahmaputra and Betwa class were installed with Type 164, 174, and 149-F sonar. The Trishul and Khukri class were outfitted with Type 170B, enhancing their ability to detect submarines, though not panoramic but sectoral sonars. The Petya-class frigates featured the first Panoramic Hull mounted MG 311 and 312 sonar. The Nilgiri class frigates were equipped with Type 184M sonar, later upgraded to 184SS in late 1970[7]. Thereafter, *IN* inducted the Rajput Class destroyers with MGK 335 sonar with a Variable Depth Sonar (VDS). The Foxtrot class submarines were equipped with an MG-200 system. These sonars were integral to the Indian Navy's ASW capabilities, enabling them to detect and counter submarine threats in the region effectively.

MGK 335 Sonar Control Panel: Picture Courtesy: ASW School Archives

[7]Vice Admiral GM Hiranandani (Retd), *Transition to Eminence*, Naval Headquarters, New Delhi, 2005, p.178.

The Late 1960s - Conception of Indigenous Sonar

During the late 1960s, the Indian Navy felt the need to evaluate the existing sonar systems installed onboard the Indian Naval ships. The Russian-origin Petya class[8] submarine chasers, which were acquired from the Soviet Union were the first to have panoramic sonar[9] systems and were also part of this evaluation process. Additionally by mid-1970s, the Indian Navy also, received the alternative of a European-origin sonar system for installation onboard Leander class frigates. However, the British sonar system *Sonar 170B,* installed onboard some of the *IN* frigates[10] was encountering performance issues, thus forcing the Indian Navy to seek further improvements. This evaluation period paved the way for the Indian Navy's efforts toward the advancement and expansion of its Anti-Submarine Warfare capabilities of that era.

Arnala Class Corvette

[8] Petya class submarine chasers, fitted with Herkules hull mounted, were first inducted in *IN* in 1968.

[9] Panoramic Sonar also known as 360-degree sonars or omnidirectional sonars, are underwater sonar systems designed to provide a complete view of the underwater environment around a submarine or a surface ship. These sonars use an array of transducers to transmit sound waves in all directions followed by analysis of the reflected waves to create a detailed picture of the surroundings.

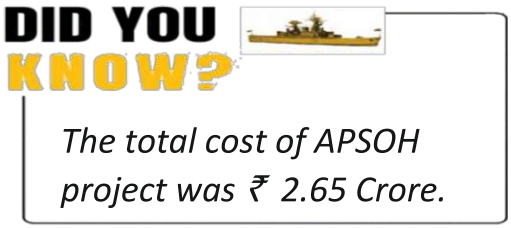
[10] *IN* Frigates-Trishul and Talwar (Whitby Class), Khukri, Kuthar and Kirpan (Blackwood Class).

The early 1970s - Overcoming Sonar 170B Limitations

The Indian Naval Officers (Late) Lt VK Jain and subsequently the then Lt Arogyaswami Paulraj, both Electrical specialisation Officers significantly contributed towards improving the signal processing capabilities of Sonar 170B. Lt VK Jain's collaboration with the Bhabha Atomic Research Centre (BARC) was intended towards advancement in sonar technology and was coupled with Research & Development (R&D) to explore new techniques, algorithms and hardware enhancements. Further, the development by then Lt Cdr A Paulraj in collaboration with IIT, Delhi considerably enhanced the sonar performance, overcoming the sonar limitations and upgrading its ability to detect and track underwater targets with improved ranges[3].

BARC technology used a technique called *Ping-to-Ping Integration* (PI). This method combined signals from multiple sonar pings to improve target detection. By averaging the signals from each ping, it reduced noise and reverberations that vary between pings, while keeping the target echoes consistent. This made it easier to discover and identify targets. In contrast, Paulraj implemented three distinct techniques, chosen based on operational conditions-Linear Frequency Modulation (LFM) pulse for improved range resolution, noise reduction using Digital Own Doppler Nullification (DODN) to mitigate clutter caused by the sonar's motion and Notch Filtering (NF) to suppress unwanted frequency components. Additionally, an A-scan storage CRT display facilitated a closer examination of echoes to intensify target recognition by providing a detailed visualisation of received signals.

1971- The Indispensable Need for a Credible Sonar



During the 1971 Indo-Pakistan War, the sinking of INS Khukri revealed a crucial need for the latest underwater sensor systems within the Indian Navy. This event prompted a reassessment of the Navy's sub-surface detection and anti-submarine capabilities. Moreover, the loss of (Late) Lt VK Jain, a key contributor to these advancements at the time, placed a temporary halt to the sonar evaluation process. (Late) Lt VK Jain's work was pivotal in addressing the Navy's challenges and enhancing operational readiness during this crucial period.

Artistic Impression of Sinking of INS Khukri in 1971[11]

1972-1975 –The Indomitable Spirit of Innovation

The Sonar 170B improvement project was launched at IIT Delhi in May 1972, with Professor Indiresan as the overall supervisor and the then Lt Cdr A Paulraj as project lead. His small team of four included two PhD scholars and two DRDO scientists. Fortunately, IIT Delhi was capable of importing ICs (Integrated Chips) and meet Paulraj's requirements. Following the development of the new transmitter-receiver prototype, numerous sea trials were undertaken onboard INS Kuthar, culminating in October 1973. These trials confirmed a notable improvement in Sonar 170B's performance. The Navy accepted the new design and Paulraj transferred the technology to Bharat Dynamics Limited (BDL), Hyderabad, for mass manufacturing and installation on 170B sonar ships. His innovative work not only remarkably enhanced the performance of existing systems, but also laid the groundwork for the future development of Indigenous sonar technologies in India[12]. The ground-breaking contributions in signal processing algorithms revolutionised the field, providing the Indian Navy with advanced capabilities for underwater detection and tracking. His research legacy continues to shape the country's naval capabilities, setting a high standard for Indigenous technological innovation in defence.

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[11] Image on left: Lt Cdr Madanjit Singh Ahluwalia (Retd), NM, *Torpedoed at Sea*, New Delhi, Notion Press, 2016. Image on right: Photo Courtesy: Cdr Arun Saigal (Retd), Painting by SLt Ravi Nambiar, then WKO onboard INS Kirpan.

[12] Vice Admiral GM Hiranandani (Retd), *Transition to Eminence*, Naval Headquarters, New Delhi, 2005, pp.175-180.

1976 - 1980 – The Genesis of APSOH

The success of mod-kit in 1976, led to the Indian Navy embarking on a pioneering endeavour and spearheaded the development of the Advanced Panoramic Sonar Hull-mounted at the Naval Physical and Oceanographic Laboratory, which was set up within the Naval Base at Kochi by 1976. The team comprised dedicated scientists, engineers, and naval personnel under the leadership of the then Lt Cdr A Paulraj. Within a short span of two and a half years, the team developed the Wire Wrap Prototype and sea trials commenced by 1979. The project APSOH thus mobilised the Indian Navy's vision and ambition for self-reliance especially in sonar technology.

The Early 1980s and APSOH's Success

The early 1980s marked the successful completion of sea trials, and the detailed Development and Engineering (D&E) design of APSOH was transferred to Bharat Electronics Ltd for production. Subsequently, in 1982, Mazagon Dock Limited (MDL) installed an APSOH prototype onboard INS Himgiri, and a Leander class frigate for extensive testing, marking a noteworthy milestone in its development. During these tests, the APSOH system demonstrated exceptional performance in detection and contact echo classification, surpassing other contemporary sonar systems. The successful testing onboard INS Himgiri till 1984 validated APSOH's capabilities in Indian tropical and hydrological conditions, showcasing its effectiveness in real-world maritime operations. In 1984, APSOH was ready in all aspects for fitment onboard new induction Project 16 - Godavari class frigates, earlier planned to be fitted with 184SS British sonars, were retrofitted with APSOH dry end and 184SS wet end. This achievement was possible due to the collaborative efforts of the Indian Navy, NPOL, BEL, and MDL, highlighting their collective commitment to a shared objective.

The 1990s and later – Development and Future Endeavours

Following the success of APSOH, the then Commander Paulraj initiated the development of a Hull-Mounted Variable Depth Sonar (HUMVAD). HUMVAD sonar was eventually fitted onboard the Project 15 destroyers, INS Delhi and Mysore in the mid-1990s. However, due to the challenges with the handling gear, the sonar was not developed further.

These projects showcase India's growing self-reliance and potential to innovate and produce world-class sonar systems customised to its unique maritime requirements.

This success empowered them to innovate further, leading to the creation of advanced ship-borne sonar systems such as Hull Mounted Sonar Advanced (HUMSA), HUMSA Next Generation (NG), and HUMSA Upgrade (UG) and various submarine sonars Panchendriya, USHUS etc.

During the 1970s, the ability to collaborate efforts of multiple stakeholders to realise an end product was a new game altogether. Cmde (Dr) A Paulraj in his interview highlighted *"Many times I felt that the research efforts would fail or collapse but the determined vision of the Organisation kept the team going"*.[13] It is now imperative to dive deeper to uncover the nuances of 'Harmonising the Talents' in the following Chapter.

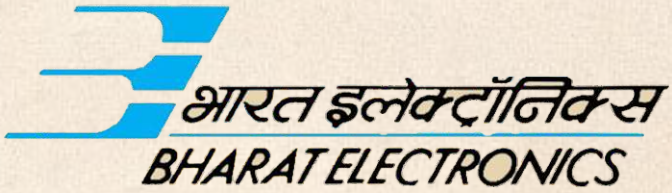
DID YOU KNOW?

APSOH array had 32 staves, each containing 13 elements; and weighed about 2 tons.

[13] Cmde (Dr) A Paulraj, Interview, Lt Cdr Nagarjun NN.

Harmonising Talents

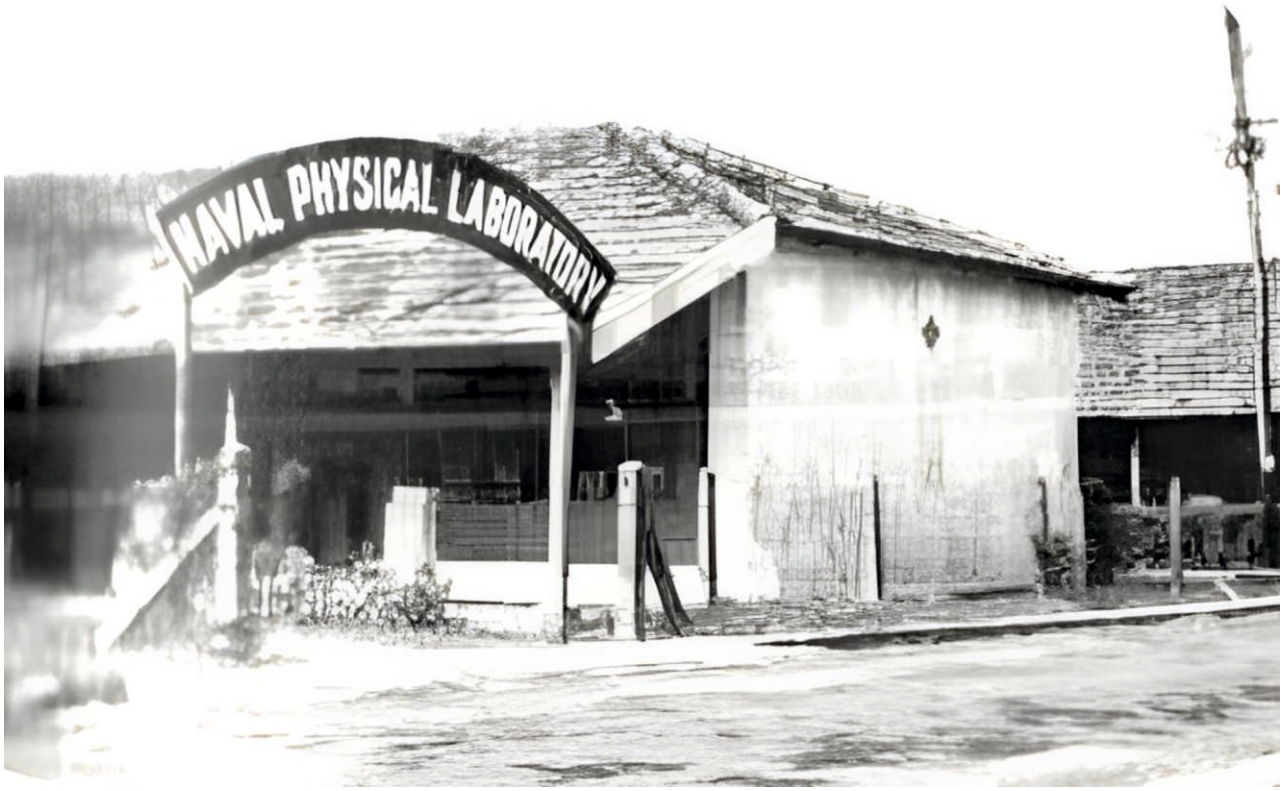
CHAPTER 3



Chapter- 3

Harmonizing Talents

The origin of the Naval Physical & Oceanographic Laboratory dates back to 1949, when Dr J. E. Keyston of the Royal Naval Scientific Service, UK was invited to India to share his insights on setting up a Scientific Organization for the Indian Navy.[14] Subsequently, the Indian Naval Physical Laboratory (INPL) was established in March 1952, in the Wartime Barracks of one of the training schools of INS Venduruthy, Kochi,[15] marking a significant development in India's naval capabilities. Led by Dr A Achuthan as the first Officer-in-Charge INPL's primary mission was to provide crucial technical support to the Indian Navy.



Old building of at the Naval Base, Kochi

The laboratory initially operated from the barracks within the Naval Base, fabricating small scientific instruments for ocean research and repairing foreign sonar transducers.

[14] Historical Background, DRDO, Ministry of Defence, *https://www.drdo.gov.in/aboutus* accessed on 04 March 2024.

[15] Vice Admiral GM Hiranandani (Retd), *Transition to Triumph*, Naval Headquarters, New Delhi, 2000, p.337.

However, in 1958 its integration with the Defence Research and Development Organisation (DRDO) led to the rechristening of INPL as the NPOL.

In the late 1960s, Shri M.S. Narayanan, a key figure at NPOL, was appointed as the Scientific Adviser to the Chief of Naval Staff at Naval Headquarters.[16] This appointment further strengthened NPOL's influence within the defence establishment. In 1968, NPOL underwent a physical shift to a new, purpose-built, four-storied building, later an eight-storied building at Kakkanad, Ernakulam.[17] This move marked a turning point, as the laboratory became a centre for revolutionary developments. The innovations that emanated from NPOL during this period played a pivotal role in reshaping the course of development of anti-submarine warfare capabilities in India.

NPOL main building at present[18]

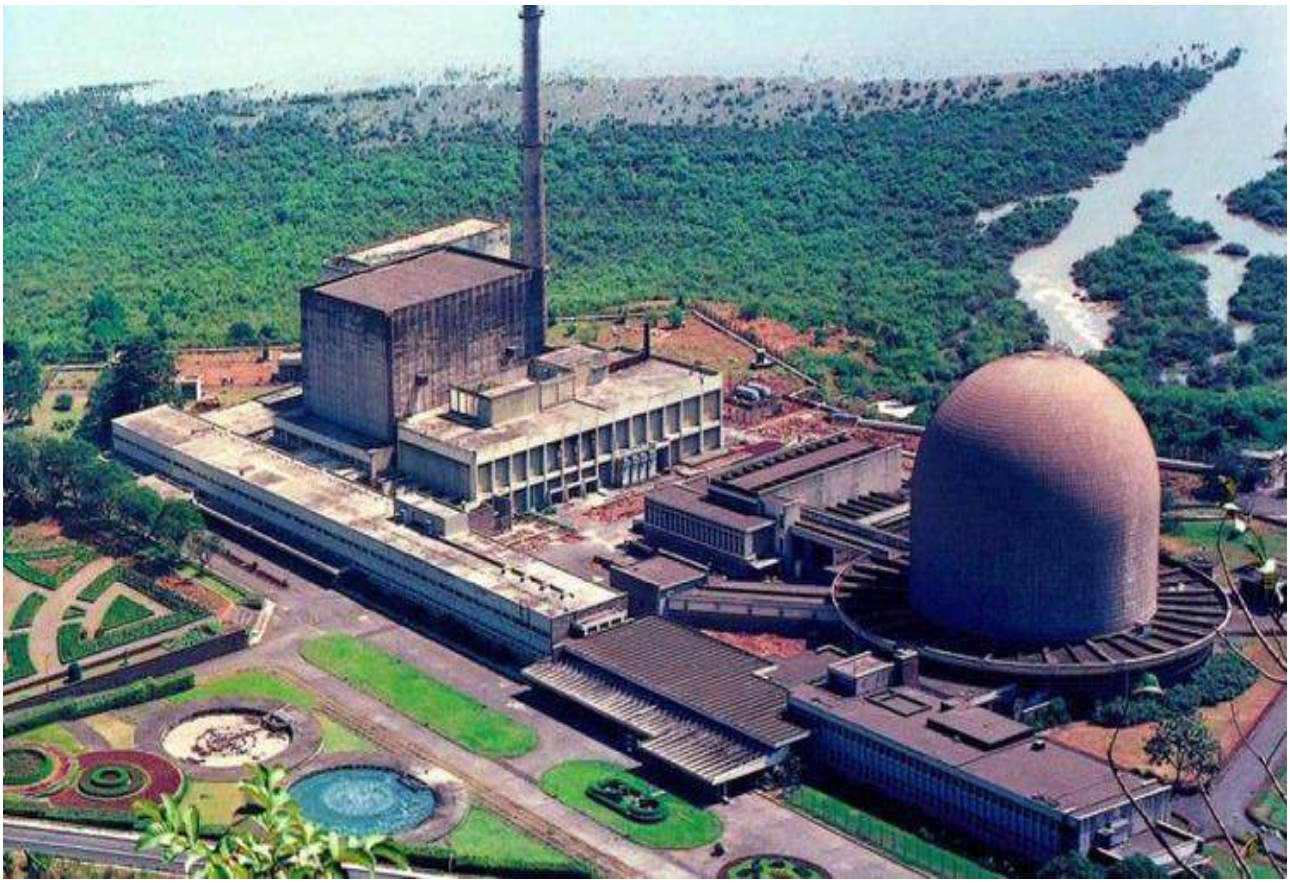
[16] Vice Admiral GM Hiranandani (Retd), *Transition to Eminence*, Naval Headquarters, New Delhi, 2005, p.177.

[17] The building had an acoustic tank of 50m x 20m x 15m. It also had the facility for transducer testing, prototype fabrication and vibration testing. Initially the building was inside Naval, Base, and Kochi later the 8- storied building was built at NPOL. Dr Anant Narayanan, (06 February 2024), *Email response*.

[18] Dr Anant Narayanan, Ex-Dir NPOL, Interaction on VC at ASW School on 31 January 2024.

The Quest for Self-Reliance

During the late 1960s, the Indian Navy evaluated panoramic sonars, including those fitted onboard Russian Petya class submarine chasers and European panoramic sonar system for the Leander class frigates. The Navy aspired to achieve self-reliance in the shipborne sonar system by putting forth the requirement to NPOL for a state-of-the-art, medium-range panoramic sonar, tailored for Indian tropical and hydrological conditions. During this period, the Indian Navy encountered various challenges linked with the performance of Sonar 170B, installed onboard the newly acquired British frigates. To address these issues and improve the effectiveness of sonars, the Navy sought assistance from BARC, leveraging its expertise to boost the sonar's signal processing capabilities.



Bhabha Atomic Research Centre Aerial View

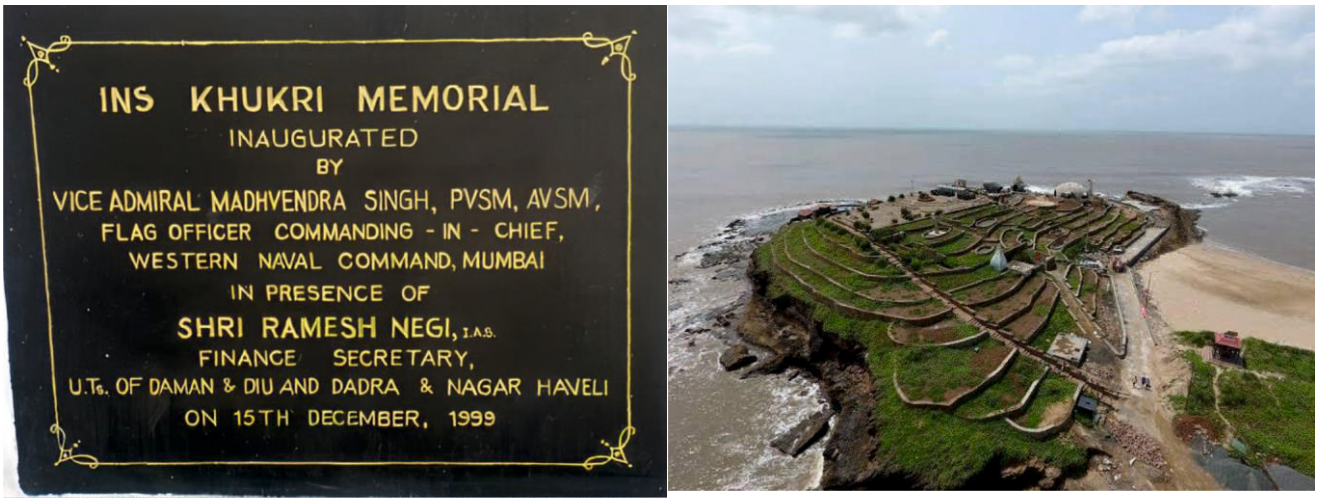
The Silent Vigilant: (Late) Lieutenant Vinod Kumar Jain

(Late) Lt Vinod Kumar Jain, having completed a sonar course in the United Kingdom at HMS Collingwood, collaborated with BARC in Bombay to augment the performance of Sonar 170B. The goal was to develop a Modification Kit that could potentially transform the

operational efficiency of the sonar system. The team at BARC, under (Late) Lt VK Jain's guidance, strived tirelessly to bring about enhancements in signal processing.

The (Late) Lt VK Jain and Dr Phadnis at BARC adapted a nuclear scintillation logging instrument acquired by Dr Phadnis from Italy for using it with Sonar 170B, recognising its potential to improve the sonar. In Cmde (Dr) A Paulraj words, *"BARC and Lt VK Jain deserve all the credit for taking the initiative to improve Sonar 170 B. The BARC-Jain initiative was crucial; without it, the IIT project, the enhancement of the Sonar 170B, and possibly even the creation of APSOH might not have been realized".*[19]

The sea trials in 1971 tested the BARC Modification Kit for the Sonar 170B, displaying promising results. Despite the Indo-Pak war, (Late) Lt VK Jain remained committed towards refining the sonar technology and continued with the research. He requested authorisation from Naval Headquarters in Delhi to conduct tests of the enhanced sonar system on the British-built frigate INS Khukri during an anti-submarine operation. Tragically INS Khukri succumbed to enemy torpedoes leading to the loss of the ship and the gallant sacrifice of (Late) Lt V K Jain. His story serves as a poignant testament to the unwavering dedication and innovative spirit of individuals even in times of predicament.



The INS Khukri Memorial at Daman & Diu inaugurated in 1999

His collaboration with BARC, trials at sea, and his relentless pursuit of implementing the modification during wartime, emphasise the critical role those technological advancements play in naval operations. While the Khukri incident remains a tragic event,

[19] Vice Admiral GM Hiranandani (Retd), *Transition to Eminence*, Naval Headquarters, New Delhi, 2005, p. 177.

(Late) Lt Jain's efforts is a reminder of the unwavering quest of excellence within the armed forces, contributing to the continuous evolution of military technology. (Late) Lt Vinod Kumar Jain was later awarded the "Nao Sena Medal" (Gallantry) posthumous, for his commendable courage and selfless actions.

The Spark at IIT, Delhi

The Indian Institute of Technology (IIT) has long been renowned for producing exceptional talent, with many of its graduates occupying top positions in global tech companies. In 1972 Paulraj's ground-breaking research at IIT Delhi, earned him a PhD in naval studies without an MTech degree, a first for the Navy. He was immediately sent to Bombay to provide his expertise on the BARC sonar module, which had been installed onboard Khukri before the war. Since his PhD thesis on Signal Estimation theory was closely related to sonar technology, he believed that the BARC sonar's approach had limited potential with the scope for improvement.

Dr D Srinivasan, Director NPOL in 1976

The then Lt A Paulraj, leveraged IIT resources to develop a modification kit for the Sonar 170B. His modification kit, developed at IIT Delhi, proved to be highly successful during sea trials and was subsequently handed over to Bharat Dynamics (BDL) for production by 1975. His expertise led him to recommend NPOL's sonar for future naval acquisitions, which was accepted by the Navy. Paulraj also participated in the assessment of foreign sonars from 1975 onwards through his visits to foreign companies like Graseby, Marconi, and Plassey as directed by the NHQ. After his visits, he concluded that he could produce a better sonar for the Navy. After joining NPOL in 1976, he and the Director, Dr Srinivasan recommended to NHQ the idea of developing an indigenous sonar, which was readily accepted, and the project along with its associated team was sanctioned for development at a project cost of roughly over Rs 2 Cr.

As a result, the Navy entrusted him with the task of taking on and improving the project, marking the beginning of the APSOH journey. *"The APSOH model and its variants were designed and built at NPOL which continue to be the backbone of Indian Navy's underwater sensors, but the mastermind behind its design was Paulraj"*[20].

BEL's APSOH Journey

In 1977, a letter from M/s BEL to M.M. Sen, Secretary (Defence Production), kindled a crucial moment in the history of the PSU. The letter triggered a debate in the Navy about the selective modernisation of their existing soviet sonar systems, versus the development of next-generation sonar systems. Following that, NPOL proposed the development of a cutting-edge sonar system in partnership with the Indian Navy, with the expertise of then Lt Cdr A Paulraj playing a crucial role in realising the project.[21] To set this partnership of indigenisation in motion, BEL led by Capt S Prabhala (Retd) took on the challenge of productionising the APSOH project. BEL was the only Sonar manufacturer associated with NPOL from 1975-76.

[20] Vice Admiral GM Hiranandani (Retd), *Transition to Eminence*, Naval Headquarters, New Delhi, 2005, p.179.

[21] S Krishnan, S Prabhala, V K Koshy, *Inside the Solid State: The Story of Bharat Electronics*, Westland, Bengaluru, 2014, p.148.

From the Left: Arun Singh, Minister of State for Defence Production in discussion with Adm R. H. Tahiliani, Chief of the Naval Staff, Gen K Sundarji, Chief of Army Staff, Maj Gen Shyamal Ghosh, CMD and Capt S Prabhalla, Executive Director, BEL Bengaluru Complex

Transducers for these Sonars were imported from UK-based company Graseby for the first few systems, while indigenous development was later undertaken by NPOL, Kochi, and transferred to BEL.[22] This project was a pioneering initiative of BEL's R&D team to undertake simultaneous design and development of a contemporary product which was much different from the norm of sequential progress. A significant milestone of project completion within six and a half years from concept to acceptance was achieved. This gave immense confidence to the Indian Navy and as a result, BEL received an order for six sonar systems, with the first system delivered timely in December 1985.

[22] Capt S Prabhalla (Retd), (02 April 2024), *Email response.*

Breaking Barriers

APSOH Team[23] with Cdr Paulraj and Dr D Srinivasan
(at the centre in the first row) May 1983

In 1976, the then Cdr A Paulraj accepted the daunting task of advancing sonar technology for the Indian Navy at NPOL, despite the lab's limited experience and resources. However, he was resolute and curated a team of new scientists, fostering their talents through his exemplary leadership. Notwithstanding bureaucratic impediments, such as the denial of permission to import essential components, Paulraj's steadfast commitment and Admiral RL Pereira's unwavering support made this task possible. Adm Pereira intervened multiple times on occasions, such as the procurement of travel waivers, which facilitated Paulraj's team to focus on their mission.

The project was steered by a committee[24] led by the then Vice Chief of Naval Staff, VAdm MR Shunkar, with Director NPOL reporting to him every quarter. The team also included key personnel like Director of Weapon Engineering (DWE) Cmde A R Khandekar, DNRD then Capt Ravi Kohli, and Deputy Director of Combat Policy and Tactics (TAS)[25] the

[23] Dr Anant Narayanan, Ex-Dir NPOL, Interaction on VC at ASW School on 31 January 2024.
[24] VAdm SCS Bangara (Retd), (17 April 2024), *Email Response.*

[25] Directorate of Combat Policy and Tactics (DCPT) akin to present day Directorate of Staff Requirements (DSR).

then Cdr SCS Bangara, alongside other members from NPOL. This Committee met every three months to drive executive decisions and ensure timely progress. BEL Bangalore was designated as the production agency, with Capt S Prabhala (Retd) and then Cdr R Venkatesh from BEL joining the Steering Committee. Their perseverance resulted in the successful maturing of APSOH in 1978. This achievement highlighted the importance of leadership, talent development, and mentorship in overcoming challenges to technological innovation.[26]

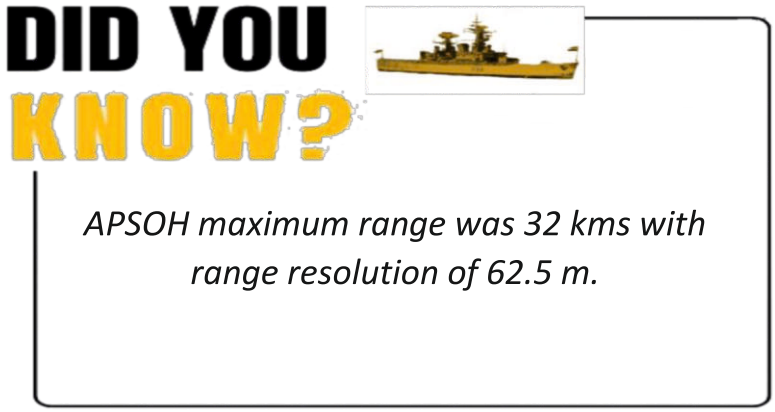
APSOH became the opportunity that brought together a diverse team of naval personnel, NPOL scientists, and experts from BEL, MDL, and other agencies. This collaboration was unprecedented, marking the first time for a versatile group from myriad backgrounds and organisations work together towards a common goal. Cdr Mohan Philip (Retd) illustrates in his words *"Led by the visionary Cmde (Dr) A.J. Paulraj (Retd), APSOH was not just another sonar; it was a leap forward in technology. It was more advanced than any other sonar available at the time, showcasing India's ability to innovate and excel in defence technology"*. APSOH's success was not just in its performance but in the impact it created, acting as a catalyst for a transition from analogue to digital systems, setting a new standard in sonar technology.

APSOH Stake Holders

[26]Gen Nitin Gadkari (Retd), (02 April 24), *Email response.*

APSOH was an inspiring culmination of varied personnel and agencies collaborating for a collective goal. Key personnel involved in APSOH such as Cdr Mohan Philip, Dr Anant Narayanan, and Dr Vijayan Pillai briefly recall that *"The APSOH sonar design was rooted in digital signal processing, featuring major subsystems like displays, active and passive search processors, and system controllers using digital PCBs with Mil-Standard ICs. The system utilised an IMP 16 Bit Slice processor, later upgraded to an AMD processor, and employed AMD 2900 Multiplier Accumulator Chips for digital filtering. To streamline manufacturing, AUWE Sonar cabinets of 184SS were modified for heat exchange using tepid water cooling, while only the Transducer Array of 184M was retained".*[27]

In the words of Cmde (Dr) A Paulraj, as documented in *Transition to Triumph* *"Now that I lead aspects of wireless technology at a worldwide level, I have a better understanding of the technology development process in the developed countries. I sometimes compare APSOH with other achievements I see in my new field. I am always amazed as to how such an inexperienced team, with such few resources, pulled off this major project in such a short period. APSOH was an impossible dream that came true for many of us."*



[27] Dr Anant Narayanan, Cdr Mohan Philip, Dr Vijayan Pillai, Interview by Lt Cdr Nagarjun NN on February 2024, Capt Vikas Sood on 30 March 24 and Lt Cdr Avinash SN on 30 March 24.

Trials Of Maiden Accomplishment

CHAPTER 4

Chapter - 4

Trials of Maiden Accomplishment

After the APSOH sonar prototype was produced in collaboration between NPOL and BEL, the trials and testing phase encountered issues with the power amplifiers, which took a while to resolve. Apart from this, the system performed superbly[28]. The sonar was developed in a DRDO lab of NPOL, manned by civilian scientists and various stakeholders geographically separated across the country, but united by the project leader who was an Indian Navy officer. Further, from environmental challenges to complexities of integration, the stakeholders encountered numerous hurdles along the way. Examples of collaboration, innovation, and perseverance were evident in addressing emerging roadblocks, ultimately leading to the successful validation and deployment of the Advanced Panoramic Sonar Hull-mounted by 1983. This extraordinary feat was possible with the organisations and individuals putting aside their differences and working as a team towards a common goal.

Acoustic Tank Testing Facility at NPOL[29]

[28]Vice Admiral GM Hiranandani (Retd), *Transition to Eminence*, Naval Headquarters, New Delhi, 2005, p.178.

[29]The acoustic tank is 50m long, 20m wide and 18m deep, and can carry out testing and calibration of sonar transducers and acoustic domes by estimating underwater acoustic properties like reflection, absorption, transmission, insertion loss and acoustic impedance. The tank was equipped with a remote-controlled EOT crane, and 2 moving platforms with turntables, which help to attain a positional accuracy of 1 cm in all 3 directions. Low frequency, high power measurements of bigger transducer arrays could also be carried out. Photo Courtesy NPOL.

The process of subsystem testing, meticulously examining each screw, nut and bolt, colloquially speaking, extended beyond the confines of the laboratory and was undertaken onboard INS Himgiri at Mazgaon Dock, Mumbai. Real-world scenarios onboard the ship provided invaluable insights into the standalone performance of the subsystems, ensuring they could meet the demanding requirements of naval operations.

Dr Anant Narayan in his interview lauded the timely decision to conduct field trials onboard a naval ship, which in turn allowed NPOL to fine-tune the components based on their performance in the dynamic conditions encountered at sea[30]. By 1980, NPOL had achieved confidence with the prototype and a realistic assessment of its operational effectiveness in the fleet.

The Factory Acceptance Trials

During 1981-82, a significant milestone in the project's timeline unfolded through the punctilious execution of the Factory Acceptance Test (FAT) at BEL, Bangalore. This crucial phase was governed by a detailed Factory Acceptance Test Schedule (FATS) document, outlining the testing procedures and schedules worked in tandem between the developers NPOL, the producers BEL, and the users the Indian Navy. The responsibility of scrutinizing the system's performance fell upon a specialized FATs team, carefully selected and appointed by the Naval Headquarters (NHQ).

During FATs, the system is subjected to rigorous environmental tests thus, examining its resilience and compliance to military industry standards. It was the primary responsibility of the team from NHQ to evaluate the sonar and its subsystems thoroughly. Capt Prashanth K Sinha, an Electrical Officer provided valuable insights and feedback from an end-user perspective. Further, Dr PK Kataria an experienced researcher in signal processing led the testing and evaluation team at NPOL, conducting simulated exercises and real-world trials to validate APSOH's performance under different environmental conditions. Mr SK Singh as the project manager at BEL, coordinated the logistics and technical support required for the testing phase, ensuring adherence to project timelines and quality standards[31].

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[30] Dr Anantha Narayanan, Interview, Lt Cdr Nagarjun NN, 21 February 24.

[31] S Krishnan, S Prabhala, V K Koshy, *Inside the Solid State: The Story of Bharat Electronics*, Westland, Bengaluru, 2014, p.378.

These tests included evaluations for shock resistance, vibration tolerance, electromagnetic interference/ electromagnetic compatibility (EMI/EMC), and rain testing. The entire testing protocol adhered strictly to the demanding JSS-55555 specifications, which served as the benchmark for the system's design and functionality[32]. Under the supervision of the Controller of Quality Assurance (Electronics) in Bangalore, the testing process ensured stringent quality assurance procedures. This evaluation not only validated the system's performance but also the delivery of a product that surpassed specified requirements.

Directing Gear Test Facility

DID YOU KNOW?

Hull Outfit 5 subsystem helped monitor/ calibrate the performance APSOH sonar.

The comprehensive nature of the tests and detailed documentation of outcomes in the FATs report established rigorous acceptance procedures. This foundational phase not only ensured the system's robustness under diverse environmental conditions but also laid the groundwork for subsequent phases, instilling confidence in the project's ability to meet and exceed expectations during deployment and operational phases.

The Installation and Harbour Acceptance Trials (HATs)

INS Himgiri, one of the frontline frigates of that time, was the first to be fitted with the APSOH sonar. The year 1982 witnessed the commencement of this pioneering installation process,

[32] Mr Ellappan, APSOH installation and trials team, BEL, Interview, Lt Cdr SN Avinash, 02 April 2024.

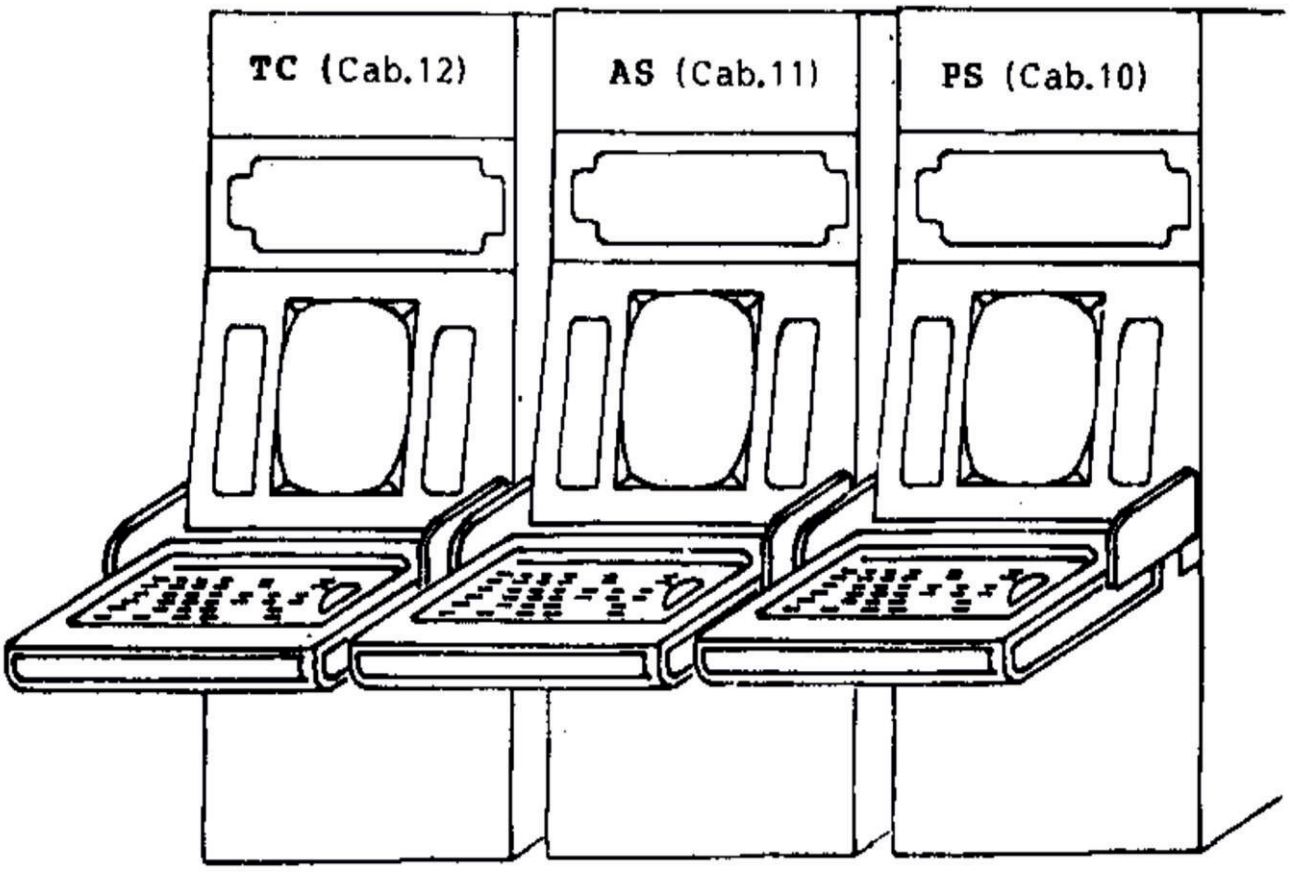
with the equipment being dispatched to Mumbai. The collaboration with Mazagaon Dockyard showcased a seamless synergy between naval expertise and dockyard precision. At the forefront of this transformative initiative was Capt Pramod Datey[33], a seasoned leader whose strategic vision and expertise in naval operations earned him several accolades throughout his naval career. Further, a submariner and a seasoned skipper Cdr VS Shekhawat (Later Chief of the Naval Staff) was the Commanding Officer of the ship who coordinated the progress of activities onboard, between Naval Dockyard (Mbi), MDL, BEL, and NPOL.

INS Himgiri was fitted with the first APSOH prototype

The installation was undertaken with delicate precision, as cabinets housing the advanced technology were transported and carefully integrated into the ship's infrastructure. Specific sections of the vessel were opened up to facilitate this integration. The major challenge was to install the new APSOH equipment into the Sonar Control Room and Sonar Instrument Compartment, alongside the existing 184 SS Sonar system. In addition, since the success of the transducer technology was yet to be realised, it was decided to keep the Hull Outfit (transducer) of 184SS as it is, and only retrofit the Dry End electronics developed by NPOL. The installation process extended beyond the physical placement of components; it entailed a sophisticated interweaving of the new technology with crucial ship systems. The

[33] Capt Pramod Datey, Oi/C APSOH Installation Team onboard INS Himgiri, 1982.

gyro, log, bridge, roll pendulum, power supply, and the nerve centre of naval operations- the Operations Room, all became integral parts of the comprehensive upgrade.



APSOH Sonar Operator Consoles

The electronic hardware of the APSOH system was distributed over 13 cabinets, located in the Sonar Instrument Compartment (SIC) and Sonar Control Room (SCR) of the ship respectively. The sonar had three operator consoles, each performing a specific function with disposable markers and cursors on the display which was a vertically mounted monochrome CRT TV screen. The three operators could interact with the system through keypad, switches, controls & Joy ball provided to each operator. Ergonomically, APSOH was optimised to provide operator comfort and ease of operation of the sonar at the same time.

DID YOU KNOW?

The transmission of acoustic signals of Sonar displayed on Operator screen is called Pulse in Water Line.

Sonar APSOH thus, was miles ahead of its contemporaries. A brief comparison of Sonar APSOH with some of its contemporaries is as follows:-

Features/ SONARS	APSOH	184SS	MGK 335	170	184M
Twin Frequency	Yes	No	No	No	No
Active/ Passive/ Classifier	Single	Separate	NA	No	Separate
Multiple Wave Forms	5	2	2	2	2
Simulator	Yes	No	No	No	No
Display	CRT	CRT	Analog	A Scan	A Scan
Auto tracking	Yes	No	No	No	Yes
Digital Processing	Yes	Limited	No	No	Limited
Fitted onboard	Himgiri	Leander and Godavari Class	Abhay class	Talwar and Khukri class	Nilgiri class

After the installation of the equipment onboard the ship, Harbour Acceptance Trials were carried out to ensure that the equipment was functioning properly. These tests had to be carried out before sea trials. These usually included electric power supply system tests, sonar protection systems tests, automation system tests, the safety of people on board and interfacing with nautical systems and lighting. After the successful completion of the HATs, the ship received a temporary certificate of seaworthiness from the authorities and was allowed to go to sea. Finally, the Sea Acceptance Trials (SAT) were scheduled for the tests that required sailing, including manoeuvring tests, stop tests and sonar performance tests.

Cdr Mohan Phillip, who was the Ex TASO (Torpedo/Anti-Submarine Officer) onboard INS Himgiri was later posted to NPOL to prepare the user document. Thereafter, he was reappointed onboard INS Himgiri at the time of installation and trials as TASO, considering his experience with the sonar. VAdm SCS Bangara (Retd) during his interview highlighted that *“In depth planning was undertaken even for personnel management of every officer who formed the core team of APSOH”.*

Cdr Mohan Philip, Chief Instructor, ASW School

He recounted the contributions of Cmde JR Patel as Officer in Charge Trials Team and Cdr KSK Prasad[34] for further refining the documentation for conducting HATs and SATs, which was eventually handed over to Tata Consultancy Services (TCS) then known as Tata Computer Systems for finalisation[35]. The culmination of this intricate installation process was marked by the successful completion of Harbour Acceptance Trials (HATs) in the year 1982. VAdm SCS Bangara during his interaction highlighted that *"Many ceilings were broken to make the sonar a success"*. These trials served as a rigorous testing ground, validating the seamless integration and functionality of enhanced systems in harbour conditions. The success of the HATs not only attested to the technical prowess of the installation team but also solidified INS Himgiri's readiness and capabilities for the dynamic challenges that awaited it on the high seas.

[34]Cmde J R Patel was the first Oi/C of APSOH Trials team, Cdr KSK Prasad who was in his team relieved him later. He was later appointed as DCPT at Naval Headquarters.

[35]Cdr Mohan Phillip (Retd), Interview, Capt Vikas Sood, 30 March 24.

The Sea Acceptance Trials

During the sea phase, Integrating APSOH with existing onboard systems on Himgiri posed compatibility challenges, leading to potential interference and performance degradation. Also, ensuring the accuracy and reliability of APSOH's measurements required careful calibration and validation procedures, particularly concerning range resolution and target classification capabilities. Further, the transducer from the 184SS necessitated in-depth understanding and associated electronics to integrate it into APSOH electronics.

The successful induction of the APSOH into the Navy by 1983 was the culmination of a rigorously executed series of Sea Acceptance Trials. The collaborative efforts of personnel from key organisations such as NPOL, BEL, and CQAE (W) played a crucial role in the testing and acceptance process[36]. The sea trials were not only focused on evaluating the system's overall performance but also included a systematic approach to identify and rectify any shortcomings observed in successive trials. This concurrent liquidation of issues showcased a commitment to excellence and readiness to address challenges promptly. The successful integration of the APSOH into the Indian Navy marked a significant growth in maritime capabilities, showcasing the collaborative expertise and commitment of the involved organisations.

Challenges and Solutions.

One of the primary challenges encountered during these trials was the variability of underwater environmental conditions. Factors such as ambient noise, salinity, temperature gradients, and sea currents posed significant hurdles in assessing sonar performance. Also, APSOH's advanced signal processing algorithms initially struggled to differentiate between genuine targets and false targets caused by underwater clutter, marine life, and natural phenomena.

NPOL and BEL utilised advanced modelling and simulation techniques to replicate diverse underwater environments and access APSOH’s performance under varying conditions. This allowed for pre-emptive adjustments to signal processing algorithms and sensor configurations. The continuous refinement of signal processing algorithms was undertaken to enhance target detection and classification capabilities while minimising false

[36] Dr Anant Narayanan, (06 February 2024), *Email response*.

alarms. This included iterative testing and validation against known targets and background noise.

The Reliability Improvement Program

To boost the performance of their products, BEL and Naval Dockyard, Mumbai jointly launched a Reliability Improvement Programme (RIP). This initiative targeted enhancements in the second and third production models of APSOH, addressing specific issues that were identified during the production and installation of the first sonar. The program included the introduction of new Printed Circuit Boards (PCBs) to replace those featuring a high number of jumpers, the substitution of unreliable connectors, and improvements in the design of Power Amplifiers to achieve higher output. These small changes helped in curbing reliability issues and elevated the performance of products, even exceeding military standards at times.

The Sonar Evaluation

A Sonar Evaluation Team (SOVAL) was appointed by the Indian Navy and was headed by Captain JR Patel, Lt Alok Kapoor, Lt RS Badana, and Lt Mohan Philip. The team extensively conducted trials of the system onboard INS Himgiri. The APSOH system underwent substantial scrutiny across a spectrum of hydrological conditions prevalent in the challenging waters of India[37]. This testing sought to validate the system's performance under diverse seasonal circumstances, ensuring its adaptability to the ever-changing marine environments and achieving enhanced ranges. The results of this thorough examination unequivocally affirmed the superior capabilities of APSOH, securing its status as a reliable and effective solution. Whether confronted with the dynamic challenges posed by different seasons or navigating the intricate nuances of tropical waters, APSOH demonstrated unparalleled prowess.

In the armed forces, the effectiveness of even the most advanced equipment is determined by the skill of its operators. The following chapter examines how this realisation drove the early development of training simulators.

DID YOU KNOW?

Rain testing technique is used to evaluate material exposed to rain, water spray, or dripping water during storage and transit.

[37] Dr Anant Narayanan, (06 February 2024), *Email response*.

Simulators For The Tutors

CHAPTER 5

Chapter - 5

Simulators for the Tutors

The retrofit of the APSOH system proved to be a leap forward in the Indian Navy's capability of detecting and tracking submerged targets. Soon thereafter, the importance of training the men behind the machine was recognised. Paulraj and his team initiated a comprehensive training initiative to ensure the APSOH sonar system was utilised effectively. An extensive training curriculum for the APSOH sonar system comprising a diverse range of theoretical and practical components was customised to equip the personnel with the requisite skills and knowledge. The curriculum was specifically designed to cater to the varied roles within the naval hierarchy, including officers, operators and technicians. The key components of the curriculum included:-

(a) **System Architecture**. Trainees were acquainted with the technical specifications, components, and subsystems comprising the APSOH sonar system. This encompassed theoretical lectures supplemented by hands-on practical sessions for enhanced comprehension.

(b) **Operational Procedures**. Emphasis was placed on imparting operational procedures for effectively employing APSOH sonar systems in various maritime scenarios. This entailed training in target detection, classification, and tracking techniques.

(c) **Maintenance and Troubleshooting**. Given the intricate nature of APSOH sonar systems, specialised training was provided in maintenance procedures and troubleshooting techniques to ensure operational readiness.

(d) **Simulation and Drills**. Realistic simulation exercises and drills were conducted to simulate combat scenarios and facilitate hands-on experience in a controlled environment.

APSIM (Acoustic Prediction System Integrated with Simulator) – ASW School

To augment hands-on training, APSIM was conceptualized. The APSIM was designed as a replica of APSOH sonar consoles in the ASW School at Southern Naval Command, for training sonar operators and ASW officers. There was an instructor’s console where customised parameters of own ship, target submarine and environmental parameter could be

fed. There was a simulator that could take control data from APSOH consoles scenario data from the operator's console, and generate desired audio-visual data on all three consoles.

APSIM at ASW School

Further, the instructor's console gave own ship and environmental data, and the initial target data of the simulation scenario. The interface controller provided the dynamically varying range and bearing values based on craft dynamics software[38] in it, to the passive and active controller subsystems. Using the above data from the system and craft dynamics software, the active controller and passive controller subsystems generated display data accordingly and sent it to the displays mimicking the APSOH Peripheral Address/ Data (PAD) bus. This data appeared on the displays showing noise and targets. The range and bearing of the target tracked by the operator, appeared on the instructor's console for evaluation. This was the simulation scheme and was completed by a team consisting of Mr. George Varghese, Mr. MX Joseline, Ms. Shobha Jay, Ms. Rajamma John all from the microprocessor division headed by Mr. M Mathurakani.

[38]Software designed to simulate, analyse and visualise the behaviour of dynamic systems over time. Examples include MATLAB/ Simulink, ANSYS and MSC Adams.

Dr VS Arunachalam, SA to RM, Dr VK Aatre, Director, M Mathurakani, DH (MP) and ASW School Officers During their Visit to APSIM Installation

A team from NPOL under the leadership of Sri S Srinivasan installed the cabinets linking them to the rear wall, similar to a ship. There was no chilled water cooling and only one 3-phase power source, which was bought from APLAB (Bengaluru-based Electronics company) to power the system. A contract was also concluded with BEL to execute inter-cabinet wiring. After this meticulous process, the system was powered up and the basic functionality was achieved.

The pioneering success of the Acoustic Prediction System Integrated with the Simulator enhanced the training. Even before the development was completed, the sailors started using the system for familiarisation and instructors expressed a lot of interest since APSOH was in their curriculum. They were also encouraged to report any discrepancies as a part of continuous evaluation. Cmde CGS Khan, the then senior instructor at ASW school recalls that *"The interest quotient in the Indian Navy for the simulators was very high and the school also proudly displayed their new asset to distinguished visitors frequently".*

Installation of APTRAC at INS Valsura

The newly formulated APSOH system also demanded maintenance and an adequate plan had to be in place to ensure a seamless flow. Hence, the maintainers of the equipment in the Indian Navy also needed to be trained in-depth about the APSOH system and various subsystems, since its maintenance at sea and life cycle was their responsibility. The various cabinets along with the consoles were installed at the Electrical Equipment School, INS Valsura by NPOL and BEL. The APTRAC was a state-of-the-art training tool designed to emulate the functionality and operation of the APSOH sonar system. It offered a high-fidelity replication of APSOH's components, interfaces, and maintenance procedures.

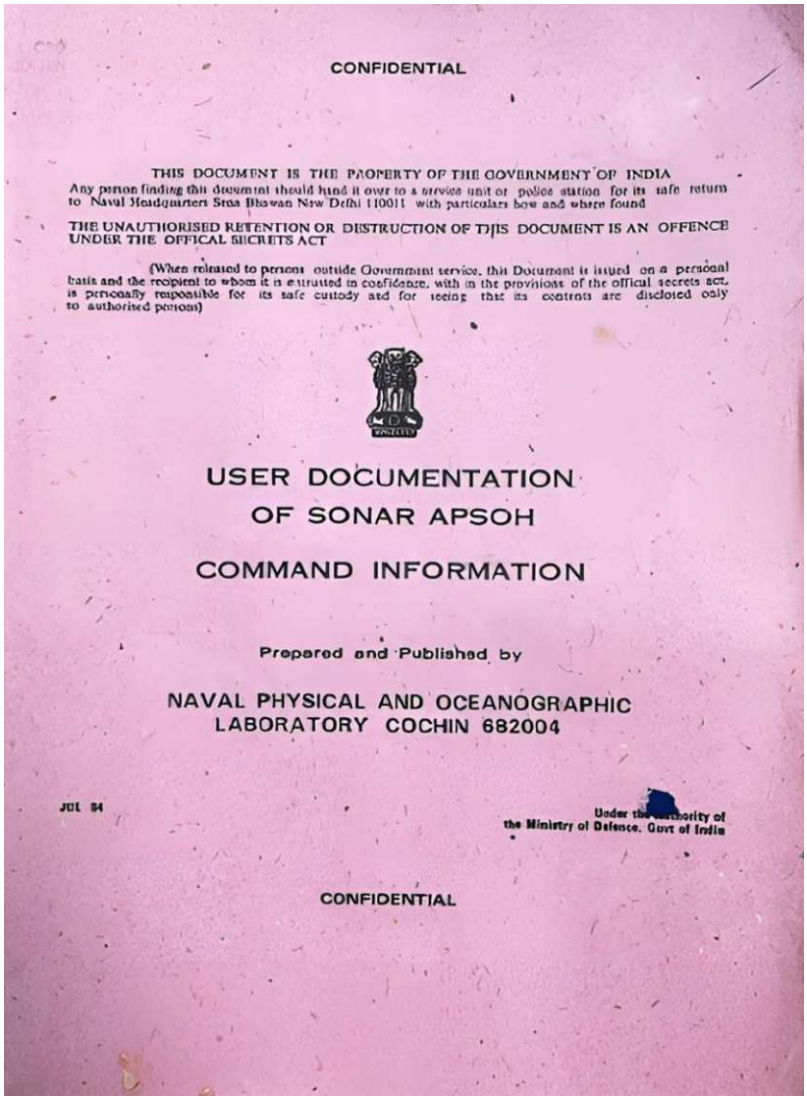
APTRAC replicated the behaviour of APSOH, including sonar arrays, signal processing algorithms, and control interfaces. The NPOL scientists along with Indian Navy instructors, created diverse maintenance scenarios, encompassing routine checks, fault diagnosis, component replacement, and system calibration.

The Then, Cdr NR Ravi was also extensively involved as the CI, Control section at INS Valsura for undertaking the maiden fourteen-week APSOH Maintainer course in 1986 for a batch of five officers and twelve sailors. The trainees were extensively using APTRAC and the last two weeks were also utilised for practical training with visits to INS Ganga at Naval Dockyard, Mumbai.

THE APSOH Documentation

A contract was concluded between TCS and NPOL to meticulously transform APSOH documentation from handwritten notes to a robust and systematic volume of manuals for users, maintainers, and its optimum use. TCS conducted a comprehensive assessment of existing APSOH sonar documentation, including manuals, guides, and training materials, to identify areas for improvement. The primary objective of this was to present the documentation in a standardised format and ensure readability. The documentation was localised to cater to specific operational requirements and customised to meet the diverse needs of naval personnel across different roles and proficiency levels. The transformed APSOH sonar documentation enhanced the effectiveness of training programs by providing

interactive and immersive learning experiences, resulting in better retention and application of knowledge by Indian Navy personnel[39].



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USER DOCUMENTATION
OF SONAR APSOH

COMMAND INFORMATION

Prepared and Published by

NAVAL PHYSICAL AND OCEANOGRAPHIC
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Under the authority of
the Ministry of Defence, Govt of India

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Cover Page of APSOH document[40]

The NPOL Scientists provided source materials, which TCS diligently compiled into nineteen volumes. The then Cdr NR Ravi extensively involved in the documentation process along with TCS, rectified and formulated the User and Maintainer manual for the APSOH system, as he was attached to the project right from 1980. He also contributed to the first APSOH prototype testing manual in early 1981. In 1983, while serving as the maintenance officer onboard, he oversaw the installation process of the APSOH system, and his experience proved worthy.

[39]Capt NR Ravi (Retd), Interview, Cdr Udit Gill, 03 April 2024.

[40]User Document held at ASW School.

This partnership between the Indian Navy and NPOL signified TCS's role in the technical documentation, adhering to industry standards and best practices, thereby facilitating a more accessible and comprehensible resource for various stakeholders involved in the project.

Training the Indian Navy.

As the APSOH project was nearing completion, the Indian Navy with the new confidence instilled by Cmde (Dr) A Paulraj, visualised the need for some derivative projects of APSOH in 1983. It included among other things, a training simulator at ASW School and a hardware maintenance trainer for INS Valsura (passive-only sonar). The training simulators played a pivotal role in maintaining a high level of system efficiency, reducing downtime, and enhancing the competence of the personnel involved. Thus, the APSOH Project was a pioneer in the field of training aids and simulators as well. The successful implementation of two follow-on projects, APSIM (Operator Training Simulator) at ASW School Kochi, and APTRAC (Maintenance Training Simulator) in INS Valsura, were conceived and produced for the training of the users and maintainers[41]. These contributed immensely in fortifying the system against challenges and criticisms, ultimately leading to its seamless and reliable operations at sea. These projects were strategically designed to address concerns related to system downtime and operator training[42]. APSIM focused on training operators in the handling of the system, while APTRAC provided maintenance training for personnel at INS Valsura. As briefed by Cdr Mohan Philip, then appointed at ASW School, Paulraj spent long hours with the operators and maintainers to explain ways to optimally exploit the Sonar.

The Outcome and Impact

Training simulators are instrumental in maximising the effectiveness of high-tech equipment by imparting realistic practical-oriented training, particularly in complex fields such as defence sector. They provide a safe and controlled environment for personnel to familiarise themselves with systems, practice various scenarios, and hone their skills without the challenges associated with live operations. The success of the APSIM and APTRAC tools highlighted the critical role of effective training in advancing sonar technology.

[41]Mr Ellappan, APSOH Installation and Trials team, BEL, Interview, Lt Cdr SN Avinash, 02 April 2024.
[42]Capt NR Ravi (Retd), Interview, Cdr Udit Gill, 03 April 2024.

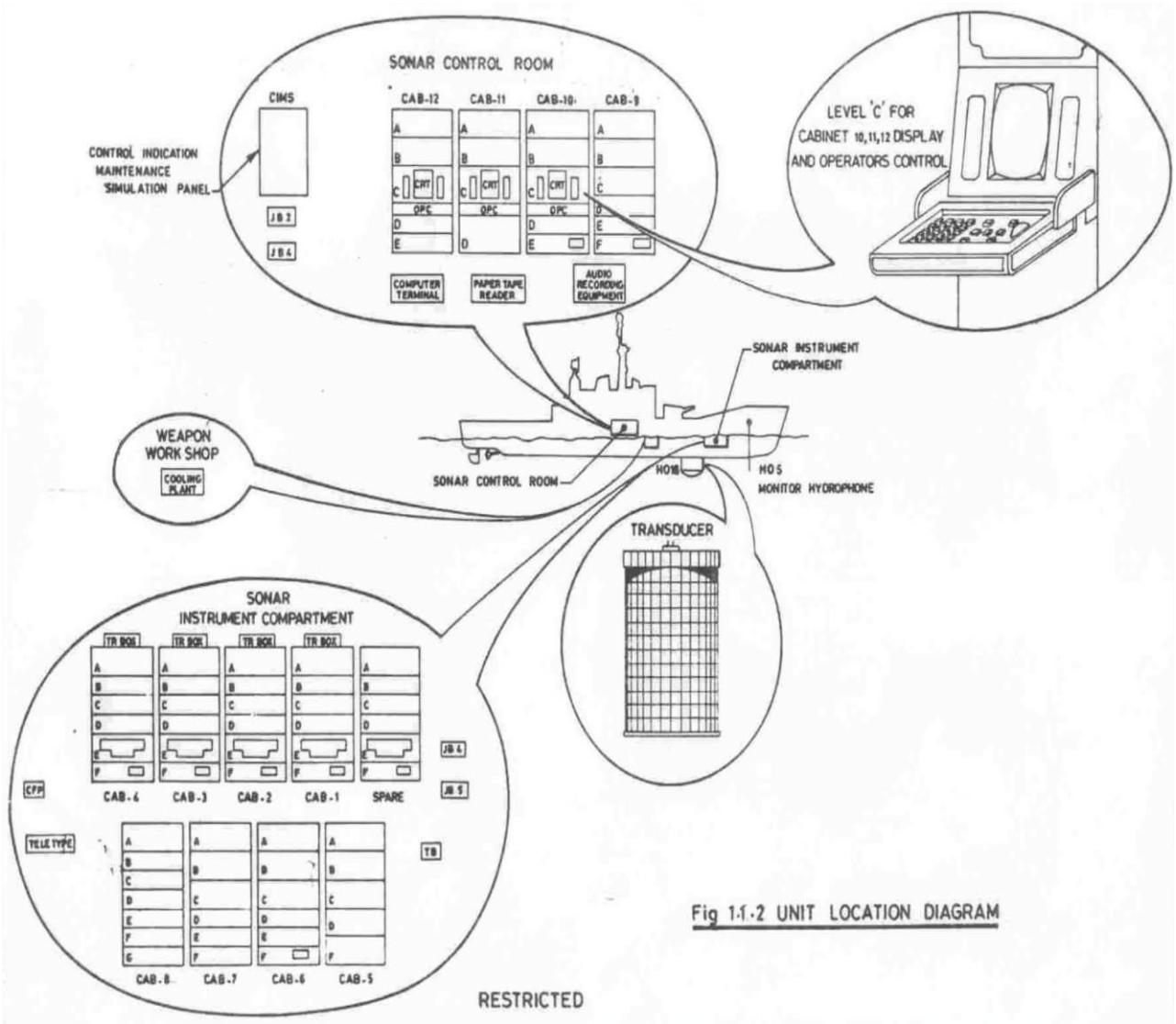


Fig 1.1.2 UNIT LOCATION DIAGRAM

The APSIM not only ensured that APSOH was effectively utilised but also helped NPOL convince DRDO HQ of the necessity for similar simulators for other projects[43]. As a result, the development and implementation of simulators like APSIM for follow-on projects of HUMSA series, USHUS and anti-torpedo system simulators have become an important deliverable of the projects for ensuring end users are able to employ these systems to their full potential.

[43] Dr Anant Narayanan, Op cit.

Submarine Sonar Simulator at INS Satavahana, HUMSA Simulator at ASW School [44]

The APSOH Project not only witnessed an improvement in its overall performance but also silenced potential criticisms by ensuring that operators were well-trained and capable. The rigorous training imparted to the personnel on APSOH sonar systems yielded significant outcomes, casting a profound impact on the Indian Navy's operational readiness.

DID YOU KNOW?

Ocean simulates how sound waves travel through varying underwater conditions, including sound speed profiles, layers bottom composition, and noise. This helps optimize sonar design and its performance.

[44] Dr Anant Narayanan, 'Technology Focus', *Bulletin of DRDO*, Vol 21, 2023, pp.13-14.

The Guiding Beacon

CHAPTER 6

Chapter - 6

Guiding Beacon

Influencing Future Development

The journey of the Naval Physical and Oceanographic Laboratory (NPOL) had a Vision - 'To be a centre of excellence for design and development of underwater surveillance systems'[45], and this was a reality with the successful development of APSOH. This achievement marked a watershed, leading NPOL transition to a matrix structure in 1984. The subsequent projects built upon the strong foundation laid by APSOH, leveraging technological leaps from monochrome to colour displays, the use of universally popular microprocessors, standardisation of PCBs and advancements in software development practices. These projects also witnessed the implementation of more powerful and compact Power Amplifiers[46], Built-in Signal Simulators and Sonic Ray Plotters, as well as the introduction of new algorithms for detection and tracking. Alongside such tangible advancements, NPOL gained intangible assets such as expertise in technology transfer to production agency; installation, trials, and collaboration with the Indian Navy and enhancing their overall capabilities in several domains.

Acoustic Tank NPOL at Naval Base, Kochi[47]

[45]NPOL, DRDO Labs, *https://www.drdo.gov.in/drdo/labs-and-establishments/naval-physical-oceanographic-laboratory-npol* accessed on 25 March 2024.

[46]Power Amplifier are electronic component of Sonar designed to control the amplitude of power of a given input signal to the Transducer for transmission of sound waves into the water.

[47]Photo Courtesy: NPOL Archives.

This progression brought to the fore the fundamental insight that a laboratory's initial success is often the catalyst for subsequent achievements, setting the stage for continuous improvement and innovation[48]. Moreover, leveraging the expertise gained from APSOH development in subsequent projects has been one of the most significant benefits of this transition. The learning curve and expertise gained by various personnel from the APSOH Project have proven to be invaluable assets, significantly reducing delays in the execution of follow-on projects and ensuring the success of successive projects like Hull Mounted Variable Depth Sonar, Hull Mounted Sonar Advanced, HUMSA Next Generation (NG) for the ships and after sonars for submarines. This has not only enhanced NPOL's reputation for excellence in Under Water Sensors but has also resulted in a better understanding of sonar technology thereby, cementing its position as a Leader in this field.

The transition to the matrix structure[49] also had a profound impact on the culture and efficiency of project execution at NPOL. This fostered a culture of teamwork and innovation, where ideas are shared freely and decisions made collectively. This has not only improved the quality of projects but has increased efficiency, as resources are allocated more effectively and project timelines are met more consistently. The broad timelines of the various projects executed in this field are as follows: -

Ser	Sonars	Sanction	Completed
1.	APSOH	1976	1983
2.	HUMVAD	1985	1990
3.	HUMSA	1986	1992
4.	HUMSA NG	2012	2014
5.	HUMSA UG	2017	2018
6.	Panchendriya	1992	1998
7.	USHUS	2001	2011

[48] Dr. Anant Narayanan, (08 February 2024), *Email Response.*

[49] A matrix organization is a structure where employees report to both functional and project managers, creating dual lines of authority. This allows for specialization in functions and projects, promoting flexibility and cross-functional collaboration.

Addressing the Critical Issue

Success does not come easy and the progress of APSOH wasn't one without several hurdles. In its early stages, the Naval Physical and Oceanographic Laboratory (NPOL) played a crucial role in developing small gadgets such as Expandable Bathy Thermograph (XBT), Sonar Ray Plot (SRP), and Towed Torpedo Decoy (TOTED), and was actively involved in transducer repair until the 1970s. During that period, electronics in the country were still in its infancy. To propel advancements in sonar technology using microprocessors and solid-state devices, NPOL recognised the need for new engineering talent. This led to a significant recruitment drive through the UPSC, bringing in fresh minds from engineering colleges.

The development and production of an intricate 12-cabinet system of APSOH marked uncharted territory for NPOL and all DRDO Labs to venture into. Despite lacking experience in the intricacies of inducting such a system into the Navy, civilian scientists surpassed expectations at every stage. The process of technology transfer to a factory on such a massive scale was unfamiliar to both NPOL and BEL, it had its share of occasional disagreements and disputes, especially those concerning the discrepancies in incentives during outstation travels and installations.

Professional differences among the Naval officers, especially between Paulraj and his colleagues at NPOL and Captain Venkatesh and Captain Prabhalla at BEL, significantly complicated the scenario. At times senior naval officers had to step in to prevent brinkmanship and salvage the project. Additionally, NPOL scientists faced challenges in their interactions with naval personnel in dockyards and ships during this period. Dr Anant Narayan mentions that the *"Indian Navy's lack of familiarity with local talent in Science and Technology made it challenging for scientists, leading to feelings of disapproval and difficulties at certain stages. Scientists at times had to stay onboard refit ship, INS Mysore or Krishna to name a few, for extended periods due to budget issues and constraints of accommodation".*[50]

Such experiences laid the foundation for creating forums and platforms for discussion, review and modification of R&D projects. NPOL scientists are widely respected and extensively interact with the Indian Navy and M/s BEL, a sharp contrast to those days when

[50]Dr Anant Narayanan, Op cit.

their contributions to Anti-Submarine Warfare technology were met with scepticism. This narrative firmly captures the transformative journey of NPOL, confidently navigating through challenges and ultimately earning respect for their pioneering work in sonar technology in collaboration with the Indian Navy. As an acknowledgement of many personnel involved with the project, a detailed list of names involved in the APSOH project is brought out in Chapter 10.

Evolution of the Transducer Development

At the heart of a Sonar is a transducer, the device that converts electrical energy into mechanical energy and vice versa through the use of various natural and man-made materials that exhibit piezoelectric or magnetostrictive properties. Before the APSOH project, NPOL's role was largely confined to repairing faulty transducers. However, the manufacturing and configuration of the Transducer for sonar was a niche activity. The APSOH Sonar used an imported British-made transducer[51] (the radiating element which is the equivalent of a radar antenna). The Indigenisation of the transducer was, therefore the need of the hour.

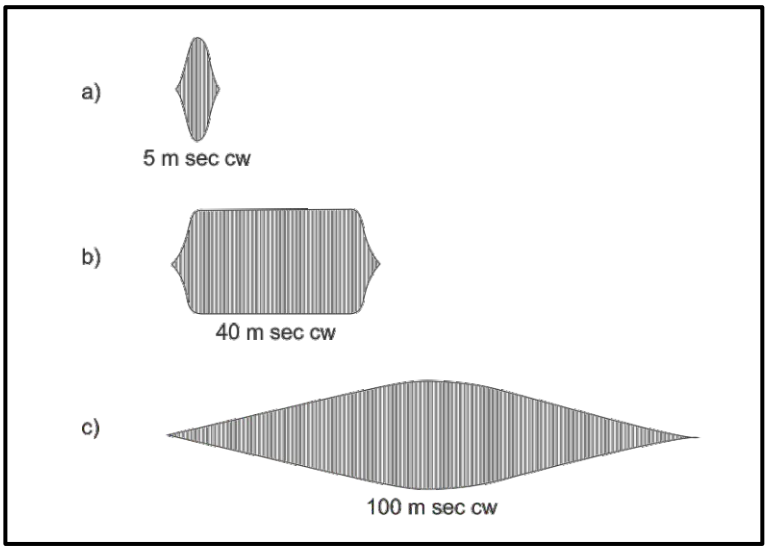
The Workshop of Vajra Rubbers, Thrissur, Kerala

The success of APSOH instilled credence in NPOL to not only develop transducers but also transfer the technology to the industry. This led to the indigenous transducer development catering to the diverse needs of the Navy across various projects. Vajra

[51] S Krishnan, S Prabhala, V K Koshy, *Inside the Solid State: The Story of Bharat Electronics*, Westland, Bengaluru, 2014, p.324.

Rubbers, Thrissur, Kerala were the indigenous manufacturers who started developing transducers and are still one of the main companies as on date.

The indigenous transducer could function optimally at two frequencies. To enhance the sonar's ability to detect targets, the design introduced five different signal transmission modes, marking a significant technological advancement. Previously, the Indian Navy sonars had only one mode of transmission. Additionally, the system offered various pulse lengths, from short bursts to longer signals, allowing the sonar to adapt to different conditions, whether in coastal or deep waters, by selecting the most suitable mode and signal length for each scenario.



A pictorial description of different waveforms

Beyond operational advantages, indigenisation signifies a commitment to cost efficiency, strategic adaptability and increased security by reducing dependency on foreign technology. In the words of Dr Anant Narayanan, Ex-Director of NPOL *"Successful integration of NPOL transducer array demonstrated Indigenous technological capabilities and positively contributing to autonomy in critical defence technologies".*[52]

[52]Dr Anant Narayanan, (06 February 2024), *Email response*.

APSOH Transducer Array

NPOL's expertise extended to designing transducers capable of withstanding high pressure, particularly vital for submarine applications. The establishment of test facilities[53] in the country further bolstered India's self-sufficiency in underwater transducers. Additionally, reliability studies conducted by NPOL significantly enhanced the longevity and performance of these crucial naval components. The transducers were optimised for Indian conditions, and thus resulted in achieving improved performance.

Indigenous Bow-Mounted Dome Undergoing Acoustic Tests at NPOL[54]

Breakthrough with the Induction of INS Sagaradhwani

[53]Various Test facilities including automatic test beds were created at BEL and NPOL which drastically reduced the testing time which enhanced R & D and production.

[54]ASW Seminar 2022 Compendium, 20 September 2022, p.48.

The need for a devoted Marine Acoustic Research Ship (MARS) was another visionary conception that came to light during the trajectory of the development of the formative sonars. The vessel would provide NPOL scientists with the much-needed flexibility to go to sea and undertake devoted marine acoustic research, thus INS Sagardhwani was conceptualised in the 1980s. Thereafter, a hull form of the then Sandhayak Class survey vessel Sagardhwani was launched in May 1991.

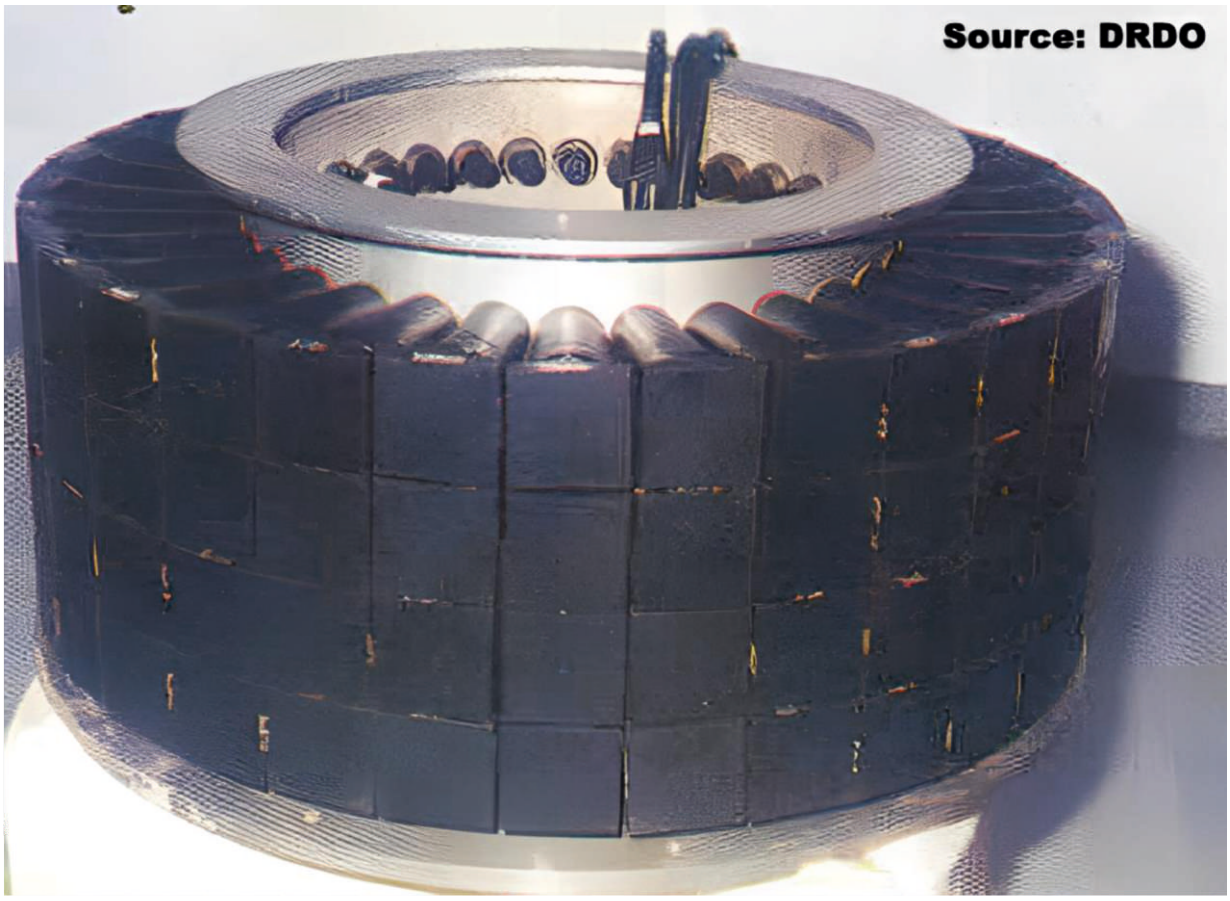
NPOL's initiative to acquire its research vessel marked a significant moment in its quest for enhanced acoustic measurements and the development of acoustic propagation models for sonar range predictions such as PROSPER. This proved to be invaluable during the sea trials of subsequently developed sonar systems. Demonstrations showcasing the relationship between range accuracy and hydrological conditions, in conjunction with NPOL's Sonar Ray Plot (SRP) models, led to a deeper understanding of underwater acoustics among Anti-Submarine Warfare (ASW) personnel.

INS Sagardhwani, NPOLs Marine Acoustic Research Ship (MARS)

Advancing Naval Capabilities.

NPOL in collaboration with the Indian Navy has developed several ship-fit sonars, including HUMVAD, a variable depth sonar; HUMSA, an advanced version of APSOH; HUMSA New Generation, a more powerful iteration of HUMSA; HUMSA Upgrade, a compact 3-cabinet version of HUMSA; ABHAY, designed for shallow water crafts; PANCHENDRIYA for the Foxtrot class (1998); sonar for the Sindhu class (2005) and UWT (Under Water Telephone), a stand-alone version. These sonars are designed to meet different naval requirements, from shallow-water operations to deep-sea surveillance; for ships and submarines and to detect in varied environmental conditions.

The NPOL along with BEL has delivered sonar systems worth more than Rs. 4000 Cr, highlighting the economic significance of its technological advancements. NPOL's success in developing and transferring technology to the industry has made India self-sufficient in the field of underwater transducers, including the test facilities for their performance established in the country.



Transducer of HUMSA

In the story of Indigenous sensor development, the Indian Navy and NPOL played a crucial role in driving rapid progress. Their close collaboration through rigorous trials and hands-on involvement, provided key insights and accelerated the growth of technologies like APSOH. This partnership was instrumental in advancing the indigenisation of modern sensors, significantly boosting India's defence capabilities.[55] With the success of APSOH on surface platforms, the submarines felt the need for the indigenisation of their sonars. The next chapter illustrates the feat of the Indian Navy submarines in this process.

DID YOU KNOW?

NPOL campus was moved from the Naval Base, Wellington Island where it stayed for 8 years to Trikkakara, 14 km away.

[55] Dr Anant Narayanan, Op cit.

Call Of The Dolphins

CHAPTER 7

Chapter - 7

Call of the Dolphins

The achievements of the Indian Navy for the successful development of Hull Mounted Sonars like APSOH and HUMSA for her warships fuelled the fire of the quest for developing indigenous Sonar systems for our submarines. This marked a significant stride towards self-reliance and technological pursuit towards designing an indigenous Sonar for the Indian Navy submarines. Among these ground-breaking achievements were the Panchendriya and USHUS sonar systems, designed specifically for Russian-origin Indian submarines, showcasing the nation's capability to innovate and engineer sophisticated defence solutions across multiple domains.

Panchendriya Sonar fitted onboard INS Karanj (S21)[56]

Panchendriya – Quest for a Submarine Sonar

The development of an indigenous sonar for Indian submarines began with a vision aimed at equipping them with advanced detection capabilities and reducing reliance on foreign suppliers. The inception of the project dates back to the early 1990s when the Indian

[56]Photo Courtesy – Submarine History Museum, INS Virbahu.

Navy identified the need for advanced sonar systems to equip its growing fleet of submarines[57]. The endeavour commenced with the development of Panchendriya[58] - the maiden indigenous sonar suite for submarines. Panchendriya was an experimental sonar suite and was built for Foxtrot class submarines, led by the NPOL. The resounding success of Panchendriya paved the way for further advanced submarine sonars in the following years.

In the wake of the collapse of the Soviet Union in the late 1980s, the Indian Navy took the initiative to develop indigenous sonar for our submarines. *"The project was proposed in the early 1990s and was completely driven ahead by the Indian Navy"*[59]. To realize this ambitious project, NPOL collaborated closely with the Naval Science and Technological Laboratory (NSTL), which focused on developing the Fire Control System (FCS) to complement the sonar system. This collaborative effort ensured seamless integration between the detection and targeting capabilities of the submarine, thereby enhancing its overall combat effectiveness.

In their pursuit of excellence, Indian scientists embarked on knowledge-sharing missions to Germany in 1989, where they studied the CSU 90-1 sonar system used in Type 209 submarines[60]. This international collaboration provided invaluable insights into the design, implementation, and operational aspects of advanced sonar technology, laying the foundation for indigenous innovation. The visit to Germany inspired the development team to implement the configuration of a Sonar Suite instead of a standalone sonar like the existing Russian-origin system. Panchendriya, as the name meant, was designed and developed to be a suite of five different sonars[61]. With renewed zeal, the development of engineering models and factory acceptance trials of Panchendriya Sonar Suite was successfully completed in 1994. The entire wet end and onboard electronics of MG 200 were to be completely replaced with Panchendriya. Cdr Nathan, the project manager appointed at NPOL liaised between the Indian Navy and other agencies for a seamless process of development and subsequently, installation.

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[57]Vice Admiral GM Hiranandani (Retd), *Transition to Guardianship*, Naval Headquarters, New Delhi, 2009, p.112.

[58]Transl Sanskrit – Five Senses.

[59]Payal sonar suite is an advanced integrated sonar system fitted onboard INS Arihant (later upgraded to Payal NG).

[60]Dr. Vijayan Pillai, Interview, Lt Cdr SN Avinash, 30 March 2024.

[61]Type 209 is a class of diesel-attack submarines developed by Howaldtswerke-Deutsche Werft of Germany. Indian Navy inducted four such submarines namely *Shishumar* class since 1986.

Sonar Dome Outfit – Panchendriya Sonar[62]

The journey towards indigenous sonar development for the submarines was not devoid of its share of challenges. One of the key hurdles faced by the project team was the local manufacturing of critical components, including transducer technology. Recognizing the importance of this aspect, collaboration with Russian experts facilitated crucial advancements in transducer technology, essential for enhancing detection capabilities in Indian submarines[63]. Indian companies like KELTRON[64] played a pivotal role in manufacturing transducer arrays, thereby contributing to the localisation of critical components and reducing dependence on foreign suppliers[65]. Philip C George (fondly called PC by his peers), the then Project Director, and his team from NPOL along with the crew of INS Karanj spent several days in the dry dock with no concern for personal comfort and total devotion to the task at hand[66].

The installation of the first Indigenous submarine sonar system onboard INS Karanj in 1998, marked a historic milestone in India's naval technology landscape[67]. The installation was followed by several days at sea for the trials of the system. The biggest challenge faced during the sea trials was that of self-noise saturation – since the

[62]Five Sonars of Panchendriya: Passive Surveillance Sonar, Active Sonar, Intercept Sonar, Underwater Communication System and Passive Ranging Sonar.

[63]Photo Courtesy – Kursura Submarine Museum, INS Satavahana History Cell Archives.

[64]Dr. Anantha Narayanan, Interview, Lt Cdr Nagarjun NN, 18 January 2024.

[65]KELTRON – Kerala State Electronics Development Corporation Limited is a Kerala state owned electronic enterprise and is a major production agency for providing sonar transducers for the Indian Navy.

[66]Vice Admiral GM Hiranandani (Retd), *Transition to Guardianship*, Naval Headquarters, New Delhi, 2009, p.179.

[67]Dr. Vijayan Pillai, Ex Director NPOL, Interview, Lt Cdr SN Avinash, 30 March 2024. PC George was the Project Director for Panchendriya from 1991 to 1996, due to health issues he was later replaced by Dr. Anantha Narayanan.

performance of the sonar could only be assessed when the submarine was dived, several new sources of noise[68] were detected and localising each of them was a learning curve for the NPOL team. During the trials, the sonar was able to pick up a Rajput class destroyer in passive search at extended ranges, which was a noteworthy accomplishment. It was a commendable feat for the first-of-its-kind prototype.

An interesting anecdote during the sea trials of Panchendriya sonar onboard INS Karanj deserves a mention. Mr. Vijayan Pillai, a greenhorn scientist from NPOL[69], and his team onboard INS Karanj were racking their brains when they noticed continuous interference on the sonar display and audio but were unable to identify it. When Dr Pillai informed the same to Cdr Aspi Cawasji, the then Commanding Officer of the boat, the CO smiled earnestly and replied, *"Congratulations, our sonar is working. It is picking up our echo sounder".*[70]

The successful integration of the Panchendriya sonar system demonstrated India's growing competence in underwater sensor technology and set the stage for further advancements in indigenous sonar development. Panchendriya sonar was far more advanced than the previous MG 200 with features like Passive Ranging, Surfacing Mode, and Intercept Sonar, whose vestiges would be integrated into Payal and USHUS sonars. It was also for the first time an Indian submarine was equipped with a waterfall display format instead of an A-scope display, something which our submariners were accustomed to having operated the MG 200. For developing the maiden indigenous sonar for Indian Submarines, the Panchendriya Project Team of NPOL was presented with the Agni Award for Excellence in Self-Reliance in 1998, by the then Prime Minister Shri Atal Bihari Vajpayee.[71]

USHUS – The Arrival of a New Dawn

With the increasing size of the Indian submarine fleet and the time-tested reliability of Panchendriya there was increased confidence in inducting Indigenous advanced Sonar suite

[68]MoD Annual Report 1997-98*, https://mod.gov.in/documents/annualreport,* accessed on 15 March 24.

[69]EMI/EMC, Action of hydroplanes, hydraulic pumps and other systems of submarine were major sources of noise interfering with the sonar. (Dr. Vijayan Pillai, Interview, Lt Cdr SN Avinash, 30 March 2024).

[70]Dr. Vijayan Pillai would later become Project Director for Sonar USHUS, Director of NPOL and Technical Director of KELTRON.

[71]Dr. Vijayan Pillai, Interview, Lt Cdr SN Avinash, 30 March 2024.

for the *Sindhughosh* class of submarines[72]. The Russian sonars originally fitted on these boats performed exceedingly well in the cold undersea environment of the White & Barents Seas but performed sub optimally in the Indian Waters. Further, after the collapse of the Soviet Union, sourcing spare parts became a strenuous task for the Indian Navy. Therefore, an indigenous integrated submarine sonar system for the *Sindhughosh* class submarines was required to replace the existing Russian MGK 400 and MGK 519 sonars. Thus, began the saga of next generation of submarine sonars..[73]

The USHUS project was sanctioned in the early 2000s and the design of the system was completed by 2003. The next two years saw the focussed efforts towards sonar fitment onboard INS Sindhughosh (in Severodvinsk, Russia) and INS Sindhudhvaj (in visakhapatnam, India). The intricate process of fitting USHUS on submarines was a testament to the concerted efforts of the Indian Navy operators, scientists from NPOL, and production agencies like BEL. Cdr Rath, an Indian Naval officer was appointed the project coordinator at NPOL who ensured efficient progress of installation and trials, liaising with various agencies and the Indian Navy. This collaborative approach ensured that the sonar system met the stringent requirements of the Indian Navy, thereby enhancing the overall operational readiness and effectiveness of its submarine fleet.

INS Sindhugosh, Refit in Russia, Photo Courtesy: Dr Vijayan Pillai

[72] DRDO Awards, *https://www.drdo.gov.in/drdo/labs-establishment/lab-awards/naval-physical-oceanographic-laboratory-npol* accessed on 29 March 2024.

[73] *Sindhughosh* class submarines are Kilo-class (877 EKM) diesel electric submarines of Indian Navy.

As Dr Vijayan Pillai fondly recalls, *"Installation and trials process for USHUS sonar was unique in several ways. In the wake of the Kargil conflict, the operational submarines were on patrol and the availability of a platform for trials was itself a challenge. Hence, the fitment and trials went hand in hand, when the NPOL team embarked on the submarine and trial results were evaluated at sea. Immediately upon returning to the harbour, necessary improvements were incorporated to the system. Having seen the Sonar performance first-hand, we could easily identify the problem areas and resolve them. Major contribution in developing the sonar would go to the Sonar Operators of INS Sindhughosh and INS Sindhudhvaj. The young men pro-actively monitored the Sonar round the clock and gave invaluable feedback. Those days were filled with adventure and a lot of learning".*[74] The evolution from Panchendriya to the USHUS sonar system represented a quantum leap in the indigenous naval technology.

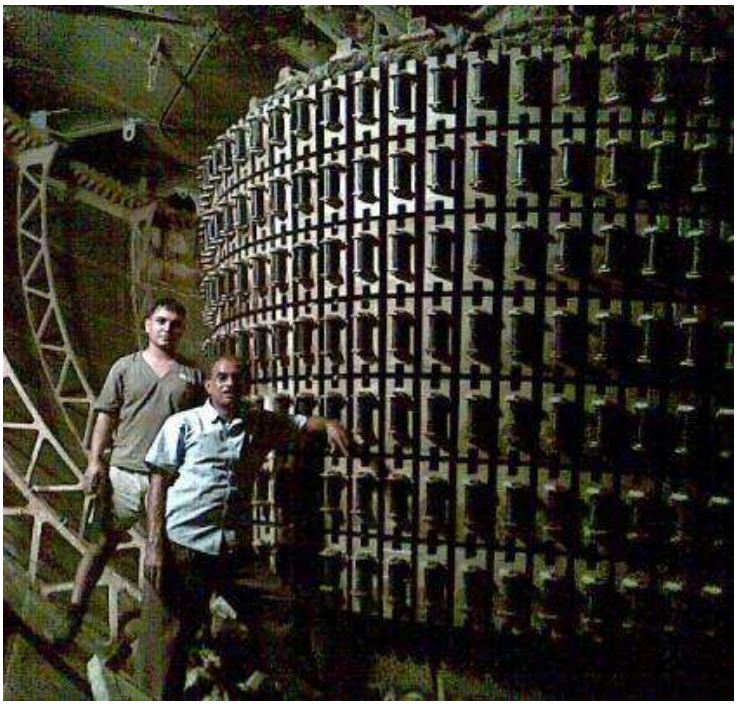
Trials onboard INS Sindhugosh

A major constraint faced during the trials of Panchendriya was power supply distribution and management. An innovative solution of the installation of isolation transformers and power amplifiers to resolve the issue was implemented. This pioneering method proved useful in developing USHUS Sonar. Completed in 2003, USHUS replaced Russian sonars on EKM submarines, highlighting India's commitment to self-sufficiency in defence technology. The successful integration of USHUS on board EKM submarines marked a significant milestone in India's journey towards indigenous submarine warfare capabilities. A special mention is warranted for Cdr Udaya Prakash of Naval Design Group, who single-handedly prepared the User Hand Book, Maintenance, and Technical Manuals for USHUS Sonar – which is one of the most exhaustive and detailed documents of the Indian

[74] Transl (Sanskrit) – Also transliterated as 'ushas' meaning New Dawn.

Naval systems.[75] As also officers and men of INS Sindhughosh[76], who actively involved themselves and expedited the fitment and trials of Sonar USHUS in Severodvinsk, Russia.

Trials and testing of USHUS showcased the meticulous attention to detail and pursuit of excellence by the project team. The NPOL team and the submarine crew of INS Sindhughosh and INS Sindhudhvaj energetically identified and rectified several major issues whilst at sea, and the Sonar displayed significantly better results by 2007. The successful completion of trials, including the ground-breaking achievement of conducting comprehensive tests within 72 hours onboard INS Sindhuvijay in 2011, underscored the efficacy of the indigenous sonar system in real-world scenarios. This demonstrated the reliability of USHUS in challenging maritime environments and further boosted the confidence of the Indian Navy in its Indigenous defence capabilities.



Sonar USHUS Trials – Corroborative and Concerted [77]

Another noteworthy fact during the development of Panchendriya and USHUS sonar systems was not just technical achievement but also served as a testament to gender inclusivity in scientific endeavours. The significant involvement of women scientists, comprising 60% of the project team, highlights the diverse talent pool driving innovation in

[75] Dr. Vijayan Pillai, Interview, Lt Cdr SN Avinash, 18 January 2024.
[76] Dr. Vijayan Pillai, Interview, Lt Cdr SN Avinash, 30 March 2024.
[77] Cdr KK Sunil, Electrical Officer, INS Sindhughosh. Vijayan Sonar EA, Cdr Rajashekar Submarine Overseeing Team.

defence technology. Their contributions not only enriched the project with their diverse perspectives but also exemplified the inclusivity ethos of India's scientific community.

The USHUS Sonar is a symbol of corroborative efforts between the Indian Navy, NPOL, and BEL, which resulted in the making of one of the finest sonars in the world at that time. This hands-on involvement ensured that the sonar systems were seamlessly integrated into the submarines and met the rigorous operational standards of the Indian Navy. For this ground-breaking achievement, the USHUS Team of NPOL was presented the Agni Award for Excellence in Self-Reliance in May 2008 by the then Prime Minister Shri Manmohan Singh.[78]

60% of USHUS Team comprised of Women[79]

The success of Panchendriya and USHUS sonar systems laid the groundwork for further advancements in indigenous defence technology. It also acted as a catalyst in the development of the next generation submarine sonar system. This ongoing commitment to innovation and self-reliance ensured that India remains at the forefront of naval technology, safeguarding its maritime interests and reinforcing national security in an ever-changing geopolitical landscape.

DID YOU KNOW?

Agni Award given by Ministry of Defence for exceptional innovation and excellence in defence technology and research, named after the Agni missile series.

[78] NPOL and BEL Scientists with the submariners onboard INS Sindhughosh and INS Sindhudhvaj. Photo Courtesy: Dr. Vijayan Pillai.

[79] DRDO Awards, *https://www.drdo.gov.in/drdo/labs-establishment/lab-awards/naval-physical-oceanographic-laboratory-npol* accessed on 29 March 2024.

During one of the meetings on USHUS in 2009, VAdm Ganesh Mahadevan, the then Chief of Material of Indian Navy reminded all the stakeholders that there is no NPOL team, BEL team or the Navy team. *"It is one team: Indian Team. And we shall work such"*.[80] The results proved that his words were followed in letter and spirit. The Indian Navy's decision to utilise INS Karanj as a test platform gave scientists complete freedom in the development of the Panchendriya sonar, which accentuates the need for a dedicated test platform for any R&D effort.

Agni Award for Excellence in Self-Reliance to USHUS Team, NPOL[81]

A befitting conclusion to this chapter would be an interesting and inspiring dialogue between the Late Dr APJ Abdul Kalam[82], who was the Principal Scientific Advisor and a young Vijayan Pillai during the Agni Award ceremony in 1999.

"Dr Kalam: You have done a great job. Who was your mentor for this project?
Dr Pillai: The Sonar operators of the Indian Navy were my mentors. It was with them and with their input we could accomplish this." [83]

[80] Dr. Vijayan Pillai, Interview, Lt Cdr SN Avinash, 15 February 2024. Photo Courtesy: Dr. Vijayan Pillai.
[81] Photo Courtesy: Dr. Vijayan Pillai, Technical Director, KELTRON.
[82] Ibid.
[83] Late Dr. APJ Abdul Kalam (15 October 1931 – 27 July 2015) served as the Chief Scientific Adviser to the Prime Minister from Jul 1992 to Dec 1999. He was later the President of India from 2002 – 2007.

Father Of Indian Sonar

CHAPTER 8

Chapter – 8

Father of Indian Sonars

Cmde (Dr) Arogyaswamy Paulraj, Padma Bhushan, AVSM (Retd)

The developmental journey of the pilot APSOH sonar gave an exponential leap to the Indian Navy, in the field of sonar technology. The success of APSOH sonar is a result of the collaborative spirit and efforts of scientists, naval officers, engineers, and many others associated with the project. Despite such concerted efforts from diverse civil and military agencies, it would be remiss not to acknowledge Cmde (Dr). Arogyaswami Paulraj's profound vision, resilience, and scientific acumen, undoubtedly mitigated what would have otherwise been a further challenging and laborious journey. An inquisitive Naval officer with a doctorate in Electrical Engineering, Paulraj is often referred to as the *'Father of Indian Sonars'* for his prominent contribution to the indigenous prowess of the Indian Navy in the field of sonar technology. Therefore, the narration of APSOH sonar's emergence in the Indian Navy would certainly be incomplete without mentioning his contributions to the conception, designing, development, and production of the APSOH sonar.

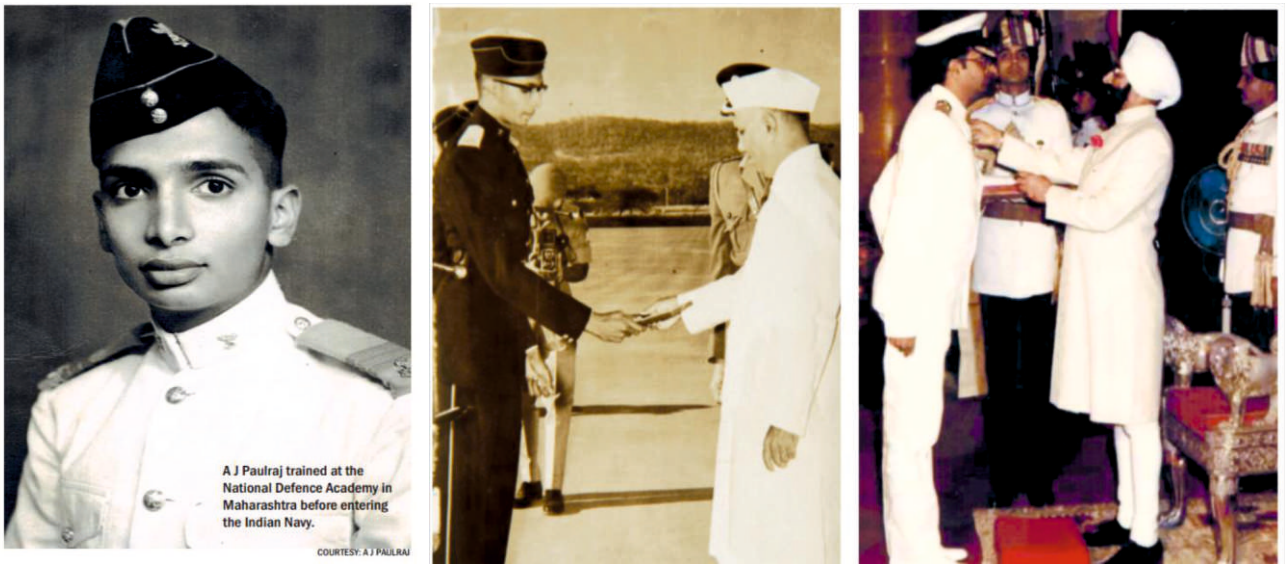
Early Life and the Indian Navy

Arogyaswami Paulraj was born on 14 April 1944, in Pollachi, Tamil Nadu, India. One of the six children of Sinappan Arogyaswami and his wife Rose. Paulraj completed his initial schooling at Montfort Boys High School in Yercaud, Tamil Nadu. During his schooling days, Paulraj often displayed his affinity for science and Physics in particular. At the age of fifteen, shortly after concluding his formative years in school, he was selected to undergo cadet training in the National Defence Academy (NDA), Khadakvasla. After completing his training, Presidents Gold Medal (PGM) awardee Cadet Paulraj, graduated from the portals of NDA and was commissioned into the Indian Navy in 1963.

Soon after passing out from NDA, science enthusiast Cadet Paulraj decided to join the Electrical branch of the Indian Navy and underwent a Bachelor of Engineering in Electrical Engineering from the Naval College of Engineering, Lonavala, India. This laid the foundation for his future achievements. In early 1969 Paulraj's passion for technology and innovation drove him to pursue higher studies, wherein he was selected for an MTech course at IIT (Delhi). Since he was an exception to the normal, Prof Indiresan from IIT, Delhi impressed with his work requested the Indian Navy and IIT to shift him to a PhD. An unseen norm in the apex institute of India at that time to permit a B.E student to pursue a PhD spoke volumes of his technical acumen. Whilst the approvals at IIT for such a warrior was easy, the Indian Navy took the decision at the apex level with Vice Admiral Krishnan, the then Vice Chief of Naval Staff giving in with a lot of persuasion.[84] He completed his PhD in 1973.

Paulraj's expertise in signal processing and deep understanding of sonar systems led to significant contributions in the field. One of his notable achievements was the development of a Modification Kit for the Sonar 170B, a British sonar system fitted on Indian frigates. This modification significantly improved the sonar's performance, showcasing Paulraj's innovative approach to solving complex engineering problems.

[84] Dr. Vijayan Pillai, Interview, Lt Cdr SN Avinash, 30 March 2024.



Middle A J Paulraj receives the Gold Medal from then Indian defense minister Y B Chavan at the National Defence Academy passing out parade in 1963 for ranking first in the Order of Merit in academic and service subjects. Right, he receives the Ati vishist Seva Medal of the Indian military in 1983 from Indian president Giani Zail Sigh.[85]

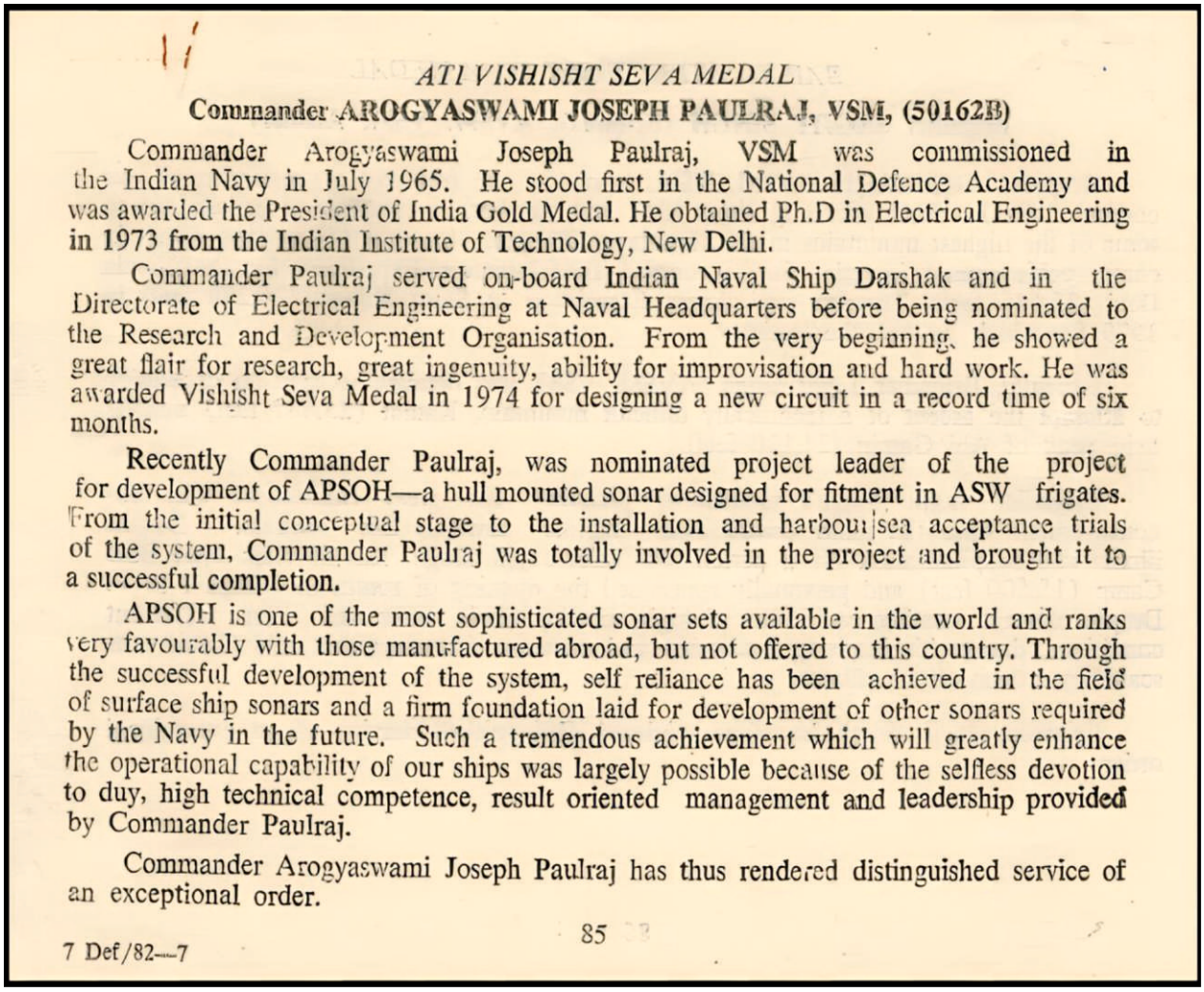
From January 1974 for eighteen months, he worked on signal processing on Admiralty Under-Water Establishment funded project at Loughborough University which gave him exposure to Europe's sonar industry and developing technology. His visits to Grasebys, Plessey and Thompson CSF made him realise that they had not really improved the sonars and that gave him the confidence to develop an indigenous sonar on his return in 1975.[86] Thus, in 1976, Paulraj took on a vital role in the development of the Advanced Panoramic Sonar Hull mounted at the Naval Physical and Oceanographic Laboratory. This project aimed to create a state-of-the-art Panoramic sonar system tailored for Indian tropical and hydrological conditions using Commercially off-the-shelf (COTS) processors. Paulraj's leadership and technical expertise were instrumental in the project's success. For his stellar contribution to the Indian Navy, Cmde (Dr) Arogyaswamy Paulraj was awarded the Vishisht Seva Medal in 1974 and the Ati Vishist Seva Medal in 1984.

DID YOU KNOW?

President Gold medal is awarded for the Best in overall merit in the Graduating Class at the National Defence Academy.

[85] VAdm Hiranandani (Retd), *Transition to Eminence*, Naval Headquarters, New Delhi, 2005, p.176.

[86] Photo Courtesy: Cmde (Dr) A Paulraj (Retd), (02 April 2024), *Email Response.*



ATI VISHISHT SEVA MEDAL

Commander AROGYASWAMI JOSEPH PAULRAJ, VSM, (50162B)

Commander Arogyaswami Joseph Paulraj, VSM was commissioned in the Indian Navy in July 1965. He stood first in the National Defence Academy and was awarded the President of India Gold Medal. He obtained Ph.D in Electrical Engineering in 1973 from the Indian Institute of Technology, New Delhi.

Commander Paulraj served on-board Indian Naval Ship Darshak and in the Directorate of Electrical Engineering at Naval Headquarters before being nominated to the Research and Development Organisation. From the very beginning, he showed a great flair for research, great ingenuity, ability for improvisation and hard work. He was awarded Vishisht Seva Medal in 1974 for designing a new circuit in a record time of six months.

Recently Commander Paulraj, was nominated project leader of the project for development of APSOH—a hull mounted sonar designed for fitment in ASW frigates. From the initial conceptual stage to the installation and harbour/sea acceptance trials of the system, Commander Paulraj was totally involved in the project and brought it to a successful completion.

APSOH is one of the most sophisticated sonar sets available in the world and ranks very favourably with those manufactured abroad, but not offered to this country. Through the successful development of the system, self reliance has been achieved in the field of surface ship sonars and a firm foundation laid for development of other sonars required by the Navy in the future. Such a tremendous achievement which will greatly enhance the operational capability of our ships was largely possible because of the selfless devotion to duy, high technical competence, result oriented management and leadership provided by Commander Paulraj.

Commander Arogyaswami Joseph Paulraj has thus rendered distinguished service of an exceptional order.

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7 Def/82—7

Citation for AVSM – Cdr A Paulraj[87]

Personal Experiences, Legacy and Impact

Paulraj's journey in sonar evolution was not devoid of challenges. He faced technical hurdles and constraints but was able to overcome them through his perseverance and ingenuity. His experiences in the Navy and at NPOL shaped his approach to engineering and innovation, emphasising the importance of collaboration and continuous learning. Paulraj's journey from the Indian Navy to becoming a pioneer in sonar technology serves as an inspiration to aspiring engineers and innovators, highlighting the significance of passion, dedication, and relentless pursuit of excellence in one's chosen field. Paulraj also served as the founding director for three major labs in India, the Centre for Artificial Intelligence and Robotics (CAIR) at Defence R&D Organization, the Central Research Laboratories (CRL) at Bharat Electronics and the Centre for Development of Advanced Computing (CDAC) at Dept

[87] VAdm Hiranandani (Retd), *Transition to Eminence*, Naval Headquarters, New Delhi, 2005, p.326.

of Electronics (as a co-founder). These labs are now significant contributors to India's vast R&D infrastructure.[88]

CAIR and LCA Programs

Cmde (Dr) A Paulraj played a key role in the development of the Centre for Artificial Intelligence and Robotics (CAIR) and the Light Combat Aircraft (LCA) program in India. CAIR, established in 1986, focuses on research and development in the field of Artificial Intelligence (AI) and Robotics for defence applications. Paulraj's involvement in CAIR contributed to the advancement of AI technologies for defence purposes, enhancing India's capabilities in this critical area. As part of the Light Combat Aircraft (LCA) program, he contributed to the development of communication and signal processing systems for the aircraft. These systems are crucial for ensuring effective communication and data processing in combat situations, enhancing the overall performance of the aircraft. Paulraj's work in CAIR and for LCA underscores his commitment to leveraging technology for defence purposes, highlighting his role in advancing India's capabilities in AI, robotics, and aerospace. Paulraj retired from the Indian Navy in 1991 at the rank of Commodore.

Life After the Navy- Wireless Communication Innovations

After retiring Paulraj embarked on a distinguished academic career, further establishing his reputation as a pioneer in the field of Wireless Communication. He joined Stanford University in 1992 as a professor in the Department of Electrical Engineering, where he continued his research in signal processing and communications. At Stanford, Paulraj's groundbreaking work in ***Multiple Antenna Technology***, known as MIMO (Multiple-Input Multiple-Output), revolutionised wireless communication. His research showed that by using multiple antennas at both the transmitter and receiver, it was possible to significantly increase data rates and improve the reliability of wireless communication systems. MIMO is the basis of present high-speed Wi-Fi, 4G, and 5G mobile networks which have revolutionised the lives of the entire world.[89] He has also authored two books and over 400 research publications and has 80 patents to his name.[90]

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[88] Photo Courtesy: Archives, INS Valsura.

[89] Biography of Cmde (Dr) Arogyaswamy Paulraj (Retd), *https://web.stanford.edu/~apaulraj/pdf/Brief-Bio.pdf* accessed on 24 March 2024.

[90] Arogyaswami Paulraj, an oral history conducted in 2022 by Michael Geselowitz, IEEE History Center, Piscataway, NJ USA.

Recognition and Awards

Cmde (Dr) A Paulraj (Retd) receiving Padma Bhushan from then President of India, Smt Pratibha Patil in 2010

Cmde (Dr) Arogyaswamy Paulraj received numerous awards and honours during his distinguished career. He was conferred the prestigious civil award - Padma Bhushan by the Government of India in in 2010[91] Paulraj's contributions to wireless communication have been widely recognised. He has been awarded the IEEE Alexander Graham Bell Medal in 2011 as well as the Marconi Prize, the highest honour in telecommunications research, in 2014. He was also a fellow of the Institute of Electrical and Electronics Engineers (IEEE) and a member of the U.S. National Academy of Engineering. He was inducted into the US Patent Trademark Office National Inventors Hall of Fame in 2018 and elected into the American Academy of Arts and Sciences (AAAS) in 2020. Cmde (Dr) Arogyaswamy Paulraj was then inducted into the Wireless Hall of Fame in 2022.

[91] Biography of Cmde (Dr) Arogyaswamy Paulraj (Retd), *https://web.stanford.edu/~apaulraj/pdf/Brief-Bio.pdf* accessed on 17 March 24.

IIT, Delhi- Hall of Fame[92]

Entrepreneurship and Industry Impact

In addition to his academic work, Paulraj has been involved in entrepreneurship and has co-founded Companies like Lospan Wireless for MIMO core technology (later acquired by Intel), and Beceem Communications for 4G chips (later acquired by Broadcom)[93], which have created a wireless technology ecosystem for manufacturing wireless devices. He also founded Rasa Networks (acquired by Aruba /HPE) for using AI tools in WiFi network analytics. Thus, his entrepreneur skill had a profound impact on the telecommunications industry, influencing the development of wireless communication standards and technologies. His work has inspired a new generation of engineers and researchers to push the boundaries of what is possible in wireless communication, ensuring that his legacy will endure for years to come.

[92] *Ibid.*
[93] *Ibid.*

While Paulraj's contributions were central in the success of APSOH, it was also shaped by the efforts of many others whose roles were crucial. The next chapter acknowledges and briefly mentions the contributions of these distinguished individuals who warrant special recognition.

DID YOU KNOW?

Wireless Hall of Fame an initiative of the Wireless History Foundation honours individuals and organizations for their groundbreaking contributions and innovations in wireless technology and communications.

Strongest Links

CHAPTER 9

Chapter- 9

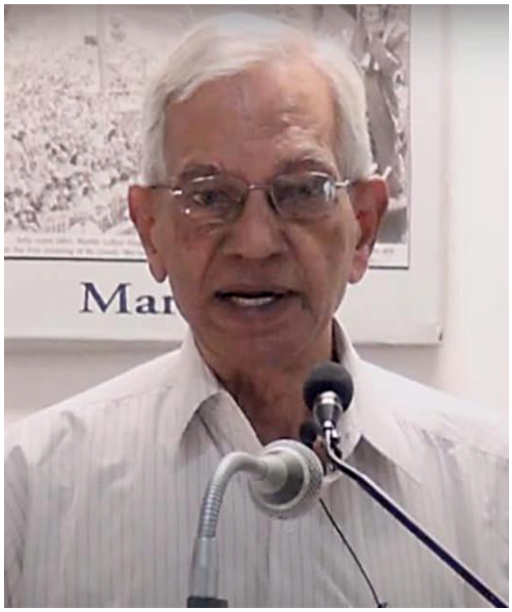
The Strongest Links

Admiral Ronald Lynsdale Pereira, PVSM, AVSM (Retd), (25 May 1923 - 14 October 1993) served as the 9th Chief of the Naval Staff from February 1979 to February 1982. A Gunnery Specialist, he commanded significant vessels like INS Delhi and INS Kuthar, and held prestigious appointments including Flag Officer Commanding Eastern Fleet and Flag Officer Commanding-in-Chief of the Western Naval Command. Admiral Pereira fondly called *Ronnie*, was a key figure in shaping the modern Indian Navy. In his key role as Director of Combat Policy & Tactics at Naval Headquarters, Delhi and thereafter as the CNS, he proactively steered the development of the APSOH Sonar, thereby enhancing the Navy's Anti-Submarine Warfare capability.

Vice Admiral Melville Raymond Schunker, PVSM, AVSM (Retd) (18 September 1924 - 04 January 2021) served as the 6th Vice Chief of the Naval Staff from 1980 to 1982. A Gunnery Specialist, he commissioned submarine tender ship INS Amba and held prestigious appointments including Flag Officer Commanding Western Fleet and Flag Officer Commanding-in-Chief of the Eastern Naval Command. Admiral Schunker as the VCNS headed the Steering Committee on APSOH development. He was a thorough professional and kept track of the project through periodic reviews and gave timely decisions to the stakeholders to ensure timely completion of the APSOH Project.

Admiral Vijay Singh Shekhawat, PVSM, AVSM, VrC, (Retd) born on 01 October 1936 was the 15th Chief of the Naval Staff of the Indian Navy from September 1993 to September 1996. A Submarine specialist he commanded the submarines Karanj and Kalveri as also INS Himgiri. He also tenanted key appointments like Assistant Chief of Naval Staff (Operations) and Flag Officer Commanding-in-Chief of the Eastern Naval Command. He was at the helm of INS Himgiri during the installation of India's first indigenous sonar APSOH in 1981-82. His invaluable contribution in liaising with multiple agencies related to the project ensured its timely fitment followed by extensive trials at sea.

VAdm SC Suresh Bangara PVSM, AVSM (Retd) joined the Indian Navy in 1966. An Anti-Submarine Warfare specialist, he commanded INS Taragiri, and INS Sidhudurg and held a prestigious appointment as Commandant at, the National Defence Academy and culminated his naval tenure as the Flag Officer Commanding-in-Chief of the Southern Naval Command. An ASW specialist, the admiral played a key role in the journey of the APSOH sonar when he was directly associated with the APSOH project whilst posted as Deputy Director of Combat Policy & Tactics (DCPT) at Naval Headquarters, Delhi. Throughout his service career, he exhibited a flair for scholarly discourse, enriching the naval narrative through influential contributions to various publications. The admiral was instrumental in publicising the glorious journey of APSOH sonar and highlighting its pioneering achievements, and also being the mentor of this document.



Captain S Prabhala (Retd), a distinguished Electrical Officer of the Indian Navy. Post-retirement, he joined Bharat Electronics Limited and was Chairman and Managing Director from 1995 to 2000. He played an important role in the production and fitment of the APSOH system onboard the Indian Navy ships, thus significantly enhancing India's naval capabilities. Leading the APSOH project from BEL, he collaborated with NPOL and the Indian Navy ensuring rigorous testing and successful installation onboard many Indian Navy ships. His dedication to advancing naval technology exemplified his commitment to serving the nation, leaving a lasting impact on India's naval defence capabilities.

Dr Devanatha Srinivasan's tenure at the Naval Physical & Oceanographic Laboratory (NPOL), began in 1957 was marked by transformative leadership and visionary initiatives. He rose to the position of Head of NPOL in 1983. Under his guidance, NPOL underwent a significant evolution by setting up the Naval Science and Technological Laboratory (NSTL) in Visakhapatnam in 1983, further expanding its scope and impact. Dr Srinivasan's most notable achievement was his instrumental role in initiating the development of the Advanced Panoramic Sonar Hull (APSOH) system in the mid-1970s. Recognising the critical importance of advanced sonar technology for naval operations, he led the APSOH project from its inception in 1977. Through diligent planning and fostering an environment conducive to innovation, Dr Srinivasan facilitated the rapid progress of the APSOH system, which was successfully equipped on INS Himgiri by early 1982. His collaborative efforts with Cmde (Dr) Arogyaswamy Paulraj, the then Project Director, exemplified exceptional leadership and cooperation, contributing significantly to the project's success.

Dr Anantha Narayanan graduated from IIT Madras in 1975 with a BTech degree in Electronics Engineering and joined NPOL in 1978, he enhanced the Indian Navy's Anti-Submarine Warfare (ASW) capabilities, notably contributing to the APSOH ship sonar project alongside Cmde (Dr) Arogyaswamy Paulraj. Thereafter, he oversaw the production of India's first submarine sonar, Panchendriya, from 1992 to 1995. Appointed as Director of NPOL in 2007, he facilitated the timely completion of numerous projects, focusing on flawless technology transfer to the Indian Navy. Under his leadership, projects such as the HUMSA NG ship sonar, Mareech Anti-Torpedo Defence System and USHUS submarine sonar were successfully completed and inducted into the Indian Navy. His contributions earned him the DRDO Technology Management Award in 2014.

Dr S Vijayan Pillai, a former airman in the Indian Air Force, joined DRDO in 1989 as a Scientist B, he progressed to the esteemed position of Director of the Naval Physical and Oceanographic Laboratory from 2019 to 2023, he brought extensive expertise in integrated circuits and electronics, with an MTech from IIT, Kharagpur and a PhD from Cochin University of Science & Technology. Throughout his tenure, he was known for prioritising user perspectives and end-use environments in system design. His invaluable achievement in the installation of USHUS systems on Indian submarines was highly appreciated. With over 36 years of experience in submarine and naval ship operations, including extensive sailing time and leadership in sonar experiments, Dr Pillai has earned accolades such as the Agni Award of Excellence. Currently, he is appointed as Technical Director for Defense Projects & Spinoffs at Keltron.

Collaborative Forces

CHAPTER 10

Chapter 10

Collaborative Forces

Key Personnel of the Indian Navy Associated with Project APSOH[94]

Ser	Name	Area of work
1.	Adm RL Pereira	Chief of the Naval Staff
2.	VAdm Melville Raymond Schunker	Vice Chief of the Naval Staff
3.	Cmde A R Khandekar	Director Weapon Equipment
4.	Capt Ravi Kohli	DNRD
5.	Cdr P K Sinha	Deputy Director Weapon Equipment
6.	Cdr SCS Bangara	Deputy Director Combat Policy & Tactics (TAS), Member Secretary Steering Committee APSOH
7.	Cdr A Paulraj	Project Director
8.	Cdr George Kuruvilla Sri S Srinivasan	Engineering and Thermal Design, Cabinets,
9.	Cmde J R Patel Cmde KSK Prasad	Trial team
10.	Capt Pramod Datey	Installation-in-charge
11.	Lt Naresh Kumar Mr John P Cherian	PCB Testing Simulation
12.	Cdr Champion	Naval Dockyard (Mumbai)
13.	Lt Cdr NR Ravi, Lt Cdr Reddy Lt Cdr Badana, Lt Cdr Mohan Philip, Lt Alok Kapoor	Sonar Evaluation and Documentation
14.	Cdr VS Shekhawat	Commanding Officer INS Himgiri

[94] CNR Report 2010, *https://www.crn.com/news/networking/227701291/broadcom-snaps-up-4g-chip-maker-beceem* accessed on 21 March 2024.

Key Personnel from NPOL Associated with Project APSOH

Ser	Name	Area of Work
1.	Dr D Sreenivasan	Lab Director
2.	Mr. V Chander, Mr GK Sadanandan, Mr Kannan	Signal processing
3.	Mr SP Pillai	Transmission Controller
4.	Mr. Philip C George, Mr Padmanabhan, Mr CK Joseph/ Mr Mukundan	Power Amplifiers
5.	Mr. K Vijayakumar, Mr PT George	Passive Sonar Signal Noise Source
6.	Mr. K Kumar, Mr R Kanakarajan	Bus system
7.	Mr. RC Agarwal Mr. Joseph Dayalan Mr. Subramaniam	Display system
8.	Mr. Lal Mohan	Fault Detection Fault Localisation
9.	Mr. A Unnikrishnan	Audio
10.	Mr. DK Chattopadhyaya, Jaya Mr. Sreedharan, Mr Varughese Chacko	System Keyboard
11.	Dr Anantha Narayanan. S	Frame Grab (FRAB), External System Interface
12.	Mr. T Hariharan, Mr PS Aravindakshan	Material Procurement
13.	Mr. Madhurakani M	
14.	Mr. T Sreeprakash	Simulation
15.	Mr. S John P Cherian	

Key Personnel from BEL[95] Associated with Project APSOH

Ser	Personnel Involved	Area of Work
1.	Capt S Prabhalla (Retd) Cdr R Venkatesh (Retd)	Project Heads
2.	Mr S K Singh	Project Manager
3.	Mr. Mohanram, Mr. Chandrasekar, Mr. Venugopal, Mr. K R Suresh, Mrs. Padmaja, Mr VKK Nair	Design & Engineering Team
4.	Mr. S R Ramarao, Mr. N. Suresh, Mr. Ananthamurthy, Mr. Ellamathy, Mr. Nandakumar, Mr. Venkatram, Mrs. Daisy George	Installation and Trial Team

Key Agencies Associated with Project APSOH

Ser	Major Tasks Involved	Organization Responsible
1.	Overall-in-Charge	Naval Headquarters/ Chief of Naval Staff
2.	Policy making, Approvals, Funding, reporting	Naval Headquarters / DRDO Headquarters
3.	Prototype development, Support for firmware development	PSI Systems, Bangalore
4.	Development of transducers	Vajra Rubbers
5.	Production Agency	Bharat Electronics Ltd, Bangalore
6.	Installation and Trial support:	Naval Headquarters, Western Naval Command, Mazagon Dockyard Ltd
7.	Inspection and Quality Assurance	Chief Quality Assurance Establishment, Bangalore
8.	Documentation	Tata Consultancy Services, Bombay

[95] Dr. Anant Narayanan, (16 January 2024), *Email Response.*

[97] Mr Ellappan, APSOH Installation and Trials team, BEL interviewed by Lt Cdr SN Avinash on 02 April 2024

Elma Searcher

The journey to conquer, our deep blue Ocean
Navy was determined, to overcome 'Biased Notion'

Learning from the past, pride and honour to save
Indian Navy heard, 'Whispers Beneath the Wave'

In Pursuit for excellence, had no time to lament
Designer, developer together, 'Harmonised their Talent'

Toil and labour of team mates, over days and months
Scripted golden journey, the 'Tale of Sonar Triumph'

Proven on test bed, fitting onboard was next assignment
Trials on Himgiri, had her 'Maiden Accomplishment'

To impart quality training, Schools were the suitors
Plans were drawn out with, 'Simulators for Tutors'

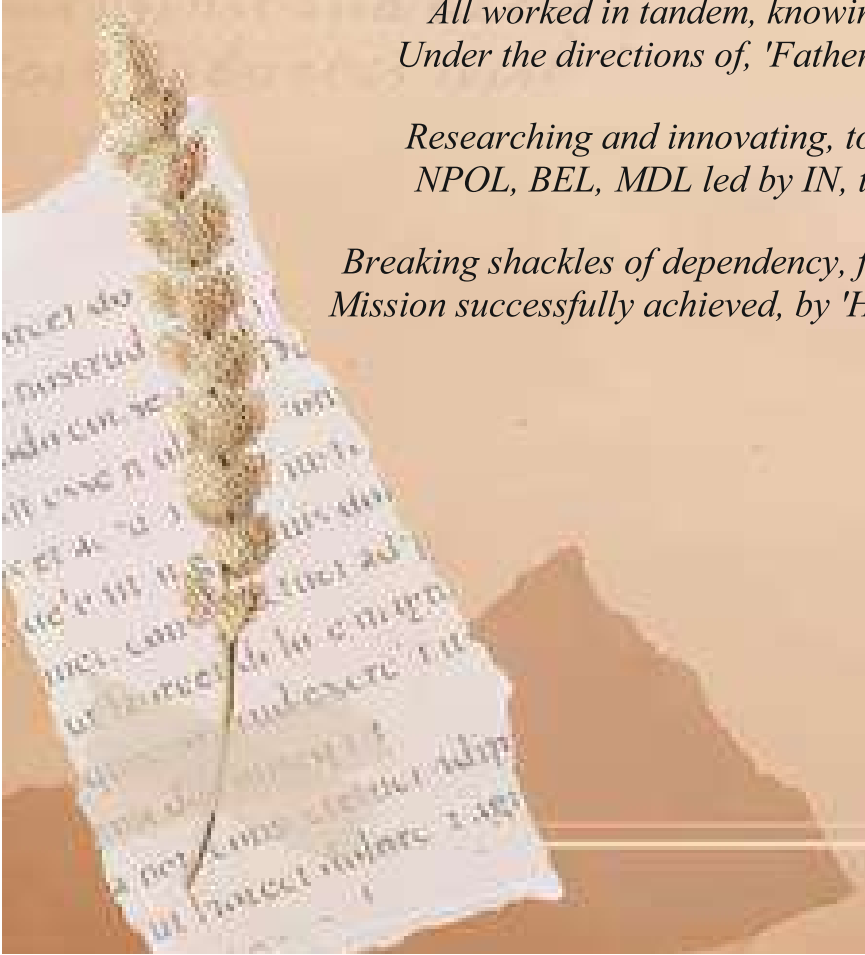
Whenever there was question, doubt or reason
Dr Paulraj was always there, as the 'Guiding Beacon'

Ship's sonar minted, had new feat destine
Set the ball in motion, for 'Call of the Dolphin'

All worked in tandem, knowing need of the hour
Under the directions of, 'Father of the Indian Sonar'

Researching and innovating, to overcome the kinks
NPOL, BEL, MDL led by IN, the 'Strongest Links'

Breaking shackles of dependency, for years that was visible
Mission successfully achieved, by 'Harmonising the Decibels'



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