Chapter -11

Deepwater Magnetic Range

Introduction

The establishment of a Deepwater Magnetic Range (DMR) is envisaged as a strategic capability enhancement for the Indian Navy, aimed at enabling high-precision magnetic signature measurement, stealth verification, and degaussing system calibration. In the evolving paradigm of modern naval warfare—where platform survivability is increasingly dictated by stealth and signature management—the capability to accurately measure, analyze, and minimize magnetic emissions constitutes a critical determinant of mission success.

Magnetic silencing continues to remain one of the most effective countermeasures against magnetic influence mines, non-contact fuzes, and undersea surveillance systems, thereby contributing directly to operational security and survivability of naval platforms.

The proposed DMR is intended to serve as a dedicated test and calibration facility capable of precise detection, quantification, and characterization of magnetic fields generated by surface ships and submarines. The facility shall cater to both fleet operational requirements—including magnetic ranging and degaussing verification—and research-oriented activities related to signature reduction technologies, field modeling, and system-level optimization.

While the DMR is designed to leverage the existing subsea infrastructure, particularly the Primary Hydrophone Junction Box (HPJB), direct interfacing with the hydrophone array is not technically viable. The existing hydrophone grid, with a typical spacing of approximately 2.5 km, is optimized for acoustic localization and does not provide the spatial resolution required to capture the magnetic field beam width of naval platforms. For accurate and reliable magnetic signature assessment, it is essential that the sensor array span the full beam width of the vessel under test, ensuring complete lateral field coverage and minimizing measurement uncertainty.

Accordingly, it is proposed to establish a dedicated optical fiber communication link from the HPJB node to a newly deployed magnetic sensor array, forming an independent but interfaced subsystem within the existing underwater test network. The magnetic sensors shall be mounted individually on the seabed using Triangular Reinforced Base Mount (TRBM) units fabricated from non-magnetic concrete sinkers, ensuring structural stability, precise alignment, and minimal magnetic interference from mounting components.

Each sensor shall be azimuthally aligned along the North–South axis, facilitating magnetic ranging in multiple vessel headings—North–South, East–West, and intermediate 45° orientations—to generate comprehensive magnetic signature profiles under varied heading conditions. This controlled orientation will provide repeatable, high-fidelity data essential for magnetic signature modeling, stealth performance benchmarking, and degaussing system validation.

This hybrid integration approach—utilizing the HPJB node for power and data transmission while deploying an independent magnetic sensor subsystem—offers both operational flexibility and cost efficiency. It establishes a modular and scalable architecture for the DMR, capable of future expansion to accommodate advanced sensor technologies, autonomous ranging operations, and fleet-wide magnetic management programs.

In essence, the Deepwater Magnetic Range will serve as a cornerstone in India's pursuit of self-reliant naval stealth capability and underwater signature control excellence, directly supporting the long-term objectives of indigenization, technological superiority, and maritime security.

2. Project Objectives

The establishment of the Deepwater Magnetic Range (DMR) is envisaged to provide the Indian Navy with a strategic and indigenous capability for precision magnetic signature measurement, degaussing system calibration, and stealth optimization of both surface and subsurface platforms.

This facility will serve as a national benchmark for magnetic ranging, degaussing verification, and stealth research, enabling the Navy to systematically measure, analyze, and manage magnetic emissions across the fleet.

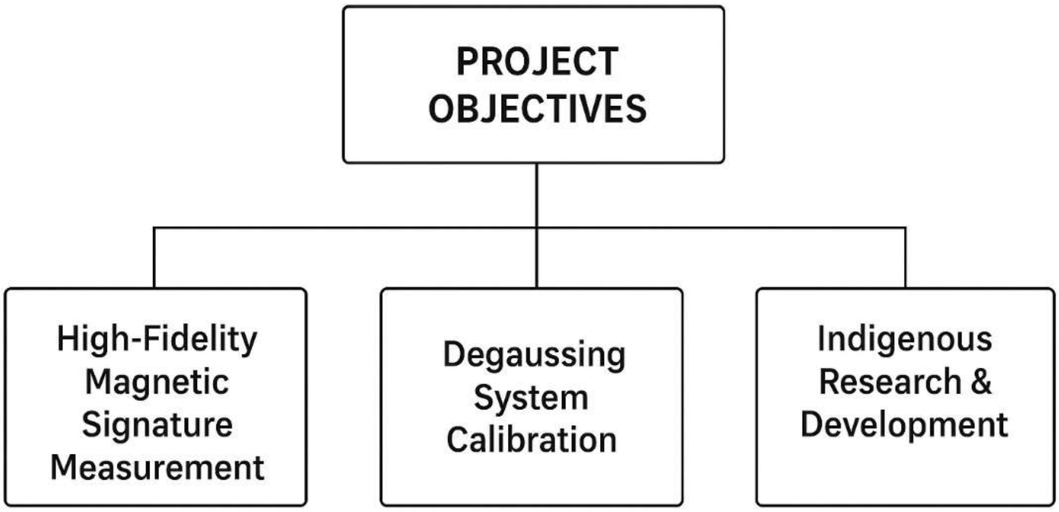

Figure: Major Project obsectives

The key objectives of the project are detailed below:

2.1 High-Accuracy Magnetic Signature Measurement

Develop and commission a state-of-the-art underwater magnetic measurement facility capable of capturing both static and dynamic magnetic signatures of naval platforms with sub-nanotesla precision.

The DMR configuration will follow established magnetic ranging design principles, ensuring complete coverage of the vessel's magnetic field envelope during a single transit. The configuration parameters are as follows:

Parameter	Specification / Rationale
Array Width	Minimum 2–3 × vessel beam to fully capture lateral and return magnetic field components.
Sensor Spacing	0.25–0.35 × vessel beam, balancing spatial resolution and array efficiency.
Sensor Alignment	Array oriented along the North–South axis for vessel passes at N–S, E–W, and 45° incremental headings.

Sensor Mounting	Sensors installed 1.5–2.0 m above seabed using TRBM (Triangular Reinforced Base Mount) units fabricated from non-magnetic concrete sinkers for stability and minimal interference.
Heading Configurations	Ranging at 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315° to capture full magnetic dipole characteristics.

This optimized configuration ensures repeatable, high-fidelity measurements of the vessel's magnetic field under multiple heading and speed conditions, providing a reliable dataset for degaussing validation and stealth assessment.

2.2 Degaussing System Calibration and Validation

Facilitate precise calibration, fine-tuning, and certification of shipboard degaussing systems across multiple vessel classes. The DMR will enable verification of:

- Residual magnetic signatures following degaussing activation,
- Effectiveness of degaussing compensation loops,
- Heading-dependent variations in field strength and polarity, and
- Long-term system stability and drift behavior.

These measurements will ensure minimum magnetic vulnerability of naval platforms to magnetic influence mines and advanced detection systems, directly contributing to enhanced operational stealth and survivability.

2.3 Long-Term Signature Monitoring and Trending

Establish a lifecycle magnetic monitoring framework for all major fleet units, enabling long-term assessment and management of platform magnetic signatures. The DMR will:

- Conduct periodic ranging trials for all operational vessels,
- Detect signature drift due to hull aging, retrofits, or magnetic property changes,
- Provide data for predictive maintenance and calibration of degaussing systems, and
- Support stealth verification and certification during refit or post-upgrade trials.

This capability will enable the Navy to maintain a dynamic magnetic signature database for fleet-wide tracking and strategic trend analysis.

2.4 Indigenous R&D and Stealth Technology Development

Create a dedicated research and development ecosystem for advancing India's expertise in magnetic stealth technologies and related sciences. The DMR will support:

- Magnetic field modeling, simulation, and inversion studies,
- Prediction and mitigation of platform magnetic signatures,
- Characterization of magnetic and non-magnetic materials, and
- Design and validation of indigenous magnetic silencing systems.

This R&D foundation will directly contribute to next-generation stealth design, platform development, and national self-reliance in magnetic technology.

2.5 Infrastructure Optimization and Interoperability

Ensure cost efficiency and system interoperability by leveraging the existing Primary Hydrophone Junction Box (HPJB) for power distribution and telemetry interface.

A dedicated optical fiber network will be deployed for the magnetic sensor array, enabling:

- Complete operational independence from the hydrophone grid,
- Low-latency, interference-free data transmission, and
- Modular scalability for expansion to support larger vessel classes and enhanced sensor counts.

This hybrid approach provides an integrated yet flexible system architecture, balancing performance, reliability, and expandability.

2.6 Strategic Self-Reliance and Capability Sovereignty

Reinforce India's sovereign capability in underwater stealth verification, magnetic signature management, and countermeasure development. The DMR will:

- Eliminate dependency on foreign magnetic testing facilities,
- Support operational readiness and stealth certification of frontline assets,
- Enhance fleet survivability in contested littoral and blue-water environments, and
- Contribute directly to the Atmanirbhar Bharat initiative within the maritime defence domain.

3. Site Characteristics

The selection of an appropriate site is a critical determinant of the performance, accuracy, and operational reliability of the Deepwater Magnetic Range (DMR). The proposed location has been evaluated with respect to geomagnetic, bathymetric, hydrographic, and environmental parameters, and has been found to be well suited for stable, high-accuracy magnetic ranging operations with minimal background interference.

Parameter	Description
Depth Range	43–44 m (Chart Datum). The depth provides adequate clearance for surface ships and submarines during ranging operations. All sensors will be standardized to a uniform elevation of 42 m by adjusting TRBM sinker heights.
Bathymetry	Flat seabed with slope < 3°, comprising uniform sand–silt material. This ensures stable sensor alignment and minimal hydrodynamic variability. *(Bathymetric plot to be inserted here.)*
Magnetic Noise Level	< 2 nT RMS (based on archival research data). A dedicated geomagnetic survey is recommended prior to deployment to establish current local field conditions and identify any minor anomalies.
Seabed Composition	Fine silt interspersed with non-ferrous sediment layers. This provides an excellent mechanical base for TRBM-mounted sensors and minimizes magnetic distortion from the seabed substrate.
Proximity to Shore	Approximately 18 km offshore and 25 km from the Underwater Test Facility (UTF). The range is within the operational limits of the proposed optical cable and subsea power link, ensuring reliable data and power connectivity.
Environmental Interference	Open source data indicates, No detectable electromagnetic contamination in the vicinity. Baseline checks show absence of major industrial or subsea power sources that could interfere with field measurements. We are recommending magnetometer survey at the range location.

3.1 Bathymetric and Seabed Stability Assessment

The bathymetric survey indicates depths ranging from 43 to 44 meters (CD) with a uniform seabed profile and gradual slope (<3°) across the proposed corridor. This consistent seabed morphology offers multiple operational advantages:

- Simplifies precise leveling of TRBM-mounted magnetic sensors.
- Provides uniform clearance for vessels across all headings.
- Minimizes seabed preparation and construction complexity.
- Reduces hydrodynamic and sediment transport effects during operation.

To ensure precise array placement, a high-resolution multibeam echo sounder (MBES) survey is recommended before installation. This survey will confirm micro-level seabed gradients and help finalize exact sensor coordinates for equal-depth configuration.

(Bathymetric chart to be inserted here with coordinates, depth contours, and corridor alignment.)

The seabed's fine silt and low ferrous content provide an ideal foundation for TRBM installations, minimizing local geomagnetic distortion and improving overall system accuracy.

3.2 Geomagnetic and Environmental Noise Baseline

Previous geomagnetic studies indicate an ambient magnetic noise level < 2 nT RMS, which supports sub-nanotesla-level measurement capability. However, these results are derived from earlier regional datasets. To ensure accurate baseline calibration, a dedicated modern geomagnetic survey shall be carried out before sensor deployment.

The proposed pre-installation survey will involve:

- Fluxgate and Overhauser magnetometer profiling along the proposed sensor corridor.
- Mapping of magnetic anomaly contours to detect minor crustal variations.
- Identification of local dip and declination deviations.
- Validation of temporal magnetic drift and diurnal variation levels.

The collected data will be integrated into the DMR's software compensation module, allowing real-time correction for local anomalies and post-processing bias removal, thereby enhancing measurement accuracy.

3.3 Operational Suitability

The combination of moderate depth, flat seabed, low hydrodynamic energy, and low background noise makes the site ideal for establishing a permanent magnetic ranging facility.

Key operational merits include:

- Adequate maneuvering corridor for surface and subsurface vessel classes.
- Excellent sensor stability and repeatability.
- Low maintenance requirements due to minimal sediment mobility.
- High measurement reproducibility across various vessel headings and speeds.
- Proximity to UTF (25 km), enabling shore-based integration while maintaining array independence.

These parameters collectively ensure the proposed site offers an optimum operational environment for high-precision magnetic ranging and long-term performance stability.

3.4 Recommended Pre-Installation Surveys

To ensure the Deepwater Magnetic Range achieves its intended accuracy and long-term reliability, the following surveys and baseline studies are strongly recommended prior to sensor installation:

Survey Type	Objective	Outcome / Application
High-Resolution Bathymetric Survey (MBES)	Map seabed contours and slopes at 0.5 m resolution.	Finalize precise TRBM sensor coordinates and uniform depth leveling.
Geomagnetic Baseline Survey	Measure background field strength and identify local magnetic anomalies.	Integrate correction factors into DMR data processing software for real-time compensation.
Sediment Core and Composition Study	Verify magnetic susceptibility and ferrous content of seabed materials.	Confirm suitability for non-magnetic TRBM deployment and refine site-specific calibration constants.
Current and Turbidity Profiling	Measure temporal variations in current speed and suspended sediment load.	Determine seasonal maintenance frequency and long-term stability of sensors.
Environmental Electromagnetic Scan	Detect any transient or anthropogenic electromagnetic noise.	Validate ambient EM quietness for sub-nanotesla-level operation.

The results from these surveys will be used to update the digital site model, refine sensor placement geometry, and optimize magnetic anomaly correction algorithms embedded in the DMR's signal processing suite.

This approach ensures high-fidelity measurement capability and software-level compensation for residual geomagnetic variations, thereby enhancing the overall accuracy and reliability of the DMR system.

4. System Architecture and Configuration

The Deepwater Magnetic Range (DMR) is designed as an integrated, modular, and scalable infrastructure capable of capturing high-fidelity magnetic signatures of naval vessels across various operational conditions and headings.

The overall system architecture is built around five functional subsystems, ensuring seamless data flow, high synchronization fidelity, and operational compatibility with the existing Underwater Test Facility (UTF) infrastructure:

1. Underwater Magnetometer Array
2. Subsea Power and Communication Network
3. Sensor Interface and Junction Infrastructure (Mag UJB and HPJB)
4. Shore-Based Control, Acquisition, and Processing Facility

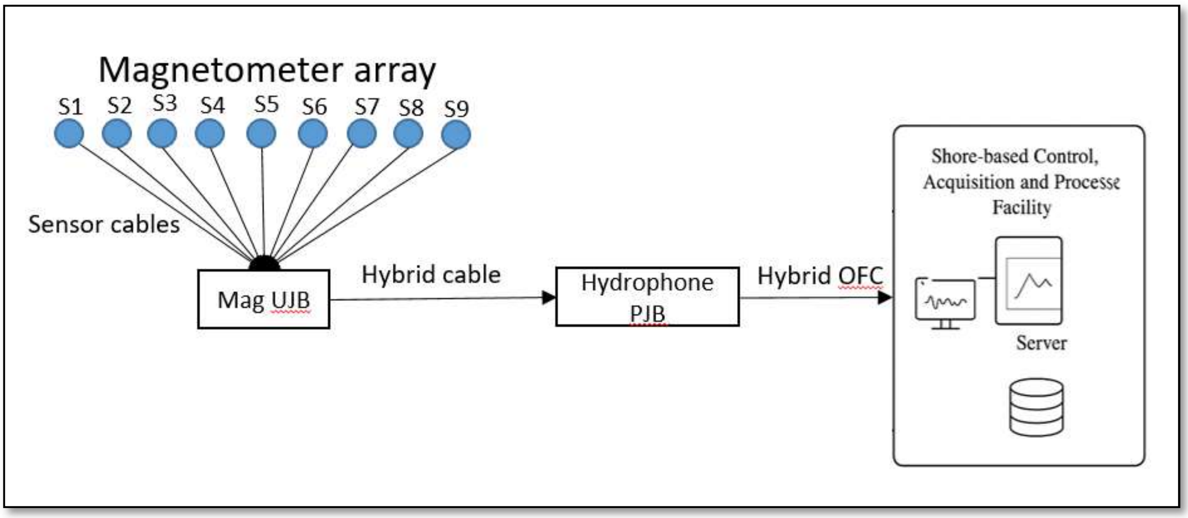

Figure: DMR System Architecture - Proposed

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This modular configuration ensures that the DMR operates independently yet synergistically with the primary Hydrophone Junction Box (HPJB) and the UTF data acquisition systems, sharing power and communication infrastructure where beneficial but maintaining dedicated data pathways for magnetic signal integrity.

4.1 Underwater Sensor Array Configuration

The Underwater Magnetic Sensor Array forms the sensing backbone of the DMR. It comprises nine triaxial magnetometers arranged in a linear transverse configuration perpendicular to the vessel track. This geometry ensures comprehensive coverage of the vessel's total magnetic field envelope and allows precise reconstruction of induced and permanent magnetic signatures.

Parameter	Specification
Corridor Width	50 m (≈ 2.5× typical vessel beam)
Number of Sensors	9 Triaxial Magnetometers
Sensor Spacing	6.25 m
Mounting Depth	1.5–2.0 m above seabed
Seabed Reference Depth	42.0 m from CD (adjusted using sinker height modification)
Array Orientation	North–South axis
Sensor Mount Type	TRBM (Triangular Reinforced Base Mount) – non-magnetic concrete
Reference Alignment	S5 at vessel keel track centerline

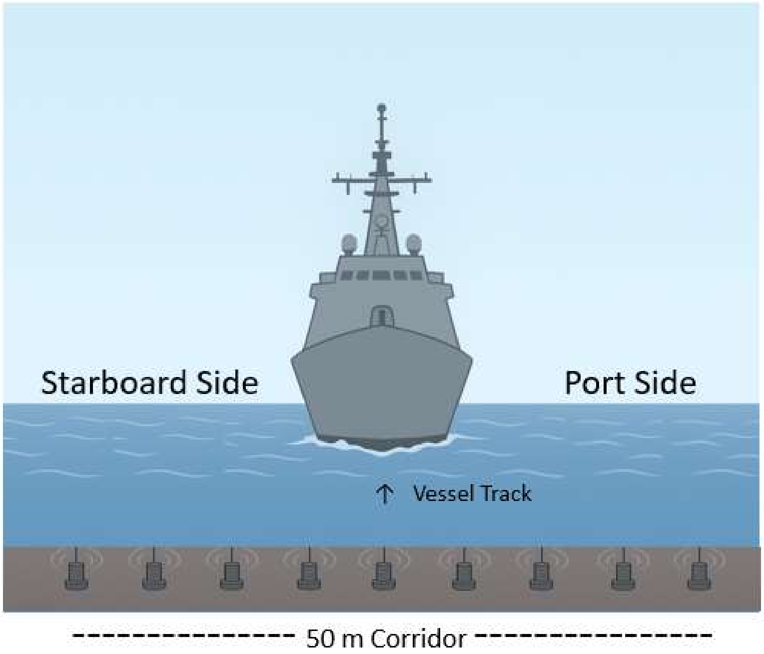

Figure: Underwater Sensor Array Configuration

Each magnetometer is mounted on a TRBM assembly anchored in fine silt sediment, providing mechanical rigidity and minimal magnetic distortion. The array geometry is optimized for corvette-to-destroyer class vessels, with modular scalability for larger platforms such as SSKs or SSBNs.

The sensors are installed such that all active sensing elements lie in a common horizontal plane (42 m depth), ensuring consistent baseline reference and uniform sensitivity for accurate magnetic field reconstruction.

4.2 Subsea Power and Communication Network

The DMR’s subsea interconnection network provides power and data transmission between the Primary Hydrophone Junction Box (HPJB) and the Magnetic Junction Box (MJB), and further to individual sensors.

Parameter	Description
Primary Connectivity	200 m hybrid fiber-optic/copper cable from HPJB to MJB
Cable Type	Hybrid subsea grade (FO + Cu cores)
Configuration	Star topology from MJB to sensor nodes

Power Supply	24 VDC distributed bus with isolated outputs
Data Communication	RS-485 or Ethernet (fiber-multiplexed)
Bandwidth	≥ 10 Mbps aggregate throughput
Latency	< 5 ms per link
Isolation	Galvanic isolation to prevent EMI coupling with hydrophone channels
Redundancy	Dual-core fiber with auto-failover capability

The 200 m hybrid cable provides logical segregation of the magnetic data path while utilizing the existing UTF power and control backbone for operational efficiency. This topology minimizes electromagnetic interference, reduces cable drag, and simplifies maintenance logistics.

4.3 Sensor Interface and Junction Infrastructure

The Sensor Interface and Junction Infrastructure facilitates subsea data acquisition, power conditioning, and time synchronization for the magnetometer array.

The Magnetic Junction Box (MJB) serves as the central distribution node for the DMR array, positioned approximately 200 m from the HPJB. It houses a Sensor Interface Module (S-I/O), which provides power, data routing, and timing synchronization to all sensors.

Sensor Interface Module (S-I/O) — Technical Specification

Parameter	Specification
Enclosure	Titanium / PEEK composite, IP68-rated (100 m depth)
Input Power	24 VDC (from HPJB via hybrid cable)
Output Power	12/24 VDC isolated per sensor channel
Communication Protocol	RS-485 / Ethernet multiplexer
Data Rate	≥ 10 Mbps aggregated
Time Synchronization	GPS 1PPS relay + IEEE 1588 PTP
Onboard Buffering	8–24 hours circular buffer
Diagnostics	Remote telemetry + fault status
Connectors	SubConn wet-mate (8-pin per sensor)
Redundancy	Dual hot-standby modules

EMI Mitigation	Internal µ-metal shielding and grounding mesh

Data Pathway:

Sensors → S-I/O → Magnetic Junction Box (MJB) → 200 m Hybrid Cable → HPJB → UTF Shore Station

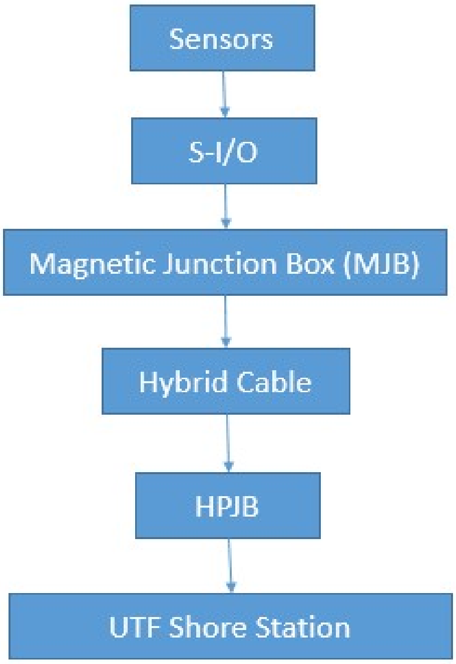

Figure: Magnetic Data Pathway

This modular setup provides:

- Simplified sensor replacement and isolation without full system shutdown
- Independent fault tolerance and real-time diagnostics
- Enhanced EMI immunity for co-location with acoustic instrumentation

4.4 Shore-Based Control, Acquisition & Processing Facility

The Shore Control and Processing Facility, located within the UTF campus, provides centralized monitoring, data acquisition, processing, and archival functions. It is built on a layered architecture to ensure high data integrity, security, and analytical flexibility.

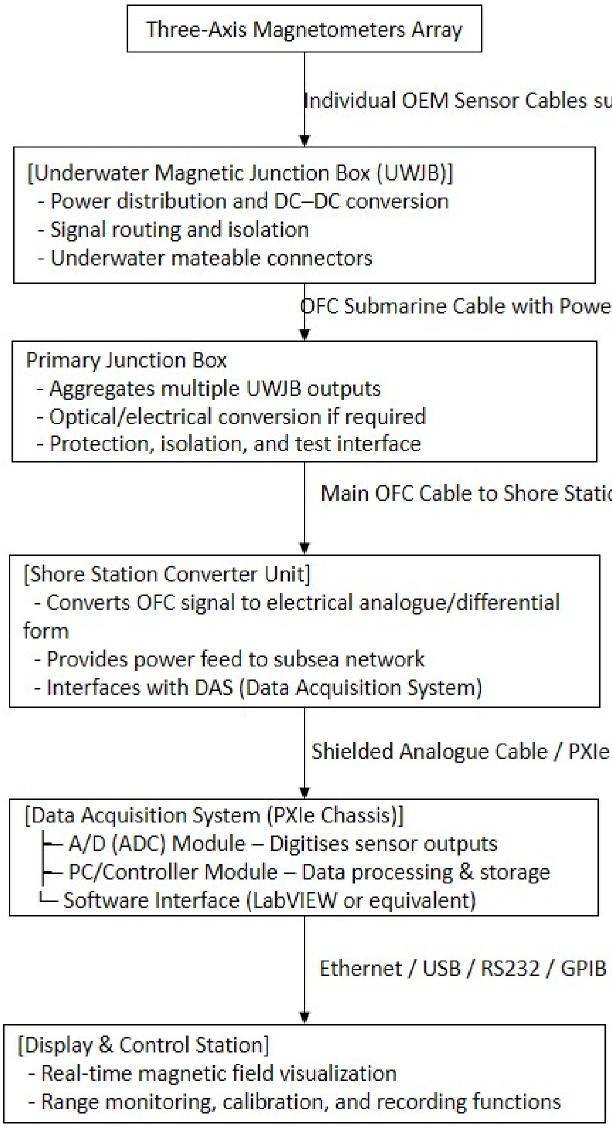

Figure: Schematic Diagram Showing Typical Sensor connections

(a) Real-Time Data Acquisition Layer

- Minimum 27 active channels (minmum) (9 sensors × 3 axes)
- Sampling rate: ≥ 3 Hz per channel
- Precision GPS-based time synchronization
- Real-time sensor status and health monitoring

(b) Data Archival and Processing Layer

- Integrated with UTF's existing RAID-6 NAS storage cluster

- Data formats: binary + CSV / netCDF for interoperability
- Automated scripts for filtering, vector decomposition, and residual signature computation
- Interface-ready for magnetic field visualization and comparison tools

(c) Magnetic Modeling & Research Layer

- High-performance workstation or small compute cluster with LabView/ MATLAB / Python / COMSOL compatibility
- Capability for:
    - Local anomaly correction and compensation
    - Degaussing model validation
    - Signature database generation for R&D purposes

Component	Specification
CPU	Xeon / Threadripper class
RAM	≥ 64 GB
GPU	RTX-class (optional for 3D modeling)
Storage	≥ 10 TB SSD / NAS
Software Stack	MATLAB, Python SDKs, Magnetic Solvers
Backup	24-hour snapshot rotation

4.5 System Security and Network Protection

The system adheres to defense-grade cybersecurity and network integrity standards to ensure safe data transmission and controlled access.

Feature	Description
Data Encryption	AES-256 end-to-end encryption
Network Segregation	VLAN isolation between hydrophone and magnetic systems
Access Control	RBAC (Role-Based Access Control)
Firewalls	Dual perimeter with intrusion logging
Compliance	MIL-STD-3023, ISO/IEC 27001

4.6 System Scalability and Expansion Provisions

The DMR is designed with forward-compatibility and modular growth in mind. Future upgrades may include:

- Expansion of sensor array beyond 9 nodes for wider coverage
- Integration with autonomous or mobile magnetic ranging systems
- Software-level upgrades for real-time anomaly compensation
- Plug-and-play sensor replacement via wet-mate connectors
- Optional interface with acoustic tracking for synchronized hybrid ranging

5. Proposed Software Architecture for the Deepwater Magnetic Range (DMR)

The Deepwater Magnetic Range (DMR) software architecture is proposed as a modular, integrated, and scalable platform to support the acquisition, processing, analysis, and visualization of magnetic signatures of naval vessels. It is designed to operate reliably in deepwater conditions while ensuring precise temporal and spatial correlation between the vessel trajectory and the magnetic sensor array.

The architecture is organized in layered functional modules, enabling flexibility, future scalability, and seamless integration with existing UTF infrastructure and the subsea sensor network.

5.1 Sensor Array Integration Layer

The sensor array integration layer captures high-resolution three-dimensional magnetic field data from the DMR's triaxial magnetometers. The proposed array consists of nine sensors installed transversely along the seabed, with the central sensor aligned to the vessel keel for longitudinal reference.

Key features:

- Sensors: 9 triaxial magnetometers measuring Bx (N–S), By (E–W), Bz (Vertical).
- Array Geometry: Transverse layout across a 50 m corridor, spacing 6–8 m.
- Orientation: North–South axis alignment for reference to Earth's geomagnetic field.
- Mounting: TRBM (Triangular Reinforced Base Mounts) at 42 m depth for uniform reference plane.
- Calibration: Absolute heading, tilt, and leveling calibration for measurement fidelity.

This configuration enables accurate reconstruction of permanent and induced magnetic moments, providing the foundation for signature analysis.

5.2 Data Acquisition and Control Layer

This layer handles real-time acquisition of magnetic data and ensures temporal alignment with vessel position provided by the vessel's navigation systems.

Proposed functionality:

- Continuous sampling of 9 sensors × 3 axes at ≥ 10 Hz.
- High-resolution timestamping for synchronization.
- Monitoring of environmental variables such as baseline geomagnetic noise and water temperature.
- Automated quality checks and flagging for post-processing reliability.

The software will log data during vessel transits along predefined headings (0°, 45°, 90°, etc.), enabling full characterization of heading-dependent signatures.

5.3 Real-Time Processing and Correction Layer

This module applies on-the-fly corrections to raw measurements to isolate vessel-induced magnetic fields:

- Sensor bias and offset removal.
- Subtraction of Earth's geomagnetic field using reference data.
- Compensation for tilt, temperature, and slow drift variations.
- Filtering to remove high-frequency noise and transient spikes.

The processed data is suitable for immediate analysis, modeling, and degaussing evaluation.

5.4 Signature Analysis and Modeling Layer

This layer extracts actionable intelligence from corrected data:

- Heading-dependent signature mapping – longitudinal and transverse field profiles, isofield contour mapping.
- Magnetic moment estimation – decomposition into permanent and induced components.
- Degaussing system evaluation – assessment of DG ON/OFF residuals and coil efficiency.

- Mathematical and scenario analysis – modeling multiple vessels, heading variations, and predictive studies.

This enables closed-loop feedback for stealth optimization, R&D, and operational planning.

5.5 Visualization and Operator GUI

A proposed graphical interface provides real-time situational awareness and post-run analytical capabilities:

- Strip charts and overlay plots for all sensors.
- Cross-sectional magnetic field visualization.
- Isofield contour mapping around vessels.
- Differential DG ON/OFF plots for coil effectiveness.
- Exportable charts and reports in CSV, netCDF, and image formats.

Operators can interactively examine data, verify measurement quality, and respond to anomalies in real time.

5.6 Modeling and Simulation Integration

The software will interface with magnetic modeling platforms (e.g., MATLAB, COMSOL, FEM solvers) to support:

- Forward and inverse magnetic modeling.
- Degaussing optimization and prediction studies.
- Scenario simulation across headings, speeds, and operational conditions.
- Validation of model predictions against DMR measurements.

This integration supports research, stealth planning, and design optimization.

5.7 Data Management and Security

The proposed architecture ensures secure and auditable storage:

- Timestamped data with vessel ID, heading, environmental conditions, and calibration state.
- AES-256 encryption for secure storage and transmission.
- Role-Based Access Control (RBAC) to manage user permissions.
- Automated backup to UTF servers and metadata tagging for efficient retrieval.

- Compatibility with standard naval magnetic range formats for collaboration and inter-range comparison.

5.8 Summary of Proposed Architecture Benefits

Aspect	Benefit
Layered Modular Design	Facilitates integration, maintenance, and future upgrades
Sensor Array Integration	Accurate field reconstruction and coverage
Real-Time Processing	Removes bias, noise, and environmental effects immediately
Signature Analysis	Quantifies magnetic moments and degaussing efficiency
Visualization & GUI	Intuitive monitoring and interactive data exploration
Modeling Integration	Enables predictive simulation and optimization
Data Security & Management	Secure, long-term, and auditable data storage

6. Project Implementation Plan

The establishment of the Deepwater Magnetic Range (DMR) involves a coordinated execution of technical, civil, and operational activities. The implementation strategy follows a phased, milestone-driven approach, ensuring systematic progress, risk mitigation, and adherence to quality standards throughout the project lifecycle.

6.1 Implementation Strategy

- Phased Execution: The project is structured into six sequential phases, covering site validation, equipment procurement, installation, calibration, trials, and operational handover. This structured approach allows systematic monitoring and ensures no critical activity is overlooked.
- Parallel Integration: Shore-based infrastructure works, sensor fabrication, and interface module assembly will proceed in parallel to optimize timelines and reduce overall project duration.
- Progressive Commissioning: Subsystems—including the underwater sensor array, HPJB interface, power distribution, and communication networks—will be commissioned in sequence to enable early functional verification and integration testing.

- Joint Acceptance: Critical milestones will be validated jointly by the project execution team, naval stakeholders, and quality assurance authorities to ensure compliance with operational, safety, and performance requirements.

6.2 Implementation Schedule

Phase	Activity Description	Duration	Key Deliverables
I	Final Site Validation & Seabed Preparation • Bathymetry verification • Geomagnetic baseline survey • TRBM sinker installation planning	3 Month	Site survey report, final sensor layout, TRBM anchoring positions
II	Sensor Procurement & Fabrication of S-I/O Modules • Procurement of 9 triaxial sensors • Factory Acceptance Testing (FAT) • S-I/O and connector assemblies	12 Months	FAT reports, certified sensors and interface modules
III	Array Installation & HPJB Integration • Laying of dedicated 200 m optical cable • Seabed TRBM installation • S-I/O integration with HPJB	4 Month	Fully installed subsea sensor array with verified data communication

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IV	Shore Station Setup • DAQ and server installation • Network configuration and cybersecurity setup • Visualization and control interface commissioning	2 Month	Operational control and data center
V	Calibration, Trials & Dual-System Validation • Sensor calibration • Live vessel runs • Degaussing system verification	2 Month	Acceptance Test Procedure (ATP) report, operational validation certificate
VI	Operationalization & Documentation Handover • SOP finalization • Operator training • Delivery of O&M documentation	4 Months	Commissioning certificate, operator training completion, long-term support plan

Total Estimated Duration: ~27 months, dependent on favorable sea conditions and logistical support.

6.3 Supporting Activities

- Safety and Environmental Compliance: Including electromagnetic emission assessments, seabed disturbance management, and regulatory clearances.
- Quality Assurance: Adherence to MIL-STD, Indian Naval QA guidelines, and international best practices at each implementation stage.
- Training Programs: Structured training for operators and maintainers on DAQ systems, software tools, and modeling platforms.

- Sustainment Planning: Establishment of a 10-year spares and Annual Maintenance Contract (AMC) framework to ensure operational continuity.

7. Budgetary Estimate (Revised)

The proposed Deepwater Magnetic Range (DMR) is a high-precision naval infrastructure project involving subsea sensor arrays, shore-based acquisition and processing facilities, optical communication links, and associated software systems. The budget has been estimated based on current market rates, vendor quotations, naval-grade equipment standards, and historical costs from comparable projects.

Component	Estimated Cost (INR)	Remarks
9 Triaxial Magnetometers (Deepwater Rated)	₹ 8.50 Cr	High-resolution fluxgate/Overhauser sensors with deepwater housings, factory calibration, pressure testing, and warranty
Underwater Frames & TRBM Sinkers	₹ 2.50 Cr	Non-magnetic TRBM mounts, alignment fixtures, seabed anchoring, deployment vessels, lifting and handling equipment
Data Acquisition Hardware & Time Synchronization Systems	₹ 2.00 Cr	Shore-based DAQ servers, 1PPS/IEEE 1588 synchronization, redundant RAID storage, HMI/GUI integration, UPS backup
Communication & HPJB Interface Modules	₹ 2.50 Cr	200 m dedicated fiber-optic cable, S-I/O modules, wet-mate connectors, multiplexers, EMI shielding, installation & commissioning
Shore Station IT & Infrastructure	₹ 2.00 Cr	Data center racks, environmental control, operator consoles, network setup, cyber-security, redundant power distribution
Power Systems (UPS + DG Set)	₹ 0.80 Cr	10 kVA DG set, 5–10 kVA UPS, power conditioning, distribution panels, surge protection

Software Development & Integration	₹ 1.80 Cr	Real-time acquisition, visualization, post-processing, magnetic modeling, simulation platforms (MATLAB/COMSOL), R&D modules
Trials, Mobilization, Documentation & Training	₹ 1.50 Cr	Sea trials, vessel mobilization, ATP execution, SOP finalization, O&M manuals, operator and maintenance training
Contingency & Inflation	₹ 2.00 Cr	~15% of total for unforeseen technical, environmental, or operational contingencies

Total Estimated Project Cost: ₹ 23.60 Cr (excluding applicable taxes)

Notes and Justification:

1. Deepwater Magnetometers are specialized naval-grade sensors designed for precise sub-nanotesla measurements in harsh marine conditions.
2. TRBM sinkers and subsea frames require precise engineering, robust material selection, and specialized deployment vessels.
3. Subsea optical communication and interface modules ensure high-bandwidth, low-latency, and EMI-free data transmission to shore.
4. Software and modeling packages include licensed commercial tools and in-house R&D modules for signature analysis and degaussing optimization.
5. Trials and mobilization account for offshore logistics, vessel availability, and operational risk management.
6. Contingency reflects inflation, market fluctuations, integration complexities, and unforeseen environmental challenges.

This enhanced budget reflects the full scope of establishing a robust, scalable, and future-ready Deepwater Magnetic Range, supporting a wide range of naval platforms and indigenous R&D initiatives.

8. Risk Assessment & Mitigation

8.1 Overview

In view of the criticality and high precision associated with the proposed Deepwater Magnetic Range (DMR), it is essential to adopt a structured and comprehensive Risk Management Framework to ensure reliability, operational safety, and measurement fidelity across all phases of the project lifecycle.

The DMR system entails complex integration of subsea magnetic and acoustic sensors, optical communication links, shore-based acquisition infrastructure, and analytical software. Accordingly, potential risks have been identified across technical, operational, environmental, and cybersecurity domains.

The proposed framework envisages a systematic process of risk identification, evaluation, and mitigation, aimed at minimizing both the likelihood of occurrence and the impact on project objectives. The strategy emphasizes redundancy, preventive maintenance, and proactive monitoring to ensure sustained performance and data integrity.

8.2 Risk Identification and Mitigation Measures

The key risks foreseen during installation, commissioning, and operational phases, along with their potential impacts and mitigation measures, are detailed in Table 8.1 below.

Table 8.1: Proposed Risk Assessment and Mitigation Plan

Risk	Potential Impact	Proposed Mitigation Measures
Sensor failure or drift	Loss of measurement fidelity, incomplete data coverage, inaccurate magnetic signature characterization	It is proposed that spare sensor nodes be provisioned to enable immediate replacement in the event of failure. The sensor array shall follow a modular design to facilitate rapid maintenance. Scheduled recalibration using baseline field data, along with built-in Helmholtz coil checks, shall be carried out to validate sensor drift.
HPJB overload or interface issues	Data packet loss, communication latency, incomplete datasets	Separate VLANs and dedicated optical channels shall be implemented for magnetic and hydrophone networks. Real-

		time diagnostics and automated alarm reporting shall be incorporated. Pre-deployment stress testing of all junction interfaces is recommended.
Electromagnetic interference (EMI) coupling	Contamination of sensor signals, erroneous signature profiles	µ-metal shielding shall be provided for all sensor modules. Galvanic isolation between power and communication circuits shall be ensured. Pre-commissioning EMI verification and periodic field audits are proposed.
Calibration drift over time	Measurement bias affecting signature accuracy, misinterpretation of degaussing efficacy	Periodic absolute and relative calibration routines shall be implemented. Baseline correction algorithms and environmental compensation (for temperature, tilt, and geomagnetic variations) are to be incorporated into the data processing workflow.
Power or communication failure	Partial or complete system downtime, potential data loss	Redundant optical links and network paths shall be established. UPS and DG set backups with seamless switchover are to be installed. Local data buffering at subsea I/O modules shall prevent loss during transient outages.
Severe sea state or adverse environmental conditions during installation	Schedule delays, potential damage to TRBM mounts and sensor modules	Subsea operations shall be planned in alignment with favourable seasonal sea states. Contractual provisions for standby vessels shall be included. Reinforced TRBM

		design and controlled deployment techniques are recommended.
Cybersecurity breach	Unauthorized access, compromise of sensitive vessel signature data	AES-256 encryption shall be adopted for data at rest and in transit. Role-Based Access Control (RBAC) shall be enforced for all users. Intrusion detection systems shall be deployed, and a physically isolated R&D network shall be used for sensitive data analysis.
Environmental degradation	Elevated ambient magnetic noise, sediment mobility affecting sensor stability	Continuous environmental monitoring is proposed. Baseline ambient noise profiles shall be established. Adaptive filtering algorithms shall be deployed to compensate for minor environmental variations. Periodic maintenance of seabed installations shall be undertaken.

8.3 Implementation Strategy

It is proposed that the above mitigation measures be embedded within the System Design, Deployment, and Operational Protocols from the initial stages of project implementation. The Project Management Team shall maintain a Risk Register to record identified risks, mitigation status, and control effectiveness. Periodic risk reviews shall be conducted during installation, commissioning, and operational phases.

The proposed risk management approach ensures that all foreseeable technical, operational, and environmental uncertainties are proactively addressed. Through embedded redundancy, calibration assurance, and cybersecurity safeguards, the DMR system shall achieve high reliability, measurement accuracy, and lifecycle sustainability.

9. Conclusion

The establishment of a Deepwater Magnetic Range (DMR) represents a pivotal strategic investment for the Indian Navy, significantly enhancing maritime stealth, operational survivability, and indigenous research and development (R&D) capacity. The facility will function as a national test bed for high-precision magnetic signature measurement, characterization, and degaussing system validation across a wide spectrum of surface and subsurface platforms.

Upon commissioning, the DMR will deliver a suite of operational, technical, and strategic advantages as outlined below:

9.1. High-Fidelity Magnetic Signature Measurement

The DMR will provide accurate reconstruction of a vessel's three-dimensional magnetic field, capturing both permanent and induced magnetic components with sub-nanotesla precision. A robust, seabed-mounted sensor array combined with precisely calibrated Mounts (TRBM) will enable repeatable measurements across varying vessel speeds, headings, and environmental conditions.

This capability is critical for stealth assessment, fleet deployment readiness, and the optimization of magnetic signature management practices.

9.2. Precise Calibration and Validation of Degaussing Systems

The DMR will facilitate controlled, repeatable trials for the calibration and validation of onboard degaussing systems.

By capturing heading-dependent and dynamic magnetic field variations, the range will enable fine-tuning of degaussing coils and control algorithms to minimize susceptibility to magnetic influence mines, non-contact fuzes, and advanced magnetic detection systems. This ensures enhanced survivability of naval platforms in high-threat environments.

9.3. Lifecycle Signature Monitoring and Predictive Maintenance

The facility will enable continuous lifecycle monitoring of vessel magnetic signatures, supporting predictive maintenance and early detection of deviations due to retrofits, hull modifications, or system degradation.

This proactive approach ensures long-term stealth integrity, operational reliability, and sustained fleet readiness.

9.4. Indigenous R&D and Advanced Modeling Ecosystem

The DMR will serve as the nucleus of an indigenous R&D ecosystem, fostering advanced research and capability development in the following domains:

- High-resolution magnetic field modeling and simulation for emerging hull designs
- Stealth enhancement studies and signature reduction methodologies
- Digital twin generation and virtual testing for fleet modernization programs
- Development of indigenous sensors, materials, and countermeasure technologies

This ecosystem will drive innovation and self-reliance in magnetic signature management technologies under the Atmanirbhar Bharat initiative.

9.5. Secure, Real-Time, and Scalable Infrastructure

The DMR will feature a modular and scalable architecture, incorporating:

- Secure fiber-optic communication links
- Real-time data acquisition (DAQ) and processing systems
- Redundant power and network infrastructure
- Secure data storage and management frameworks

These design elements will ensure reliable data capture, high system availability, and the ability to accommodate future vessel classes, including large hulls and submarine platforms.

9.6. Operational and Strategic Sovereignty

A fully indigenous DMR capability will substantially reduce dependence on foreign facilities, reinforcing strategic autonomy and sovereignty in critical naval technologies. It will strengthen India’s position as a regional leader in maritime defence research, providing the Indian Navy with enduring advantages in stealth management, operational planning, and survivability in contested maritime domains.

Architectural and Functional Highlights

The DMR design and operational framework will ensure:

- Accurate and repeatable magnetic measurements through precision subsea sensor deployment and calibration
- Robust and secure data acquisition, supported by low-latency redundant communication paths
- Advanced analytical, modeling, and decision-support capabilities for both operational and R&D purposes
- Long-term data integrity, secure archival systems, and interoperability with national naval data networks

Once operational, the Deepwater Magnetic Range will serve as a national centre of excellence for magnetic signature management, degaussing optimization, and stealth technology validation. It will underpin India’s long-term strategy for indigenous capability development, fleet survivability, and maritime technological leadership.

Subsystem Specifications for Magnetic Range

Three-Axis Range Magnetometer

General Description

The three-axis range magnetometer is designed for precision magnetic signature measurements and marine surveillance applications. It is suitable for long-range underwater installations, operating reliably over cables of up to 2 km and capable of submersion to depths of 100 m.

Installation and maintenance are simplified through the use of underwater mateable connectors, available in stainless steel or titanium construction. Connectors may be integral to the housing or provided on a cable tail, depending on installation requirements.

A compatible multi-channel data acquisition system can be employed to sample, record, process, and display outputs from multiple magnetometers simultaneously.

Key Features

- Measuring range options: ±100 µT, ±200 µT, or ±300 µT
- Bandwidth: DC to 3 kHz
- Built-in test facility (BIT)
- Cable lengths up to 2 km
- Underwater mateable connectors (stainless steel or titanium)
- Optional bowspring mounting for accurate alignment within cylindrical housings (120–250 mm ID)

Typical Applications

- Magnetic signature measurement of naval vessels
- Degaussing range instrumentation
- Marine surveillance and anomaly detection

Product Configuration

Configuration Parameter	Options
Connector Type	Underwater mateable connector
Tail	None or 5 m flying tail
Connector Construction	Stainless steel or titanium
Measuring Range	±100 µT, ±200 µT, ±300 µT

Example Configuration Code:

Underwater mateable connector, 5 m tail, titanium housing, ±300 µT range

Orientation and Marking

- Sensor axes engraved on lower enclosure end.
- Range, designation, and serial number engraved on flat face.
- The flat face and locating pin at the top indicate the **X-axis** direction for alignment.

Technical Specifications

Performance

Parameter	**±100 µT**	**±200 µT**	**±300 µT**
Number of Axes	Three		
Polarity	Positive, non-inverting output when pointing North		
Bandwidth (-3 dB)	3 kHz (±10%)		
Measurement Noise Floor	< 20 pT rms/√Hz at 1 Hz		
Scaling	100 mV/µT	50 mV/µT	33.33 mV/µT
Scaling Temp. Coefficient	10 ppm/°C	20 ppm/°C	30 ppm/°C
Offset	±30 nT	±60 nT	±90 nT
Offset Temp. Coefficient	±0.2 nT/°C	±0.4 nT/°C	±0.6 nT/°C
Scaling Error	±0.5% (DC)		
Orthogonality Error	< 0.2° (all axes to reference face)		
Linearity Error	< 0.0015%		
Frequency Response	DC to 1 kHz (±5%)		
Hysteresis (within range)	< 1 nT		
Hysteresis (beyond range)	10 nT at 1 mT		
Power Supply Rejection	1–3 nT/V		
Excitation Breakthrough	< 10 mV pk–pk at 15.625 kHz		

Built-In Test (BIT)

An active low (TTL-compatible) input generates a 1 µT (±10%) magnetic field change on each axis for calibration verification. Test calibration data can be provided for each sensor.

Environmental

Parameter	Specification
Operating Temperature	–10°C to +50°C
Ingress Protection	IP68, submersible to 100 m
MTBF	75,000 hours
Compliance	EMC (BS EN 61326:2013) and RoHS

Mechanical

Parameter	Specification
Enclosure Material	Polyacetal
Dimensions	582.5 × Ø50 mm (standard) / 516 × Ø50 mm (with tail)
Weight	1.1 kg (sensor only), 1.65 kg (with bowspring assembly)
Connector	Underwater mateable type (stainless steel or titanium)
Mounting Options	Adjustable bowspring and centering studs for cylindrical housings (Ø120–250 mm)

Electrical

Parameter	Specification
Supply Voltage	+15 V to +30 V (absolute range: +12 V to +30 V)
Current Consumption	40–50 mA at 25 V
Power-On Surge	210 mA
Output	±10 V differential (each output ±5 V, 0 V at zero field)
Output Impedance	10 Ω
Maximum Cable Length	Up to 2 km (dependent on cable type)

Cabling Specification

Marine-grade cables are available in lengths up to 2 km. Cables include sealed underwater connectors and are constructed for long-term submersion and durability in marine environments.

Cable Construction:

- Polyurethane outer sheath
- Five screened twisted pairs with overall screen

- Underwater mateable connectors at the magnetometer end
- Water-sealed terminations
- Optional Teredo worm barrier

Cable Properties:

Parameter	Specification
Maximum Length	2 km
Overall Diameter	15.3 mm (±0.5 mm) with worm barrier
Minimum Bend Radius (Static/Dynamic)	123 mm / 184 mm
Weight in Air	276 kg/km
Weight in Seawater	87 kg/km
Max. Conductor Resistance	40.1 Ω/km
Spark Test Voltage	6 kV
Working Voltage	750 V
Insulation Resistance	>500 MΩ/km (core–core and core–screen), >10 MΩ/km (screen–screen)

Data Acquisition Compatibility

The magnetometer is designed for integration with multi-channel magnetic range data acquisition systems capable of sampling, recording, and processing up to 80 three-axis sensors simultaneously.

System Overview

- PXIe-based data acquisition chassis with plug-in A/D cards
- Up to **8 Decaport analogue interface modules**
- Each Decaport connects up to **10 three-axis sensors**
- Total system capacity: **80 sensors (240 analogue channels)**
- All housed in a rugged 19” rack-mount case

Main Features

- Compatible with long sensor cables (up to 1 km)
- Differential or single-ended inputs (software-selectable)
- Selectable filter frequencies: **10 Hz, 100 Hz, 1 kHz, 10 kHz**
- ±10 V signal range
- Built-in sensor power supply (±12 V or ±14 V, 50 mA per channel)
- ESD and over-voltage protection
- Operates from **85–264 V AC, 50/60 Hz**
- PC-based monitoring and configuration software (LabVIEW™ compatible)

Performance Summary

Decaport Analogue Interface Module

- Inputs: 30 channels (10 × 3-axis sensors)
- Input voltage: ±10 V differential / single-ended
- Common-mode voltage: ±8 V (diff) / ±3 V (SE)
- Absolute max input: ±15 V
- Power output: ±12 V or ±14 V @ 50 mA per channel
- Filter: 2-pole Butterworth low-pass, 12 dB/octave
- Cable length: up to 1 km (sensor dependent)
- Size: 19″ × 1U (482 × 44 × 254 mm)
- Weight: 3 kg
- Operating temperature: –20 °C to +70 °C

PXIe Data Acquisition Unit

- PXIe chassis with 8 expansion slots
- ADC module: 16-bit resolution
- Sampling rate: up to **2 MS/s (single channel)** or **1 MS/s (multi-channel)**
- Input range: ±0.1 V to ±10 V (selectable)
- Processor: Intel i3 2.4 GHz, 4 cores (or equivalent)
- Memory: 8 GB RAM, 512 GB SSD
- Power: 100–240 V AC, 50/60 Hz
- Operating temperature: 0 °C to +40 °C

Environmental

- Operating: –20 °C to +70 °C (modules)
- Humidity: up to 90 % RH, non-condensing
- EMC: Designed to meet IEC/EN industrial standards

Software

- Supplied with Windows-based application for configuration and monitoring
- LabVIEW™ source available for custom range control and processing
- Allows live data display, recording, and sensor verification

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Magnetic Underwater Junction Box (UWJB)

Specification – For Magnetic Signature Measurement Systems

General Description

The Underwater Junction Box (UWJB) provides sealed electrical interconnection between submerged magnetometers and the shore-based data acquisition system. It distributes regulated power and differential signal lines while maintaining signal integrity and waterproof reliability during long-term marine deployment.

Key Features

- Supports multiple three-axis magnetometers (typically 4–10 units)
- Integrated DC–DC power converters for isolated sensor supply
- Waterproof to 100 m (IP68 or higher)
- Underwater mateable stainless-steel or titanium connectors
- Surge, reverse-polarity and over-voltage protection
- Simple internal access for inspection and repair
- Designed for marine range and degaussing applications

Electrical

Parameter	Specification
Input Voltage	+15 V to +30 V DC
Output (per channel)	±12 V or ±15 V, max 50 mA
Converter Efficiency	≥ 85 %
Signal Type	Differential analogue ±10 V
Channel Capacity	Up to 30 signal lines (10 sensors × 3 axes)
Isolation	> 500 MΩ @ 500 V DC
Protection	Surge, short-circuit, and reverse polarity
Cable Length	Up to 1 km (sensor dependent)

Mechanical / Environmental

Parameter	Specification
Housing Material	Stainless steel or titanium or Inconel
Dimensions	~250 × 200 × 120 mm (typical)
Depth Rating	100 m (min.), optional 300 m
Sealing	Dual O-ring or oil-filled pressure-balanced
Connectors	Underwater mateable (Hydrobond/SubConn type)
Mounting	Bracket or frame-mounted
Operating Temp.	–10 °C to +50 °C

Storage Temp.	–20 °C to +60 °C
Humidity	0–100 % RH non-condensing