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Design and Development of Redeployable Underwater Data Communication Link for Defence Application

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ABSTRACT

Testing of underwater system for defence application is carried out from submersible platform at specified depth. The underwater platform houses the article under test, equipment and instruments required to conduct the test and to control the platform. During development phase of defence systems, large numbers of sensors are mounted on the test article and data is collected to validate the design. Data acquisition system, video camera and high speed video cameras are positioned on the platform to record physical parameters and observe visually the performance of the article under evaluation. Since the data and video signals are parallely recorded on ship, the bandwidth demand for real-time data communication from underwater platform to control station is very high. The existing technology presently used for underwater communication has limitation of bandwidth and not suitable for defence application. This paper describes in detail the design and development of a re-deployable data communication link by laying a specially designed negatively buoyant fibre optic cable in high-sea from ship to underwater platform to provide higher bandwidth required for defence application. The link has been successfully used for sea state less than one during evaluation of underwater defence system. The availability of bandwidth from underwater platform to control system can be increased significantly by laying fibre optic cable in high sea. It also provides unlimited bandwidth for the above requirement.

Keywords: Underwater platform; Re-deployable data communication link; Data acquisition system; Bit error rate

NOMENCLATURE

NMS	Network management system
PMS	Power management system
RS-I	Remote station I, ship
RS-II	Remote station II, mooring Buoy
RS-III	Remote station III, underwater platform
NWS	Network switch
RBD	Reliability block diagrams
OLTE	Optical line terminal equipment
MTBF	Mean time between failure
BER	Bit error rate

1. INTRODUCTION

Remote controlled and remote operated instrumentation system installed on a platform which can be submerged in high sea at required depth by remote operation is needed for underwater testing. The instrumentation system consists of launch control system, data acquisition system, data communication system, power management system, video instrumentation system and network management system. The main objective of underwater instrumentation system is to conduct test on underwater platform, record physical parameters and provide bi-directional high bandwidth reliable data communication link between underwater platform and the control station, located either near sea shore or on a ship positioned in high sea. The defence activities that can be carried out from under water platforms are torpedo, underwater mines, submarine launched missile and underwater nuclear bomb testing. Instrumentation system required during development phase for underwater testing is totally different from ground based system. It becomes a complex and challenging task to plan a comprehensive instrumentation system to record maximum parameters during testing. Fault rectification and emergency handling is also an issue on submerged platform. The underwater platform (RS-III) used for missile launch during development phase is designed for two pressure hulls[1]. One pressure hull is used to locate equipment required for controlling the platform and the other hull is used to locate equipment required for missile launching and data acquisition. The canisterised missile is positioned on a launcher in a container at the centre of the platform. There are two more floating platforms, one is ship (RS-I), the main control centre for controlling missile launch activities at sea. Another floating platform called Mooring Buoy (RS-II) is emergency station. The link between RS-I and RS-III is fibre optic and between RS-II and RS-III is copper cable. RS-II will be positioned next to the RS-III and maximum data transmission distance is approximately 250 m. The ship will be positioned according to the objective of the test from minimum 500 m to 3500

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m. Approximately 256 physical parameters are required to be monitored and acquired in real time at a sampling rate of 1k to 10 k samples/s/channel at RS-III and simultaneously recorded at RS-I during the test to protect recorded data in case of mishap. 10 analogue video channels are transmitted in real time to RS-I to monitor the launch activities along with simplex audio signal. All the equipment are powered by power management system[2] specially designed to power various onboard equipment.

2. TECHNOLOGY OPTIONS FOR DATA LINK

Literature survey was carried out for various technology option suitable for requirement. Submersible and semi submersible platforms are mostly used for study of sea-bed, benthos, underwater inspection of objects, oil exploration and under water scientific studies. Due to attenuation of radio waves in water with increase in conductivity and frequency, under water acoustic communication though is relatively slow compared to radio communication is widely used for such application. Autonomous underwater vehicles equipped with sensors in underwater acoustic network[3] are used for exploration of underwater natural resources and gathering of scientific data. The other methods are used is underwater optical communication where laser passes through water channel and possible to transmit data at higher bandwidth[4]. Laser communication has also been tried on German ships and behaviour of laser has been observed by injecting air bobbles in the path of laser and it was possible to transmit data between 7 mb/s to 10 mb/s upto a distance of 20 m[5] with BERs less than 0.0001. Most of laser cannot penetrate through the sea and are absorbed but the blue green laser has the minimum energy fading in the sea hence it can penetrate 100 m to 1000 m in the sea and this features is called window effect and using this, submarine communications equipment has been developed[6]. Electromagnetic wave propagation in fresh water[7] is being tried and work is going on as fresh water has conductivity of 0.01 S/m compared to seawater conductivity of 4 S/m. Combination of acoustic and electromagnetic wave for underwater military application[8] is possible to take advantages of both systems. Underwater defence application has higher bandwidth requirement during the development phase. Torpedo testing, underwater mines, submarine launched missile and nuclear bomb testing are few examples. No literature is available through open-source about underwater data communication for defence application. Validation and demonstration of missile launch from submarine doesn't need much bandwidth[9], acoustic and telemetry systems are adequate for this purpose. Towed buoyant cable antenna that allows two-way voice and digital data communication between a submerged submarine and a surface ship or an aircraft to overcome limitation of existing radio-frequency and underwater acoustic communication systems[10]. If missile is launched from an underwater platform the data is transmitted through cable to a floating station and subsequently relayed to unmanned aerial vehicle[11] or support ship for command and control. The bandwidth limitation is due to radio transmission from floating platform to support ship or aircraft. Since the data bandwidth requirement was very high as mentioned above different methodology was used for data communication from submerged platform to the support ship by laying single mode fibre optic cable in high sea for required length.

3. SYSTEM DESCRIPTION

The underwater platform and mooring buoy is towed to the designated location in high sea where test will be conducted. The ship, which is also the control station is positioned at a distance from the underwater platform as per test requirements. RS-II is positioned nearer to the underwater platform.

The optical data communication link consists of 12 core single mode fibre optic cable, fibre optic underwater connectors and corresponding OLTEs at RS-I and RS-III and copper link consisting of composite cable having co-axial, power and shielded twisted pairs, underwater connectors and optical isolators between RS-II and RS-III. The schematic of two data link requirement is as shown in Fig. 1.

The ship carries the fibre optic cable rolled over an electro hydraulic winch, which provides connectivity between ship and RS-III. The cable is laid by a cable laying boat from ship to underwater platform. The inner end of the cable on winch is terminated on a receptacle connector fixed on winch and the outer end of cable is terminated on a plug connector. The receptacle connector will be interfaced to OLTE equipment on RS-I and plug connector will be terminated on feed through connector at RS-III and interfaced with OLTEs as shown in Fig. 2. To protect the connector at RS-III a mechanical termination is used to take the tension and pulling load on the cable. During winching operation plug connector of OLTE on winch is disconnected from receptacle. After completion of cable laying operation, plug connector is mated to the receptacle on winch and data communication link is established. It is necessary to switch on PMS/NMS and few OLTEs for establishing data communication link to RS-III from both the Remote Stations before lowering the platform in water. PMS/NMS including standby are important subsystems of data communication. The input power of OLTEs is controlled by PMS through network switch. Similar method is followed for deployment of composite link. There are many subsystems but only optical link is discussed in this paper. The physical parameters measured during the test are strain, temperature, vibration, gas generator pressure and underwater pressure for evaluation of platform and launcher. Onboard parameters on missile are acquired by telemetry system and relayed back to RS-I by delayed transmission technique once missile comes out of water. The cable is specially designed for the required depth and winching operation. Cable for underwater application, encounters two types of pressure i.e. radial pressure and axial pressure. To counter the radial pressure the thickness of outer sheath of the cable is increased or decreased as per depth requirement. The outer sheathing material of cable is either polyurethane or polyethylene. Polyurethane is very tough for hostile environment, its surface roughness is not suitable for winching operation.

Polyethylene as outer surface is very smooth and suitable for winching operation but is prone of breaking due to impact force. Polyurethane surface can be repaired easily by cold moulding process, whereas polyethylene is to be welded at

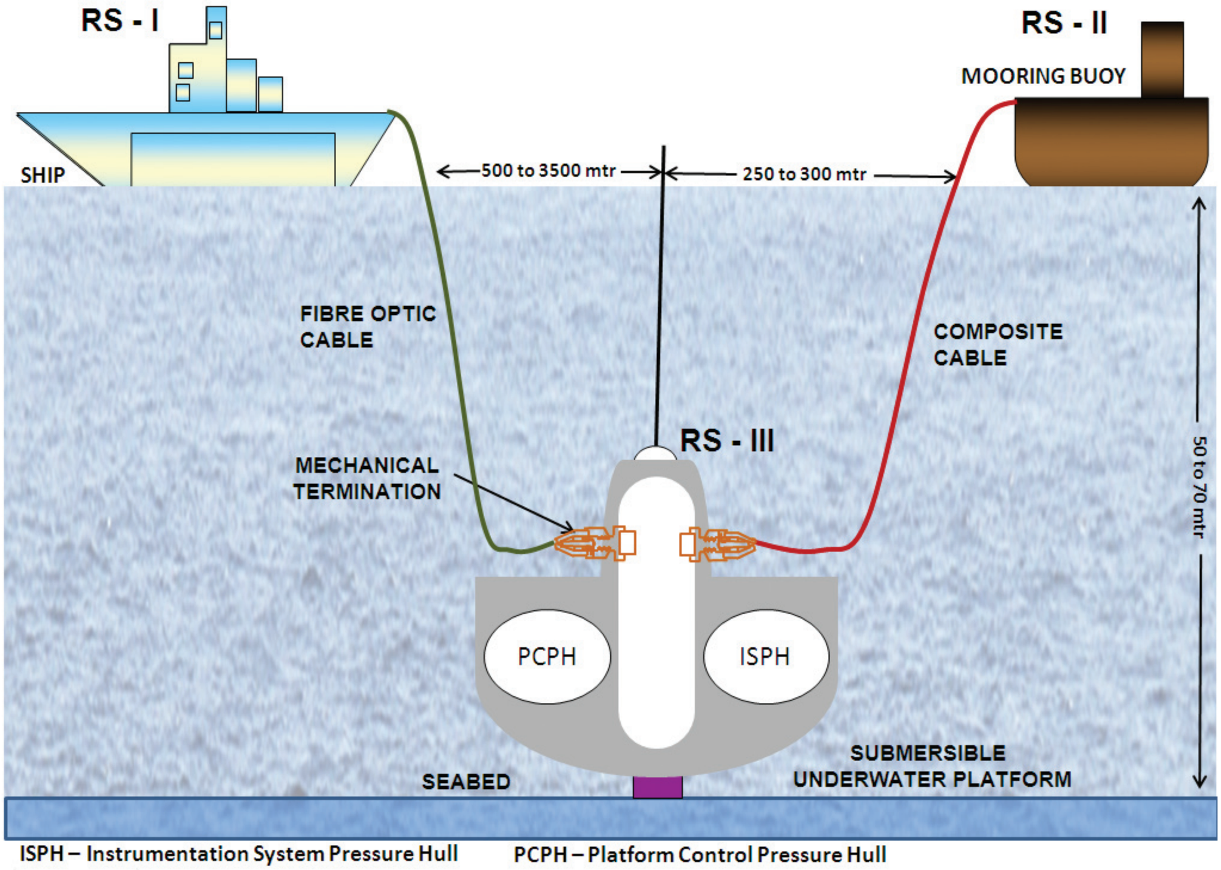

Figure 1. Fibre optics cable laying scenario and cable connector network.

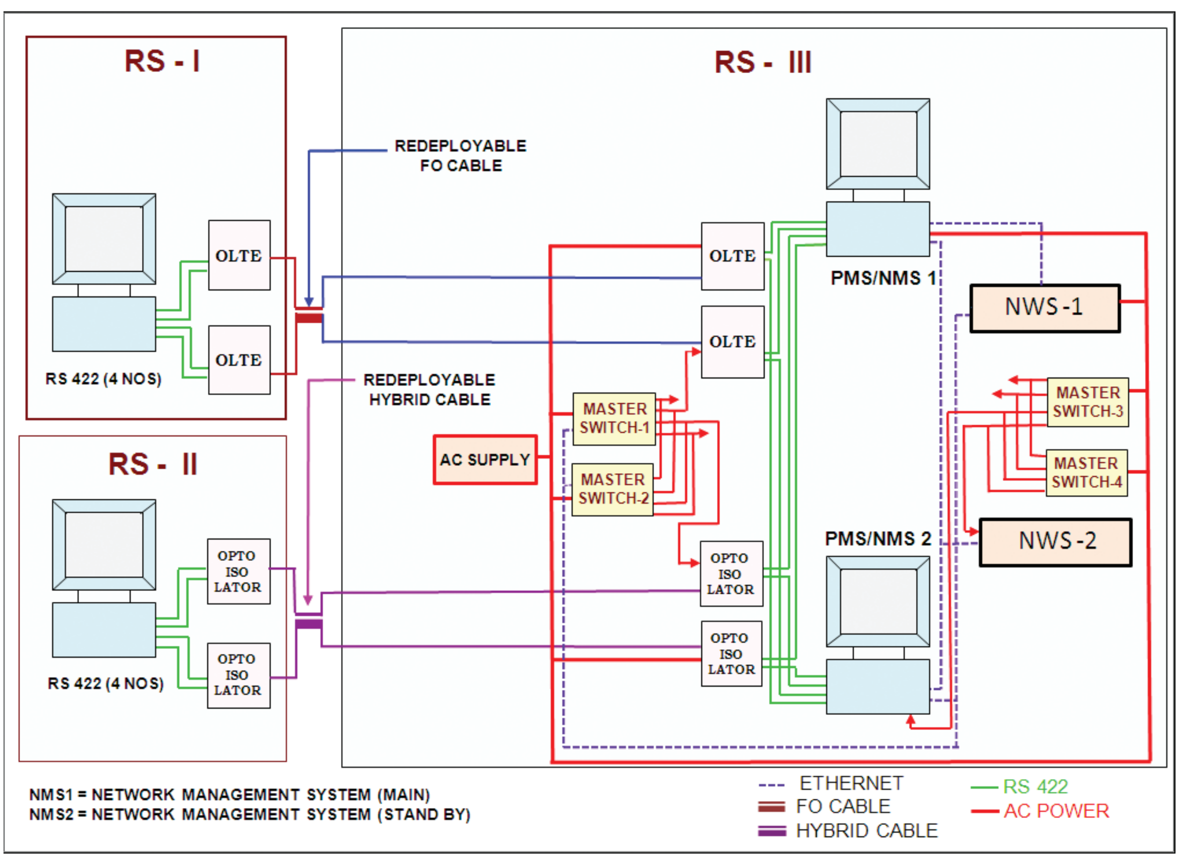

Figure 2. Schematic diagram of data communication system.

high temperature. The cable will experience axial pressure in case of cut or fish bite, water will enter the cable at pressure depending on the depth of cut or damage. To prevent this, cable voids are filled with gel and this type of cable is called water blocked cable. Now cables are also available with dry water blocked technology. Since the depth of operation was less and link is re-deployable, polyethylene sheathed cable without water blocking feature was used. Underwater connector was used on pressure hull, which will prevent water entering in the pressure hull. During winching operation cable will encounter force and stress[12] due to various factors like cable weight in water, water pressure at the depth of operation, pulling and tension force. To address mechanical forces cable is designed with torque balanced steel armour with higher flexure cycle. Winch is designed to accommodate entire length of cable on its drum. The groove of cable drum is designed according to the diameter of the cable and power of winch to retrieve cable for entire length of deployment. Connector is designed and selected after selection of cable. Considering all components of link, future requirement and gain margin, link design is carried out[13] and OLTEs are selected available commercially.

4. DESIGN AND LINK BUDGET ANALYSIS

During missile launch communication interface needed are shown in Fig. 3 the interfaces used are RS-422, TTL, IRIG, PCM, Analogue Video. Simplex and duplex audio and ethernet interface. Keeping the present and future requirement data communication link is designed keeping sufficient gain margin.

The Basic equation of available power, where

$G = P_t - P_r - M_a - M_s$

P_t Transmitted power = 0 dBm

P_r Receiver sensitivity = -24 dBm

M_a Margin of source aging (1-3) dB = 2dB

M_s Margin of safety (1-3) dB = 3dB

Total loss $L = l_c L_c + N_{con} L_{con} + (N_s + N_r) L_s + L_{pc}$

l_c Fiber length = 3.5 Km

L_c Fiber attenuation = 0.4 dB/Km

N_{con} No. of connector = 13

L_{con} Maximum connector loss = 1 dB

N_s No. of installation splices = 4

N_r No. of repair splices = 0

L_s Maximum splice loss = 0.2 dB

L_{pc} Passive component loss = 0 dB

Loss margin (M)= G - L

I. P_t = 0 dBm M$_a$ = 2 dB P_r = -24 dBm M_s = 3 dB

G = 0 - (-24) – 2 – 3 = 19 dB

II. l_c = 3.5 Km N_{con} = 13 L_c = 0.4 dB/Km L_{con} = 1 dB

N_s = 4 N_r = 0 L_{pc} = 0 L_s = 0.2 dB

L = (3.5 x 0.4) + (13x1) + (4+0) 0.2 + 0 = 15.2 dB

Unused margin (M) = 19 dB – 15.2 dB = 3.8 dB

5. TESTING

During the acceptance test the optical link was subjected

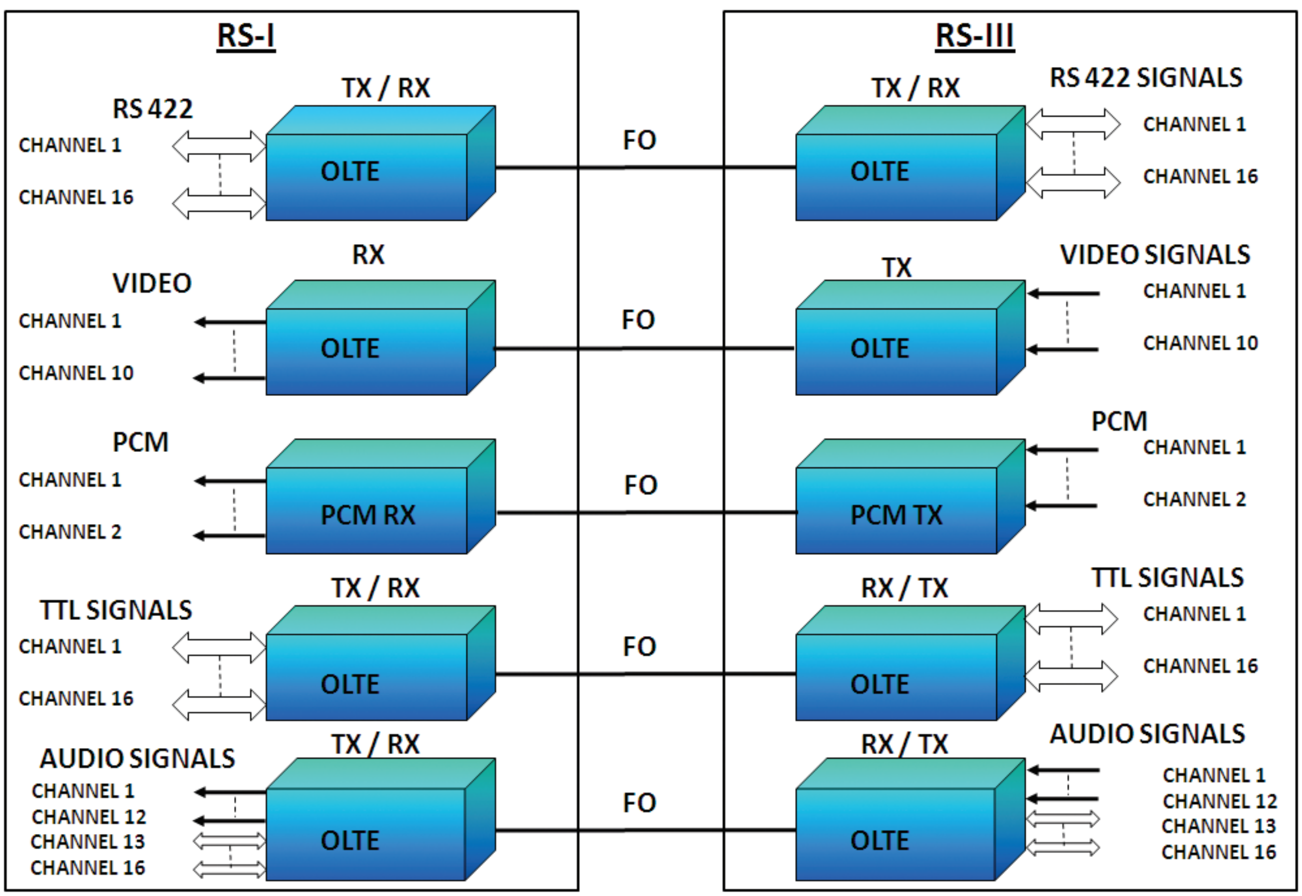

Figure 3. Data communication link schematic.

to extensive testing by a data link analyser. The optical link was tested and validated by a data link-analyser in loop back configuration by transmitting and receiving RS-422 signals at required data rate and comparing errors in transmitted and received data. Video and other interfaces were also tested during the acceptance test. For RS-422, the test was conducted for more than 6 h to enable the link-analyser to transmit 10^{12} bits data without single bit error in transmission[14]. Hence link was cleared for a BER better than 10^{-12}. For performance test, optical link was established between RS-I and RS-III. All equipment on RS-I and RS-III were switched on to carryout endurance test for 48 h as shown in Fig. 3. Link was tested for various operation including system crash test.

6. RELIABILITY PREDICTION

Design and development of power management system of unmanned underwater platform for defence application[2] published by the author is a subsystem of this data link and reliability prediction will be similar. The underwater platform is being controlled by two remote stations, one controls through optical link and other controls through hybrid link. In case one link fails other link will take care of the operation. To increase the reliability and availability of complete systems, redundancy features have been introduced for all the subsystems. Redundancy in subsystems has increased the fault tolerance in the operation of PMS and NMS, which is the combination of series-parallel configuration. This configuration will prevent single point failure. RBDs method for predicting the reliability is used for the re-deployable configuration. A RBD is a graphical representation of how the subsystems of a system are reliability-wise connected. Each block in an RBD represents a subsystem of the overall system that is represented by the RBD. Following are the details of the life distribution data for each sub systems required for RBDs to predict the reliability of the data communication system. The MTBF considered has been taken from the technical literature of the respective systems.

a. RS-Iand II :- Reliability model: Exponential distribution, MTBF: 30000 h
b. OLTE:- Reliability model: Exponential distribution, MTBF: 122640 h
c. Opto-isolator:- Reliability model: Exponential distribution, MTBF: 37037037 h
d. PMS-IandII:- Reliability model: Exponential distribution, MTBF: 30000 h
e. NWS-IandII:- Reliability model: Exponential distribution, MTBF: 100000 h
f. Master switch:- Reliability model: Exponential distribution, MTBF: 4901960 h

The above values were provided as input for RBD and system reliability was calculated. The value is as follows.

Reliability @20000 h = 99.9997%

Reliability @30000 h = 99.9990%

RBD for the re-deployable configuration is as shown in Fig. 4.

7. CONCLUSIONS

(i) It is possible to establish high bandwidth data link for transmission of real time data from underwater platform to control station by laying fibre optic cable in high sea

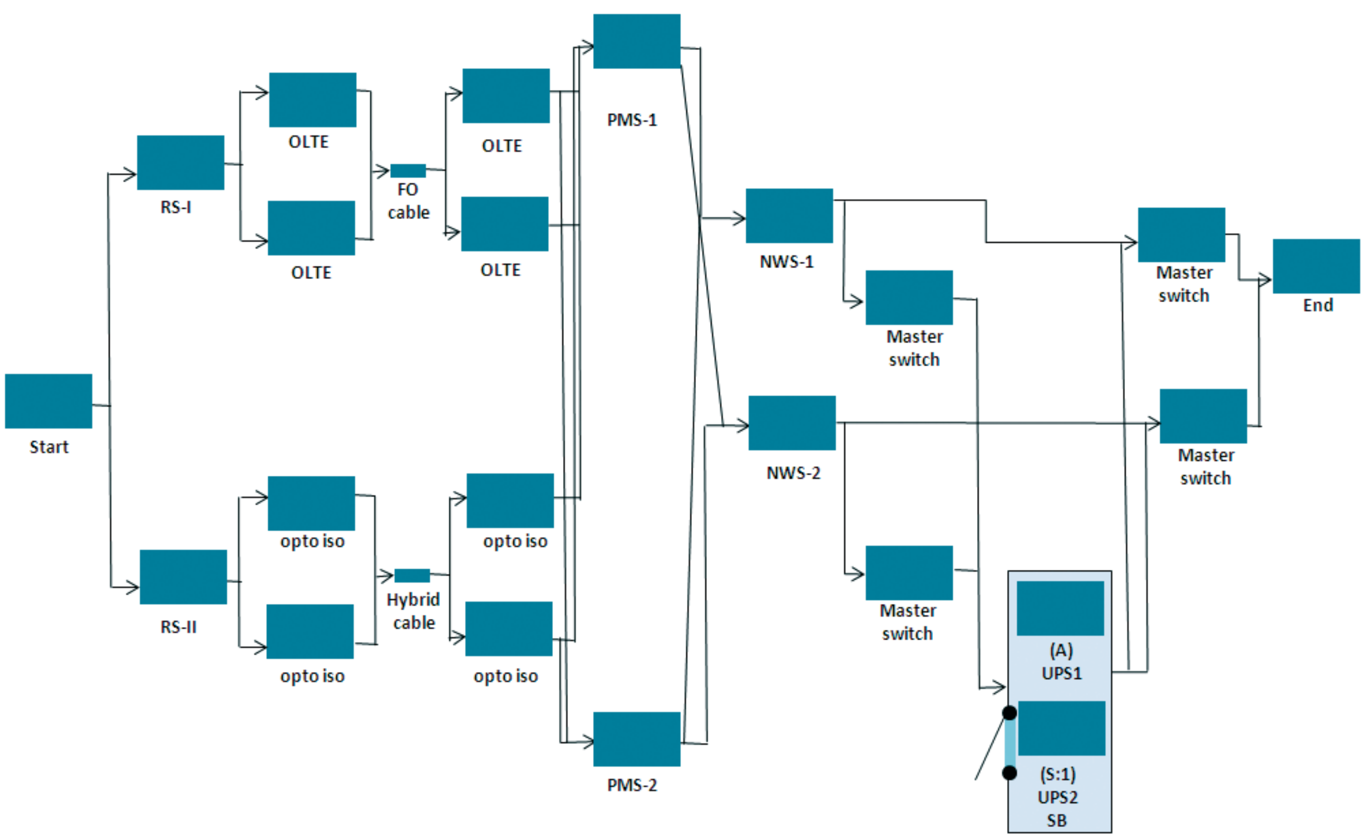

Figure 4. Reliability block diagram.

for a short distance for sea state less than one, beyond this though it doesn't affect the specification of cable, it is extremely difficult to handle cable in high sea. Test results of various subsystem suggest that high bandwidth requirement of data communication was met successfully.

(ii) Installation and operation is simple and link can be retrieved easily after the test. The link is based on underwater connector not on cable glands, dismantling and maintenance of link is easier.

(iii) It is possible to record data at RS-III and RS-II and also transmit the data by radio communication from RS-II to RS-I at limited bandwidth for a longer distance.

(iv) This system has been successfully used for one of the defence application and similar type of implementation scheme has not been reported elsewhere. This scheme provides almost unlimited bandwidth for data transmission.

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Contribution in the current study, he is designer of the system. System has been developed and realised by him.

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Contribution in the current study, he has given many valuable suggestions in the current study and reviewed the work.