Flying Plug: A Small UUV Designed for Submarine Data Connectivity (U)

Steve Cowen

NCCOSC D746, Advanced Concepts Branch, San Diego, CA 92152

Abstract

(U) In the context of an information-based society the ability to reliably retrieve, transfer and process large quantities of data in a timely fashion becomes a critical technology issue. In the context of integrating submarine offboard sensors and physically supporting data connectivity with terrestrial networks: reliable, high bandwidth communications ranks as an extremely difficult technical problem. Few operating environments place more limitations on the ability to transfer high bandwidth data than underwater. The conductive medium places strict limits upon RF propagation, visibility greatly restricts the bounds of optical transmission and noise, ray-bending and multipath dominate the acoustic environment. Data transfer rates are usually limited to at most a few kilobits per second unless a hard connection via a cable is established. But adverse logistics inherent with underwater cables and their associated infrastructure often renders a cabled system totally impractical from a technical or economic standpoint.

(U) A small Unmanned Underwater Vehicle (UUV) can provide the means to establish the physical connection required for fiber optic data transfer [2]. A Flying Plug UUV can be launched from a submarine while it is in the vicinity of a cooperative data node. The node can be connected either to an offboard sensor to enhance the platform's situational awareness or can it provide a gateway to a terrestrial network to enhance its communications capabilities. Both the Flying Plug and the submarine deploy spools of fiber optic microcable while transiting: similar to a wire-guided weapon. This permits the submarine to remain fully connected during data transfer while not requiring it to loiter in the immediate vicinity of the underwater node. The UUV docks with the node and establishes a fiber optic data link between the submarine and the offboard data

sensor or communications network while docked. Signal processing and guidance and control functions required during UUV transit are implemented by computers located aboard the support platform via the high bandwidth fiber optic communications channel provided by the microcable. The optical channel subsequently supports high speed data transfer after the vehicle has docked with the node. The Flying Plug can be scuttled after each mission because it is much more difficult to retrieve something than to launch it from a submarine. Partitioning of the hardware and software in this manner keeps the system inexpensive and ultimately permits an expendable UUV.

1.0 Introduction

(U) In many applications the measure of the overall effectiveness of communications is a strong function of the effective data throughput rate of the channel, i.e. its bandwidth as measured in bits per second. In both military and commercial, terrestrial and satellite communications systems effective channel throughputs have been increasing geometrically in recent years such that data rates in the megabit and gigabit per second range are now becoming commonplace. Data transfer requirements, in turn, have simultaneously expanded to more than meet this rapid improvement in technology. Large file transfers, high resolution video, multimedia and interactive data networks can tax today's terrestrial and satellite communications channels to their limits.

(U) Unless a submarine surfaces for the express purpose of extending its antenna mast, current and planned submarine communications systems will continue to rely on inherently low-bandwidth technology such as acoustic modems and submerged ELF antennas to support communications. Such techniques promise effective data throughputs of kilobits per second or less: 4-6 orders of magnitudes below current terrestrial practice. Furthermore, as future data throughput requirements continue to expand these technologies offer no path for improvement, only a tradeoff between bandwidth and range, because ELF and acoustic performance is strictly limited by the basic physics governing wave propagation in a medium. The inescapable conclusion is that, unless alternative technologies are considered, submarines will increasingly be forced to operate at periscope depth with an antenna exposed during operations, reducing covertness and increasing vulnerability. The difficulty of establishing a reliable high-bandwidth communications link from a submarine at depth and speed greatly limits the effectiveness of both offboard submarine sensors and precludes Global Grid access. This in turn limits the submarine's degree of overall situational awareness and its practical utility during joint exercises.

(U) Optical fiber is the only known transmission medium which is capable of transferring gigabits of data underwater over long distances [8]. Fiber optic technology developed during the 1980's enabled reliable torpedo and underwater vehicle (UUV) guidance via expendable, submillimeter diameter fiber optic microcable (FOMC) [5,6,7,10,11,12,13]. A problem remains, however, in establishing dynamic underwater connectivity required to utilize FOMC for other than point-to-point applications. In a wide class of missions, a submarine needs to establish a high-bandwidth communications link, transfer data and break off the link repeatedly. This architecture goes well beyond simply utilizing FOMC as a transmission medium to support point-to-point weapon guidance. This paper discusses an advanced underwater connectivity concept: the Flying Plug, which enables a submarine to establish a physical fiber optic connection with a remote underwater data node upon demand. Prior to discussing details of this technology, some potential applications for Flying Plug will be discussed in the context of both offboard underwater sensors and underwater telephone booths to provide data connectivity of submarines to the Global Grid.

2.0 Data Connectivity with Offboard Sensors

(U) The requirement to support surveillance operations in a tactical vs. a strategic fashion, often in the littoral zone, means that cold-war paradigms often cannot be employed effectively. In the strategic context it proved adequate to deploy a fixed (or surface towed) acoustic infrastructure around the globe and maintain these sensors for decades. This approach dictated a hard connection to a shore processing site (or surface ship) via an armored coaxial cable. In a tactical context this approach simply is not possible any more, given the fact that diesel-electric submarines cannot be reliably detected at great distances. Also, the extended staging and installation time required to deploy such strategic surveillance systems, which was acceptable during the cold-war, is unrealistic today given the fact that we often do not even know who our next adversary will be much less the specific theater of combat. Additionally, third world adversaries are likely to rely heavily on mine warfare, which has the potential to exact an unacceptable cost upon the Navy for many types of essential missions such as amphibious operations. It is apparent that to be viable in a tactical context future surveillance systems must be rapidly deployable, applicable to more than just ASW and achieve reliable operation for periods ranging from a few weeks to one year.

(U) The deficiencies above have been recognized by the Navy and rapidly deployable surveillance systems such as the Advanced Deployable System (ADS) are being developed to address the situation [8,9]. Significant progress has been achieved in the area of wet-end sensors, trunk cable miniaturization and data multiplexing. However, little progress has been evident in the critical area involving the transfer of data collected by the surveillance system to the ultimate user. Usually an armored cable to shore is depicted to achieve this end, although it is doubtful that the old paradigm will be that effective in a world where economic blackmail is often the reward for cooperation with the United States. The Gulf War has taught us that even friendly airspace is not always ours for the asking and friendly shores can be quite distant from the theater of operations. Pop-up buoys linked to satellites are sometimes depicted as an alternate means to convey data, but the Gulf War also taught us that satellites become heavily overloaded during a conflict and bandwidth comes at a premium. Additionally, the high data throughput of an ADS puts stringent limitations upon the types of buoy antennas and communications satellites required to support this scenario even if sophisticated data compression schemes are employed. This deficiency can be viewed as a symptom of a pervasive generic data connectivity problem.

(U) A submarine has the unique ability to serve as the recipient of externally gathered surveillance information to enhance its operational awareness and also as a superb surveillance platform in its own right. Moreover, submarines are highly mobile and covert. Integration of a submarine with unattended offboard sensors (Figure 1) further enhances this capability but will necessitate dynamic underwater connectivity if high data transfer rates are to be sustained. From a technological standpoint the ability to effectively link submarines with offboard sensors is primarily limited by communications considerations [1,3,4].

3.0 Global Grid Connectivity

(U) With the advent of Internet and the global data transmission network consisting of fiber optic cables and communications satellites the requirement to be able to pass data around is becoming increasingly important. The Global Grid will eventually reach into literally all corners of the globe. A map of the ocean floor a few years hence will be crisscrossed with numerous high bandwidth fiber optic cables linked to high speed ATM data switches, enabling data packets to be quickly routed in an arbitrary manner between all circuits (Figure 2). In the future there will be few places on the land or in the air where global data connectivity cannot be readily accessed.

(U) Underwater access to the Global Grid is another matter entirely, even though ironically a majority of high speed telecommunication trunk cables physically lie on the floor of the ocean. Unless provision is made prior to telecommunications cable deployment to tap into these undersea cables it will not likely prove to be practical to access them in the future. Flying Plug technology has the potential to act as a positive driver for this situation, however, since its implementation would permit submarines and other platforms to connect and disconnect from a nearby undersea data node at will. One might imagine undersea telephone booths installed near potential hot zones and used for the purpose of submarine and unattended sensor communications (Figure 3). The undersea data node would be joined via a spur cable to the nearest preinstalled tap point on a telecommunications cable of opportunity [9]. Data routing from the tap point to all other locations would then be handled by commercial means.

4.0 Testbed Flying Plug Vehicle Subsystem

(U) A testbed Flying Plug vehicle has been constructed by NRaD (Figure 4) [14]. It is sized so that, conceptually, it could be launched from the trash disposal unit of a nuclear submarine. The testbed vehicle is nine inches in diameter and 50 inches in length. It separates in the middle into two independent sections. The vehicle is ballasted such that it is neutrally buoyant in seawater. It has a design depth of 1000 feet, carries a 4500 foot coil of FOMC to support communications and has a dual speed propulsion controller which drives a single 0.1 HP thruster, providing speeds of 2.5 and 3.5 knots --- in both forward and reverse. Steering is by means of airfoil shaped fins placed aft in the propeller wash, which gives the vehicle good steering authority and excellent stability at low speeds. The fins are operated by model airplane servos via bellcranks. The free-flooded aft hull section contains the thruster, steering mechanism, recovery systems and FOMC coilpack and the forward section with free-flooded lexan nose bumper contains the batteries, sensors and electronics. A transparent acrylic section in the forebody hull provides a window for the data couplers and allows the system status LED's to be viewed. Hotel power for the vehicle is sequenced on by momentarily activating a magnetic reed switch located in the forebody. The testbed vehicle incorporates an emergency recovery system consisting of a fail-safe drop weight, a 9 KHz pinger, a flashing strobe light and an attachment bail which permits recovery by a trained NRaD California sealion if this should ever prove to be necessary.

4.1 Fiber Optic Telemetry Subsystem

(U) Three independent data telemetry signals are transmitted over the single optical fiber in the FOMC using wavelength division multiplexing. The command/control downlink is implemented from the control point to the vehicle at a wavelength of 1550 nm and an identical status uplink is implemented from the vehicle to the control point at 1330 nm. The latter has two modes: command/control (identical format to the downlink) and data-transfer (digital data is transferred from the Socket to the Flying Plug via the data couplers and sent back to the control point). Additionally, a second uplink transmits a color video signal from a CCD television camera located in the nose of the vehicle at a third wavelength, 850 nm, to aid in evaluation and debugging of the prototype system.

(U) The data multiplexing scheme is based upon Tri-Quint™ GaAs Hot-Rod parallel-serial-parallel chipsets. This greatly simplifies the electronics in the vehicle and topside interfaces by using a scheme which we have dubbed spatial multiplexing. 40 bidirectional lines (each having an effective throughput of about 3 Mbits/second) are serialized and transmitted over the fiber optic link at 400 Mbits/second by each Hot-Rod chip. At the receiving end of the link the serial signal from the optical fiber is converted back into a replica of the original parallel format. This is equivalent to having 40 bidirectional 3 Mbit/second digital data links between the vehicle and the

Socket. The data lines are used in the Flying Plug to transmit switch closures, serial RS-232 data, parallel data to and from DAC's and ADC's, high-speed serial data from the sigma-delta ADC in the optical docking system, the hard limited analog acoustic signal and even the pulse width modulated servo position signals; all with negligible signal degradation and minimal interface complexity.

4.2 Testbed Socket Subsystem

(U) Several docking station designs were considered during the initial phases of the Flying Plug project including funnels, vertical poles and buoyed riser cables. While each approach has advantages and disadvantages, a funnel was chosen for implementation with the testbed system due to the relative ease of achieving physical alignment between the Flying Plug and the Socket after docking -- which greatly facilitates data transfer. The main disadvantage of a funnel is the requirement to orient it so that the vehicle tends to approach the funnel mouth with its nose pointed into the current. Otherwise a vehicle bow thruster is required for docking in high currents, which is not consistent with the requirement for low recurring cost in an operational Flying Plug system.

4.3 Acoustic Homing System

(U) High frequency acoustic short baseline homing is used to guide the Flying Plug vehicle into visual range of the Socket (Figure 5). Worst case occurs for submarines and UUV's (when they have not taken a recent GPS fix) where a 1000 foot acquisition range is required. Use of frequencies in the 200 KHz range provides covertness beyond 1500 feet due to the high acoustic attenuation of seawater at this frequency. The Socket is a cooperative transponder using a three element array which determines and transmits the azimuth of the received signal. The Flying Plug knows its depth by virtue of its own sensors, receives it's azimuth from the socket transponder and infers it's range from the transponder's time-of-arrival delay; giving the Flying Plug its polar coordinates re: the mouth of the Socket, in the Socket's frame of reference, with each ping.

(U) The use of a high acoustic frequency and low ping duty factor results in inherent covertness and LPI due to the high acoustic attenuation coefficient of seawater above 150 KHz. One acoustic watt emitted by an omnidirectional transducer is a reasonable compromise between covertness, implementation difficulty and received signal-to-noise ratio. The configuration selected uses three transducers on the docking station and one on the vehicle. Because the acoustic transducer is the single most expensive component on the Flying Plug vehicle this partitioning is consistent with the goal of achieving minimum recurring cost.

(U) Modeling indicates that operation in reasonably shallow water is possible if the ping is short and acoustic baffles are employed at both ends to attenuate multipath. Testing of the Flying Plug prototype in San Diego Bay (which is seldom deeper than 50 feet) is a requirement for budgetary reasons, therefore this geometry determined the parameters of the acoustic homing system. A pulse width of 700 microseconds is used as a compromise between the signal processing gain, using a replica correlator for detection, and multipath rejection. The Flying Plug transducer is baffled in such a manner that it cannot acoustically see the surface and the Socket array is baffled such that it cannot see the bottom. An operational range limit of 600 feet in 40 feet water depth was predicted analytically before multipath interference occurs. 1200 feet maximum range was predicted in deeper water and is limited by the signal-to-noise ratio of the received ping.

(U) Pulse position modulation is employed to encode the azimuth received at the Socket for transmission to the Flying Plug during the transpond cycle for simplicity and robustness. Two slightly offset frequencies are employed to suppress reverberation when the pings are received by the Flying Plug. All received acoustic signals are hard limited, allowing transmission as digital levels over the optical fiber. The onboard receiver requires only a preamplifier, passive bandpass filter and comparator at each hydrophone to implement.

(U) Tests conducted from a small boat in about 80-90 feet of water off Point Loma confirmed a maximum range of 1000-1200 feet, as predicted. Azimuth resolution of approximately +/-1 degree was observed at 300 feet separation, degrading to several times this amount at 1000 feet. Tests in 30-50 feet of water in San Diego Bay confirmed that multipath interference limited the maximum range to about 300-600 feet separation. The Bay tests also pointed out that interference from nearby depth sounders on pleasure boats was present at 200 KHz and that false alarms were also evident due to snapping shrimp noise. Postprocessing the bearing data using a digital median filter proved quite effective at removing most of the outlying points from the data stream. To remedy the depth sounder interference problems the operating frequencies were modified to 166 KHz and 171 KHz and a sharp notch was placed at 200 KHz. This modification was easily accomplished because the ping waveforms are generated by a topside computer so that they can be readily altered via software changes. Because signal generation and detection is controlled by software the potential exists for more complex ping waveforms such as chirps and pseudo-random sequences to be employed, without modifying the vehicle hardware, should enhanced LPI or antijamming properties need to incorporated at a later time.

(U) The acoustic system in Flying Plug has two operating modes: homing mode and fathometer mode; which mode operates is determined solely by the algorithm employed to interpret the data topside. The homing algorithm gates out the bottom-bounce return and listens for the transponder while the fathometer algorithm interprets the bottom-bounce return and ignores the transponder signal. The latter mode is intended to calibrate the pressure transducer on the vehicle in order to accurately estimate the vehicle’s altitude above the seafloor because altitude is the actual metric required for docking, not depth below the surface. Because the Socket is infrastructure which is surveyed during installation the bathymetry is well-known.

4.4 Optical Docking System

(U) Optical guidance is employed for final approach and docking (Figure 6). The optical docking sensor is based upon a hyperfocal lens and quadrant detector, similar to a Sidewinder missile, which provides an error signal which is processed topside and used to point the nose of the Flying Plug vehicle toward an incandescent light source in the mouth of the Socket docking funnel. The light source is chopped at 40 Hz to permit the tracker to distinguish it from sunlight in shallow water, where all testing to date has taken place. Hand off between acoustic homing and optical docking occurs when the optical signal is detected: all guidance beyond this point is optical but the acoustic system remains operating during final homing to provide range information.

(U) The Flying Plug optical tracker is designed and constructed to fit within a 2.5 inch diameter cylinder and optimized signal processing software has been designed and implemented in the topside computer to process its raw signals. Low noise electronics is utilized in the front-end to improve sensitivity and active linear phase bandpass filters make the detector less susceptible to filter ringing caused by noise. Analog to digital conversion is performed on-card in two switchable gain ranges using a 22 bit serial output delta-sigma ADC for wide dynamic range.

(U) The optical docking system has two operating modes: detection of the presence of the optical docking beacon and tracking of the position of the beacon. A LabVIEW simulation implemented on a Macintosh computer was used to develop an optimized docking beacon detection algorithm based both upon both adaptive energy detection and spatial light distribution cues from the quadrant detector. The algorithm has a very low probability of false alarms and rejects forward scatter, which permits it to be used with confidence to determine whether a valid situation exists for a hand off to occur from acoustic to optical guidance mode. After development the algorithm was implemented on a dedicated single-card computer located topside.

4.5 Latching and Data Transfer Systems

(U) The vehicle flies into the mouth of the docking funnel where it is captured by a mechanism controlled by the Socket (Figure 7). The Flying Plug is retained in the funnel by means of a pair of pins which are extended into the throat of the Socket upon sensing the presence of the Flying Plug. A bumper at the end of the funnel exerts force against the nose of the Flying Plug forcing two V grooves at the aft of the vehicle to align with the Socket pins. This accurately positions the Flying Plug with respect to the Socket. When data transfer is complete the pins are retracted by the Socket and the Flying Plug backs out and flies away to be either scuttled or refurbished, depending upon the specific mission. A failed Flying Plug would be pushed out of the mouth of the

Socket by a plunger and would fall to the seafloor, preventing a failed vehicle or one with a broken FOMC from jamming the Socket mechanism, which must be reused.

(U) Data transfer is by means of optical couplers, which are arrayed radially around the Flying Plug forward midbody. These transmit and receive light through transparent windows in the hulls of the Flying Plug and Socket. Multiple data channels and bidirectional communications is fully supported by using multiple optical couplers. Each pair of couplers and their associated interface electronics correspond to an electro-optical repeater with an optoisolator formed by the data couplers inserted between the receiver and transmitter sections: when mated, the optoisolator passes data between the sections, completing the data link. Advantages are that physical alignment tolerances are not critical, considerable fouling on the Socket window can be tolerated with no bit error rate degradation (because only the presence of a 1 or 0 needs to be detected, not much light is required) and a high data rate consistent with fiber optic telemetry is supported using the same coding formats as are used with the optical fibers themselves.

(U) The Flying Plug testbed vehicle carries 4500 feet of coiled FOMC which is deployed during transit. The propulsion battery provides adequate energy to deploy all the communications coil. Vehicle power is provided by rechargeable NiCad battery packs. At a speed of 3.5 knots a typical 1000 foot docking run requires only a few minutes of thruster operation. Enough energy is provided by a separate battery to permit several hours of hotel operation to support data transfer. Data couplers for transmitting digitized color video, requiring a data rate of 100 megabits/second and 10baseT ethernet data, requiring 10 megabits/second, have been demonstrated. Data couplers supporting other data formats are possible. The testbed vehicle carries a color television camera transmitting video over the FOMC link during operations (the camera is only useful in shallow water where sunlight is available) for mission monitoring purposes.

(U) In order to keep the recurring cost of a Flying Plug vehicle low and the system capability flexible all signal processing functions are bidirectionally remoted to the topside computers using the deployed fiber optic communications link: the Flying Plug vehicle is designed to be dumb -- dedicated desktop computers which are physically located at the control location manage all vehicle functions. Acoustic waveform generation and replica correlation detection is accomplished by one computer, optical guidance by another, mission control by the third. The vehicle contains only A to D and D to A interfaces, a single acoustic transducer with power amp and preamp, data couplers, batteries, propulsor, fin servos and sensors. By design, the Flying Plug vehicle provides remote, mobile infrastructure for the system --- not signal processing. This makes software development and system evaluation much easier than with traditional UUV's and holds down both the nonrecurring and recurring costs. This partitioning of functions also permits easy upgrades and mission modifications to be made because it simply involves changing software residing on the remote computers.

Acknowledgements

The author wishes to acknowledge the past and present members of the NCCOSC Advanced Concepts Branch who played significant roles in the Flying Plug and Distributed Surveillance Sensor projects. Specifically, without the dedicated assistance of James Peugh, Susan Briest, James Dombrowski, Joseph Aboumrad, William Marn, Susan Morales, Michael Kuntzman and Matthew Scallon it is unlikely that a successful technology demonstration of this concept could have taken place in a timely fashion. Also, the ONR sponsors of this work: A.J. Faulstich, T.B. Curtin and D. Davison are recognized for their dedication and support.

References

1. Curtin T., Bellingham, J. G., Catipovic, J., and Webb, D., *Autonomous Ocean Sampling Networks*, in Oceanography, Vol. 6, No. 3, pp 86-94, 1993.

2. Cowen, S., Briest, S., and Dombrowski, J., *Application of Robotic Undersea Vehicles to Underwater Data Connectivity*, presented at PACON 96, Honolulu, HI on 20 June 1996.

3. Walton, J., *Evolution of a Search System: Lessons Learned with the Advanced Unmanned Search System*, NRaD TR 1529 of Nov 1992.

4. Walton, J., *Advanced Unmanned Search System*, IEEE/OES Oceans '91 of October 1991

5. Kono, M.E., Brininstool, M.R., Cowen, S.J., *Fiber Optic Telemetry for the REGAL Torpedo*, NOSC TR-920 rev. A of 1 May 1984.

6. Briest, S.G., Hampton, S.L., Peugh, J., Cowen, S.J., *Fiber Optic Microcable Winding of Deployment Packs*, NRaD TR-1444 of 1 Dec 1991.

7. Dombrowski, J.H., Kerr, W., Cowen, S.J., *Development and Fabrication of the Fiber Optic Microcable*, NRaD TR-1620 of 1 Oct 1993.

8. Brininstool, M.R., Evans D., *Advanced Deployable Surveillance (ADS) Optical Technology Assessment*, of 25 Oct 1993.

9. Young, C.M., *Sea-Floor Survivability and Hazard Susceptibility of Small-Diameter Fiber Optic Tethers*, NRaD TR-1625 of 1 Nov 1993.

10. Cowen, S.J., Young, C.M., Dombrowski, J.H., *Fiber Optic Microcable Produced with Radiation-Cured Composite*, US Patent 5,259,055 of 7 Jul 1980. (3)

11. Cowen, S.J., Dombrowski, J.H., Young, C.M. and Kono, M.E., *Process for Fabricating Fiber Optic Microcable using Radiation-Cured Composite*, Navy Case 70,706 of 21 Jul 1987.

12. Cowen, S.J., Young, C.M., *Structural Composite Material Utilizing Radiation-Cured Polymer*, Navy Case 70,676 of 27 Oct 1988.

13. Cowen, S.J., Dombrowski, J.H., and Kerr, W., *Fiber Optic Microcable Produced with Fiber Reinforced Ultraviolet Light Cured Resin and Method for Manufacturing Same*, Navy Case 75,320 of 5 Oct 1993.

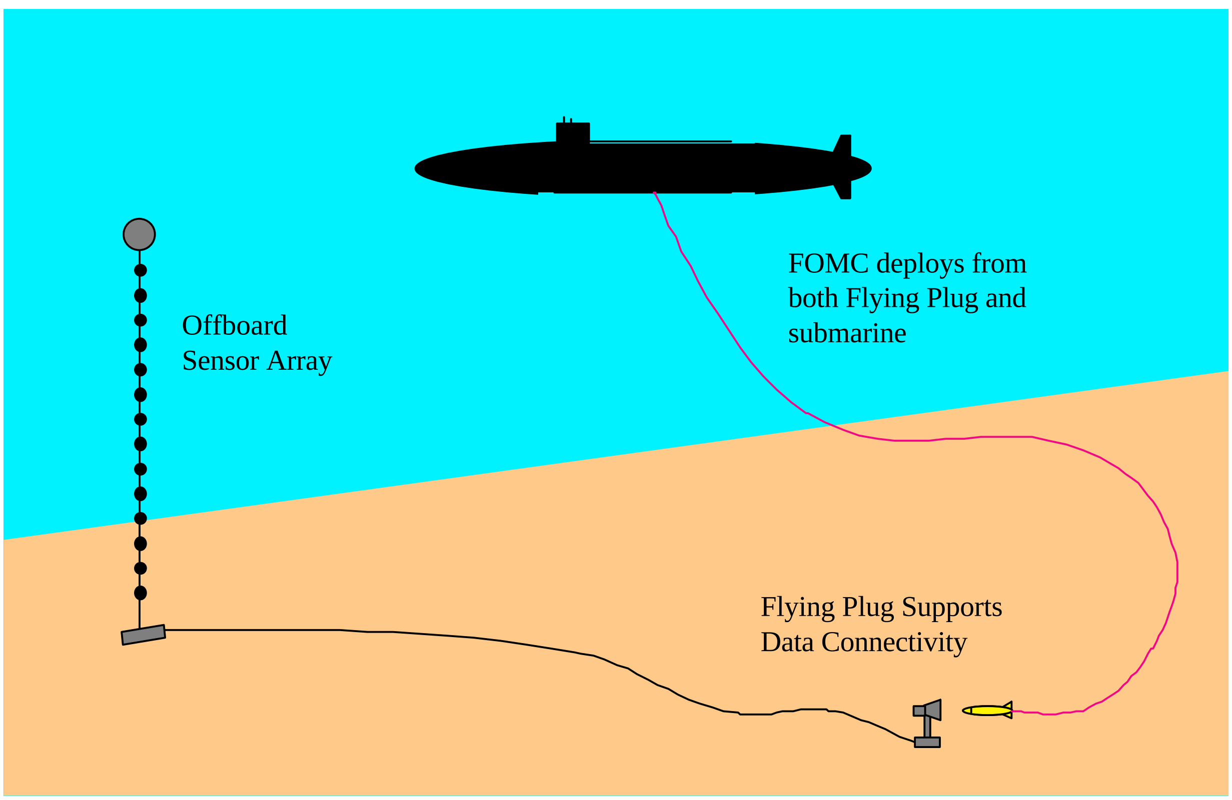
14. Cowen, S., *Distributed Surveillance Sensor Network*, Final report for ONR-3220M of October, 1996.

Author Biography

Steven J. Cowen received his Ph.D. in Electrical Engineering from the University of California at Santa Barbara in 1974. He currently heads the Advanced Concepts Branch of the Ocean Technology Division at the Naval Command/Control and Ocean Surveillance Center in San Diego, California. His group of scientists and engineers are tasked with the concept, development, demonstration and transition of state-of-the-art fiber optic technology relevant to US Navy undersea applications. The Advanced Concepts Branch has spearheaded a number of advanced technology demonstrations based upon high-payoff emerging technology. Dr. Cowen is a member of the review board of *Fiber and Integrated Optics* and holds numerous patents and several awards including the Federal Laboratory Consortium Award for Technology Transfer.

Figure 1

Offboard Sensors Can Augment the Capabilities of a Submarine



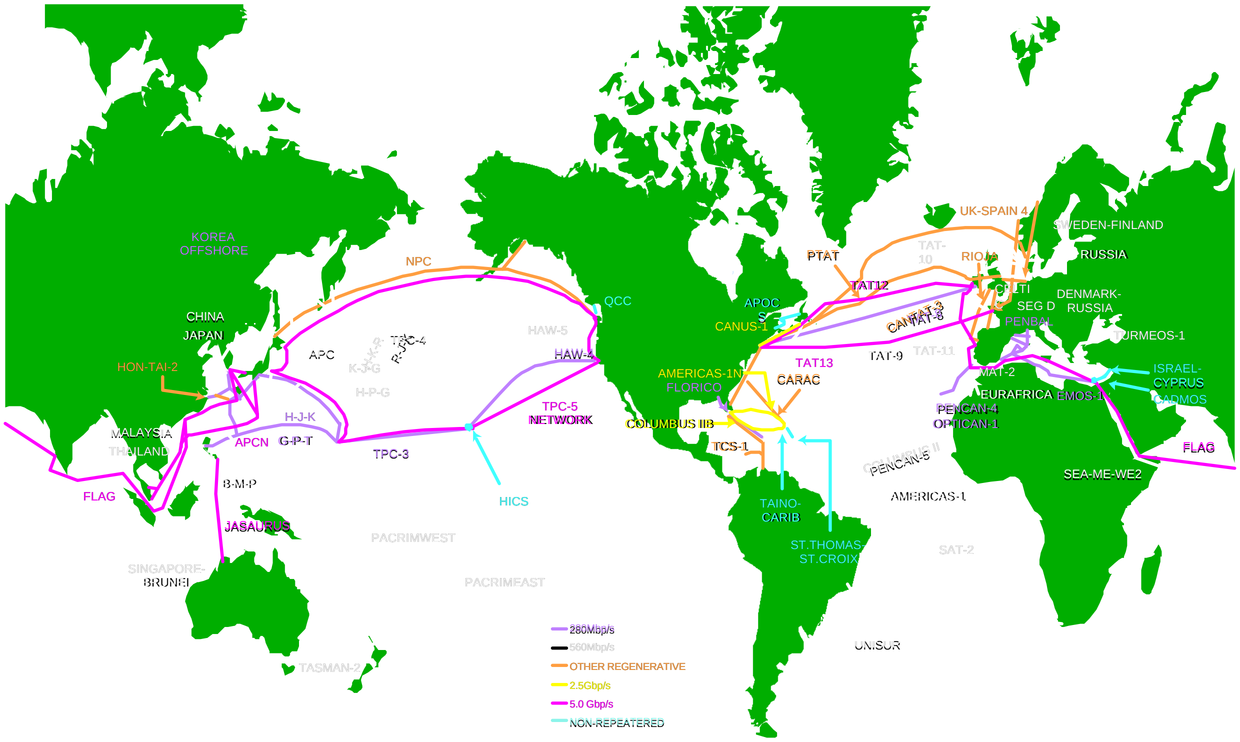
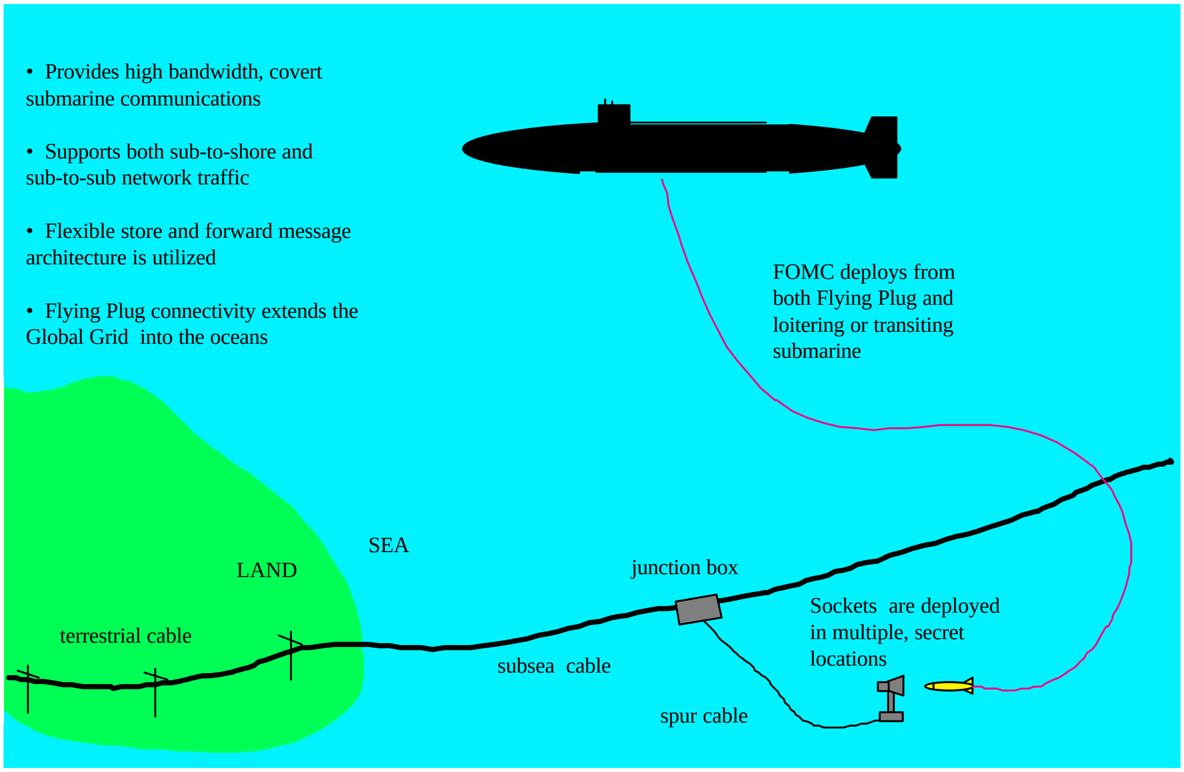


Figure 2 (U) Routes of Transoceanic Fiber Optic Cables

Figure 3

Underwater Telephone Booth Accessed by Flying Plug



NRaD

Prototype Flying Plug Vehicle

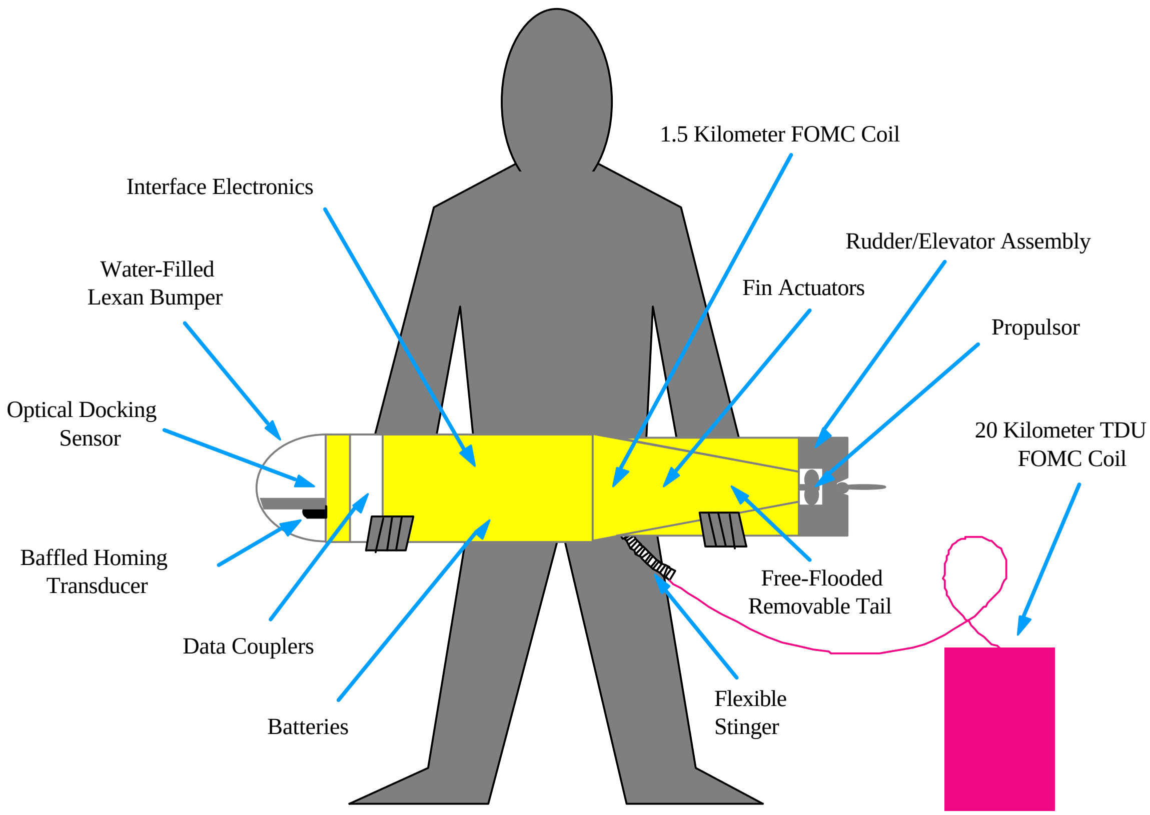


Figure 5 (U) Acoustic Homing System

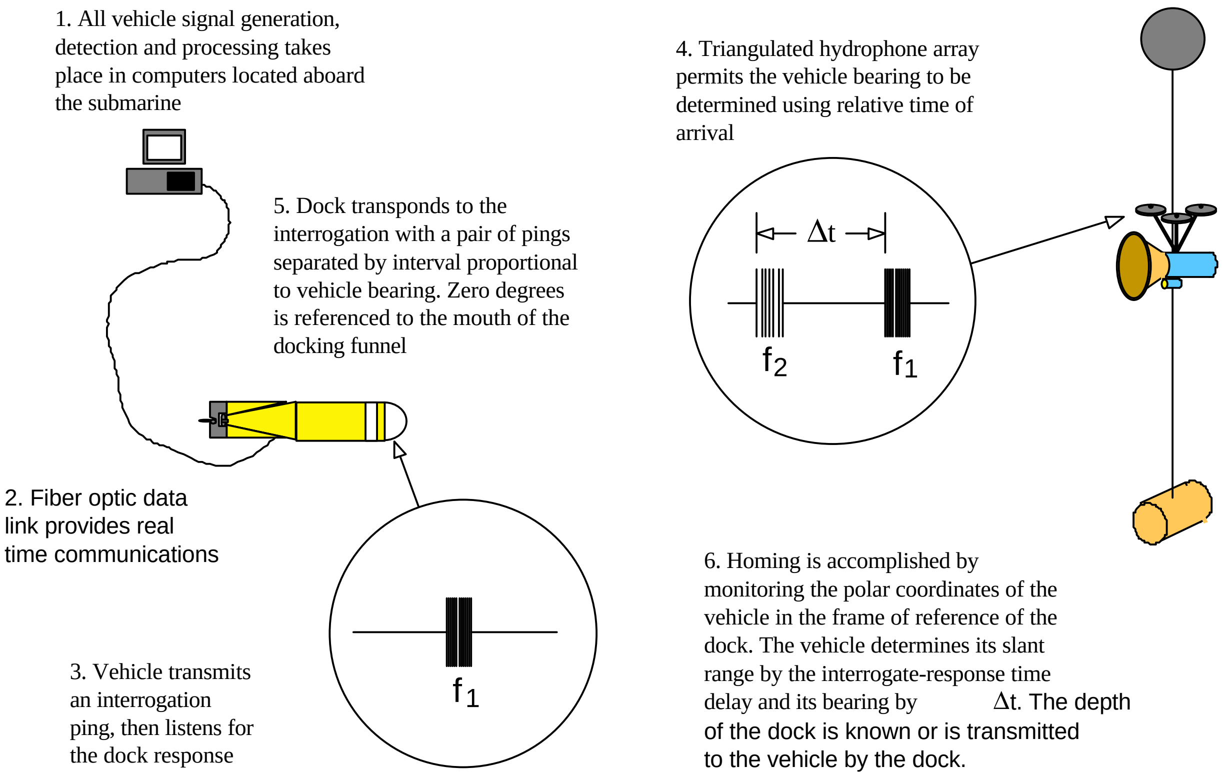
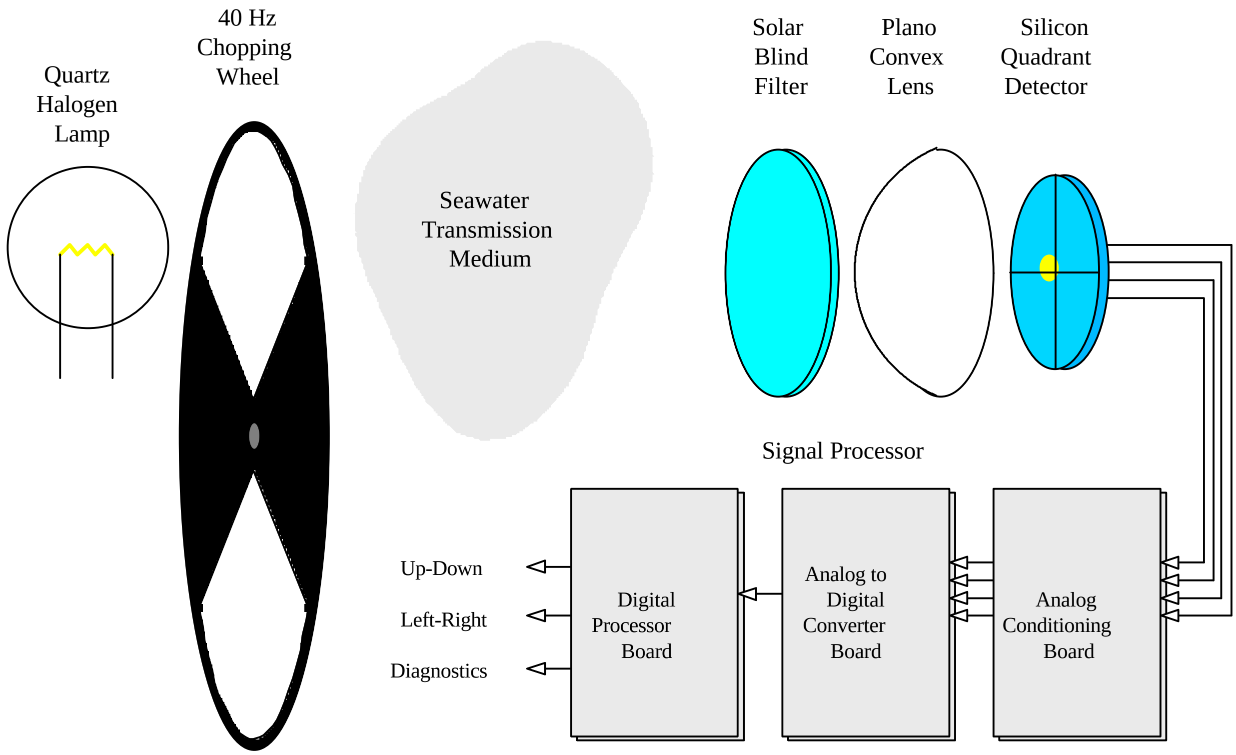
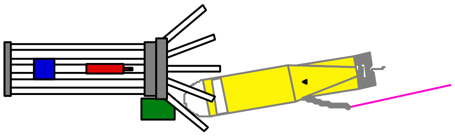


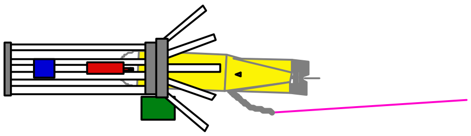
Figure 6 (U) Optical Docking System



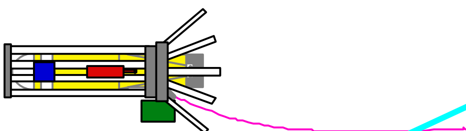
Flying Plug Entering Underwater Socket
Latching Mechanism Details
Data Coupler Alignment Details



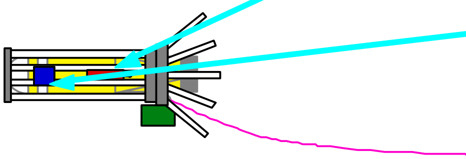
Track on Docking Beacon



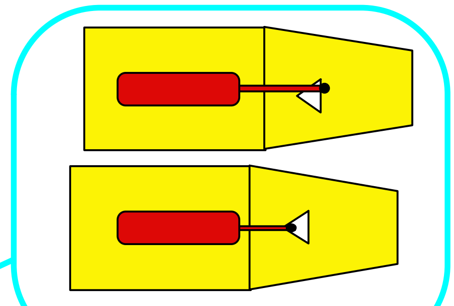
Skid into Funnel Throat



Thrust to end of Cage



Engage Alignment Latches



Latching Mechanism

Data Coupler Alignment