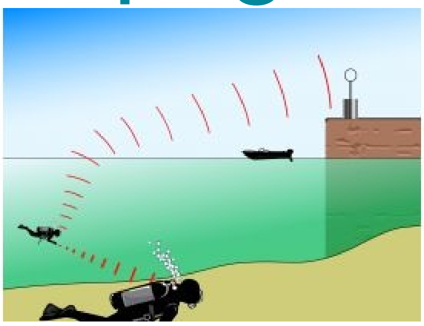
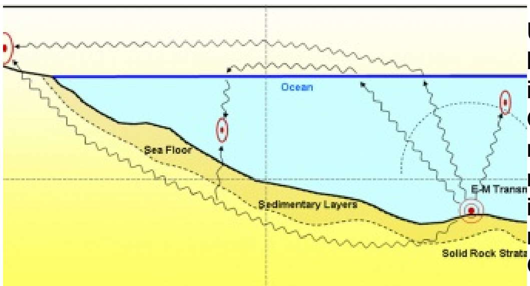
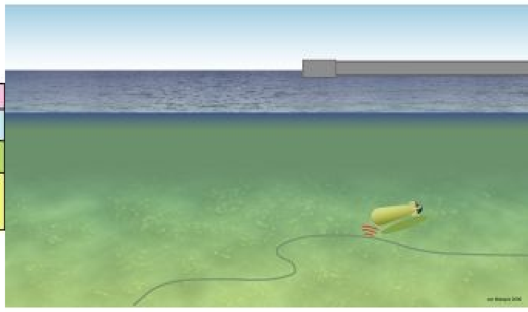
RE-EVALUATING WIRELESS CAPABILITIES

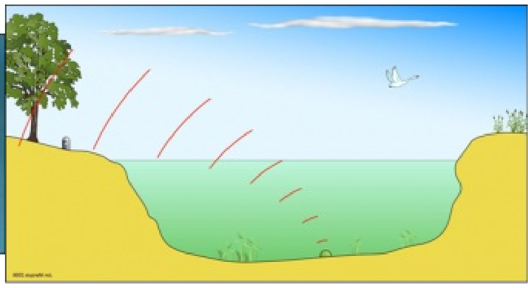
Technology in Focus: Underwater Electromagnetic Propagation

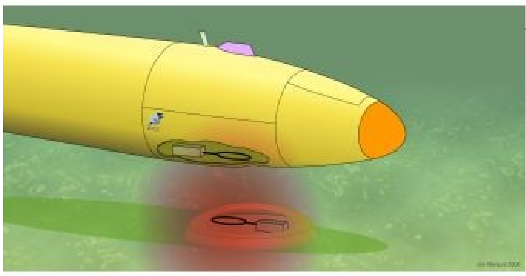




	0.2 m	1-2 m	10 m	50 m	200 m
Seawater	10-100 Mb/s	1-10 Mb/s	20-60 kb/s	1-10 kb/s	50-100 b/s
Freshwater	10-100 Mb/s	5-20 Mb/s	100-200 kb/s	3-10 kb/s	100-200 b/s
Applications	Contactless connector replacement for fast data transfer	Data capture from logging devices to AUV	Diver voice and low frame rate video	Image transmission, networking	AUV control, diver synthesised voice, data logging







Underwater wireless communications links have almost exclusively been implemented using acoustic systems. Optical links have proved impractical for many applications. Although underwater radio links were experimentally evaluated in the pioneering days of radio, they did not meet the requirements of the time. Given modern operational requirements and digital communications technology, the time is now ripe for re-evaluating the role of electromagnetic signals in the underwater environment.

Background

Underwater electromagnetic communications have been investigated since the very early days of radio, and again received considerable attention during the 1970s. Then terrestrial radio typically delivered manual digital communications (Morse code) or full bandwidth analogue voice communications over long range, and research was aimed at delivering these types of service in the underwater environment. In fact, the Extremely Low Frequency (ELF) submarine communications system is believed to be the only successfully deployed subsea electromagnetic application. This system operated at 76Hz for the US system and 82Hz in the Russian system and allowed transmission of a few characters per minute across the globe. It implemented a one way 'bell ring' to call an individual submarine to the surface for higher bandwidth communications using terrestrial radio. Through water, full-bandwidth, long-range, analogue voice communications were found to be impractical and there rapidly developed a 'perceived wisdom' that electromagnetic signals had no applications in the underwater environment.

Electromagnetic

In the digital era we have become familiar with the benefits of short-range, high-bandwidth communications systems such as Bluetooth. At the same time, the oil industry and military operations have changing requirements that have created demand for reliable, connectorless short-range data links. An initial investigation revealed that electromagnetic signalling, coupled with digital technology and signal-compression techniques, had many advantages that made it suitable for niche underwater applications.

Theory

Electromagnetic propagation through water is very different from propagation through air because of water's high permittivity and electrical conductivity. Plane wave attenuation is high compared to air, and increases rapidly with frequency. With a relative permittivity of 80, water has among the highest permittivity of any material and this has a significant impact on the angle of refraction at the air/water interface.

Conductivity of seawater is typically around 4S/m, while nominally 'fresh' water conductivity is quite variable but typically in the mS/m range. At-tenuation of em signals is much lower in fresh water than in seawater, but fresh water has a similar permittivity. Relative permeability is approximately 1, so there is little direct effect on the magnetic field component. Loss is largely due to the effect of conduction on the electric field component. Propagating waves continually cycle energy between the electric and magnetic fields; hence conduction leads to strong attenuation of electromagnetic propagating waves

Faster than acoustic

Above 10kHz, electromagnetic propagation is more than a hundred times faster than acoustic. This has import-ant advantages for command latency and networking protocols, where many signals have to be exchanged. Doppler shift is inversely proportional to propagation velocity, so is much smaller for electromagnetic signals.

Another important consideration is the effect of the air to water interface. Propagation losses and the refraction angle are such that an electromagnetic signal crosses the air-to-water boundary and appears to radiate from a patch of water directly above the transmitter. The large refraction angle produced by the high permittivity launches a signal almost parallel with the water surface. This effect aids communication from a submerged station to land and between shallow submerged stations without the need for surface repeater buoys.

The air path can be a key advantage. For example, if two divers are 1km apart at 2m below the surface, attenuation will be significantly less than anticipated from the 1km through-water loss. In comparison, acoustic signals cannot cross the water-to-air boundary, so 1km through-water loss would apply. A similar effect is seen at the seabed, where conductivity is much lower than the water. The seabed is an alternative low-loss, low-noise, covert communications path. Figure 2 illustrates the propagation paths that can be exploited for communications. In many deployments a single propagation path will be dominant.

Loop antennas

Submarine ELF systems use line antennas trailed by the vessel while submerged, but this system implements ‘receive’ only at the submerged node. Magnetic coupled loop antennas are the most compact practical solution for duplex submerged systems. Loop antennas are directional in nature and this property can be exploited to allow selection of a single propagation path. Alternatively, omni-directional antennas can be implemented by crossing two loops so that their planes intersect at right angles.

Applications

Underwater electromagnetic signals have a range of practical applications in navigation, sensing and communications. Short-range navigation systems can be based on the signal magnitude gradient seen in electromagnetic propagation. For beacon applications, sonar systems must use phase information to sense wave-front direction, and suffer from multi-path effects and pressure gradients. UUV navigation systems based on electromagnetic signals will measure increased signal strength as a direct response to movement towards a beacon, which will enable a very simple, robust control loop. Distributed cables can be designed to radiate an electromagnetic signal along their length. This type of distributed transducer has no equivalent in the acoustic domain. A cable can provide short-range navigation and reduces the range required for mobile communications. This arrangement allows implementation of a 'tram-line' that can be tracked by UUV while allowing periodic excursions. A continuous tram-line is easily intercepted on the UUV's return.

Bandwidth only exceeds that possible using acoustics at very short range. In most applications it is the unique propagation mechanism that delivers a host of niche advantages to complement the use of existing underwater systems.

Advantages

The following are the niche advantages of electromagnetic signalling when applied to navigation, sensing and communications systems:

- crosses water-to-air boundary; long-range horizontal communication using air path, water to air or land without surface repeater
- unaffected by pressure gradient; allows horizontal propagation
- broadband, frequency agile capability; no mechanical tuned parts, as in an acoustic system
- multi-path less of an issue, due to higher attenuation and smaller reflections from the surface and seabed
- distributed transducers; radiating cables can deliver unique navigation and communications functions
- immune to marine fouling which makes long-term deployment of optical systems impractical
- high Joules per bit efficiency; for short-range, high-bandwidth applications high bit rate results in short transfer times, so the system can be very efficient in terms of Joules per bit, extending deployment times for battery-operated equipment
- immune to acoustic noise; operation unaffected by wave action, engine noise or heavy work on intervention UUVs
- potential for high data rates; use of MHz carrier; does not require precise navigation for hard docking of connector-based system; improved reliability vs connectors; avoids marine fouling, particulates and alignment issues seen in laser-based systems

- high propagation speed; low Doppler shift, low propagation delay, especially important for networking protocols requiring multiple exchanges of information for handshake and error checking
- compact, portable units; small antennas deliver acceptable performance
- unaffected by low visibility; sediment disturbed at seabed has no operational effect, while laser systems fail to operate
- immune to aerated water; operation in surf zone, communication through cavitating propeller wash, communication at speed
- covert localised communications; using high-frequency carrier for high attenuation, also close spatial frequency re-use
- no known effects on marine animals; effect of acoustic signals on marine mammals is becoming an issue.

Applications

Consideration of the advantages of electromagnetic signalling has resulted in the following suggested applications that exploit the strengths of this technology:

- real-time control of UUVs from shore, submarines and surface vessels
- wireless through-hull transfer of power and data
- high-speed transfer of data between UUVs and surface vessels
- real-time transfer of sensor data from UUVs when submerged
- communications between UUVs and subsea sensors
- UUV distributed navigation systems for shallow harbours and ports
- UUV docking systems
- subsea navigation beacons; asset location, asset protection
- subsea networks
- data transmission from underwater sensors to surface or shore without surface repeaters
- harvest data from submerged sensors via Unmanned Airborne Vehicles
- communications; UUV to UUV, submarine to UUV, UUV to Unmanned Surface Vehicle, UUV to Unmanned Airborne Vehicles
- diver communications (speech and texting)
- underwater navigation
- underwater sensing.

Development

Wireless Fibre Systems (WFS) has been exploring this area of technology for over two years, in collaboration with a number of government bodies including the UK National Physics Laboratory, several univer-sities and industrial partners. This area has been largely neglected in the digital communications era and WFS has filed ten related international patent applications covering communications, navigation and sensing. Experimental work began in 2004 and has progressed from fundamental propagation experiments through data transmission demonstrations to the point of launching our first communications products in the third quarter of 2006. WFS is currently developing two product ranges of underwater telemetry links.

S1510 Medium Range Communications System

In September 2006 we launched the S1510 underwater em modem. This system has been designed to transmit signals of up to 16kbps over 20m in seawater. At lower data rates, signals can be transmitted over 200m.

The S1510 can provide periodic two-way telemetry updates during a one-year deployment powered from a small battery pack.

This product has been targeted at a variety of applications such as environmental monitoring, AUV real-time control, data harvesting from underwater sensors and diver communications.

Electromagnetic communication links are particularly suited to shallow-water applications where difficult conditions apply or where non-obtrusive solutions are required, such as in rivers, estuarine waters, in harbours or around industrial facilities on the coast or offshore. Signals pass through ice with low attenuation, so all-year data collection is possible even when surface water is frozen.

S5510 Short Range, Broadband Electromagnetic Communications

The end of 2006 will see the launch of the S5510, a broadband electromagnetic telemetry link aimed at customers who require transfer of large amounts of data (1-10Mbps) over short distances (<1m) under water. This has been designed to support the rapid harvesting of data from underwater sensors by UUVs, with-out the need for a hard docking and at very high Joules-per-bit efficiency. It provides duplex operation with Ethernet bridge functionality. In practice, each deployment has unique requirements. While the S5510 and S1510 platforms provide the bulk of the system functionality, each solution has uniquely to balance parameters such as antenna design, transmit power, duty cycle, data bandwidth, antenna size and local noise sources to achieve an optimised solution for the specific application.

Concluding Remarks

Communications technology and operational requirements have radically changed since underwater electromagnetism was first evaluated. Wireless Fibre Systems has pioneered commercial developments in this area and has launched the world's first underwater em communications product with unique capabilities. We believe the impact of this technology will prove disruptive in a broad range of industries, including defence, offshore oil & gas and environmental monitoring.