No longer through the looking glass: Submarine optronic masts transform the above-water picture

The growing maturity and increasing performance of non-hull penetrating optronic mast systems are gaining the appreciation of submarine operators and designers alike. *Richard Scott* reports on the latest developments

The image of a steely eyed submarine commander raising a periscope to search for prey above is classic celluloid. Yet, it also bears testament to the fact that for more than a century, submarine commanders remained wholly dependent on direct-view optical periscopes to gain an appreciation of the above-water situation while submerged.

HMS Ambush pictured in the Clyde approaches. One of the two Thales CM010 optronic masts serving the boat's visuals system is raised. (Royal Navy)

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These opto-mechanical devices evolved over time to incorporate improved optics, the introduction of electrical drives, and line-of-sight stabilisation. From the 1970s onwards came the initial introduction of adjunct electro-optical (EO) sensors - such as lowlight TV image intensifiers, and thermal cameras - into conventional daylight periscopes so as to improve performance at night or

in conditions of degraded visibility. However, these sensors were still slaved to the direct-view optical line of sight, and as previously, their output was presented to the commander in the eyepiece at the base of the periscope.

Over time, the remote-viewing potential afforded by EO sensor packages was progressively exploited by the introduction of supplementary imagery displays elsewhere in the control room, and then by decoupling the sensors entirely from the direct-view optical channel. This allowed the introduction of a 'quick-look round' (QLR) facility, whereby the televisual sensor, mounted on a motorised platform atop the periscope, could be raised above the water line, quickly scanned through 360 degrees, and then immediately retracted. The recorded imagery from the sensor could then be analysed in slow time, avoiding the risk of counter-detection by a potential adversary.

Further evolution of the 'electronic periscope' was to make the periscope and its integral optronic sensors fully remotely controlled from dedicated or multifunction consoles. This meant that tactical data could be viewed by eyepiece injection, or on a remote console display.

However, the intrusive mechanics associated with a conventional direct path periscope - which requires a deep well through the submarine to accommodate the optics tube - still impose a number of tyrannies on whole-boat design. Periscopes demand a large penetration into the pressure hull and the attendant support of a complex and heavy hoist mechanism - suitably engineered to ensure watertight integrity - within the structure of the fin or sail.

Also, to meet the immediate needs of the submarine commander or watchkeeper, the rotating ocular boxes of the respective search-and-attack periscopes are sited centrally in the control room where they occupy a significant volume of the available space. Another constraint of the direct-view periscope is to condition internal layout such that the control room is necessarily beneath the fin or sail.

The advance of technology has now changed the paradigm. The last three decades have seen the development and progressive introduction to service of a new generation of modular, multi-sensor optronic mast systems that no longer demand a mast penetration through the pressure hull; instead, they require only an electronic cable to link them into the submarine's interior.

Inside the boat, it is the ability for remote-viewing that has offered submarine designers a new-found flexibility with regard to the location and layout of both the fin and the control room. The modularity of optronic masts also makes sensor maintenance and upgrade much more straightforward, and additionally provides scope for the user to adapt or upgrade individual systems according to the demands of a specific mission profile.

Given the generally risk adverse nature of navies, and the wholly understandable conservatism of the submarine community, it has taken some time for the optronic mast concept to gain acceptance from operational practitioners. This has been reflected by the trend for many navies to specify new-build submarines with one optronic search mast system and one conventional attack periscope. This so-called '1+1' solution was seen to provide a degree of redundancy in the event of failure, although it meant that the design tyranny imposed by a penetrating periscope remained.

Today, there is far greater understanding of optronic mast technology and the benefits it brings apropos improved discretion, reduced ship impact, and superior hull integrity or safety as compared with penetrating designs. Also, manufacturers have been able to amass significant evidence to support claimed availability, reliability, and maintainability.

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CM010 in service

Thales UK is the inheritor of the Govan-based business that was once Barr & Stroud, later Pilkington Optronics. This year marks a notable centenary, in that it was in 1917 that the company supplied its first CH01 optical periscope for installation on a UK Royal Navy (RN) H-class submarine. Barr & Stroud and its successors have remained the RN's sole supplier of submarine periscopes ever since.

Barr & Stroud (as was) began investigating optronic mast technology back in the 1980s and took the decision in late 1992 to invest in the development of the CM010 optronic mast system. Design was completed in 1993, with the company subsequently building a prototype for an at-sea demonstration and reliability growth trial. This system was in 1998 fitted on board the Trafalgar-class nuclear-powered attack submarine (SSN) HMS *Trenchant* .

The CM010 system comprises a single-window sensor head unit that houses the EO sensors, environmental sensors, and stabilisation mechanisms in a sealed pressure vessel; an azimuth drive module that supports and rotates the sensor head; and mast-raising equipment to raise the combined payload of the sensor head and azimuth drive. Below decks, an optronics processing unit accepts the video data from the optronic sensors: this data is then enhanced and displayed on a sensor control unit. A key feature of the CM010 optronic mast is its three-axis stabilisation system, which enables a 'solid' picture (stabilised to sub-pixel accuracies) to be presented to the command regardless of submarine movement at periscope depth in rough sea conditions.

Another view of Ambush with a CM010 mast raised. Each mast system comprises a single-window sensor head unit, which houses the electro-optical sensors. (Royal Navy)

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The CM010 system was in 2000 competitively selected to meet the visuals system requirements of the RN's first three Astute-class SSNs: in 2008, a follow-on contract was won, again in competition, for Astute boats 4-7.

Each Astute boat is fitted with two non-hull-penetrating electronic imaging systems, one combining a high-definition colour television (HDCTV) camera and a 3-5 µm thermal imager, the other incorporating an HDCTV and an image intensification device. An electronic support measures (ESM) antenna is mounted above on each mast. A total of 14 prime systems (seven boat sets) plus spares have been delivered to BAE Systems to date. Additional prime systems and spare systems are in build or on order.

In June 2005, Thales signed a contract with Mitsubishi Electric Corporation (MELCO) in Japan to deliver a CM010 optronic mast variant for the Soryu-class conventional submarine it is building for the Japanese Maritime Self-Defense Force. This was preceded by a technology transfer and manufacturing licence agreement signed in May 2004 for the optronic mast subsystems to be manufactured and initially assembled by Thales in Govan, Scotland, with subsequent assembly performed by MELCO in Japan.

The Soryu-class combines a conventional periscope with a single CM010 mast fitted with an HDCTV and thermal imager. An ESM antenna, provided by MELCO, is fitted above the sensor window.

Eight prime systems and two spare systems have been delivered to date; one additional system is in build, with another on order. Seven out of the 10 system modules have been designed by MELCO, with the remaining three units provided by Thales as sub-systems that are assembled, tested, and integrated in Japan by MELCO (as in-country prime). First to third line maintenance is also performed by MELCO.

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Second generation

Leveraging its knowledge from the development, introduction to service and support of the CM010 family, Thales UK has now embarked on the development of a second generation of optronic masts to capture lessons learned and take advantage of advances in sensors and processing. The objective is to reduce the size, weight, and cost of the mast system, and capitalise on advances in thermal, visual, and lowlight sensor technology, while at the same time maintaining the positive attributes of the current CM010 design with regard to three-axis stabilisation performance, single-window design, and low signature.

The current development programme is intended to deliver a single set of 'building blocks' underpinning two separate systems: a 190 mm-diameter low-profile variant (LPV) suited to all submarines; and an 80 mm-diameter ultra-low profile variant (ULPV) for special operations.

According to Thales, the LPV will provide essentially the same functionality as the CM010, but will be significantly smaller, less expensive, more modular in design, and able to host up to four sensors in a smaller volume. Current plans call for LPV mast development to complete by the end of 2017, with a full-function system demonstrator ready for sea trials during 2018.

The ULPV variant is seen as a 'special fit' option. This mast option accommodates dual sensors (HDCTV and an image intensifier or thermal imager) in a sensor head with a visual profile

comparable to that of an attack periscope. Thales acknowledges that stabilisation performance is reduced for this version, and there will also be some fall-off in sensor performance.

Another focus for the development programme is the adoption of common interfaces designed to enable a more straightforward upgrade path for masts fitted to existing submarines. Also, it is intended to make the LPV and ULPV variants essentially interchangeable, allowing for swap-out and replacement in approximately one hour.

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Search mast family

French sensor and navigation systems house Safran Electronics & Defense (previously Sagem) has achieved significant sales success, both at home and abroad, with its Series 30 Search Mast System (SMS) family. The dual-axis stabilised Series 30 SMS is a non-hull-penetrating optronic search mast able to accommodate up to four EO payloads (a high-definition mid-wave thermal imager, HDCTV camera, low-light camera, and an eyesafe laser rangefinder [ESLRF]), electronic warfare, and GPS antennas, in a lightweight sensor head.

The dual-axis stabilised Series 30 SMS optronic search mast is able to accommodate up to four electro-optical payloads. (Safran)

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All optronic channels are available simultaneously. Operational modes include QLR, long-range surveillance (using a panoramic display with multiple full-resolution windows), optronic air threat warning and direction finding, and digital video and snapshot recording. The sensor head can support GPS, electronic warfare (EW), or communications or AIS antennas.

According to Safran, the lightweight sensor pod has no air or water cooling requirements. Processing is hosted in a single compact cabinet below decks; this includes a backup command and control laptop.

As well as being selected for the French Navy's Barracuda SSN programme, the Series 30 SMS has been exported to Brazil, Chile, India, and Malaysia on the back of sales of the DCNS Scorpene conventional submarine. The Series 30 SMS 30 has also been contracted by DSME for South Korea's new KSS-III diesel-electric submarines, and by Saab Kockums for the Royal Swedish Navy's (RSwN's) two new A26 submarines, as well as the mid-life modernisation of two existing RSwN A19 Gotland-class boats.

Safran has latterly developed the low-signature Series 30 Attack Optronic Mast. (Safran)

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By adapting the Series 30 SMS design, Safran Electronics & Defense has developed the low-signature Series 30 Attack Optronic Mast (AOM). Also able to accommodate up to four sensor modules and an ESM/GPS antenna, the Series 30 AOM later has been selected to equip Barracuda SSNs.

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OMS family grows

Hensoldt Optronics (formerly known as Airbus DS Optronics), through its antecedents in Carl Zeiss Optronics GmbH, traces a heritage in submarine periscope and visuals systems going back to 1903. It began engineering development of a purely optronic mast system back in 1992, with a first prototype going to sea in 1995. This led to the OMS 100 optronic mast system, which entered series production in 1999.

The OMS 100 has achieved significant sales success with thyssenkrupp Marine Systems over the past 15 years, with the system being sold in combination with the SERO 400 direct-view periscope for new-build Type 209 Mod (Egypt and South Africa), Type 209PN (Portugal), Type 212 Batch 2 (Germany and Italy), and Type 214 submarines (Greece, South Korea, and Turkey). It has also sold the SERO 400/OMS 100 combination into Greece and India for Type 209 modernisation programmes, and to Daewoo Shipbuilding and Marine Engineering (DSME) for Indonesia's three new-build DSME 209 submarines.

An improved OMS 110 optronic mast was brought to market in 2012, introducing improved cameras, fibre-optic video transfer, and new signal processing. The dual-axis stabilised OMS 110 sensor package incorporates a high-resolution TV camera and a mid-wave thermal camera, both of which incorporate a zoom function and an ESLRF. The QLR mode facilitates a fast programmable 360 degrees-panoramic sweep in less than three seconds; continuously recorded images from all cameras can be stitched together to form a 360 degrees-panoramic view.

Designed to perform the functions undertaken by an attack periscope, the OMS 200 uses a small single-window sensor head containing a high-definition TV camera, a SWIR camera, and a laser rangefinder. (Hensoldt)

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Hensoldt Optronics later introduced the more compact and lower profile OMS 200 multi-sensor mast into its product portfolio. Designed to perform the functions historically undertaken by an attack periscope, the reduced signature OMS 200 uses a small single-window sensor head

containing a high-definition TV camera, a SWIR camera, and an ESLRF. An OMS 200 IR variant additionally incorporates a mid-wave infrared camera fitted atop the main sensor head.

An OMS 200 prototype was provided to the US Navy (USN) for trials on board a Virginia-class SSN in 2014. It is understood that the OMS 200 has been specified for the upgrade of the Pakistan Navy's three Khalid-class Agosta 90B submarines (replacing the legacy ST5 95 attack periscope).

The latest addition to the family, introduced to market in late 2016, is the OMS 150. Building on the pedigree of the OMS 100 and OMS 110, the new search mast variant introduces new sensor, electronics, and image processing technologies. Key features include the integration of a SWIR camera, a new sensor pack that is able to host up to five cameras, and an upgraded slip-ring configuration to confer the benefit of full-digital fibre-optic data transfer. Antenna interfaces are provided for ESM/direction finding (DF), GPS, and VHF/UHF communications.

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Photonics evolution

The USN has been both a leading advocate and early adopter of non-penetrating optronic mast technology. It's interest goes back some three decades to the Defense Advanced Research Projects Agency's (DARPA's) Non-Penetrating Periscope (NPP) effort, which was established in the late 1980s as part of a wider Advanced Submarine Technology programme.

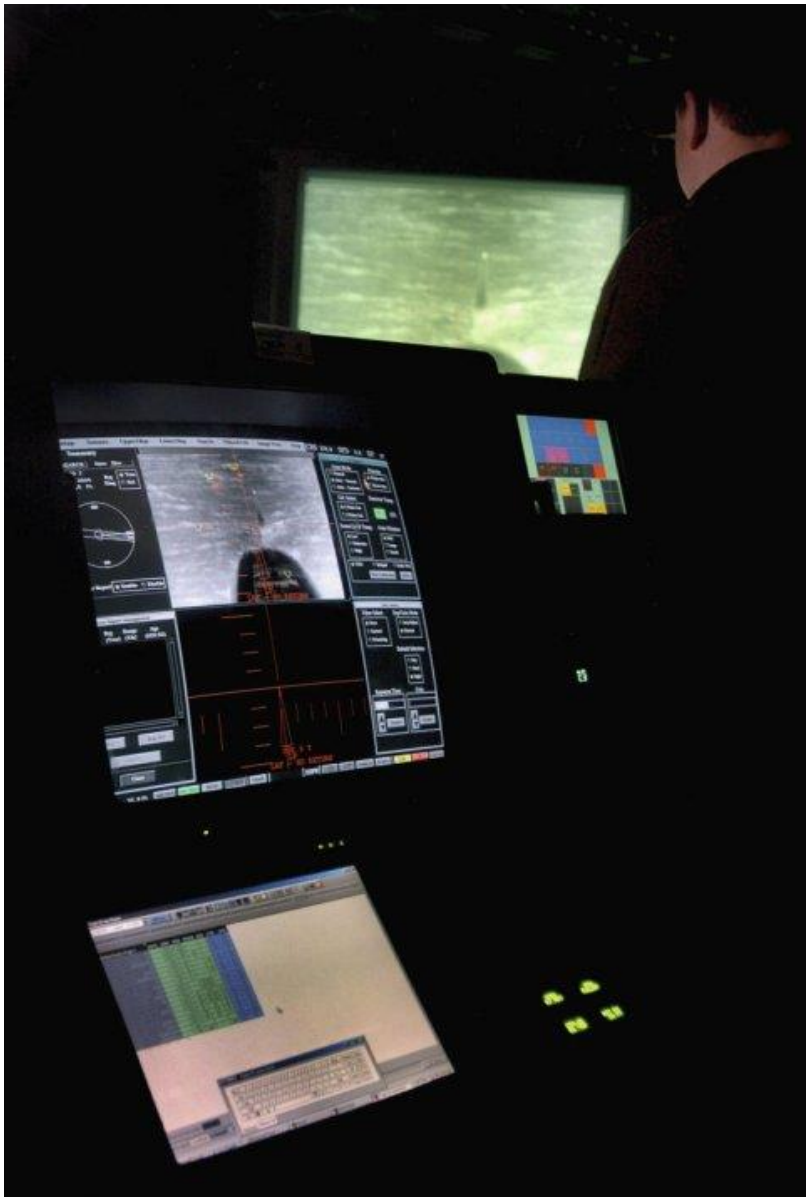
DARPA in September 1988 contracted what was then Kollmorgen Electro-Optical - now L3 Technologies KEO - for the build of the NPP mast prototype. This system - using commercial HDTV (monochrome), colour TV and thermal imaging cameras, and combat console control - was mounted to a Universal Modular Mast and demonstrated on the SSN-688 Los Angeles-class SSN USS Memphis in 1992. The NPP was later upgraded to an Improved NNP (INNP) standard with new sensors (notably a 3-5 µm thermal imager to replace the original 8-12 µm Micro-FLIR unit), new electronics, and a remote-control console, going back to sea on board USS Phoenix in 1995.

While the NNP/INNP programme was running, the USN had generated its Photonics Mast Program (PMP) requirement, for which Kollmorgen was awarded a development contract in January 1995. Drawing on the INPP design baseline, the PMP incorporated both high-resolution colour and monochrome TV sensors, and a 3-5 µm thermal imager, which shared a common multispectral head window and an ESLRF.

The PMP has subsequently entered service in the guise of the AN/BVS-1 Photonics Mast system equipping the USN's Virginia-class SSNs, each of which carries two masts. The multi-spectral AN/BVS-1 has introduced a variety of capabilities, including infrared and visual imaging, digital image processing features, laser range finding, stealth features, and an ESM antenna suite with monopulse DF.

Kollmorgen was subsequently contracted to develop an AN/BVS-1(V) Photonics Mast Variant (PMV), as an adaptation of the original PMP, for the USN's Ohio-class nuclear-powered cruise missile submarine (SSGN) imaging modernisation programme. Incorporating HDCTV, an intensified monochrome camera and thermal imager sensors, plus an ESLRF, the PMV - which replaced the legacy Type 15L periscope - includes modifications to the ESM/DF provisions and the display and control (imaging centre) console.

In support of the USN's submarine imaging requirements, Lockheed Martin has since 2004 developed and delivered the AN/BVY-1(V) Integrated Submarine Imaging System (ISIS) to integrate inboard electronics with digital video and still images from outboard sensors - either photonics masts or periscopes - and present real-time imagery and analysis on crews' existing control room tactical displays. ISIS also provides submarine operators with additional image enhancement and analysis tools; active and passive range-finding control; and recording, storage, and recall options for imagery and associated data.



An officer on board USS Virginia uses the infrared function on the photonics mast display. (US Navy)

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First installed in a USN submarine in 2006, ISIS components have been delivered for Los Angeles-class SSNs (which retain their legacy Type 18 search and Type 2 attack periscopes), three Seawolf-class SSNs, the four Ohio-class SSGNs, and the Virginia-class SSNs. L3 KEO is a major subcontractor to Lockheed Martin for the ISIS suite.

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maximum ceiling value of USD157 million. Production deliveries are planned to start in 2018.

AMPPM prototype

Beyond the LPPM, the Office of Naval Research (ONR) is already investigating a next-generation photonics mast through its Affordable Modular Panoramic Photonics Mast (AMPPM) Future Naval Capability project. Panavision Federal Systems was in October 2010 awarded a USD12.7 million contract by the Naval Research Laboratory to develop the AMPPM prototype, with the objective of engineering a mast offering improved reliability, easier maintenance and lower total cost of ownership while increasing imaging performance.

From a logistics standpoint, the goal is a 50% reduction in total life-cycle cost (attributed to significantly reduced periscope mast fabrication and maintenance costs), the introduction of an open architecture design that provides for rapid component upgrades, and increased systems availability and safety through modular component design. At an operational level, the AMPM is designed to achieve reduced target search time at visible and IR wavelengths, leading to decreased mast exposure and better performance in cluttered/littoral operations with autonomous target detection.

USS Minnesota running on the surface. The two AN/BVS-1 Photonics Mast systems are both clearly visible atop the boat's fin. (US Navy)

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Making use of a number of technologies proprietary to Panavision, including optical designs, communications protocols, heat dissipation methods, stabilisation algorithms, and mechanics for sealing and pressurising mast modules, the AMPPM prototype utilises visible, lowlight SWIR, and IR cameras arranged for a 360 degrees-panoramic search capability with a 65 degrees-vertical field of view. A common mechanical/electrical interface allows for mission configurable

applications and the use of current and future RF antennas. The mast itself is non-rotating, so as to increase system reliability.

New Spinel-based window materials are being used to increase transparency at wavelengths from 0.35-5.00 µm, while at the same time increasing hardness and durability. A high-definition format SWIR sensor (developed by Raytheon) is used for low-light-level conditions and to penetrate marine haze; a near-IR/SWIR hyper-spectral sensor is used to augment the detection of targets with spectrally unique signatures.

In September 2014, Panavision was awarded a sole-source contract valued at almost USD1 million to both modify and complete the AMPPM prototype ahead of a planned installation on board a Virginia-class submarine. These changes include a new long-wave camera module design, a change in the optical prescription, alterations to the main mast structure that holds the imaging modules in place, and other system integration efforts.

In September 2016, Panavision Federal Systems was awarded a USD11 million indefinite-delivery or indefinite-quantity contract by the US Naval Undersea Warfare Center (NUWC) Newport Division to modify and upgrade the AMPPM prototype and support at-sea submarine testing. According to NUWC Newport Division, the most recent contract covers the modification and upgrade of the AMPPM, temporary alteration development, and installation, testing, and submarine deployment in support of the Ohio replacement and Virginia-class submarine programmes.

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The dual-axis stabilised OMS 110 sensor head can perform a 'quick-look round' 360 degrees-panoramic sweep in less than three seconds. (Hensoldt)

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