Laser beams hold promise for submarine communication

by Robert L. Gallagher

The science of "nonlinear laser spectroscopy" may be providing the U.S. Navy with a solution to a problem that has plagued its submarine operations for three decades: How to communicate with a submerged submarine reasonably quickly without giving away its position to the enemy.

At present, the only methods the U.S. Navy has to communicate at reasonably high data rates with submerged vessels, require that the submarines come within a few meters of the ocean surface and either expose a detectable high-frequency radio antenna or tow a long antenna from the stern to pick up low-frequency radio transmissions. These techniques expose the submarine to detection by enemy naval patrol aircraft and ocean surveillance satellites. They also place limitations on the course the vessel may take and increase its noise emissions, lending it to acoustic detection via sonar.

The submarine must leave its underwater station to receive messages via these radio frequencies. So, in order to retain some flexibility in carrying out their mission, attack submarines try to receive a broadcast at least once every fixed number of hours. They invariably get messages late. Frequently, after coming to the surface and rigging themselves to receive, there are no messages for them.

As a result, naval operations command does not know when a sub has received a message for a period as long as 8 to 12 hours after its initial broadcast. The submarine cannot acknowledge receipt by return broadcast, as that would definitely give its position away to alert enemy anti-submarine warfare forces.

Although these procedures may seem awkward, rigorous communication discipline is essential to effective submarine operations. By many accounts, Germany lost the battle of the Atlantic in World War II due to a lack of such discipline. Communications sloppiness by Japanese submarine commanders also helped the United States defeat Japan in the Pacific.

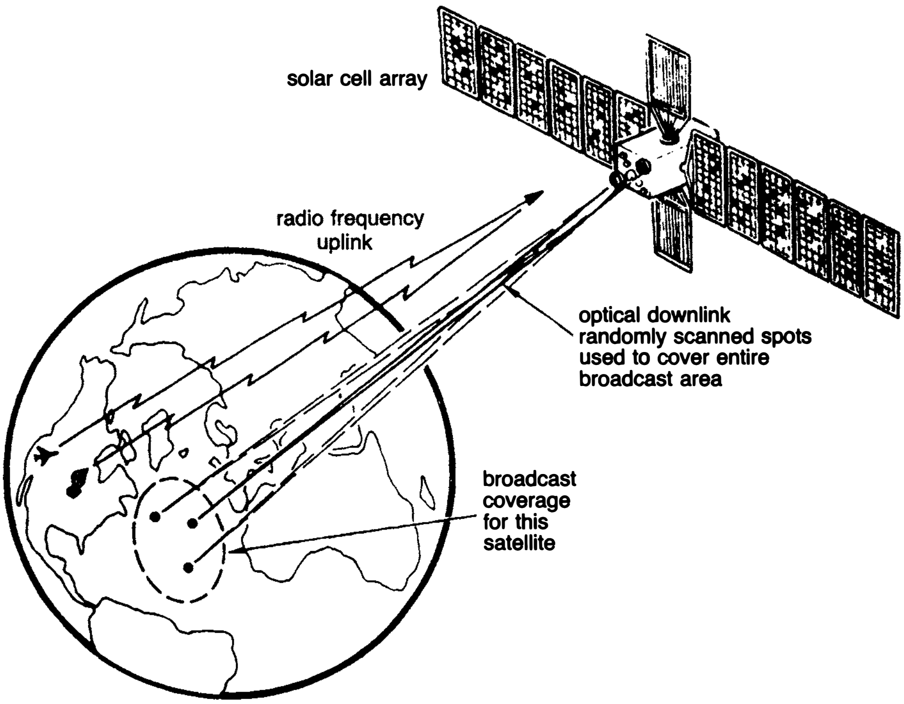
However, in the age of nuclear surprise attack, communication procedures that leave a submarine commander ignorant of his orders for as long as half a day after a conflict breaks out, obviously leave something to be desired. What good is information for targeting an enemy submarine or task force if it is received from headquarters so many hours late? American military commanders are haunted by the scenario where a ballistic missile-carrying submarine comes to the surface to receive its transmissions several hours after the U.S. National Command Authority has been destroyed by a Soviet surprise attack.

In the last several years, the U.S. Navy has done something to prevent at least that. After decades of obstruction from every conceivable quarter, the service made operational a transmitter of extremely low-frequency (ELF) radio waves located in Wisconsin. ELF waves broadcast from the American Midwest can penetrate deeply into the oceans around the globe to the stations where U.S. submarines are hiding, awaiting orders. But because of their extremely low frequency, ELF transmissions are limited to extremely low data rates. The U.S. ELF transmitter is reportedly only practical for sending an "emergency message" to alert submarines to approach the surface and pick up a detailed, higher-frequency transmission, containing their orders. Naval commanders hope they won't be picked off under those conditions.

None of this really solves the problem of timely communication with submarines, and so, when laser scientists pointed out that blue-green light can penetrate the ocean by as much as hundreds of feet, the U.S. Office of Naval Research and the Defense Advanced Research Projects Agency (DARPA) began looking into ways to use lasers that produce blue-green light, to communicate with submerged submarines. The program has come a long way since its inception in the 1970s, has widespread support, and seems certain to produce a workable system. The Naval Ocean Systems Center in San Diego now manages the effort, known as the Satellite Laser Communications (SLC) program.

As presently envisioned, ground-based radio transmitters will send messages intended for U.S. submarines to satellites in orbit around the Earth. The satellites will translate the messages into a kind of Morse code and transmit them to the submarines below, via flashes of blue-green laser light (see **Figure 1**). Now, 100 years after the introduction of radio—first amplitude modulation (AM), then frequency modulation (FM)—the U.S. Navy is using advanced laser physics and spectroscopy to reintroduce light flashes (time modulation) as a vital military communications medium for the 21st century. (DARPA is also investigating a proposal from General Telephone and Electronics for basing the blue-green lasers on aircraft.)

FIGURE 1
Satellite Laser Communications system



The Satellite Laser Communications system will transmit messages for submerged U.S. submarines to obtaining satellites via radio communications. The satellites will then transmit to the subs via flashes of blue-green laser light.

Source: General Telephone and Electronics.

Perfect tuning

A few moments of reflection, however, will raise the following question: How in the world will a submarine pick up relatively weak flashes of laser light through the glaring sunlight of a clear day? Although the Sun is brighter than any laser, its light is spread over a wide range of frequencies. A receiver that is sensitive only to the wavelength of light produced by a space-based laser, can pick its flashes out of the Sun's glare, because it "sees" only light with the wavelength of the laser.

This is the principle upon which the Atomic Resonance Filter, the onboard submarine receiver for the Satellite Laser Communications system, is designed.

The filter contains cesium gas. The cesium gas absorbs a single frequency of blue-green light having a wavelength of about 480 billionths of a meter (480 nanometers) and does so with a precision of 99.999%. Technically, this means that the "bandwidth" of the filter is only 0.0006 nanometers. Light with a wavelength that varies only by at most that amount, is absorbed by the cesium. With this precision, the Atomic Resonance Filter can pick out the flashes of blue-green laser light from the Navy's satellite in the full glare of the Sun. The luminescence of the cesium gas atoms relays the "Morse code" from the satellite to the submarine's computers.

The design of the system is based on our knowledge of the spectrum of electromagnetic radiation that is absorbed by cesium gas. At the wavelength of the blue-green light emitted by the satellite laser, this spectrum contains a sharp discontinuity known as an "absorption line." The cesium absorbs this wavelength maximally. Absorption of a single photon of blue-green light sends a cesium atom through what is called a "quantum transition" into an "excited state." From there, it emits an infrared photon to relay the message from the satellite. (A photon is a unit of electromagnetic radiation equal to one full rotation of an electromagnetic wave.)

Nonlinear action

The blue-green portion of the spectrum of electromagnetic radiation has other important special characteristics. The ocean attenuates most electromagnetic waves exponentially with depth, but there is a "hole" in the blue-green region where the attenuation is less than elsewhere by a factor ranging from 1 million to 100 million (60-80 decibels).

Blue-green light is nonetheless subject to attenuation by 90% (10 decibels) per hundred feet of depth. The attenuation varies as a function of the number of microorganisms growing in the water. In water deeper than 250 feet, the attenuation for blue-green light may be as low as 32% per hundred feet (or 5 decibels), because there is not sufficient sunlight at those depths to support plant growth. At a depth of 350 feet, ideally the blue-green light signal would be attenuated by *only* a factor of 1,000, or 99.9%. I emphasize only, since out of a light pulse of 100,000 photons hitting the ocean surface, under ideal conditions, 100 photons could be picked up at a depth of 350 feet and that's more than enough for the Atomic Resonance Filter receiver.

That all sounds very promising for a sunny day, but what about clouds? A general purpose communications system must be able to communicate with subs through bad weather. It turns out that a cloud will scatter perhaps 90% of the blue-green light away, which compared to attenuation through water, isn't really very much, for a communication system based on nonlinear spectroscopy.

DARPA reports that measurements in towering thunderheads off Oregon, in water clouds off Hawaii, and less extreme clouds elsewhere, have shown that clouds are not nearly as big a problem as was once thought.

A submarine commander can adjust his ocean depth by 100 feet or so to compensate for a 90% signal loss due to a cloud. As part of the SLC system, sunlight sensors on the submarine can inform the commander how cloudy it is, and help him determine his maximum communication depth.

In addition, satellites broadcasting messages through clouds or bad weather can adjust the blue-green laser beam spot size and scan patterns to make up for losses as well.

Unlike a radio broadcast system which can cover a large area at once, the Satellite Laser Communications system will illuminate *a spot* on the top of the ocean or clouds, send its message and then move on to cover another spot. Many spots are needed to cover broad areas, but cover broad areas they must, for in order to preserve their stealth, our own submarines are not to tell us where they are in the ocean. Although this may at first appear awkward, this characteristic makes the SLC system more flexible in certain ways than other systems.

For example, if a submarine is known to be deeper than the nominal communication depth, the spot size can be narrowed. This, in turn, reduces the area coverage rate. If that is not acceptable, one can increase the coverage rate by shortening the message, by using a data-compressing code, or by waiting until night or for clearer weather. One could even direct another, lower-priority submarine to sign off from the SLC system so that the system can use the extra time to scan the ocean with the other submarine's message. According to DARPA, two high-orbit satellites can provide continuous coverage for the vast majority of Northern Hemisphere ocean areas of interest to submarines.

In addition to attenuating the signal, the ocean also diffuses the blue-green laser light into a broader beam which is spread over 120° of angle at the receiver. By employing a broad field of view, the receiver can capture much of this diffuse light.

State of SLC program

DARPA program manager U.S. Navy Cdr. Ralph E. Chatham recently reviewed the state of development of the technology for the Satellite Laser Communications program in the *Journal of Electronic Defense*. We summarize his report:

Cesium filters already built by two contractors bring Satellite Laser Communications from a technology with great promise to one that is real. But the laser must be chosen to match the wavelength of absorption of the cesium gas. An SLC laser must not only match the cesium absorption line—a criterion which so far has thrown out all but one candidate system—but it must be capable of doing virtually everything that a laser can do all at once. It must be efficient enough so that the limited power supplies in space can provide sufficient energy to overcome the exponential loss in seawater. It must be compact, and capable of withstanding launch shocks. Finally, it must be reliable enough to operate for years in high orbit.

The single candidate laser that comes close to meeting these extreme requirements is a xenon chloride laser, the output of which is converted to blue in a Raman process in lead vapor. There is no fundamental flaw in the science or technology of xenon chloride-lead shifted lasers that would prevent their use in space. What is required to make them practical for space deployment is extremely careful attention to process control and manufacturing.

Tests of U.S. Navy environmental models using airborne lasers and receivers on submarines were conducted in 1981, 1984, and again in 1986. They have shown communications capability with submarines at operational depths under extreme water and cloud conditions and in several different ocean areas.

The remarkable success of these experiments must be tempered with the caveat that they have not yet been done with the blue laser and receiver technology. Airborne transmitter-to-receiver tests using the blue technology are scheduled for 1988.

Commander Chatham concludes:

"The SLC offers extremely high tactical utility and strategic benefit from a modest system. . . . If deployed, it could deliver urgent messages when sent, not some unknown time later. It could do this regardless of the submarine's operating parameters . . . the submarine commander knows his minute-to-minute maximum communication depth as a result of measuring the sunlight penetrating to his ship. SLC will provide an alternative strategic communications link, which has different strengths and different vulnerabilities from current systems.

"The technology is real. There are no unresolved scientific issues. All that is left to do in order to realize the potential of SLC is careful, clever (and consequently, expensive) engineering, and commitment from the service which will benefit from it."