From Knowledge, Seapower!

On a night in December 1972, Ira Richer and Arthur Levasseur, members of the Lincoln Laboratory Project Sanguine team, boarded an operational nuclear submarine, the USS *Tinosa*, in the inner harbor of Naples, Italy, for an Atlantic crossing. The submarine had been equipped with an experimental Laboratory ELF receiver, with its digital portion implemented on a Varian 620/L-100 computer. The Naval Underwater Systems Center provided a trailing wire antenna that could be deployed from the sail of the submarine.

A demonstration of the entire ELF receiving system performing in an operations environment was conducted while the submarine was in transit to New London, Connecticut. The goal of this critical test was to see if a submerged submarine could receive an ELF message transmitted at long range from the United States. The test was conducted with the submarine submerged and under way in the North Atlantic at approximately 45°N latitude and 30°W longitude. At a low data rate (0.03 bps) and with a test transmitter that radiated less than 1 W, a binary minimum shift-keying bandspread technique on a 76 Hz carrier was used to transmit the twenty-character message.

When decoded on board the USS *Tinosa*, the message that firmly established the technical basis for ELF communication with submerged submarines was the motto of the U.S. Naval Academy — ex scientia, tridens! — which roughly translates as "from knowledge, seapower!"

Extremely Low-Frequency Communications

For the nation's fleet of missile-carrying submarines, establishing a credible and secure command communication link is especially important and difficult. The physical characteristics of the ocean that make it attractive as a secure operating environment for a submarine also make it essentially opaque at all the conventional radio communication frequencies. However, there is a transmission window that offers the opportunity for communication in the extremely low-frequency (ELF) band.

At frequencies below 100 Hz, electromagnetic waves can penetrate deeply into sea water. Moreover, above the surface, propagation at these frequencies takes place in the waveguide formed between the earth and the ionosphere; low propagation losses allow nearly worldwide communication from a single transmitter. By contrast, transmissions from satellites (which are at higher frequencies) cannot be received underwater. Because of these properties, the U.S. Navy sponsored a program at Lincoln Laboratory from 1966 to 1975 that examined the natural parameters of the ELF channel in general and with respect to the design of a system for communicating from a U.S.-based transmitter to submerged submarines worldwide.[11] This activity was pursued under a program named Project Sanguine.[12]

Particular emphasis was placed on designing an ELF system that could withstand a severe direct nuclear attack on the transmitter and propagation medium. The very large transmitter antenna array (tens of miles on each side) was to be built with considerable redundancy. Because the system was so large and induced voltages into neighboring conductors, such as fences and telephone wires, it sparked considerable controversy with regard to both its feasibility and its effect on the environment.

Project Sanguine was a national effort, and Lincoln Laboratory was one of the major technical contributors. The Laboratory performed and analyzed signal and noise propagation measurements and carried out system engineering of the overall communications system. The most significant of the Laboratory's accomplishments resulted from the evaluation of ELF atmospheric noise effects on Sanguine system operation. It was established that a factor of 100 reduction in transmitted power over the previous Sanguine system design was possible because of the statistical properties of atmospheric noise in the ELF band.

The savings resulted primarily from nonlinear noise processing and efficient signal coding. Since reduction in transmitter size reduced cost and environmental impact, this achievement made the design considerably more feasible.

The Laboratory developed a highly power-efficient and jamming-resistant signal structure that applied minimum FSK modulation to binary convolutional coding. A submarine receiver with adaptive nonlinear processing and ocean filter compensation was implemented and ran in real time on a minicomputer. It included adaptive nulling of local power interference and an efficient sequential decoder; Michael Burrows designed and tested a long-wire, magnetic field sensing antenna that allowed submarines to receive signals without changing course. The Laboratory helped to resolve a number of technical issues related to the antennas. For the transmitting

1955

Round Hill field station

Notes

11 The visible band can also be used for submarine communications. During this period, the Laboratory conducted a parallel program on optical submarine communication and developed such components as the atomic resonance filter for optical communication. *Quarterly Technical Summary, Division 6, Space Communication*. Lexington, Mass.: MIT Lincoln Laboratory, 15 June 1971, DTIC AD-887036l.

12 Lincoln Laboratory's Project Sanguine activity was summed up in a 1974 article: S.L. Bernstein, M.L. Burrows, J.E. Evans, A.S. Griffiths, D.A. McNeill, C.W. Niessen, I. Richer, D.P. White, and D.K. Willim,"Long-Range Communications at Extremely Low Frequencies," *Proc. IEEE* **62(3),** 292–312 (1974), and in an IEE book on the subject: M.L. Burrows, *ELF Communications Antennas*. Stevenage, England: Peter Peregrinus, 1978.

Figure 4-8
ELF propagation receiver sites for signals sent from the Wisconsin Test Facility in the Chequamegon National Forest near Clam Lake, Wisconsin.

antenna, the Laboratory worked on the design of grounding systems and the effect of burial. For the towed-wire receiving antennas, various antenna noise sources were evaluated and techniques were developed to reduce them.

A series of experiments was conducted in which modulated signals were transmitted from the Navy's Wisconsin Test Facility and received in real time at locations worldwide (Figure 4-8). The first tests took place in August 1972 with a receiver on Plum Island, Massachusetts; the follow-up tests, also land based, used receiving sites in Norway, Malta, Saipan, and elsewhere; the third and most telling demonstration was made with a receiver aboard the nuclear submarine USS *Tinosa* in submerged transit from Naples, Italy, to New London, Connecticut. Excellent results were obtained during the tests, with successful message decoding occurring consistently at all times. Both the transmitter and the receiver operated reliably, and time synchronization between the two was maintained over long periods. The Navy ELF transmitter at the Wisconsin Test Facility was radiating less than 1 W, and yet the signal was decoded more than 6000 km from the source.

By April 1974, the Navy had accepted the feasibility of ELF communications, and Lincoln Laboratory began working on a concept validation system in preparation for going operational. The Lincoln Laboratory ELF program ended in July 1975 with a system design in place.

The Navy ELF system went into operation with two jointly operating transmitter sites, one in Wisconsin and one in northern Michigan. The official Navy command activation ceremony was held at Sawyer Air Force Base, Michigan, in July 1985.

Texas Tower communication antenna

Tropospheric scatter communication antennas, Thule, Greenland