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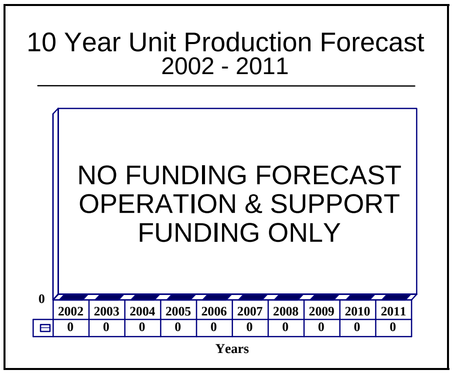
ELF Submarine Communications - Archived 04/2003

Outlook

- Operation and support activity remain
- Continued development for signal processing enhancement
- Minor continued funding under various naval communications programs
- "Peace activist" intervention likely to be non-threatening following September 11th terrorist attacks



Orientation

Description. Extremely Low Frequency (ELF) radio strategic signal system used for communication with submerged submarines.

Sponsor

US Navy
US Naval Undersea Warfare Center
USA
(Lead laboratory, program manager)
US Naval Electronics Center
Charleston, South Carolina (SC)
USA

Contractors

DynCorp
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USA
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Web site: http://www.dyncorp.com
(Acquired former prime contractor GTE Government Information Systems in December 1999)

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(ELF satellite communications)

Status. The system is in active service and underwent a major upgrade effort during the last few years. Research activity related to hull-mounted antennas is ongoing.

Total Produced. A total of two shore transmitters and approximately 161 submarine receivers (including 20 developmental models) are estimated to have been produced.

Application. Strategic submarine communications.

Price Range. ELF submarine receivers were believed to cost approximately US$299,000 (in FY92 US dollars). The overall program effort is believed to have cost US$14 million minimum.

Technical Data

Design Specifications. ELF signals are transmitted at a nominal 76 Hz. The shore transmitters operate in the 40-80 Hz frequency range, with emphasis on 76 Hz.

The two transmitter sites are located over a region of low-conductivity bedrock, which strengthens ELF propagation and enables the transmission of a 2,500-mile-wavelength signal. Orthogonal antennas with low-resistance ground terminals at either end are strung horizontally over the bedrock. A rough loop antenna is formed as current is fed and driven deep into bedrock from one terminal to the other. The signal is then sent into the atmosphere where it propagates along the area between the Earth's surface and the ionosphere out to submarine operational areas. The ELF signal penetrates sea water hundreds of feet in depth, where the intended submarine receives it through an antenna reeled out astern. The message is then decoded by onboard ELF receivers. During equipment testing conducted in 1983/84, the ELF station in Clam Lake, Wisconsin, was able to communicate reliably with a submarine cruising at depths to 400 feet at 16 knots.

The transmitter at Clam Lake was constructed in 1969 and has been operating as a facility for the testing of the environmental effects of the use of advanced-development ELF receivers. GTE upgraded this transmitter and also has built a transmitter facility based in Michigan. Now that the entire system has been completed, the two transmitters run synchronously to boost the signal's power, allowing it to reach all submarine operating areas. Both sites are capable of operating independently at different frequencies. This serves to increase the message capacity in situations that would not require use of the maximum signal strength to transmit to the submarines farther out.

The prototype ELF receivers, which embodied computerized digital processing and automatic built-in testing, included Unisys UYK-44 reconfigurable processors, the first production application of the Navy's newest computer. In order to maximize transmission reliability from the Clam Lake ELF transmission facility, GTE installed high-power solid-state amplifiers. GTE also installed signal processors that allow the encoding of messages, equipment to protect electronic gear from electromagnetic pulse environments, and diesel generators for emergency power.

Operational Characteristics. Submarine communications have presented a persistent command and control problem because conventional RF signals degrade rapidly while penetrating sea water. For this reason, submarines must leave the relative safety of the deep at scheduled times to deploy receiving antennas at or near the surface. Detection is much more likely when submarines are operating near the surface, and while submarines are hiding at depth between communication intervals they are unable to receive vital communications.

ELF signals are transmitted at 76 Hz and can reach hundreds of feet through sea water, thus allowing one-way message transmission to deep-running subs that are maintaining a low profile. ELF-equipped submarines are freed from the need to periodically ascend to copy radio traffic.

ELF advantages include: extremely long range (attenuation in atmosphere much less than with higher frequency bands) with only one transmitter required for worldwide communication; immunity to unreliable propagation conditions; electromagnetic pulse invulnerability; and jam proofing (a jammer would need a much larger ELF antenna using a transmitter several times more powerful than the signal of the system being jammed).

However, there are also disadvantages to ELF. Because the most efficient transmitter antenna is one that is about the same span as the wavelength, an antenna 4,000 kilometers long would be optimal, but would be very vulnerable to hostile action. ELF antennas also have a very low efficiency, necessitating a power input of several megawatts to generate a signal of several watts power that must travel thousands of kilometers while competing with electromagnetic interference. Also, ELF can send only very simple messages, with a three-letter message needing four minutes for transmission.

After extensive research it was found that the best way to address the drawbacks was to use a long horizontal aerial cable set up parallel to the surface of the earth, with the earth's crust forming part of the antenna loop. The positioning of the antenna over highly electrically resistant rock (ancient granite rock formations in particular), with grounding at both ends, allows the use of the rock strata to extend the antenna's effective length by forming a ground loop. This also allows much higher power output.

ELF's low message capacity is being addressed. A partial solution has been the adoption of a continuous-phase frequency modulation system called minimum shift keying. This process superimposes data on the carrier signal through modulation (shift) of the frequency several times per second, with each shift representing one data bit. However, messages still need to be repeated in order to ensure that they can be heard above magnetic storm interference.

Extremely Low Frequency (ELF) submarine communications. The SubHDR Antenna Installation on USS PROVIDENCE (SSN 719). The current periscope mounted system is just to the left of the larger SubHDR antenna

Source: US Navy

Variants/Upgrades

Upgrade work involved new signal processing algorithms, specifically to provide an enhanced data rate to make up for current signal-length restrictions. Both hardware and software were designed and modified. Message compression was one of the known areas of effort.

Program Review

Background. The US Navy had been attempting to develop and field an ELF system since 1958, when research began to provide survivable one-way transmissions to US nuclear-powered ballistic missile submarines. In 1962, a 175 kilometer propagation test antenna was constructed in Virginia and North Carolina. This test facility successfully demonstrated the concept, with transmissions being received both on submerged submarines and on land, including distant locations in Greenland, Iceland, Labrador, and Norway. In 1968/69, a further test antenna was erected at Clam Lake, Wisconsin. This facility was concerned with further propagation research and with the potential environmental impact of ELF.

The US Navy then put forward a plan for an operational ELF system to be installed in Wisconsin, with the name Sanguine. Sanguine would have been a completely buried system that was nuclear survivable and had a sufficiently high data rate to send emergency action messages to SSBNs. However, by 1975, the Soviets had so improved the accuracy and quantity of their nuclear warheads that Sanguine was rendered obsolete.

After a redefining of Sanguine, the communications project was renamed Seafarer. Although still able to transmit emergency action messages, the system was unable to withstand nuclear blast. Because of political fallout from local opposition to the transmitter site, Seafarer was canceled in the late 1970s.

As a result, President Ronald Reagan in 1981 directed the US Department of Defense to restart development of an ELF system as part of a general effort to improve communications with submarine forces. The latest ELF version would not survive a nuclear blast, but its signals are inherently resistant to the effects of electromagnetic pulse with the transmitters being EMP hardened. A major difference between Seafarer and ELF is that Seafarer would have required a 2,400-mile-long buried grid antenna, and ELF only needs a total of 84 miles of antenna – 56 miles at the Michigan transmitter facility and 28 miles at Clam Lake.

ELF's mission was also redefined. Because its rate of data transmission is much slower than Sanguine's and Seafarer's, ELF will not be used to send emergency action messages. It will be used primarily as a peace-time submarine communications system to reduce the vulnerability and enhance the operational capability of both ballistic missile and attack submarines.

The ELF system is controlled by Commander Sub-marine Force, US Atlantic Fleet Headquarters (Norfolk, Virginia) and Sawyer AFB (Michigan).

In the last few years of the program, activity surrounding ELF centered on software modifications. In FY94, an advanced demonstration of enhanced data rate (EDR) capabilities was completed. Further development of these capabilities continued in FY95 and was scheduled for completion by the end of 2000. (To date, the completion has not been confirmed.) Additionally, both hardware and software were designed and modified, and underwent further testing to validate EDR. In FY95 and FY96 transmit antenna ground well arrays were developed and installed.

In January 1995, Senator Russ Feingold (D-WI) introduced a bill to the Senate Armed Services Committee calling for the termination of the ELF program. The senator believed ELF's message delivery system was lacking and that the program was un-necessary because the system would not be useful during a nuclear attack, as submarines do not usually surface to receive messages. Feingold said that in the absence of a Soviet nuclear threat, it was hard to justify the need for ELF. Feingold additionally stated that the ELF testing grounds more than qualified as candidates for base closures, thereby saving even more program money. FY95 was the last year the ELF program received funding under the Navy's Fleet Communica-tions effort.

This is not the official end to work on the ELF system, however. Ongoing development efforts to improve the ELF antenna (specifically hull-mounted models) are being carried out under the Navy's Space & Electronic Warfare (SEW) C^3 Technology program and the Submarine System Equipment Development program. In FY99, the Navy conducted residential noise tests on the on-hull ELF submarine antenna. This development provided submarines with the capability to receive ELF transmissions without having to deploy a long trailing wire.

The Navy performed some minor ELF work during FY00, with efforts focusing on transitioning the on-hull ELF antenna to the Submarine Integrated Antenna System (SIAS) effort. Sea tests were conducted aboard the USS Dolphin during February and April 2000 to collect data for the development of noise mitigation techniques to improve system performance. This test was conducted with the hopes of increased maneuverability and flexibility while the submarine maintained a stealth posture at deep depths and in littoral waters. During FY01 and FY02, work continued on ELF and signal processing integration.

<u>"Peace Activists" Target ELF Facility</u>. Two peace activists claiming they were committing an "act of nonviolent direct disarmament and crime prevention" cut down three poles supporting transmission lines for the ELF system in Clam Lake, Wisconsin, in June 2000. According to NukeWatch, this was the fifth time since

1984 that the ELF system had been shut down by activists who were able to simply walk up to the communications poles that support the 28-mile-long transmitter antenna and cut them down with simple handsaws. All previous actions resulted in federal prosecution and prison sentences. Other protests and concerns surrounding ELF involve environmental issues, with some believing that the transmission of such signals harm the environment and surrounding wildlife.

It will be interesting to see how American environmental activists conduct themselves after the September 11, 2001 terrorists attacks on the World Trade Center in New York City and the Pentagon building in Washington, DC. With security tightened throughout the US, it should be more difficult to perform so-called "environmental sabotage" and also much more dangerous. Any type of "assault" on a US defense facility is pretty much being met with a "take no prisoners" attitude. Additionally, any such action is now out of disfavor and viewed as totally "un-American." This all puts the environmental "Peaceniks" in a bit of a quandary.

ELF Alternative. An interesting alternative to ELF turned up several years ago as the result of work funded by the US Navy's Office of Naval Research. A team of Pennsylvania State University scientists working in Fairbanks, Alaska, aimed a one-megawatt radio beam into the sky above the city. This resulted in the heating of charged particles in the ionosphere 30 to 60 miles above the Earth's surface, forming a "natural" antenna. This antenna reflects low-frequency signals efficiently, with the signals capable of saltwater penetration.

GTE Sells Government Sector. In December 1999 it was announced that DynCorp had finalized its purchase of GTE's Government Information Systems and the company's broad range of integrated telecommunications services and information technology solutions offered to the US and to foreign governments. Details of the sale were not publicly disclosed.

Funding

ELF has not longer received individual funding allocations since 1996, instead being given limited funding through various naval communications improvement programs such as the US Navy's Submarine System Equipment Development, Undersea Warfare Surveillance Technology, and Space & Electronic Warfare (SEW) C^3 Technology programs. Below is funding for ELF under the US Navy's Fleet Communications program's Shore to Ship Communications Systems effort which is doing continual work on ELF and signal processing integration.

US FUNDING

	FY00		FY01		FY02		FY03	
	QTY	AMT	QTY	AMT	QTY	AMT	QTY	AMT
RDT&E (US Navy)								
PE#0204163N Fleet Communications Project X1083 Shore to Ship Comm. Systems	-	6.6	-	8.0	-	9.1	-	N/A

All $ are in millions.

Source: US Department of Defense (DoD) FY2002 RDT&E Budget Item Justification (R-2)

Recent Contracts

No recent public source contracts over US$5 million have been identified.

Timetable

Month	Year	Major Development
	1958	Development of ELF concept
	1969	Experimental transmitter built

Month	Year	Major Development
	1975	Overhead antenna configuration selected
	1976	Shipboard receivers tested
	1977	Initial environmental impact study for transmitter
	1978	President Carter cancels Seafarer ELF project
	1979	General Accounting Office report recommends termination of ELF program
	1981	President Reagan orders program reactivated
	FY82	Michigan site surveyed; Wisconsin site improvement begins
	FY83	660 kW amplifier installed at Wisconsin site
	FY84	Michigan site construction begins
Jan	1984	Injunction granted to suspend work on ELF
Aug	1984	Supreme Court allows construction to continue
May	1985	Navy successfully conducts tests using a submarine of the Pacific Fleet and prototype ELF receivers
Jun	1986	Initial Operational Capability achieved
2Q	FY87	Milestone III (production approval)
Mar	1988	Contract for 139 receivers awarded to GTE
Jan	1990	Deliveries of 139 receivers begun
2Q	FY90	Material Support Date implementation
2Q	FY91	Full Operational Capability achieved
APR	1992	Deliveries of 139 receivers contracted for in 1988 completed
2Q	FY92	ELF Full Operational Capability scheduled
	FY92	Development of anti-jamming and enhanced data rate capabilities
	FY93	Contract for development of anti-jamming engineering development model hardware and software
	FY96	Major upgrade completed, with production transitioning to spares and support
	FY00	Enhanced data rate development efforts to be completed. Transition of the on-hull ELF antenna development work to the Submarine Integrated Antenna System (SIAS) program
Feb	2000	Sea tests for new signal processing aboard the USS Dolphin conducted
June	2000	Peace Activists sabotage ELF system transmission

Worldwide Distribution

ELF is a **US Navy** system. Although funding documents list no international cooperative agreements, both the **United Kingdom** and **France** have expressed interest in ELF. British efforts have been thought to be concerned with technically validating the ELF concept before determining its utility. An experimental system was to be constructed (Glengarry Forest in the Highlands of Scotland) using a 22.5-kilometer-long antenna. The trial installation was to demonstrate the practical characteristics of the system. Survey work for the site was to be handled by an American company, with the hardware for the test installation produced by the British. The British were being provided with some technical data from the US Navy's ELF program. No recent information is available on this effort.

The French also received technical assistance from the US Navy. Two companies, Thales (formerly Thomson-CSF) and Alsthom-Atlantique, were known to have conducted ELF research on behalf of the French Navy.

Russia reportedly fielded an ELF system known as Zevs located northwest of Murmansk on the Kola Peninsula, which meant its Delta IV ballistic submarines, supported by its ELF, "could be almost as responsive as an ICBM for destroying time-critical targets," according to the US Department of Defense. The Russians are not constrained by the environmental considerations that the West faces, and thus it is easier for them to field more powerful equipment. Some sources say that the Russian ELF equipment is more powerful and carries a longer distance than that of the US. There are supposedly three Russian ELF shore stations.

Forecast Rationale

Stealth is a submarine's greatest weapon, and rising up to a reasonable depth to receive communications is one a submarine's greatest foes. The Extremely Low Frequency (ELF) range continues to be critically important to the US Navy, especially in terms of communicating with submarines undersea. A submarine's ability to transmit and receive radio signals is affected by how deep the submarine is and the amount of water the radio wave has to penetrate. ELF allows a submarine to remain deeply submerged and still have the ability to receive communications from above, although they are usually very limited communications.

Unfortunately, ELF does have its limitations, especially its inability to transmit extended messages. Its main mission is to notify submarines to come up to a shallower depth to receive messages on VLF or LF. ELF likely is transmitting three-letter coded messages that represent a unique phrase in a code book. It is estimated that 17,576 different combinations are possible using only the letters in the alphabet. ELF will thus help to limit submarine time in shallow depths.

Most of the US Navy ELF efforts are believed to have transitioned to operation and spares support, with remaining R&D efforts focused on developing an anti-jamming capability, antenna modifications, and an enhanced data rate (EDR) for ELF communications. The EDR capability seems to have become the main focus of the developmental efforts, with no mention of the anti-jam effort appearing in current program documents. These efforts are likely being funded under programs dealing with each area's specific concern. Funding specifically designated for ELF has not been listed since FY95. (Continuing development efforts are being funded in other US Navy programs such Fleet Communications.)

One should expect ELF to remain in operation for some time, but it is doubtful that a great deal of funding, other than for operation and maintenance, will be pumped into the program unless there is some advanced technological breakthrough that will allow ELF to transmit more meaningful signals.

Ten-Year Outlook

The forecast chart has been omitted. Only minimal operation and spares support funding is seen at this time.

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