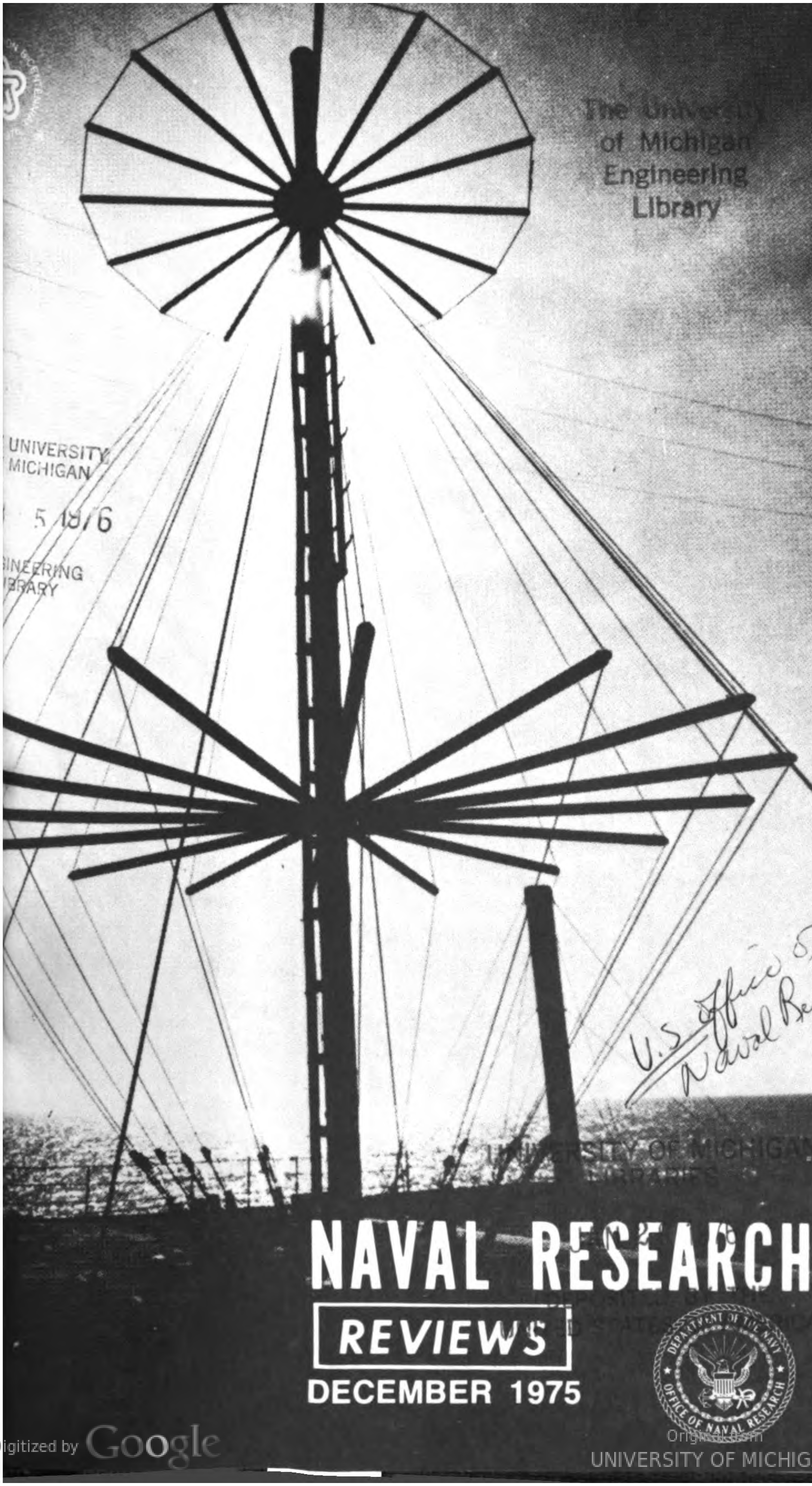

NAVAL RESEARCH REVIEWS

DECEMBER 1975

DEPARTMENT OF THE NAVY · OFFICE OF NAVAL RESEARCH

PROFILES IN SCIENCE

Dr. Peter Franken, who is Director of the Optical Sciences Center, at the University of Arizona, is renowned for his pioneering work in the development of nonlinear optics and level crossing spectroscopy. For these contributions, as well as inventing the metastable helium magnitometer, he was awarded the 1967 prize of the American Physical Society. Dr. Franken served as Deputy and then Acting Director of the Advanced Research Projects Agency from 1966-68. He continues to serve on numerious advisory groups which include Chairmanship of the Research Board of the Naval Research Advisory Committee and on the Executive Panel for the Chief of Naval Operations.

Navy Telecommunications Past and Present

A. Shostak*
Northrop Systems, Inc.

Introduction

The first transmission of time signals and weather broadcasts by the Navy was in 1904 from the Boston Navy Yard Radio Station. Other pioneering efforts to and from ships and shore by electromagnetic means were fleet broadcast and time signal transmissions from the station NAA, Arlington, Virginia in 1913 and NSS, Annapolis, Maryland in 1918. These were sent by spark gap and later by Poulsen-arc at wave-lengths above 200 meters. The nether regions, being considered relatively useless at that time were reserved for radio amateurs (Figure 1).

Other early milestones were the experimental transmissions to determine high-frequency propagation phenomena conducted by the Naval Research Laboratory (NRL) with the co-operation of amateurs. It was not until 1924 when NRL used high power with a water-cooled tube that a circuit was established with England. This circuit was used by the Navy for a year and a half for regular traffic. At this time high frequency meant below 200 meters. The water cooled tube used in this transmitter was developed by the General Electric Company. These experiments showed the real practicality of HF for long distance interfleet communications. During and after World War II, stations operating at HF became major elements in Naval operations.

Very-low frequency (3 to 30 khz) signalling, was accelerated in 1926 by development of the water-cooled copper-anode amplifier tube and also by the evolution of radio broadcasting. As this entertainment medium mushroomed, listeners could not tolerate the interference (arc-mush) generated by low-frequency stations used by the Navy in that period. This resulted in a demand for stable, narrow-band operation in a lower frequency band (VLF). In addition, the VLF signals provided an opportunity to communicate from the beach to slightly submerged submarines, enhancing security of operations of the "silent service."

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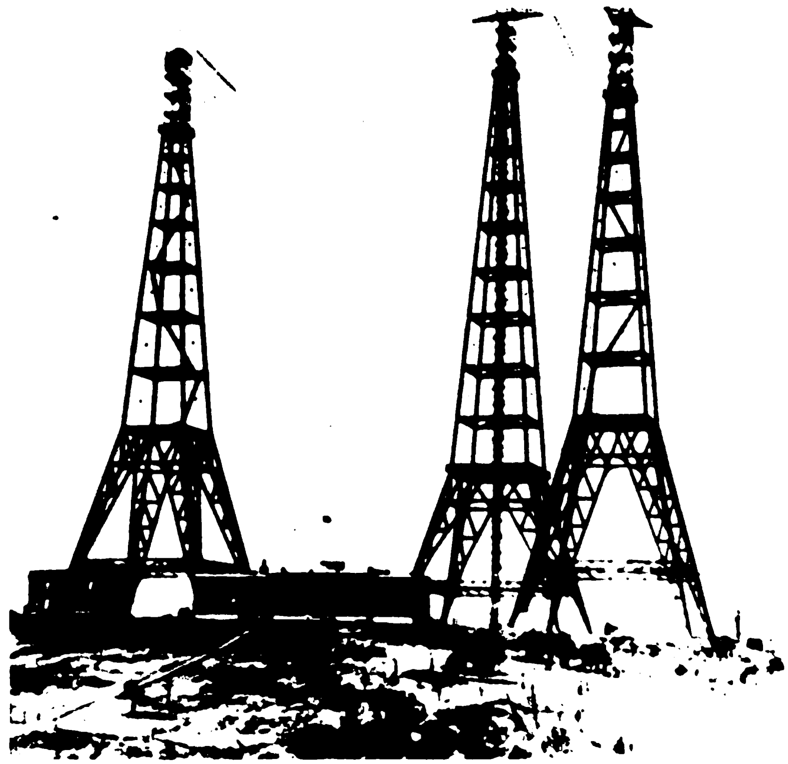

Figure 1 — Navy radio transmitting antennas, Arlington, Va. 1913. Known as "The 3 Sisters," for many years the worlds most powerful radio station.

World War II saw a great advance in Naval communications, with very high, ultra-high and microwave frequency regions of the spectrum put to work for the first time. Velocity-modulated tubes such as the traveling-wave amplifier, as well as magnetrons and klystrons, opened the way for this use. At the same time, investigations were conducted leading to the development of antennas and wave guides which could operate at the high frequencies of this region of the spectrum. Navy laboratories were in the front lines of these advances, and quick to incorporate the new knowledge into improved tactical communications as well as into radar, navigation, and other functional systems for fleet and shore operations.

Unified Communications

As modern fleet requirements became more complex and diversified, the role of naval communications had to expand to meet the needs of the fleet. In addition to intre-Navy circuits, there now exist networks of the Defense Communication Agency, operating under the broad policy direction of the Office of National Communications Systems. All communications circuits of the Defense Department must be compatible with these networks. Thus there are executive circuits which allow the Commander-in-Chief to communicate with low-echelon units. Also coming into being are compulsory tactical switching techniques introduced into the Navy by the Director, Telecommunications and Command and Control Division of the Secretary of Defense (DTACCS). This Division with authorities similar to the earlier Office of Secretary of Defense Telecommunications (OSD-T), Directs evolution of the Tri-Service tactical switch (TRITAC),* a silicon-controlled-rectifier-based, extremely intricate, completely automatic switching unit which enables high-speed selection and routing of properly addressed traffic (including digitalized voice) from any unit to any other unit in the Navy, Marine Corps, Army and Air Force, as well as with other agencies connected in the network.

Other requirements for compatibility in equipments and techniques are dictated by U.S. commitments in the NATO, SEATO, and similar alliances, in which inter-connectibility and operability of air, sea, and land operations must be considered.

Operational Use

Naval operating communications include:

(a) Executive communications from the White House and Emergency Centers to fleet, shore and other units of the Navy and Marine Corps.

(b) Fleet broadcasts, including operational information, certain SECNAV and OPNAV instructions, weather and other general services (record traffic).

(c) Emergency sortee instructions.

(d) Logistics support messages, as well as personnel matters.

(e) Line-of-sight tactical and special messages, relaying information on deployment, course, speed and other aspects in battle- and peace-time maneuvers. (Modern combat direction systems are evolving in the direction of passing encoded digital-data among platforms,

*The AN/TTC-39 Tritac switch is completely automatic; its predecessor, the TTC-38, is semi-automatic.

at high speed, to optimize effectiveness of anti-ship and submarine warfare as well as anti-aircraft and anti-missile offensive operations.) Other line-of-sight fleet operations include logistic and station-keeping communications.

(f) Dedicated data links are relaying information to, from, and among ships and fighter, reconnaissance and support aircraft. Typical of these are the Naval Tactical Data Systems (TDS) and links from carriers to ASW patrol and search aircraft (S-3) and helicopters (LAMPS).

(g) Scheduled ship- and submarine-to-shore communications.

(h) Shore-to-submarine, submarine-to-submarine and other submarine-related communications.

(i) Bridge-to-bridge, man-on-the-deck, shore patrol and industrial security communications.

(j) Ocean surveillance communications, as in Ocean System Information System (OSIS), Anti-Submarine Warfare Centers Command and Control System (ASWCCS), and in specialized surveillance nets. Many of these operations employ time-multiplexed cables, whilst others use high-frequency radio.

(k) Time and time-interval transmissions. Local meteorological data.

(l) Air-traffic control and general aviation service communications. Distress communications.

(m) Marine Corps activities, including landing operations, battery fire direction, forward air-controller and other afloat and ashore communications.

The above constitutes but a brief listing of the types of communications which the U.S. Navy depends upon to insure effective operations.

Communications Program

To cope with the formidable effort of providing efficient, reliable and effective equipments, techniques and systems required in fulfilling its mission, the Navy has started a big program in research, development, test, evaluation, procurement, training and use of efficient communications methods. At the forefront of this program are fundamental contributions in radio-wave propagation, information theory, digital computer science, electronics circuits, components and sub-systems, investigated by the Office of Naval Research, Naval Research Laboratory, Naval Electronics Laboratory Centers and other Navy offices, laboratories and contractors. It remains for the Naval Systems Commands, under the direction of the Office of the Chief of Naval Material to implement the ONR-NRL research into improved systems. This process of materialization is a difficult one, requiring very careful engineering, program management, operational testing and continued up-grading of systems and techniques.

The present telecommunications program is a very large one, involving Research, Development, Test and Evaluation (RDT&E), the Shipbuilding Program (SCN), Planes and Missiles (PAM), Operations and Maintenance (OMN) and other budgetary categorizations. The large RDT&E effort constitutes a major part of the Consolidated Telecommunications Program (CTP). Acquisition efforts, as in the SCN program, are labeled "Non-CTP." Major elements in the consolidated RDT&E program are:

(1) General Communications;
(2) Strategic Communications;
(3) Communications Security (COMSEC);
(4) Fleet Satellite Communications (FLTSATCOM).

In the area of *general communications*, much emphasis is directed toward automatic message handling, as in the "General Address Reading Device" (GARD) and the "Message Processing and Distribution System" (MPDS). The general idea in these systems is to reliably expedite the passing of message traffic to intended individual addressees. This is done by use of digitalized signalling and mini-computer (usually AN/UYK-type) processing of the messages, to ensure accurate routing.

The GARD device, developed at the Naval Electronics Laboratory Center, San Diego, California, is used as an adjunct to receiving teletypewriters, providing for pre-selection and precedences of addressees, and is capable of blocking the print-out of unwanted messages. MPDS analyzes headings, recognizes duplicate messages, stores, retrieves, distributes and makes a log of all messages.

Other aspects of the *General* communications program include:

- Quality control of data transmission, by on-line monitoring of links and loops.
- Development of ultra-high-frequency modems (modulators and demodulators) for line-of-sight task force communications.
- Investigation and implementation of means for replacing mile upon mile of interior communications cable aboard ship (by use of coaxial lines, as well as by means of fiber optics).
- Development of adapter sub-systems, enabling real time interconnection between Autovon, Autodin and other external circuits, with shipboard and FLTSATCOM systems.

● Man-on-the-move helmet type communications systems for use by deck personnel.

The classified *Strategic* program involves submarine, covert, and special tactical communications.

The *Communications Security* (COMSEC) program affords protection to Naval circuits by use of measures which deny information of value to unauthorized persons. These measures may be cryptographic, or may be designed to mislead unauthorized persons in interpreting their reading of our Navy's communications. Cryptosecurity, physical security and transmission security are aspects of this program.

The *Fleet Satellite Communications program*, described later, includes such projects as one designed to allow interconnection of Navy ship and shore terminals, which operate in one frequency band, with the circuits of the Defense Satellite Communications System, which may operate in another band.

Navy Programs

Hindsight studies, which trace the organizational development and research contributions in the metamorphoses of military systems, are rarely clear-cut and convincing. Frequently the practical attainment has been preceded by the efforts of many investigators, some filling in much of the jig-saw puzzle and some contributing but one critical piece. In the case of the Navy's role in communications there are several important and continuing programs of which the Navy's Satellite Communications and Project Sanguine programs will be discussed below.

Fleet Satellite Communications

The space age had hardly commenced when deep-space satellites, especially designed for reflecting, or for actively relaying communications signals from and to the earth, were launched. Project "SCORE" (U.S. Air Force, 1958) orbited an Atlas-ICBM-type rocket, equipped with 150 pounds of communications gear which enabled transmission of a voice message from President Eisenhower to audiences in Georgia, Texas, and Arizona. This was done by tape-recording the messages in the rocket (of elliptical orbit, perigee 114 miles and apogee 928 miles), and subsequently re-transmitting the signals back to earth. The "Echo I" (1960) satellites showed feasibility of "real-time" relaying by reflecting signals off these metallized 100-foot diameter satellites. The Echo I satellite was an effort to provide an alternate for the moon to extend the operational time of the circuit when the moon was not available. Transmissions from Holmdel, New Jersey, to Goldstone, California, via Echo showed that at least 98% of the energy falling on that satellite was reflected as usable signal. Other early tests included those of NASA's Telstar, an active circuit-type of communications satellite (1962), and the Lincoln Laboratory West Ford experiment, consisting of a cloud of metallic dipoles strewn high in the earth's atmosphere, which was capable of passively reflecting signals from one point to another on earth (1963). NASA, with its Early Bird (also called "Intelstat"), and the Soviets, with their "Molniya" series, further advanced the art by showing the practicality of transmitting television signals by satellite relays. NASA also showed the feasibility of using geostationary satellites by successfully launching SYNCOM into synchronous orbit in 1963.

The *first* regularly operating satellite telecommunications service in the world was initiated by the U.S. Navy, on January 28, 1960, when communications via MOON BOUNCE was publicly demonstrated. This service, which continues to this day, expanded U.S. Naval message traffic capability from Washington, D.C. to Pearl Harbor, Hawaii (Figure 2). It is interesting to note that radar astronomers at Army's Signal Corps, Fort Monmouth, New Jersey (Project "Diana," 1946) has shown that earth-generated signals were easily reflected off the moon. It was thought that these signals were diffusely reflected in a broadly scattered manner which sent energy in every direction. However, Naval Research Laboratory experiments* subsequently showed that moon bounce was specular because reflection was confined to an area around the center point of the moon's projected disc. This discovery, which clearly demonstrated the importance of fundamental radar astronomy to the military, enabled design and operation of the Navy moon-bounce communications system.

As further advances in the field were made, the Navy went into a broad program to use the satellite mode of communications. The

*In experiments conducted in 1951, J. H. Trexler at NRL had shown that UHF voice signals could be successfully bounced off the moon and received back on earth. This "monostatic" experiment was conducted with a round-trip delay of 2.6 seconds in 1954. Also, another moon-bounce experiment (this one "bi-static") was conducted in 1959, when signals were sent from Jodrell Bank, England, to the Air Force Cambridge Research Laboratory in Massachusetts. ONR at that time was sponsoring research at the University of Manchester, which included partial support of the 250-foot "dish" used at Jodrell Bank in this experiment.

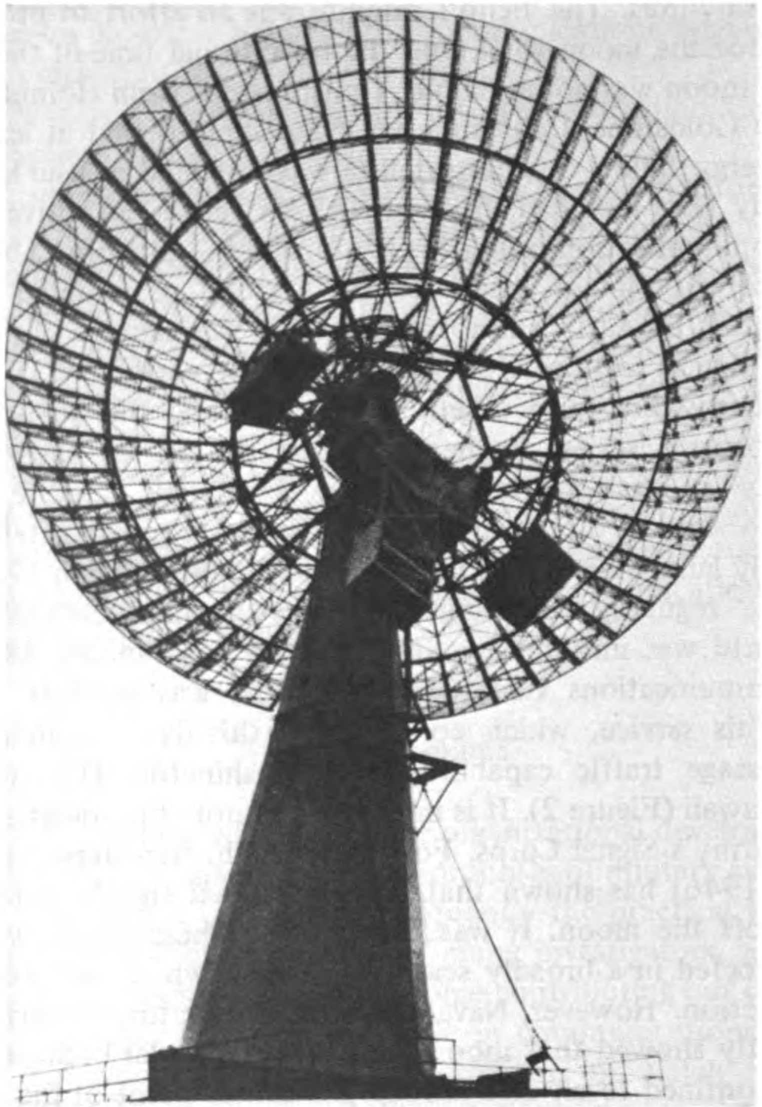

Figure 2 – 84-ft dish–Navy's moon relay station–Hawaii

primary impetus behind the decision to go in this direction was the fact that high-frequency (HF) circuits, vulnerable to the vagaries of solar cycles, sun spots, and to so-called "magnetic storms," cannot be counted on to operate reliably at all times. Satellite relay communications at UHF and higher frequencies, which are relatively insensitive to the deleterious effects of the solar disturbances, could operate under all circumstances. It remains to be seen whether the satellites are vulnerable to enemy shoot-down and other counter-measures, position-drifting, and scintillation propagation effects, which may deteriorate their operations.

In 1970 the Navy evaluated the satellite communications program by testing TACSAT I and LES-6; TACSAT I failed in 1972; LES-6 (Lincoln Experimental Satellite) is still in orbit, providing limited operational use. In concert with the acquisition of the "birds," a parallel program was pursued leading to design and availability of earth terminals and a series of digital data transfer systems. Among the latter are "CUDIX" (Common User Digital Informational Exchange Subsystem).

The current program, termed SATCOM, uses synchronous satellites provided by the Defense Satellite Communication System (DSCS I and II). Air Force also uses the DSCS satellites. These provide limited broadcast service to fleet and shore stations in the Pacific. The DSCS "birds," built by TRW, Inc., weigh about 1200 pounds, are spin-stabilized and can handle voice, teletype, digital data and video signals. Their expected lifetimes are about five years per bird.*

The next important augmentation of the Navy SATCOM program was the leasing of a "Gapfiller" satellite from Communications Satellite Corporation (COMSAT) in the Spring-Summer of 1975. This system when launched will provide additional channels enabling extension of services as in fleet broadcast with higher traffic-handling capability.

Beginning late in 1976, three or four more "birds" (geostationary with world-wide coverage) will be launched over a period of a year. These are the FLTSATCOMS which will provide communications by digitalized voice, by teletypewriter and other standard methods. In addition, these satellite links will be able to pass computer-to-computer-like data, ensuring real-time readiness of ocean surveillance, combat direction and other nets which are absolutely essential to proper functioning of a modern Navy.

Underlying the complex technology which is essential to a successful Navy SATCOM program are the results of years of Navy-supported fundamental research. Because a complete listing of all programs contributing to SATCOM technology would be ponderous, only a few of the better known programs are listed below:

(a) Traveling-wave tube research, especially in the Tri-Service program at Stanford University, leading to the availability of broad-band amplifiers used aboard spacecraft.

*DSCS-I failed in September 1975 when bearings on de-spin platform became inoperative.

(b) Evolution of error-correcting codes,* as well as pseudo-random codes and digital filters, the last two of which are used in spread-spectrum anti-jam circuits of Navy satellite communications circuits. Much of this was done at Naval Research Laboratory, Massachusetts Institute of Technology, and Polytechnic Institute of New York, in the Joint Services Electronics Programs.

(c) Contributions in antenna design, led by Harvard's Division of Engineering and Applied Physics (Professor R. W. P. King's group) and at the University of California, Berkeley (Professor S. Silver's group).

(d) Use of micro-electronics and large-scale integration of active and passive circuits (led by Naval Research Laboratory under Mr. A. Brodzinsky, and by Naval Electronics Laboratory Center, San Diego, led by Doctors P. Russell and R. Bergmann).

(e) Studies in radio-astronomy, leading to knowledge in the use of steerable "dishes" and interferometers for pointing to and tracking of deep space satellites. ONR mounted a sizable program in Radio Astronomy at California Institute of Technology, University of Michigan, and elsewhere. The NRL group has been at the forefront of research in radio-astronomy, led by C. Mayer and H. Friedman.

(f) Design and development of on-board processors, to assure efficient use of the multi-channel system. These processors discriminate high priority and flash signals, and also allocate channels for the numerous Navy SATCOM users. NRL has pioneered in this effort.

Many more contributions have been made, as in information theory, communications security codes and error-correcting codes, code generators and demodulators, radio-wave propagation and circuit design. ONR and NRL have maintained vigorous programs in all those fields.

Without proper management to funnel the products of research and development into efficient, cost-effective systems, the Navy SATCOM program would make slow progress. It is to the credit of Navy officers, engineers and scientists in OPNAV, NAVELEX, ONR, and to numerous Navy laboratories, offices and contractors, that there now exists a well-balanced Navy satellite communications capability.

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*There are two principal types of codes in common use in Naval data transfer. The first of these are called error-detecting and correcting codes, whose purpose is to provide redundancy in a stream of digitalized data, so that if information is lost, it may be reconstructed. (These codes are also known variously as "Block," "Convolution," "Product," "Concatenated" or "Burst" Codes.) Codes of the second type are also pseudo-random. Their purpose is to provide anti-jamming features to a communications signal by spreading out the operating frequency in a random (but repeated) way.

Project Sanguine

Since the dawn of history, electromagnetic waves of extremely- and ultra-low frequency (3000 to 0.001 cycles per second) have spread around the world, guided by the duct between the concentric spheres of earth and ionosphere. These natural waves are generated by lightning strokes in the earth's atmosphere (the lightning accelerates charges, as in an antenna), or by the interaction of the solar wind (a stream of charged particles which emanates from the sun), with the earth's magnetic field (waves from the latter phenomenon may be looked upon as corresponding to those generated and propagated when a "rubber-band"-like set of magnetic tubes of force is plucked). The lightning-generated waves are called "sferics"; the "solar-wind" derived disturbances are called "micro-pulsations" of the earth's field, or "hydro-magnetic" waves.

In the years from about 1955 to 1962, ONR sponsored research in the properties of "sferics" and "micro-pulsations." A group at Stanford University, under Professor R. A. Helliwell, studied velocities of propagation, dispersion and magnetic conjugate-point phenomena of "sferics" instead of relying on nature to generate sferics, a special keying unit was installed in several Naval very-low-frequency stations, so that time and frequency control of the man-made "sferics" was ensured. Another group, including ONR contractors at the University of Texas, Massachusetts Institute of Technology, University of Alberta, and Canterbury University (New Zealand), developed synoptic information on field strengths, directivity and correlation of the events and characteristics of "micropulsation" waves with other natural phenomena such as polar-cap cosmic-radiation. These studies served to provide a background of information on noise, on wave propagation and on instrumentation unique to reception of such waves, all of which was available when Naval communications systems operating at extremely-low-frequencies were evolved.

Simultaneously with the U.S. studies, a group headed by Professor Schumann of Technische Hochschule in Munich, Germany, was studying the theory of extremely-low-frequency (ELF) waves which propagated in the earth-ionospheric duct. Spherical Bessel Wave Solutions of the wave equation for this case showed that ELF waves of nine cycles per second, and higher integral values, would "stand" (resonate) in the duct, so that strong signalling could be accomplished by this mode of propagation.

In 1962, ONR let a contract with DECO Laboratories, Boulder, Colorado, to actually perform an experiment in launching man-made

ELF signals. Drs. D. Watt and E. Maxwell, of those laboratories, using an antenna made of about 45 miles of power transmission line, which ran from Laramie to Cheyenne, Wyoming, and harnessing power from the Grand Coulee Dam, showed for the first time, that such signals could be sent and received. Some 480,000 watts into, and 80 milliwatts out of, the General Services Administration's Wyoming power line, at 60 cycles per second operating frequency, were received unambiguously at Los Angeles, California, in this experiment. Thereafter, the Naval Electronics Systems Command, following a program chaired by Dr. N. Christafilos, of the University of California, and with significant input from the Radio Corporation of America (contractor under program "Pangloss") pursued the actual development of the ELF signalling program, now termed "Sanguine." Significance of this kind of communications program derives from the fact that electromagnetic waves which penetrate the sea experience attenuation which varies inversely with the square-root of the wavelength. Accordingly, an ELF signal may be expected to be picked up at hundreds to thousands of feet deep in the sea. Thus, the Sanguine system is attractive, in that it may be used to send one-way messages to deep-lying submarines (albeit at low message-traffic rates, owing to the narrow band-widths involved in the signalling process).

Unhappily, "Sanguine"-type waves require very long antennas, operating over low-conductivity granite earth paths, making for a large real-estate investment. Also, the extremely low frequency alternating currents involved in the system have a tendency to ring telephone bells, to turn on house lights, and perhaps, to cause physiological effects. The Navy goes forward with this program, testing out each phase of its development (and at the same time considering cost-effectiveness implications), so that some day there will be a fail-safe system to communicate with the Poseidon and Trident fleet.

Oil Analysis in Perspective

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This paper reviews the methods of oil analysts in order to show their weaknesses with respect to improving future lubrication system design and reliability. Also changes are recommended that appear necessary for good "oil analysis" services for future high performance equipment. Detection of component malfunction in lubrication and hydraulic systems, prognosis of the course, and remaining system life and possible diagnosis of the types of failing components have been the primary objectives of most oil analysis activities.

Oil Analysis Methodology

Present "oil analysis" methodology may be subdivided into three parts. The first phase is sampling which assumes, sometimes mistakenly, that the oil and the particulates in it are representative of those in the system. The second part, composition determination, is accomplished in a calibrated commercially available instrument which measures the *wear metal* concentration in the oil sample. Wear metal comprises the particulate matter composed of suspended metal or metal oxides and the metal compounds desolved in the lubricant. This data, along with available information such as operating hours since the last sample, and oil change, is then used by the oil analyst to infer that the rate of production of metal in the system is increasing, decreasing, or remaining the same. In the third step the oil analyst makes periodically updated estimates of the wear metal production rate based on this data. The ideal wear metal concentration, its concentration change with time, and possible oil consumption, and other data are inputted by the oil analyst into the equation in Figure 1 to obtain the metal production rate. If the filter in the system is removing only a small fraction of the particulates that are formed (i.e. the filtration rate is small), the rate at which particulates

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$$r_{\text{PRODUCTION}} = r_{\text{ACCUMULATION}} + r_{\text{REMOVAL}}$$

$$= m_l \frac{dc}{dt} + \frac{c\,dm_l}{dt} + r_{\text{filter}} + r_{\text{settling}} + r_{\text{deposition}}$$

$r_{\text{PRODUCTION}}$, $r_{\text{ACCUMULATION}}$, r_{REMOVAL} - RATES OF METAL PRODUCTION IN, ACCUMULATION IN, AND REMOVAL FROM THE SYSTEM (GRAMS/SEC)

m_l - MASS OF LUBRICANT IN SYSTEM, (GRAMS)

c - CONCENTRATION OF WEAR METAL IN LUBRICANT (GRAMS METAL/GRAM OF LUBRICANT)

r_{filter}, r_{settling}, $r_{\text{deposition}}$ - RATES OF WEAR METAL REMOVAL BY FILTRATION, SETTLING AND DEPOSITION MECHANISMS (GRAMS/SEC)

Figure 1 — Definition of wear metal production rate

are settling to sumps and the rate at which dissolved metal is depositing on the system's surfaces are low, then the "oil analyst" can make a fine prediction of the wear metal production rate, its change with time, and a reliable assessment of any change in machinery condition.

The original success of the analyst in predicting problems in diesel and other systems engines which are generally equipped with coarse filters (40 + micron) therefore is understandable. However, other mechanical devices such as the hydraulic systems, which are installed in Naval aircraft and which are equipped with relatively fine micrometer filters, are not as responsive to conventional oil analysis methodology (5). As a consequence the spectrometers are not sensitive to the small concentrations of particles present in the system and the comparatively slow rate of change of metal concentration with time, even when the system is wearing at abnormal rates. Unfortunately for the oil analyst this trend is continuing because machine designers are beginning to recognize the benefits to be obtained by specifying filters that remove a high fraction of particulates which can be deleterious to the life and reliability of the equipment. For example, the T-700 engine developed for the UTTAS helicopter is to be equipped with 3 micron filters originally tested on the T-53 engine (5,6).

Particle Size/Concentration and Machine Reliability/Life Relationships

Examination of the relationship between particle size, concentration and machinery reliability and life is best begun by comparing particle size and lubricant film thickness as a function of application for naval equipments. I have chosen aircraft derivative bearings and gears, hydraulic system components and journal bearings typical of those supporting steam turbines as extreme examples. As may be seen in Figure 2, the film thicknesses in these equipments range from 0-0.1 micrometers to 25 micrometers, and installed filtration capability begins to compare favorably with film thickness only in the hydraulic and steam turbine journal bearing application. Only in the case of the steam turbine journal application can sufficient particulate matter be expected to be in suspension to be truly susceptible to spectrometric analysis and at the same time not be deleterious to the mechanical system. These conservatively designed systems are inherently very reliable and are not a priority item for oil analysis. The aircraft hydraulic system, because its sliding components are very susceptible to deterioration by particulates and therefore is much less reliable, is equipped with efficient filters and renders spectrometric analysis almost ineffectual. Only in the case of the aircraft bearings and gear systems is the lubrication system susceptible to spectrometric oil analysis because they are not *now* equipped with efficient filters. The extent of the application of spectrometric oil analysis will decrease as finer filters are installed in these systems to increase life. Preliminary evidence indicates bearing lives and presumably the lives of these film gears can be increased many times by using effective filtration techniques (7).

To illustrate the relationship between wear particle size, concentration detection limits, wear particle-surface interaction rate and surface damage (see Figure 3). A part per million of iron as iron oxide particles with one cubic micrometer volume in oil results in a particle

	FILM THICKNESS MICROMETERS	FILTER CAPABILITY MICROMETERS
GAS TURBINE BEARINGS, GEARS	0.1-1	10-40
HYDRAULIC COMPONENTS, AIRCRAFT	0.5-3	5
SHIP JOURNALS	25	25*

* ANTICIPATED

Figure 2 – Moving surface separations

1 GRAM IN 1,000,000 GRAMS FLUID

1 GRAM IN 275 GALLONS FLUID

500 BILLION PARTICLES IN 275 GALLONS

1.8 BILLION PARTICLES IN 1 GALLON

400,000 PARTICLES IN 1 CUBIC CENTIMETER

PARTICLES - 1 CUBIC MICROMETER OXIDE PARTICLES

Figure 3 — Wear particle concentrations — 1 PPM iron

number density of approximately 400,000 particles per cubic centimeter. A part per million represents 1 gram in approximately 275 gallons of lubricant or, in other more familiar volumetric terms, 1 drop of vermouth in 16 gallons of gin (Figure 4). A part per million of iron in oil is below the sensitivity of Navy emission spectrometers which actually are not sensitive to concentrations below 2 parts per million (2000 parts per billion). In an elastohydrodynamic contact of a ball bearing with a micrometer film operating a surface velocity of 1000 in/sec, the particle interaction rate with ball is approximately 1 per second. At a film thickness of 0.1 micrometer, the passage of a boulder 1 micrometer in size would occur on the average of every 10 seconds. Experimental evidence indicates these presently unfiltered particulates slowly but surely interact with the surface and initiate surface fatigue cracks, a fraction of which propagate into the interior

CONCENTRATION OF IRON (PPM)	READING (PPM)	RANGE (PPM)
0	0 or 1	0-1
0.5	0 or 1	0-1
1	± 1	0-2
10	10 ± 2.2	8-12
100	100 ± 10.2	90-110

1 PPM = 1 DROP IN 16 GALLONS; 80 "FIFTHS"

1 CENT IN $10,000

1 INCH IN 16 MILES

1 MINUTE IN 2 YEARS

Figure 4 — Emission spectrometer sensitivity

of the bearing surface and thereby limit life. In addition, skidding damage to future high DN aircraft turbine bearings during thrust reversals will probably be aggravated by particulates.

Oil analysis using today's methodology and tomorrow's spectrometric techniques, such as atomic florescence in well filtered systems, will not improve the situation appreciably because most of the wear debris will be in the filter. However, the detection limits for iron of atomic florescence spectrometers equipped with flame atomizers and pulsed hollow cathode lamps is 6×10^{-4} parts per million, which is a significant improvement over emission spectrometers in use today (8).

Oil Wetted Surface Condition Monitoring/Options for Future Lubrication Systems

The application of filters efficient in the 0.1 to .1 micron range in hydraulic and lubrication systems will require that current oil analysis methodology and instrumentation be abandoned or changed. An oil analysis system using today's methodology and spectrometric instrumentation sensitive in the low parts per billion range will only rely on the presence of newly created wear metal particles, the small number of statistically available particles that have previously passed through the filter, and changes in soluble metal compound content to detect abnormalities in the lubrication system. Abandonment of these oil sampling and analysis procedures and introduction of inline detectors, although presently unavailable, to detect the concentration of the available wear debris or wear debris and dissolved metal and to provide time averaged concentrations and approximate wear metal production rate data, is a second alternative. However, attempts to use light scattering, high energy fluorescence, capacitive,

BASIS:

GAS TURBINE BALL BEARING CONTACT

25 METERS/SEC SURFACE VELOCITY

1 MICROMETER FILM THICKNESS

1 PPM IRON - 1 CUBIC MICROMETER OXIDE PARTICLES

RATE: 1 PARTICLE PER SECOND

Figure 5 — Particle surface interaction rate

and neutron activation detectors which have been developed or proposed, or even inline Ferrographic devices for these purposes, would be probably frustrated by the low wear metal concentrations. As a third alternative, design into and installation of centrifugal particle separation devices in hydraulic and lubrication systems would provide wear debris for microscopic and spectrometric analysis, and would be desirable in some equipments. In other equipments, where redesign is not practically or economically feasible, new types of filters may provide the particle separation capability needed to improve equipment performance and life, and provide wear particulates for diagnostic and prognostic analyses of machinery condition. High gradient magnetic separators, which separate ferro or paramagnetic materials by magnetic forces, may provide a measure of the desirable characteristics listed in Figure 6 and are being evaluated for these applications.

0.1 - 1.0 MICROMETER

HIGH DEBRIS CAPACITY

LOW PRESSURE DROP

PERMANENT FILTER ELEMENTS

WEAR PARTICLE RETRIEVAL FOR ANALYSES

NO EXTERNAL POWER

Figure 6 — Ideal filter characteristics

To conclude, it is appropriate to mention the report of Alan Beerbower's study of mechanical failure prognosis through oil debris monitoring (5). Although the study was restricted to assessment of current oil analysis methodology and suggestion for the improvement of oil analysis techniques for helicopter transmissions, his recommendations are generally applicable. Beerbower finds that nearly 100% of transmission failures could be detected *if* spectrometric analysis is augmented by particle analysis of the larger particles which are collected by chip detectors or the presently installed filters. Beerbower's report, in addition to providing the data upon which to base his recommendations, provides a description of wear mechanisms, wear particle size distributions, and description of non-spectrometric oil analysis tools available today.

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Unique Holographic Data-Storage Technique

Sponsored by the Office of Naval Research, scientists at the Naval Research Laboratory, have developed a holographic data-storage material with a capacity substantially greater than is possible with methods currently available. The new technique also provides for selective erasure or rewrite of partial or entire holograms of data planes in a stacked array.

Dr. Irwin Schneider, the principal investigator for the program, says the use of optical storage, which employs the three dimensionality and inherent parallel-processing capability of holography, could provide a means of achieving large storage capacities without sacrificing fast access times. Conventional computers must be designed to compromise these two conflicting parameters.

The NRL method uses a storage medium whose operation depends on an optically controlled polarization effect. This medium is composed of alkali halide crystals with polarizable color centers (atomic-sized defects which can by oriented), thereby making the material exhibit a dichroic property — a property whose selective absorption of polarized light (which yields light and dark areas) is well suited to storage of computer notation.

By using the polarization properties of photodichroics, much higher density holograms can be stored. Furthermore, light scattering can be essentially eliminated, so that even weak holograms become easily detectable. And the medium is grainless, since the recording elements are uniformly dispersed and atomic-sized in dimension, resulting in very high storage densities.

New Tools for ALVIN

Glen Reem*
Raytheon Corporation

Recently three new tools designed by ARPA for the U.S. Navy Deep Submergence Vehicle, ALVIN, were tested at the Navy AUTEC Facility at Andros Island, Bahamas. These tools which will greatly improve ALVIN's capabilities are: the Wide Angle Illumination System, the Modular Sonar, and the Self-Contained Ancillary Modular Platform.

Alvin

ALVIN is operated by the Woods Hole Oceanographic Institution (WHOI) for the Office of Naval Research under the Deep Submergence Research Vehicle Program. The purpose of this program is to "carry scientists into the depths of the sea in support of the scientific program at the Woods Hole Oceanographic Institution and elsewhere, and to perform tasks requested by the Office of Naval Research and other appropriate sponsors." Designed by Dr. Alln Y. Vine of WHOI. ALVIN was built by Litton Industries. She was certified for operation to 6000-foot depths in August 1965, the first manned non-combatant submersible so certified by the Bureau of Ships. She began duty in 1966 and has carried out her mission most effectively, except for 18 months when she was out of commission following a launching accident in 1968. During her winter overhaul in 1973–74, a titanium alloy personnel sphere built by the U.S. Navy at the Mare Island Naval Shipyard was installed. This is the first use of titanium for a manrated pressure hull. The new hull increased ALVIN's operating depth to 12,000 feet. The payload of ALVIN was also increased because the 12,000 foot titanium sphere is lighter than the previous 6000 foot steel sphere and because buoyancy material was added to increase ALVIN's freeboard on the surface.

Today ALVIN is the only U.S. deep submersible mainly committed to non-military research. She has been assured of operating through

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the summer of 1977 by current operations funding. Her physical characteristics include a weight in air of 16 tons, a length of 25.5 feet (7.8 meters), beam of 8.3 feet (2.5 meters) and a height from top of sail to bottom of hull of 12.6 feet (3.8 meters). She carries a 3-man crew (pilot and two observers on shallow dives, 2 pilots and one observer on maximum capability dives) in an 80″ inside diameter personnel sphere, along with control and scientific equipment. Maximum dive time is 10–12 hours, depending on battery drain rates during the dive, with emergency life support for an additional 60 hours. ALVIN's payload is about 900 lbs, weight-in-water. Some electrical and hydraulic capacity is available for outboard experiment equipment. ALVIN is available to scientists who need to place experiments or observe on the bottom of the ocean or in mid-water anywhere in the Atlantic Basin.

Modular Sonar System

The Modular Sonar System is a unique combination of transducers, displays, a minicomputer and recording equipment designed to examine the acoustic characteristics of the water column or the sea bottom at close range. This can include volume reverberation and bottom topography studies and bottom reflectivity/scattering measurements. All these can be done directly at the volume or bottom point to be examined by moving the sonar there with ALVIN. Previously these physical details could only be inferred because the testing was done with surface-borne systems that were far from the scatterer, or its position was only approximately known. In addition, the flexibility and frequency range of this system, its directional or side scan modes and various display options will allow much more thorough examination of the area under test. The close approach to the point of interest also will materially reduce extraneous noise pick up. At the same time, other tools on ALVIN can be utilized to sample or record bottom or floral and faunal characteristics of the point being measured acoustically. These tools include still and motion picture photography; bottom sampling with hammer, drill and core; and faunal sampling with nets. This combination of point location and system flexibility is unique among measurement systems today.

Many of the possible uses of this Modular Sonar System are particularly relevant to the needs of the U.S. Navy and its acoustic systems. The scattering of sound from the bottom is an important factor in long-range transmission systems, but the predictive ability of surface experiments has been limited. Now with the new ALVIN detailed studies of small areas, correlated with long range use of the same area, might improve ways of determining characteristics.

The side scan and PPI modes can be used for detailed area survey to speed bottom studies by covering larger areas than otherwise possible. The E-scan mode allows profiling to be done quickly. The acoustic survey can be combined with bottom sampling to allow intelligent placement of bottom stations and structures. A block diagram of this system is shown in Figure 1 and a photograph of the equipment in Figure 2.

ALVIN carries two one-octave bandwidth transducers at a time, one mounted on a two-axis trainable mount, the other hull mounted. Transmitted frequencies and waveforms are generated by a coherent frequency synthesizer under control of the minicomputer. This minicomputer allows rapid sequencing of tests and wide flexibility in these tests including transmitted waveform changes, provides automatic control of data recording, and has been programmed for some on board signal processing to allow real-time variation of experimentation during a mission. The display is a CRT which can present several different information modes: PPI, L-R scan (side scan), elevation-range scan (E-scan), range-amplitude scan (A-scan), paint ("echogram") and can be used for "built-in-test" and servicing of the system. All data, the systems operating parameters and a voice channel are recorded on magnetic tape for later analysis. The display is photographed periodically by an integral camera. Manual operation of the Sonar is accomplished through a switch panel, for simple experiments, for variations in preplanned operations or in case of failures during a dive.

The initial software library for the minicomputer has been generated as far as potential application can be foreseen, and further experiments can be programmed using the peripheral equipment. The software interface with the rest of the system was checked out during the test period at Andros Island.

The complete system was assembled at Andros, tested ashore, and then installed aboard ALVIN. The first in-water tests aboard ALVIN showed some transmitted noise during receive and relatively high noise levels in the receiver. During a second in-the-water on-the-cradle test, one transmitter silver-cadmium battery pack exploded, terminating all testing efforts since the cause could not be determined and no spares were available.

The system can be made fully operational by relatively simple modifications. Transmitter power is now available from ALVIN and the battery packs can be eliminated. An outboard battery powered

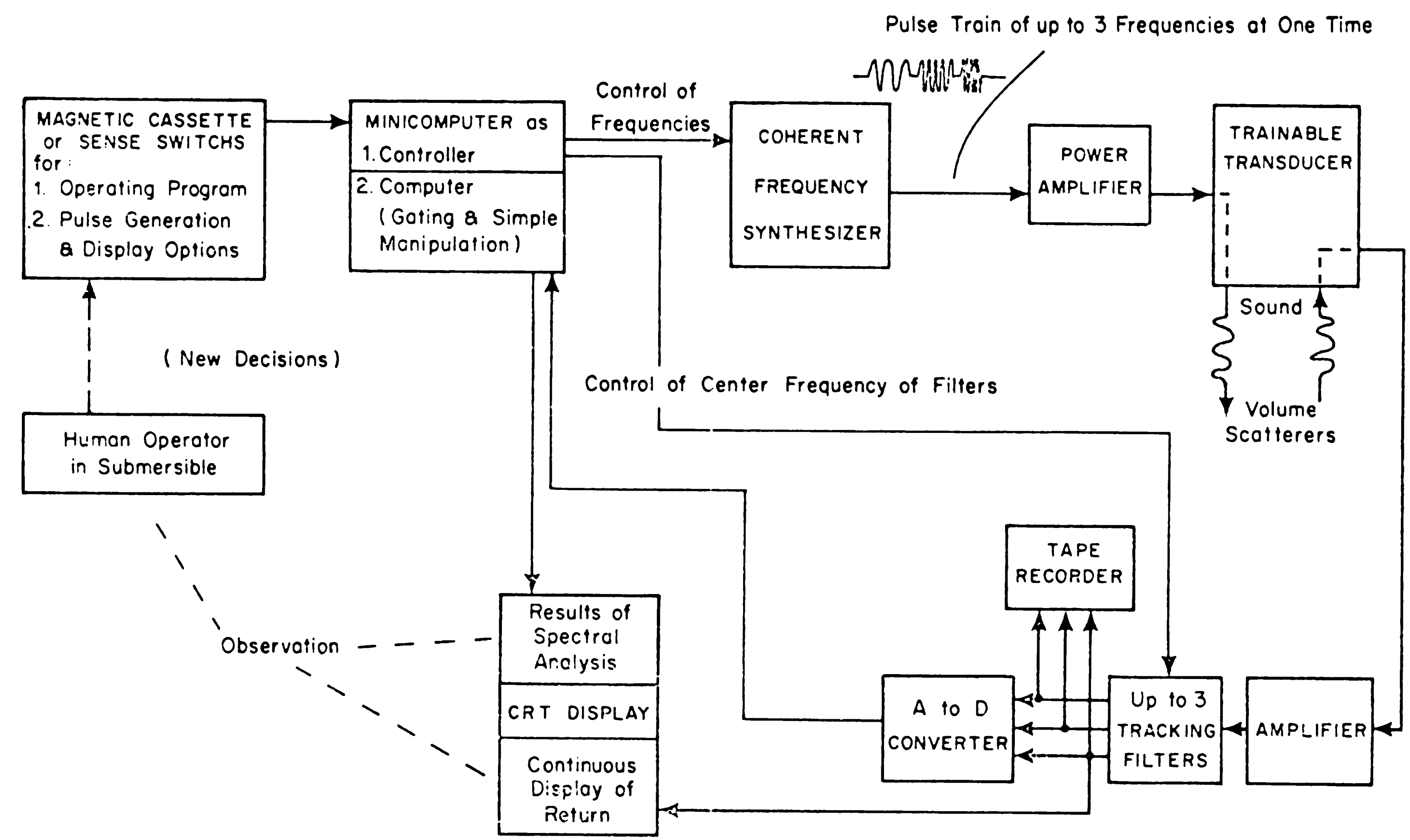

Figure 1 — Diagram—programmable system

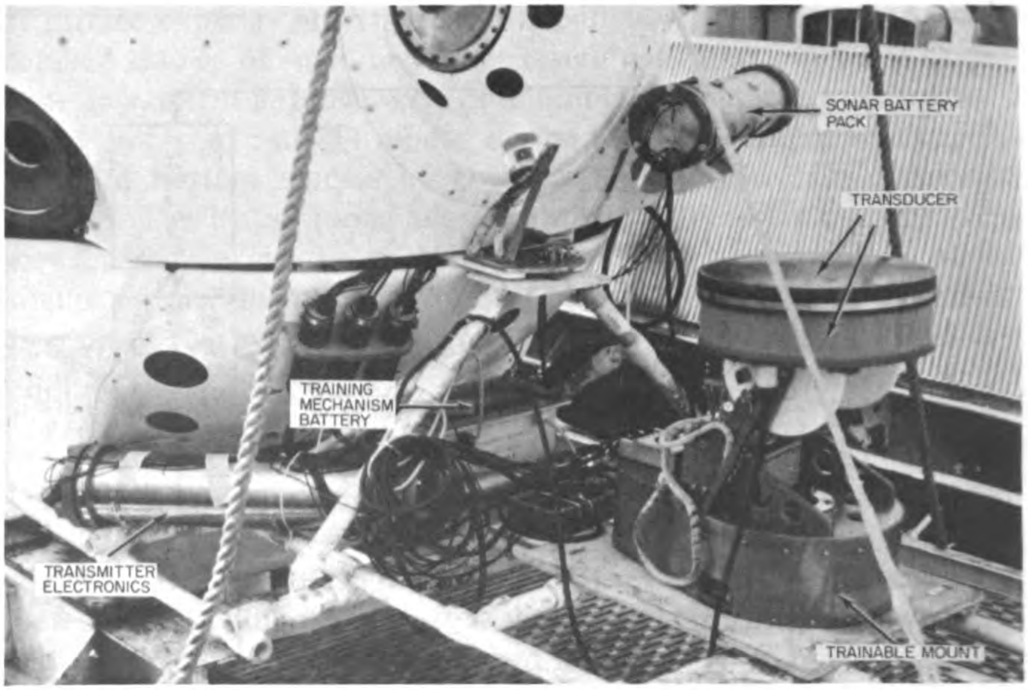

Figure 2 – ARPA modular sonar mounted on Alvin which is setting in her cradle on Lulu

preamplifier operating in the differential mode to a balanced shielded pair running inboard should solve the receiver noise problem. The induced transmitter noise level can be reduced sufficiently by using a balanced transformer coupled drive from the synthesizer. Synthesizer output power is adequate and the thru-hull connections are available for all these leads. Accomplishment of these changes and completion of testing would provide the Navy and scientific communities with a uniquely versatile tool in the combination of ALVIN and the Modular Sonar System.

Wide Area Illumination

The purpose of this task was to determine the feasibility of increasing the range of vision from ALVIN by using lights not attached to the vehicle itself. The problem has been that light from ALVIN's illumination has been reflected from particles in the water, obscuring vision to objects further away and therefore more dimly lighted. These particles are always present to some degree, either indigenous plankton and detritus or material stirred up by action of the submersible. Since ALVIN operates at depths where the only illumination is its own lights, this has been a major limitation, with vision constrained to 30-40 feet. The condition is closely analogous to fog or rain on a dark night illuminated by car headlights.

In automobiles, vision is improved under these conditions by lowering headlights as close to the road as possible. This somewhat sidelights the particles, as seen by the driver, reducing the intensity of light scattered to the driver and allowing him to see dimmer, further away objects. It was thought that a similar improvement could be achieved by bouying a light above ALVIN on a tether. This would sidelight the suspended particles and also better illuminate objects further away, giving better vision. Any wider range of vision will materially increase the data available to ALVIN for observation and reduce the time required for visual search missions.

As implemented the light consisted of an inverted V-shape float housing two lights and connected to the submarine by a tether and power wires. Thus the light floated about 20 feet above ALVIN with the axis of the V athwartships. When ALVIN is underway at her 1.5 knot cruising speed the V tilts slightly aft so the lights shine further forward, facilitating searches. A photograph of the experimental light is shown in Figure 3.

The float is about 30 inches long with a V shaped cross section about 20 inches across the arms. It is made of 2 inch thick 34 lbs. per cubic foot weight "syntactic foam." This consists of .010 inch

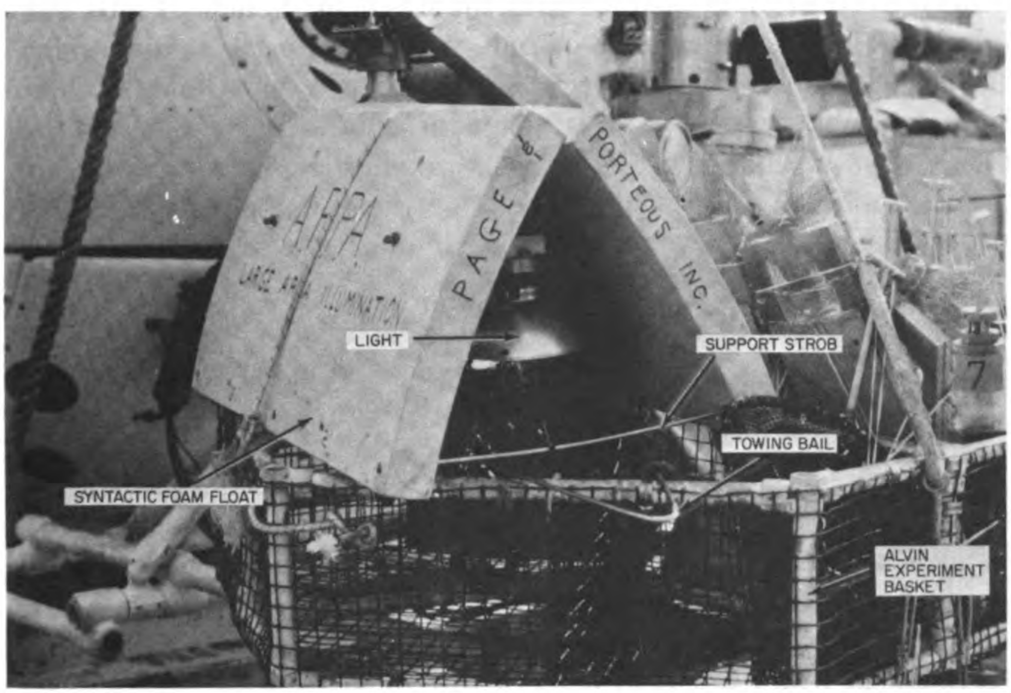

Figure 3 – ARPA "large area illumination" test unit mounted for launch on Alvin's experiment basket

diameter hollow glass beads bound by plastic. It is virtually incompressible and inert in seawater making it an excellent bouyancy material for deep ocean operations. A similar 36 lb. per cubic foot foam is a main bouyancy agent for ALVIN and is widely used elsewhere. The bridle is a pair of stainless steel bails connected to a Y in the tether. It is simple and does an excellent job under the gentle dynamics of ALVIN's slow speed.

Two lights were used in this experiment, each with two 350 watt filaments, powered by cable from ALVIN's batteries. This wattage appeared to about double the range of visibility from ALVIN compared to the hull mounted thallium iodide (TI) lights. This is the more significant since the TI lights radiate a green light with good transmissivity in sea water and the test lights are broad spectrum white lights. This light system was designed and built by the Deep Submergence Engineering and Operations Group at WHOI with Clifford Winget as Principal Investigator.

In view of the success of this experiment, WHOI now plans to build another float using more powerful lights. It will probably be deployed from ALVIN by the swimmers as she dives and picked up by them as she surfaces and before here recovery by LULU.

A camera and electronic flash package is being made that will be towed in the same manner to take wide area photographs of the bottom surrounding the submersible. This will be used first in January 1976 in dives planned into the Cayman Trench to look for evidences of the submergence of one plate of the earth's crust under another that is believed to occur in the deep ocean trenches. The wide area photographs will supplement and locate the close-ups taken by the hull mounted and through-the-window hand-held cameras, and show the relationship between the details and the surrounding areas. They will also continuously document the path covered by ALVIN.

Self Contained Ancillary Modular Platform (SCAMP)

SCAMP is a self contained platform that can be clamped to ALVIN and "flown" to specific locations on the bottom. This has several benefits to ALVIN's work. Experiments that are to be left on the bottom for some time, especially ones requiring electrical power during their stay, can be attached to SCAMP and located precisely by ALVIN, which then detaches from SCAMP, leaving it on the bottom. This is an improvement over the experiments on "bottom towers" (bouy strings) that must be dropped from the surface to come to rest where they will. SCAMP also can supply the homing transducers, for several successive experiments, instead of each providing its own. Since SCAMP is mounted centrally under ALVIN it can increase the science payload because the in-water-weight on SCAMP does not require counter balancing as it would when located in front of ALVIN. A photograph of SCAMP is shown in Figure 4.

SCAMP also mounts 3 suction pods which can be used to hold SCAMP and ALVIN to the bottom with several hundred pounds force, depending on the bottom consistency. This will enable ALVIN to do tasks that require the application of force to the bottom, as in coring or taking geological samples. Since ALVIN is neutrally bouyant and also balanced around her center of bouyancy, any force applied by her to the bottom in the vicinity of her bow will cause rotation or translation opposed only by her inertia not by her in-air weight. SCAMP then is a universal mounting base for science apparatus.

SCAMP is clamped to ALVIN's skid rails by pumping sea water into sections of fire hose, expanding the hose against the skids. The force developed is sufficient to hold SCAMP's in-water weight and inertia. Power is provided by lead acid batteries on SCAMP's driving pumps or motors as required. These batteries are oil covered to provide pressure compensation at depth, as are other electrical and mechanical circuits.

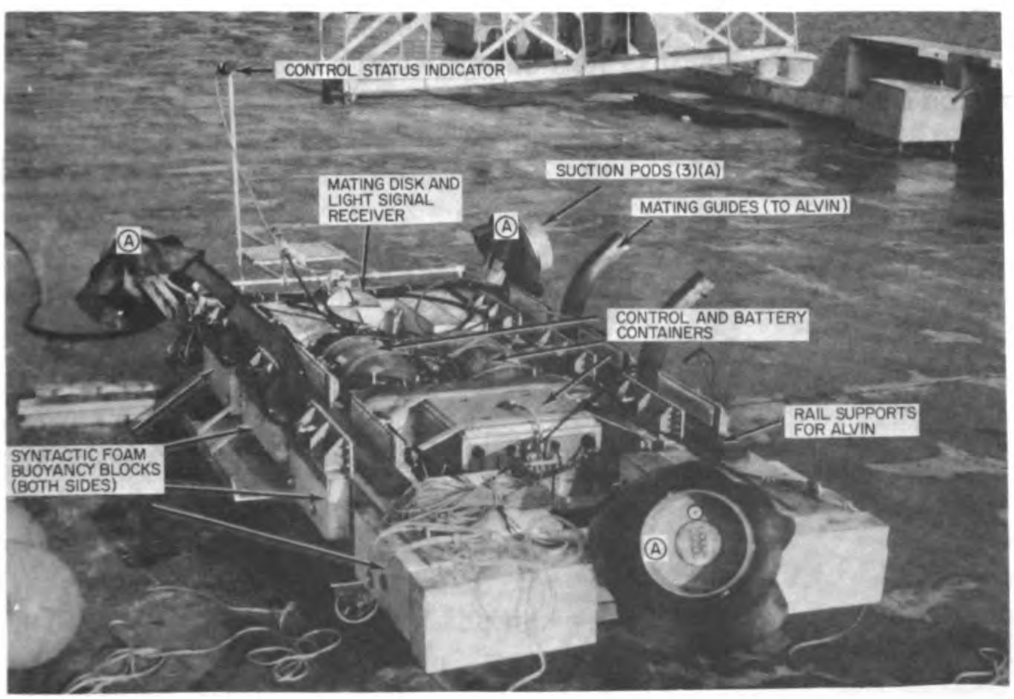

Figure 4 – ARPA "SCAMP" on pier at Autec range, Andros Island

A unique feature of SCAMP is a pulsed light control system that eliminates all hard connections between SCAMP and ALVIN. This has several advantages. For safety of life, all things attached to ALVIN must have an emergency jettison disconnect system. In SCAMP this is effected by simply a quick disconnect in the seawater clamp lines instead of through an electrical disconnect system. Also no through hull connections to SCAMP are required because the pulsed light is projected out through the sphere bottom viewing port when SCAMP is to be operated. When SCAMP is to be recovered from the bottom, ALVIN needs only place herself in the clamp rails on SCAMP and use the light to activate the clamps without having to mate connectors which would be extremely time consuming because of the slow movement of the manipulator. Pulse light commands are relayed in milliseconds and new commands can be entered each 100 milliseconds. Thus the pulsed light control really makes SCAMP a practical tool.

Commands are initiated through a switch box which sets a command number into binary coded decimal language. The BCD sequence for the particular command is impressed on the light of a *Strobotac*. This light pulse train is transmitted through ALVIN's viewing port to a sensor on SCAMP where it is decoded and the proper relay actuated to activate SCAMP. A *LED* display on SCAMP tells the ALVIN operator what command has been executed as a check on system operation.

During tests at Andros, the light command system and mating with ALVIN were demonstrated before ALVIN was preempted for a mission on the AUTEC range.

Research Note

Solvent Roles in Chemical Reactions

Professor C. Gardner Swain of MIT, has been working for the past two years on a more accurate equation for correlating solvent effects in chemical reactions. The program, which is supported by the Office of Naval Research, has not only led to the development of an equation which appears to be fulfilling the announced objective but has also resulted in a number of contributions to computer technology.

During the past three or four decades, a variety of equations based on linear free energy relationships were developed in physical organic chemistry research which correlate chemical reactivity with structure. All of these are approximations, involving two independent properties but assuming that one of these factors is insignificant or essentially unchanged in the reactions under study. In the case of solvent effects, it is clear that the two independent properties that are important are acidity (anion-solvating power) and basicity (cation-solvating power). Investigators have tended to ignore the cation-solvating power or have adopted arbitrary assumptions to assess its influence. In the present research, Dr. C. Gardner Swain and his collaborators have developed a two-parameter correlation equation which renders it possible to separate both acidity and basicity in solvolyses. To obtain the pure numbers required, an entirely new approach has been devised involving a dual factor analysis employing orthogonalization of the two solvent factors (x and y) to force the calculated terms (ax and by) to represent the two physical modes of interaction in pure (nonhybridized) form.

This new treatment, called "Dual Orthogonal Vector Evaluation (DOVE)," makes it possible for the first time to evaluate separately and accurately the cation- and anion-solvating powers in a variety of solvents and for a large number of reacting species. With these measures available, it will be possible to obtain a true physical and chemical understanding of diverse numbers of solvent interactions. It should be possible to obtain ionic activity coefficients, rendering it unnecessary to make use of the cumbersome and somewhat inaccurate approximation of the mean activity coefficient. It should also be feasible to determine true transport numbers for ions in electrolytic solutions, both aqueous and nonaqueous, and to obtain other basic information on electrochemical reactions. These results should prove useful in the development of improved electrochemical energy sources. The enhanced understanding of the behavior of ions in solution should provide new opportunities for developing ion-polymer reactions, novel approaches to catalysis and enzyme systems, and render it possible, in general, to attach specific groups in specific places on substrates in order to provide localized ionic activity in chemical reactions for synthetic and catalytic purposes.

In addition to obtaining promising results for the primary effort, the investigators, in the course of overcoming unexpected technical difficulties, developed several new, faster, and more economical computer techniques which have saved considerable expense on this project and could similarly save money on other tasks.

There are other areas in which research conducted on this project may have broader benefits than a better understanding of solvent effects, ion reactivities, activity coefficients, and ion transport in solution. Swain, in order to try to find an alternative mathematical method to check the results of their Dual Orthogonal Vector Evaluation (DOVE), turned to factor analysis, a known technique for analyzing data and making decisions. This procedure has been widely used by psychologists, medical researchers, political scientists, and military strategists. Factor analysis routines are incorporated into available computer program packages such as Data-Test (Harvard), BMD (UCLA), SPSS (University of Chicago), P-Stat (Princeton), and SSP (IBM). These procedures were all tested and found wanting in that all of them gave biased or incorrect results when it was necessary to estimate missing data. In coming to this conclusion, Professor Swain and his collaborators had the benefit of a chemical system which was rigorous enough to make it possible to spot false deductions from factor analysis procedures, whereas workers in these other fields could not as easily recognize misleading or completely erroneous conclusions because of the less exact nature of their sciences. By use of the DOVE program it was found possible to correct for these errors by calculating all missing data with high levels of precision and confidence. Since the technique of dual orthogonal vector evaluation is quite general, its application in factor analysis should prove useful in a variety of fields. The method will be written up for publication to make it generally available.

Thus, this ONR-sponsored research project in chemistry may result in applications in other fields far beyond the originally envisioned goal of the program. This seems to be a good illustration of the potential universality of good basic research in defense of those of us who believe that strict relevance is not always the best route to useful results.

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Cover Caption

Broadband HF Communication Antenna aboard ship.

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