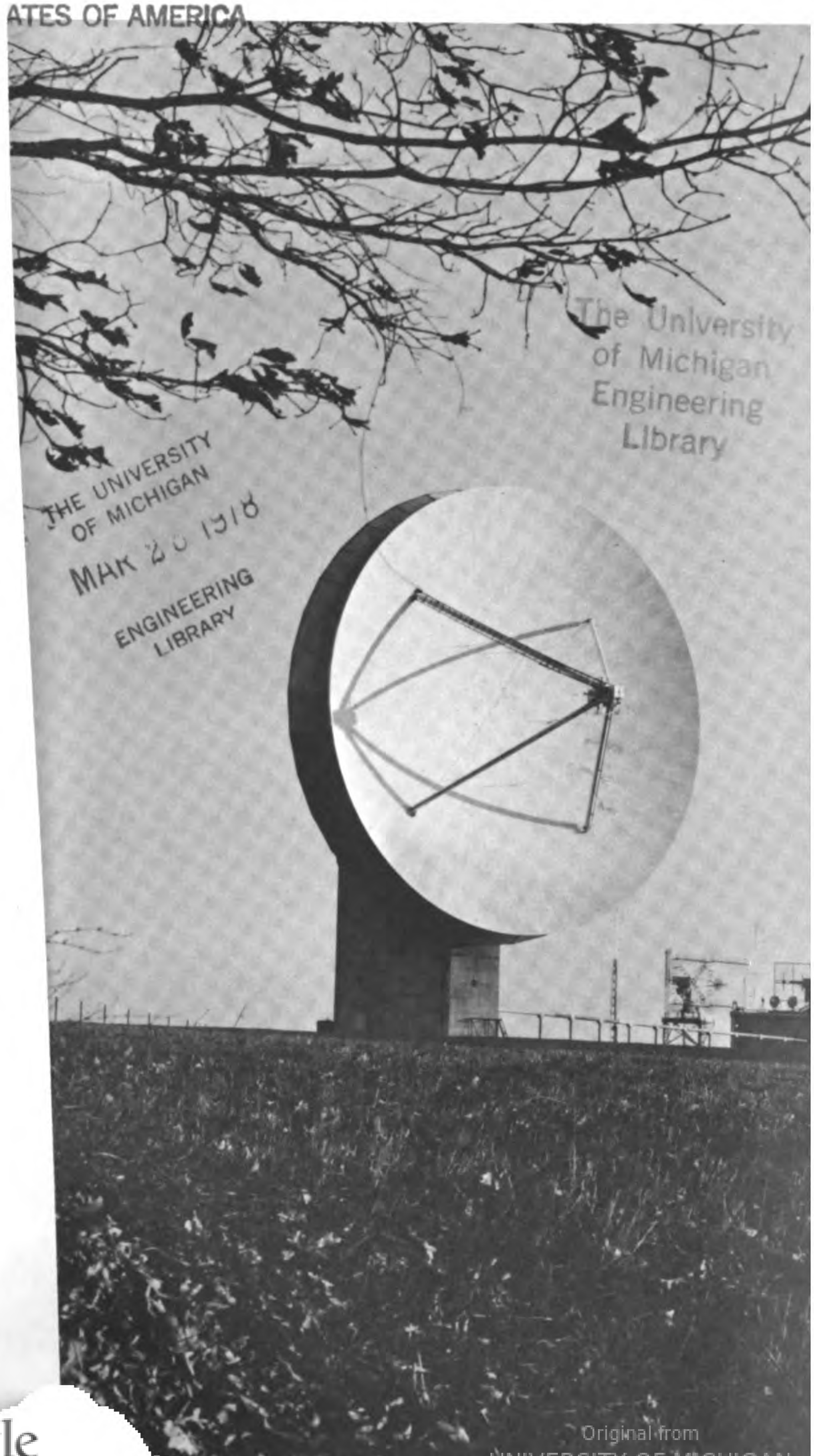
NAVAL RESEARC

REVIEWS

DECEMBER 1977



PROFILES IN SCIENCE

Dr. Morris Cohen

Dr. Morris Cohen is Institute Professor and Ford Professor of Materials Science and Engineering at the Massachusetts Institute of Technology where he has been since 1929 when he started as a student. Professor Cohen is a world renowned physical metallurgist devoting most of his research to the properties of iron and steel. Of great scientific significance has been his many years of research on understanding the martenstic transformation. His work has been the base on which many of the modern developments in high-strength ductile steels have been built. Since its establishment The Office of Naval Research has supported Professor Cohen's work.

He is a member of the National Academy of Science and the National Academy of Engineering; he chaired the National Academy of Sciences Survey of Materials Science and Engineering (COSMAT) 1970-75. President Carter recently awarded Professor Cohen the National Medal of Science.

Basic Research — A Necessary Resource for the Navy*

Rear Admiral Robert K. Geiger, U.S.N.
Chief of Naval Research

Government Funded Science

I am delighted and honored to be here tonight with you distinguished representatives of the various fields of engineering sciences, and to share my views on science and research.

Most of you are familiar with the Office of Naval Research. Many of you have been associated with the Office of Naval Research for years. So I will not spend too much time in repeating what you already know.

What I hope to contribute is a view of the role of Naval Research in the total research and development process (R&D), its contributions to the technology base and the relationship with the civilian scientific community. Naturally, this will lead to the present role of the Office of Naval Research within the context of federally-supported research and academic science.

Federal Government involvement in academic science is a relatively modern phenomenon. The Constitutional Convention of 1787 explicitly rejected efforts to grant the Federal Government authority to pursue scientific inquiry, only patents were mentioned in the Constitution.

In 1862, one year after the first American Ph.D. was awarded at Yale, Congress passed the Morrill Act, which granted public lands to the states to be sold and the money recovered to be invested and its income used to maintain at least one college "where the leading object shall be, without excluding other scientific and classical studies and including military tactics, to teach such branches of learning as are related to agriculture and the mechanic arts." In 1887 the Hatch Act was passed to provide federal funds for the support of agricultural research in colleges and universities.

In the years prior to World War II, the Federal Government supported some science, but outside of agriculture and some geology, very little in the universities. It supported the Smithsonian Institution, the National Bureau of Standards (which was founded in 1901), the Coast

*A speech presented by RADM Geiger at the "Society of Engineering Science, Inc.", Lehigh University, Bethlehem, Pennsylvania, November 15, 1977.

Survey, the Bureau of Mines, the National Advisory Committee for Aeronautics (NACA) (founded in 1915), and some of other activities; but the total investment in science was small. In those days, funds for university research came from a number of highly selective philanthropic foundations and from the meager operating funds of the universities themselves.

When World War II broke out, the scientific talent of this nation was mobilized to the war efforts through such mechanisms as the Office of Scientific Research and Development. Most of the research was, of course, applied research. It was recognized that the wartime technical triumphs of applied science were based on the utilization of the results of researchers of earlier decades.

The Office of Naval Research was the result of this recognition — that new scientific facts have to be discovered continuously through a basic research program if technological success must be repeated.

Aside from being the first Department of Defense (DoD) research organization, ONR became the first permanent federal agency with the primary mission to fund basic research performed by the civilian scientific community. ONR's work ranged over all areas of science that were new and important—nuclear research, low temperature physics, solid state physics, radio astronomy, basic biological studies, computer and information sciences. Most of the 15 nuclear accelerators built after the war at universities were started with the support of ONR. ONR was responsible for the construction and operation of the first large radio telescopes. Work in solid state and quantum physics in the 1950's was instrumental to the modern age of electronics. The world leadership of the United States in basic research in the two decades following World War II has been attributed in great part to the timely and imaginative work of the Office of Naval Research. An indication of this is the number of U.S. Nobel Laureates that were at one time or other working on projects funded by ONR.

In later years, ONR's role as the only national research organization changed as civilian federal agencies were created to do scientific research.

The basic mission of ONR has not changed. We believe that a civilian agency cannot effectively perform the mission-oriented research of the Navy. Although many of our needs are common, many more are distinctive from those of other organizations. The technology employed in a fighter aircraft is not quite the same as that of a 747. There are only few common needs between a nuclear submarine and a pleasure boat; there are few civilian counterparts to most of our weapons. Since the second best in defense will not suffice, we must work at the frontiers of technology to insure a technology base from which our future systems can be developed.

The Office of Naval Research primarily funds basic research. In addition it conducts a limited program of exploratory development.

The work is performed at universities, other non-profit organizations, and at the Navy's own laboratories, principally ONR's field activity, the Naval Research Laboratory.

Industry does little basic research. "If we except General Electric and Bell Labs, the contribution of industrial research laboratories to fundamental science has been suprisingly small. The basic notions on dislocations and strength of materials did not originate in steel companies. The theory of electronic states in organic molecules owes little to the work in chemical firms. Nor does our knowledge of RNA, DNA and the genetic code come from the pharmaceutical industry." The above statement is quoted from *Reviews of National Science Policy*, H.B.G. Casimir in 1968. It is quite relevant today. We are in the process of conducting a survey of 28 major industrial concerns in the U.S. The information we have gathered indicates that hardly any risk research is being done in industry. This is particularly true of the aerospace industries interviewed. Several people commented on this, indicating they felt that the government - the DoD and Navy - should do the high risk work.

It seems particularly significant for the DoD that those industries which are the main suppliers of high technology products do very little fundamental work to feed the industry. It reinforces the position that the DoD must support its own research and that much of that research should be carefully considered high risk work.

Our research includes scientific study and experimentation directed toward increasing knowledge and understanding in those fields of the physical, engineering, environmental, biological-medical, and behavioral-social sciences related to long-term national security needs. It provides fundamental knowledge for the solution of future military problems. It also provides part of the base for subsequent exploratory and advanced developments in defense-related technologies and of new or improved military functional capabiliites in areas such as communications, detection, tracking, surveillance, propulsion, mobility, guidance and control, navigation, energy conversion, materials and structures and personnel support.

Some Contributions to Technology

The contributions that this research has made to the technology are countless and I will mention only a few.

High Temperature Gases

In 1947, ONR began a program of basic research at a few universities in high temperature gas dynamics. Specifically, ONR felt it was important to know how gases in the atmosphere behaved when they were extremely hot. It was known that a body traveling at very high speed through the atmosphere heats the air or gases surrounding it, which in turn heats the body itself. Although gaining this knowledge was not an immediate problem, the Navy realized that future technology in aerodynamics would require it.

Long-Range Ballistic Missile

Research funds were concentrated on a pioneer program aimed at adapting a device known as the shock tube to produce high temperature gases. The shock tube, which could send a shock wave through a gas and thereby heat it instantly, was able to provide exact details of what happens to gases heated to extremely high temperatures.

In the mid-1950's, the Navy found that it needed a long-range ballistic missile. A critical question that had to be solved was the reentry problem. A missile had to be designed that could survive the heat generated when it reentered the atmosphere at a speed of 20,000 feet per second. A missile at that speed would actually create a shock wave and thus heat the air to incandescence. Knowledge gained from ONR's shock tube research program made it possible to determine the reentry environment with sufficient precision so that a successful missile could be developed.

Blood Storage

Pioneer ONR-supported research in the freezing and thawing of blood led to significant extensions in storage capabilities for this vital material. These techniques made possible the use of frozen blood banks in Vietnam and eventually were utilized by civilian hospitals.

Laser Technology

Research in microwave spectroscopy going back to 1951 led to conceptions of controlled electromagnetic radiation forming part of the theoretical base for masers and lasers. After lasing was achieved, research was accelerated in fields relating to laser technology: light propagation, absorption and scattering, glass and other materials, flash guns, and molecular physics. New laser concepts and the construction of new lasers including gas lasers, tunable lasers and lasers in new parts of the spectrum were developed. This research investment going back more than twenty years with increasing emphasis during the last decade has helped create a completely new technology.

Many of the advances depend on better materials. The Navy must operate at the surface of the water, under it, and in the air, in the tropics or on and under the arctic ice. The severe stresses that these environments place on the Navy systems require materials that can stand corrosion, temperature extremes, chemical or biological fouling. The ONR program of research in this field has resulted in several advances.

Boron Chemistry

The technology base for boron chemistry has been established and has led to boron-containing rubbery materials useful at high temperatures (300°C) and to compounds for burning rate accelerators. Evidence for the scientific merit of the boron chemistry program was the receipt of the 1976 Nobel Prize in Chemistry by Professor William Lipscomb for his ONR-supported research in this area.

Lithium Battery

A new battery with very high energy density has been developed as the direct outgrowth of ONR sponsored basic electrochemical research. The research, which was derived from work on liquid lasers and on electroluminescent processes, is based on the electrochemistry of the reactive metal lithium and inorganic electrolytes. Large scale versions of the battery are currently being developed for military applications, especially by the Air Force. In non-military applications, small versions of the battery are in use as power sources for cardiac pacemakers which have been implanted in several thousand patients.

Fluorourethane Coatings

Poly coatings as they are called have been developed at NRL which have a Teflon-like resistance to oil and grime, but unlike Teflon may be easily applied to a surface by standard painting procedures. The high resistance of the coatings makes them prime candidates for coatings for easily fouled surfaces such as ship bilges. These coatings would allow simple "water wash-down" in addition to providing outstanding protection of the covered metal surface from corrosion.

Present thrusts in materials research are aimed at producing such new or improved substances as ceramics for high-temperature applications in turbines and rocket nozzles and for more sensitive transducers; composite materials; fire retardant, conducting polymers; high-strength metals and alloys; as well as methods for welding these exotic alloys through laser technology.

We are also aiming at techniques to provide higher resistance to shock waves by submarines as well as more effective crashworthiness for aircraft and pilots, through better structure, safer ejection seats and better protective gear.

The Status of Basic Research

The point I am trying to make is that basic research is essential to the development of needed new technology. It forms a vital resource whose health should be protected. This resource, unfortunately, is affected by many fators and its health has not always been in the pink.

In the last decade or so several changes have taken place in the evolution of the Office of Naval Research. Although we are still a significant part of the research effort in the United States, we no longer play the part we played 30 or 20 years ago. Most of the changes are of course due to the advent of civilian agencies for the conduct of basic science, and the explosive changes within science itself.

Beginning about a decade or so ago, we began to phase out our support of nuclear accelerators and moved away from nuclear physics, even though the Navy had been the first to make practical use of nuclear power. We sharply reduced our support of astronomy although it is the basis for ship navigation. We have been directed that programs in fundamental biology and cosmic rays are not relevant and marginally justifiable as leading to improved naval systems.

These changes are set against a general background of declining level of efforts by DoD and a national preoccuptation with the applications of research, rather than with science itself. This decline is of particular concern to me, not only because of the fact that research is a vital element in building the technology base, but also because the slowing down of scientific efforts may have a snowball effect that will be difficult to reverse. It endangers the relationship with the performance of basic research, principally the university. We presently have a twofold operating policy. In areas where there is long-term Navy interest, like materials, we want to be a steady supporter, conscious that the output in these areas is not only new materials but also people. In other areas we have the posture more of a discriminating gambler, or investor, always with an ear to a new idea and with ability to encourage those we think promising.

The university is the cornerstone of scientific activity in the United States. It is at these places of learning that advances in scientific understanding and the development of technological capabilities are undertaken. And it is the university that provides the training which produces our scientists and engineers. It is a national resource that must be sustained if the leadership of American science in the world, in the face of worldwide challenges, is to be maintained.

Over the years, the cooperation between the Federal Government and the university has built a strong national system for the performance and conduct of a broad spectrum of research. In order to carry out these programs, the universities have built new laboratories, enlarged their staffs, and generally expanded their facilities.

The decline in research funds, the sometimes excessive concern for "relevance", the increasing administrative procedures, are putting this capability in danger and marring the relationship between the university and the government.

The remarks made about a year ago by the president of Ohio State University are particularly appropriate. Speaking to a congressional delegation on the subject, he said, "A fundamental change is taking place in the relationship between Washington and the nation's colleges and universities, a change which I find deeply disturbing. Once we were partners working together to solve national problems. Now we view each other with suspicion, almost as adversaries. We overregulate on one hand and overreact on the other. We have placed our partnership in peril. And if it is to be restored, it urgently needs our attention and understanding."

If this relationship is allowed to deteriorate and the research efforts to decline further, the process of rebuilding it will be a long one and the cost will be much higher than the cost of maintaining it on a healthy basis.

The amount of research funds provided to academic institutions has shown a continuous decline in the last decade. While in 1965 the universities received some 45% of the ONR funds, in 1977 this constituted about 40%.

We at ONR, which depends heavily on the talent of academic scientists for its research program, are keenly concerned about reestablishing a healthy relationship with the universities and increasing the DoD funding of fundamental research at these institutions.

A new Department of Defense program (DESP) is aimed at rekindling and stimulating the interests of the university science community in problems of national defense. The objective is to improve the national defense long range capability by making greater use of the innovative potential in U.S. universities for defense related research and by broadening the relationship between the defense community and the university science and engineering community. An important part of this is the aim to increase the number of first rate fundamental scientists, including younger investigators willing and able to advise the DoD.

We intend to build a better relationship between the university scientists or engineer and his counterparts in the Navy laboratory, to familiarize the acadmic scientist with the Navy problems and facilitate the application of his work to naval problems.

You have, I am sure, been aware of the recent concern about the possible loss of technological initiative by the United States. I do not share the view that we are headed toward scientific and technological bankruptcy. Nevertheless, I do think that our leadership is facing serious challenges which must be faced and met vigorously, least our own national security and survival may be in jeopardy.

In the 1950's the U.S. produced 82% of the world's major innovations. This dropped to 55% by the 1960's. A decade ago foreign inventions made up 18% of the patents issued in the U.S. By 1973, this foreign share had risen to 30%.

We cannot tolerate the U.S. being a follower and not a leader in any field of science and technology.

With leadership and cooperation across all elements of government, of universities, and of industry, we have the capability to prevent such an occurrence.

Radio Wave Propagation in the Solar-Terrestrial Environment: Perspectives for the Future*

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Even in the daytime man's ability to see objects at a distance is variable, since it can be strongly affected by smoke, mist, and mirages. At such times, as well as at night, the Navy depends on radio waves in situations where the eye would otherwise be used. But radio waves, like light waves, are not immune to time and space variations imposed by the environment, and these restrictions must be understood and if possible avoided if the Navy is to use electromagnetic radiation as efficiently as it must.

Habituation makes it easy to overlook the enormous contributions made to the quality of civilian life by radio waves in their various forms. Broadcasts bring us news at breakfast or on the way to work; long-distance telephony (much of it handled by satellite or microwave repeater) helps transact the day's business; data networks using similar routes facilitate banking and virtually every aspect of commerce, and TV broadcasts provide the evening amusement or edification.

All of these functions (with the exception of the last) are required by our naval forces afloat, and a great many more beside. Since a moving ship is a self-contained unit and has no umbilical cord in the form of a bundle of wires connected to the Bell System, radio waves must be used for navigation, detection (radar), fire control, remote control (of bombs and RPV's), and of course communication. In addition, if the ship is a carrier, it is a moving platform from which other self-contained moving platforms (aircraft) operate.

Great as the benefits of using radio waves in naval operations are, their Achilles' heel must never be forgotten; transmissions of the normal kind inevitably betray the location, the type, and sometimes even the identity of the source. A naval combatant, unless it is groping along "blindfolded" with everything shut off, is roughly as conspicuous as a floating lighthouse. Thus each side in a naval engagement must be prepared to spoof or blind the other. The use of radio waves for intelligence and counteraction is an application whose importance easily

*Reprinted from "Science, Technology, and The Modern Navy", Thirtieth Anniversary Publication, Office of Naval Research, ONR-37, Edward Salkovitz, editor, U.S. Government Printing Office, pp. 265-276.

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equals that of the ones mentioned above. For every use of radio there is now a corresponding scheme or device capable of degrading effectiveness. It is no wonder that the art of detecting, locating, and then deceiving or otherwise effectively neutralizing an opponent's electronic assets has been dignified by the name "electronic warfare" (EW).

Since we live in air rather than in a perfect vacuum, all those systems and antisystems that depend on radio waves are affected to a greater or lesser extent by the atmosphere. Normally the air can be ignored, but there are many situations in which it cannot.

Radio waves have been in naval use for over 70 years, and it might seem surprising that the details of their propagation cannot be said to be perfectly understood even now. This expectation would be reasonable if requirements for propagation knowledge remained static. But military technology is constantly expanding in complexity and sophistication; new uses and new precision of older uses require constant improvement of our understanding of the way in which radio waves interact with our surroundings.

Our "sourroundings," in this instance, can be divided into two major categories, in addition to the neutral gas (consisting of air, water vapor, etc.) with which we are concerned at low altitudes, there is the invisible ionized component higher up. The energy of sunlight knocks electrons out of gas atoms or molecules to produce ions; the free electrons, being charged and light in weight, have a surprisingly strong effect on radio waves. The effect is most profound at the lower radio frequencies, but it is noticeable even at microwave frequencies. Even the positively charged ions can affect the longest radio waves of interest to the Navy. Ionization of our atmosphere is significant at heights from 60 to tens of thousands of kilometers; it is strongest in the 200-400 km interval, where about 1 atom out of 1000 is ionized.

Some Current Research

Some randomly selected examples of recent research results may help set the scene for comments on future trends and possibilities.

Improving Communication with Submerged Submarines

No one will dispute the necessity for the national command authorities to be in contact with attack-or ballistic-missile submarines at all times. Modern nuclear submersibles of either type are able to operate for long periods at very great depths.

Their commanders understandably prefer to stay as far down as possible, since the safety of a submarine depends on concealment and concealment is best when there is plenty of water between the submarine and any possible attacker.

It is well known that the longer the radio wavelength, the deeper the wave can penetrate into saltwater. The present-day standard system for submarine communication uses Very Low Frequency (VLF) transmission (roughly 20 kHz,) which can be received at depths on the order of 100-200 ft (30-60m). The Navy would like to supplement VLF with the controversial Seafarer (formerly Sanguine) system whose waves, some 400 times as long, suffer far less attenuation in seawater.

Since the frequency interval to be used for Seafarer is not far from the world powerline frequencies of 50 and 60 Hz, it may come as no surprise that the "antenna" takes the form of a *buried* wire, rather than one suspended from a mast.

Communication of sorts could in principle be maintained at even greater depths if still longer waves could be employed. Serious consideration is, in fact, being given to the use of frequencies in the range from 0.5 to 2 Hz, where the free-space wavelength would be on the order of 10 times the circumference of the Earth. Of course, enormously long waves such as these carry information at a tortoiselike pace, but this is not so serious a disadvantage as it might seem. The transmission could still perform an alerting function, effectively advising a submarine to come closer to the surface, where it can receive more detailed instructions on a different waveband.

The essential problem in any of the systems using very long waves is the problem of launching them efficiently from structures of affordable size. As a result, a number of ingenious schemes are being explored. In one approach, plain old-fashioned induction fields, such as were tried and discarded in the earliest days of radio, are being considered. Another suggestion is to radiate from an electrically conducting column of gas in the sky, using electrons knocked temporarily free by collisions with particles beamed vertically from a high-energy accelerator. Such a column would represent an essentially massless and practically indestructible antenna. Somewhere in the collection of possibilities lies the practical answer.

Propagation research in support of the submarine communication mission takes many forms. For example, in the 50 Hz-to-100 kHz part of the radio wave spectrum the waves are deflected downward and thus prevented from escaping into space by the lowermost part of the ionosphere, where the gas is comparatively stable owing to its relatively high density. (This is why VLF is so effective for time signals and navigation.) Even here, though, the reflection height changes appreciably from day to night, thus changing the mode structure and leading to wave interference. As a result, signals crossing the sunset or sunrise lines may undergo an undersirable amount of strength variation.

Furthermore, particle bombardment such as would accompany high-altitude nuclear explosions can also cause signal strength changes. Although treaty limitations of course prevent use of nuclear devices for testing, nevertheless infrequent bursts of natural radiation of various kinds can give rise to rather similar disturbances. By judicious extrapolation these natural events can be used to verify theoretical models from which the nuclear environment can be predicted.

It was once thought that the only source of significant incident radiation was the sun, which is characterized by occasional flarelike outbursts. We now know that the Earth carries around with it its own store of radiation. This takes the form of high-energy particles trapped by the terrestrial magnetic field in what is left of the earth's atmosphere in the height range from 500 km to several tens of thousands of kilometers. At such heights, most of the gas is ionized by incident solar radiation, and the particles are few enough to be contained by the magnetic "pressure." This extremely tenuous "magnetosphere," of global dimensions, where electron mean free lifetimes are measured in hours, has provided as rich a hunting ground for new physical effects as Africa provided for wild animals in the days of the early explorers. For example, in the magnetosphere radio waves can either add energy to or abstract energy from the particles, in a manner reminiscent of, but only distantly related to, the processes of maser or laser amplification. This interaction between waves and particles makes the region surprisingly dynamic; the distribution of particle and wave energy is constantly changing.

Interestingly, the radio waves responsible for all this activity can be either natural or manmade. If strong enough, they can cause some of the trapped particles to be released into the lower ionosphere in quantities sufficient to perceptibly affect propagation of waves of interest to the Navy traveling in the earth-ionosphere "waveguide." (See Figure 1.)

Efforts are underway to measure the space and time variation of the streams of energetic particles by means of instruments carried in satellites. The aim is to predict the effect of charged-particle spills on propagation at Seafarer and other frequencies.

The complexity of the various wave-particle interactions is fascinating to contemplate. For example, it now appears that a burst of particles from the Sun (effectively a gust in the solar wind) can impart energy to the radio noise background, and effectively amplify it, thus giving rise to a noise emission at VLF (5-15 kHz). Not surprisingly, manmade signals in this band, such as the navigational service Omega, may also be amplified. At the same time, energetic particles spilled from their magnetic-field "traps" by such a disturbance [1] can cause a change in received signal strength at 100 kHz, and the basic disturbance itself can additionally give rise to a spontaneous emission in the micropulsation band, from 0.1 to 10 Hz. The relationships among these various events are just now being perceived, and their implications in possible Navy communication systems of the future are beginning to come into focus.

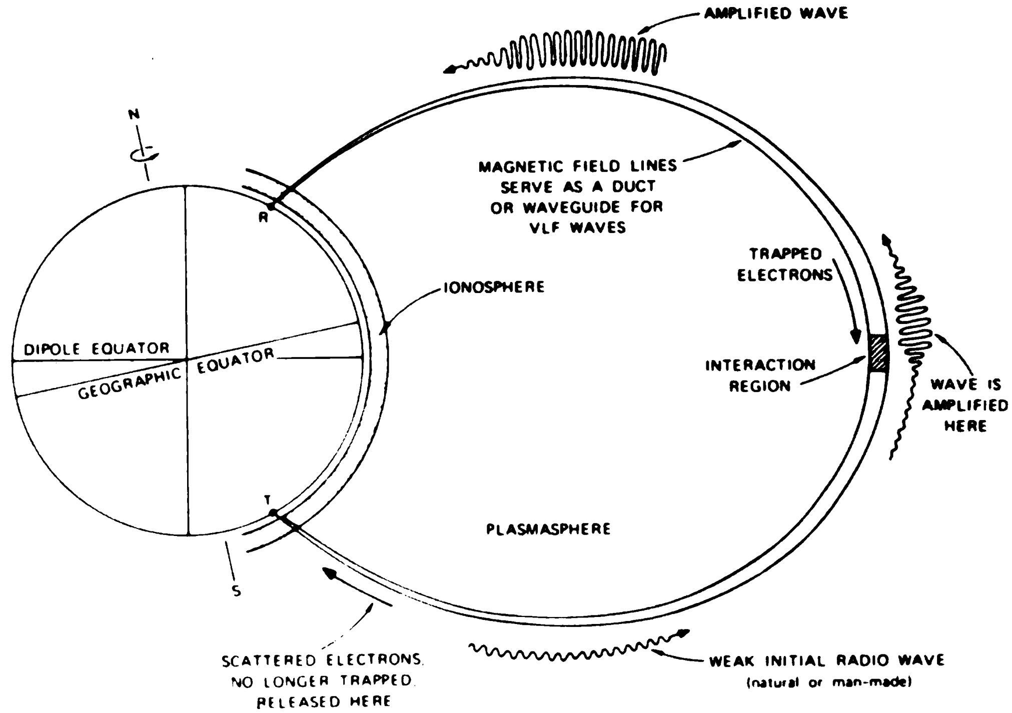


Figure 1 — Far above the equator, energetic electrons from the solar wind are trapped by the earth's magnetic field. Spiraling around magnetic lines of force, they travel from hemisphere to hemisphere, reversing direction after each transit at "mirror points" well above the ionosphere. Natural or manmade VHF signals (for example, "atmospherics" caused by lightning flashes) follow similar paths, except that they travel essentially from surface to surface. Within the "interaction region" shown, some electrons give up energy to waves, which are thereby amplified, but in the process the interacting electrons become untrapped. Such spilled electrons penetrate lower into the ionosphere before giving up the rest of their energy in collisions. They thereby change the electron dnesity of the radio-wave reflecting layers of give rise to signal-fading effects.

Reversibly Remodeling the Ionosphere For Communication Purposes

The following research was motivated by the perennial need for beyond-line-of-sight communication at VHF. Although some remarkable capabilities were uncovered, the attendant cost proved to be not inconsiderable, so that at the moment other options seem more attractive. Nevertheless, like all good research, this opens vistas whose extent we cannot at the moment fully perceive; for example, it is possible that knowledge of ionospheric plasma behavior gained by this means may help us understand and explain ionospheric characteristics of immediate importance, such as the unexpected scintillations that affect satellite radio transmissions under certain conditions.

By way of background, we may recall that Kennelley and Heaviside in 1902 postulated the existence of an electrically conducting region in the upper atmosphere, to explain Marconi's success in communicating across the Atlantic. Until very recently, users of the ionosphere have had to be content with whatever reflections nature happened to provide. Therefore it can be said that something of a landmark in the history of man's control of his environment was passed in April 1970, when a team directed by W.F. Utlaut of the Department of Commerce at Boulder, Colorado, succeeded in causing a substantial (but, happily, reversible) change in the reflecting properties of the principal ionospheric layer by heating it with the aid of a very high power radio transmission [2]. The antennas they used are shown in Figure 2.

The underlying principle is analogous to heating foodstuffs containing moisture in a microwave oven. Both water and the electron "gas" of the ionosphere are imperfect — and therefore lossy — dielectrics. But there is this difference: foodstuffs are confined in an enclosed cavity, so that energy piped in has essentially no place to go but into the water. In the case of the ionosphere, radio waves tend to either travel right through or be completely reflected, in either case losing little strength. Fortunately there proves to be a wonderfully simple trick that can be played on the waves, and that is to make the frequency of the heating tranmission very close to the so-called "plasma" frequency, or, as radio engineers would say, the "critical" frequency of the

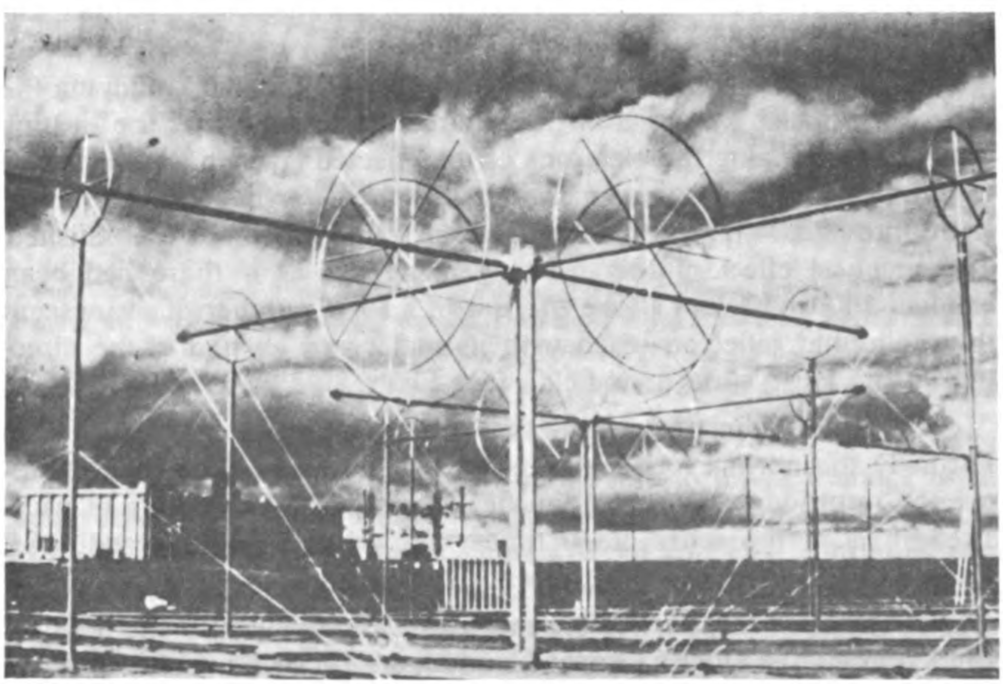


Figure 2 — From this bizarre collection of wires and aluminum irrigation pipes, 10 million watts of power are radiated straight up. When the right radio frequency is chosen for ionospheric heating, "plasma" 300 km overhead is modified sufficiently to produce a tenfold increase in its normal radio-wave reflecting power. Effects disappear shortly after the heater is turned off.

layer at its densest part. As this frequency is approached, the heating waves slow down drastically in their speed of travel, with the result that there is ample time for them to lose a substantial fraction of their energy to dielectric losses during their passage. The idea of heating the ionosphere in this manner goes back a long time, but modern interest in the matter was sparked by calculations that suggested that measurable effects could be achieved with an affordable investment in equipment. The Soviet scientist A. V. Gurevich, who made such a prediction in 1962, deserves the credit [3].

It was originally thought that heating would result in expansion of the affected region, giving rise to a dome or incipient bubble roughly 160 km in diameter. This does, in fact, take place. But while observing the magnitude of this effect with vertical-incidence sounders, the Boulder group discovered to their astonishment that the heating was also causing to appear a condition known as "spread F," in which a clearly defined layer echo becomes extended (either in frequency or in slant range), as if the otherwise homogeneous region had become corrugated.

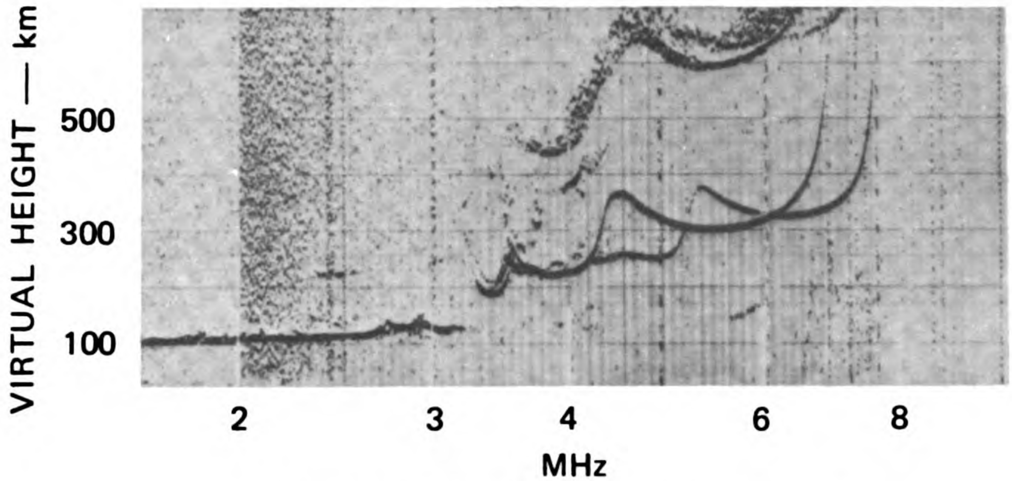
Such spreading occurs sporadically in Colorado as a natural event. At more northerly latitudes it is seen much more frequently, usually in association with auroral disturbance. Since the "artificial spread F" appeared when the heating transmissions were turned on and disappeared when they were shut off, the Boulder investigators received the impression that they had at least one facet of auroral disturbance under human control (See Figure 3.).

Even more unexpected was the discovery, by a group studying the effect of artificial layer tilts on radio direction finding, that the heating was also rearranging the electrons of the affected layer in such a way as to permit VHF signal transmission at distances far beyond the line of sight, provided that certain geometrical requirements were satisfied. The practical effect of this rearrangement was as if there had been created, 200 to 400 km above the Earth, a large number of evanescent thin columnar reflectors, each with its major axis aligned in the direction of the Earth's magnetic field. (See Figure 4.)

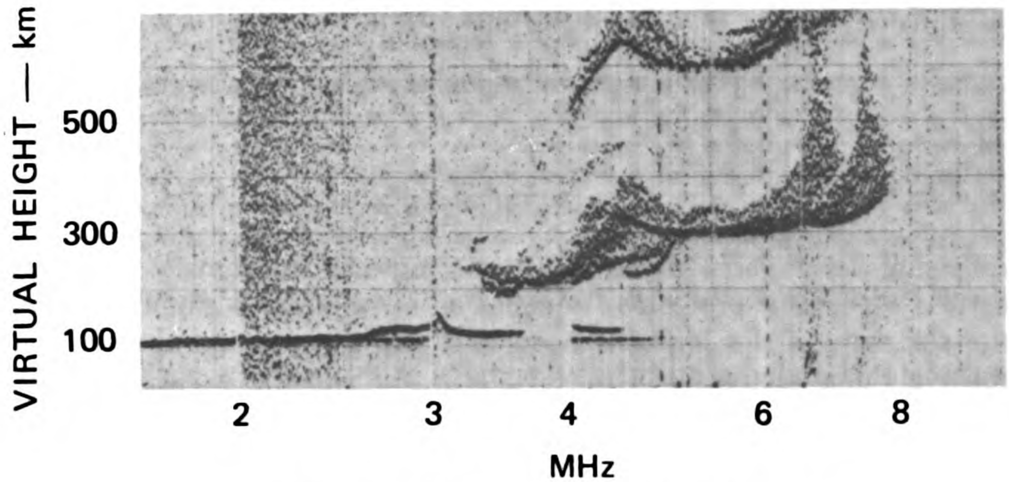
Now the highest frequency that is (on rare occasions) returned to Earth by the normal ionosphere is roughly 40 MHz. The highest frequency returned to Earth by the heating-associated reflectors in usual strength is in the order of 10 times that value. Thus the additional channel width thereby opened up is impressive [4].

To generate these reflectors requires heating power on the order of 100 kW if a large antenna system is used, or 1 MW if a simpler array is employed. Either way, the capital investment is not inconsiderable.

The fact that the ionospheric reflectors are directional imposes constraints on the choice of transmission paths, but jamming and intercept of circuits thus established becomes proportionately more difficult.



(a) 11 OCTOBER 1972, 1848 GMT



(b) 11 OCTOBER 1972, 1859 GMT

Figure 3 — An example of artificial "spread F." The lower echo-sounder trace in part (a) is a first-order reflection from the unmodified ionosphere and shows a typical variation of time delay with radio frequency, plus reflection from a smooth surface. The spread appearance in part (b), characteristic of considerable layer roughness, was caused by several minutes' operation of the heater in Figure 2.

Heated ionospheric gas is not vulnerable to physical attack in the same sense as is, say, an orbiting satellite. To the author's knowledge, the effect of nuclear explosions on artificial spread-F communication has not yet been considered. It is known that high-altitude nuclear explosions generate effects rather similar to the natural aurora. Therefore it seems that nuclear events would be more likely to enhance, rather than diminish, artificial propagation. After the explosion, the heater presumably could be turned off until normal conditions returned.

While layer profile changes associated with ionospheric heating can be large enough to degrade the accuracy of present-day direction finders (which of course depend on the tacit assumption that the

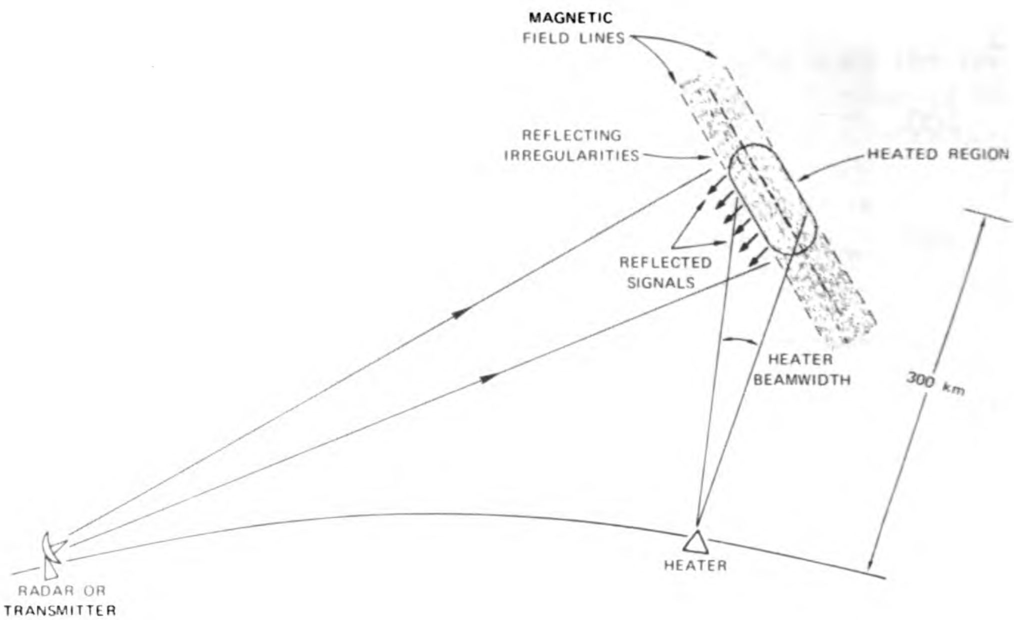


Figure 4 — Heating creates the equivalent of reflecting irregularities in the ionosphere, elongated in the direction of the earth's magnetic field. These form powerful, if highly directional radio-wave reflectors.

reflecting layers are for all practical purposes concentric with the earth), the logistic problems attendant on attempting to modify an area the size, say, of the Mediterranean Sea, turn out to make the scheme relatively unattractive.

Outwitting Satellite Signal Scintillations

Heating the ionsophere has uncovered some interesting new possibilities for future naval communication. It has also had an indirect payoff because it has brought to light unexpected new properties of plasma, which may help in understanding the surprising fading (or scintillation) observed on microwave transmissions to and from satellites. This is observed when the line of sight to the satellite passes through the equatorial (and, occasionally, the auroral) ionosphere. Fading ranges of 7 and 3 dB, peak to peak, have been measured at 4 and 6 GHz, respectively. An amount of fading as small as this might not seem serious, but satellite circuits tend to be operated with very low signal-to-noise ratio margins, so that even a small degradation has a noticeable effect (See Figure 5.).

The story of the discovery of microwave ionospheric scintillation is interesting. The possibility that waves of 5-cm length could be affected appreciably by passage through the upper ionosphere, where electron mean free paths exceed 1 km, was once regarded as wildly improbable.

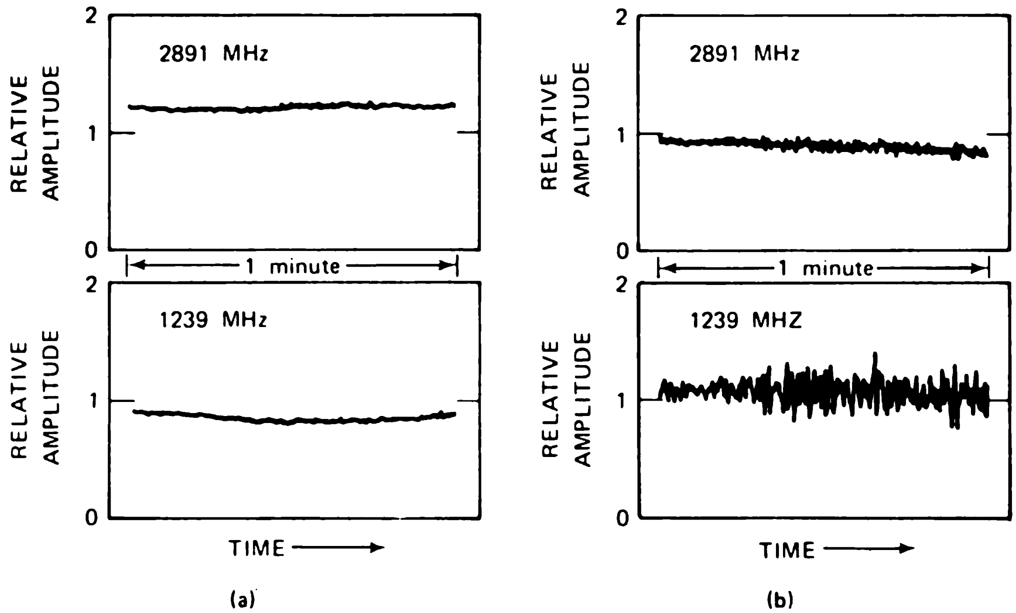


Figure 5 — An example of fading imposed by the ionosphere on a 25-cm signal from a satellite. (A longer wavelength is shown as reference.) Although far above the radio-reflecting layers, the source (P76-5, portrayed in Figure 7) is nevertheless moving with respect to the receiver at Ancon, Peru. Part (a), at 0344 GMT, shows the normal condition; 4 min later the line of sight is passing through electron-density irregulariaties, as shown in part (b), at 0348 GMT. In this instance most of the fluctuations are due to motion of the satellite. However, since the irregularities are also drifting in position, even transmission from nonmoving (geostationary) satellites show similar fading when irregularities are present. (Record courtesy of the Defense Nuclear Agency.)

Scintillations can be caused only by irregularities in refractive index along the line of sight, either moving or time-varying. To have a strong effect, such irregularities must be at least roughly comparable with the wavelength in size. But a mean free path of given length tends to smooth out variations in electron density between any two points spaced closer than that length. Therefore it was difficult to imagine any arrangement of electrons either physically small enough or dense enough (or both) to interact significantly with such shortwaves.

Before the space age, knowledge of the extent to which the ionosphere refracts or perturbs radio signals passing completely through it was derived almost entirely from measurements using the so-called radio stars. These represent essentially pointlike signal sources superimposed on a background continuum. Both signals and continuum are time-varying and noiselike. Although easy to pick out at VHF, the radio stars are progressively more difficult to identify against the background as microwave frequencies are approached. Most star measurements, therefore, were at VHF and led investigators to deduce values on the order of 1 km for the crossfield scale size of the scintillation-producing irregularities. This deduction was quite correct for the radio frequencies employed. However, in interpreting these measurements a

Gaussian form for the spatial distribution of the irregularities had been postulated. Such an assumption, together with the above deductions derived from observations, led to a considerable underestimation of the magnitude of scintillation at frequencies much higher than the original observing frequency, which is why microwave effects over the equator were so unexpected.

In the years since the discovery of microwave scintillation, two important revisions of the original interpretation have come forward. First, it has been found that a power-law spectrum is a much more realistic approximation than its Gaussian counterpart. It is, in fact, the spectrum shape that describes the way turbulence breaks down into eddies of ever-diminishing size. In addition, it is now appreciated that scintillation measurements are subject to an effect called Fresnel filtering; a measurement at a particular radio frequency, when a low-pass spatial spectrum is present, tends to be most sensitive to electron-density fluctuations comparable to the size of a Fresnel zone. (See Figure 6.) (For a distant transmitter, the radius of a Fresnel zone at a dis-

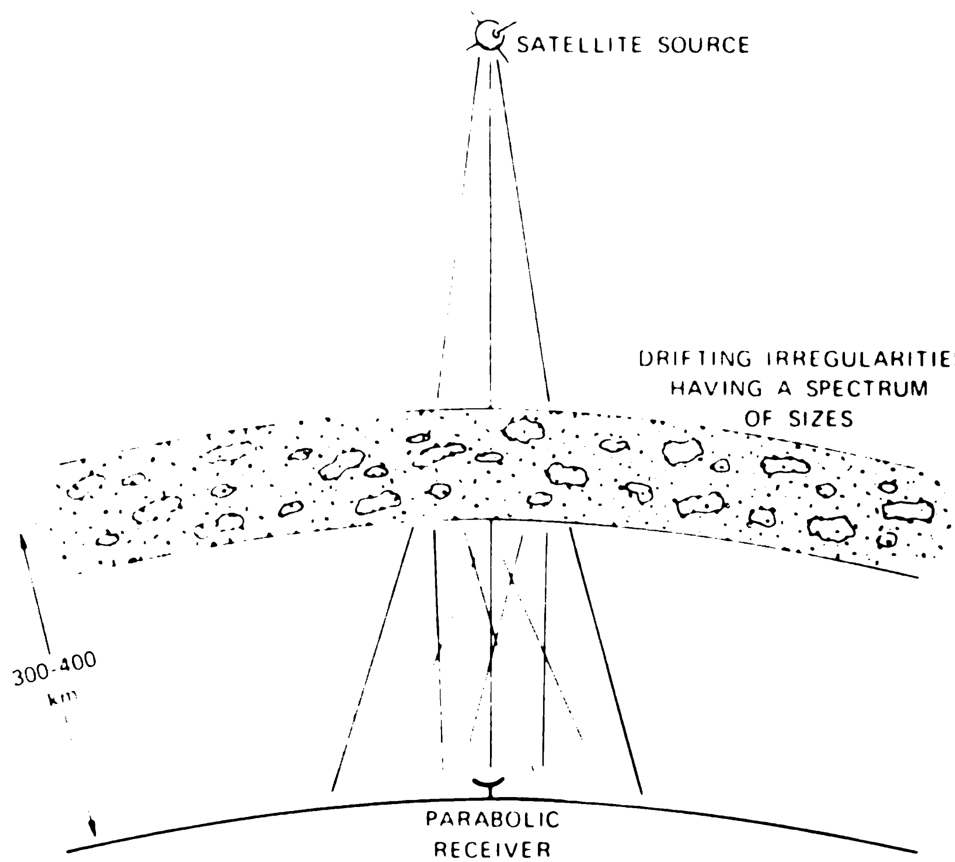


Figure 6 — The geometry of "Fresnel filtering." At any given radio frequency, when a normal "low-pass" spatial spectrum of irregularities is present, the received signal is most disturbed by those irregularities whose size is comparable with that of a Fresnel zone at the irregularity height.

tance z from the receiver for a signal wavelength λ is $\sqrt{\lambda z}$. Thus, the radius depends on both λ and z.) Out of a low-pass spectrum of irregularities of different sizes, measurement of amplitude fluctuations (or scintillation) at a single radio frequency will tend to favor — to a surprising degree — those irregularities having a size close to that of the Fresnel zone. Correct extrapolation of scintillation data to predict effects at other radio frequencies or distances unfortunately requires accurate knowledge of the irregularity spatial spectrum. A straightforward way to make such measurements calls for data from one source at a variety of radio frequencies; this was not feasible prior to satellites and cannot be done very readily even now.

Once the full ramifications of Fresnel filtering were appreciated and initial direct measurements of the ionospheric spatial spectrum by satellite-borne probes became available, more accurate predictions became feasible. The more plausible choice of a turbulencelike power-law spectrum (a three-dimensional index approximately equal to 4 is reasonable) certainly falls off less rapidly with increasing spatial frequency that does the Gaussian. But even the above power-law spectrum, by itself, is not sufficient to account for the observed levels of scintillation at GHz frequencies.

Two main lines of thought have arisen in attempts to explain the observations. Both are alternatives to postulating unrealistically high electron densities or implausibly strong spatial modulation of the density. One is the suggestion that the region of structured plasma, where scattering occurs, may encompass not only the equatorial F layer but also an appreciable fraction of the magnetosphere, possibly out to several earth radii [5]. Such a thick region would enhance scintillation at all frequencies by virtue of the very long raypaths through the structure region.

The second explanation takes into account the concept of Fresnel filtering plus the best available estimates of the underlying spatial spectrum of the scattering irregularities in deriving a frequency dependence for the scintillation. It then proposes that localized nonmonotonic features in the spatial spectrum (which might be called "spatially resonant plasma instabilities") are responsible for GHz scintillation [6].

Although the vast majority of measured ionospheric spatial spectra show monotonically decreasing (turbulencelike) behavior, there are some interesting exceptions. Certain measurements actually made in the topside equatorial ionosphere show distinct spatial resonances (i.e., regularities) at wavelengths between 1 and 10 km [7]. If similar events also occur in the wavelength regime between 0.1 and 1 km, which seems plausible, they could greatly enhance the magnitude of GHz scintillation for a given level of VHF-UHF scintillation.

Since the above spatial regularities were observed within a few degrees of the magnetic equator, and in the same local-time hours in which GHz scintillation occurs, there is clearly reason to suspect that similar resonances at somewhat smaller scales might be responsible for the surprisingly strong GHz effect.

There turns out to be no reason to view the two leading hypotheses about the origin of equatorial GHz scintillation — an extended plasmaspheric layer and nonmonotonic spatial spectra — as mutually exclusive. What is needed is better understanding of the way irregularities are distributed in height and of the circumstances under which they can have size distributions that differ from that characteristic of the decay of turbulence.

An experiment potentially able to provide valuable new information was begun on May 22, 1976, with the launching of the P76-5 satellite, carrying the Defense Nuclear Agency (DNA) 002 coherent beacon. Orbiting at a height of 1000 km, in a nearly circular but highly inclined orbit, this probe will radiate a "comb" of radio frequencies from VHF to SHF, all coherent in phase. In the past, space probes have provided only one or two frequencies for study, typically noncoherent and only available incidentally to another mission. (An exception is the ATS-6 satellite, but its highest coherent frequency is 360 MHz.) In the DNA experiment, mapping the ionosphere is the central theme; the spread of frequencies is wide, and the fact that the phase is coherent permits collecting considerably more information (such as total electron content and its variations, and data from which crude images can be constructed) that would otherwise be possible. Figure 7 is an artist's conception of the satellite and its orbit.

Future Possibilities

Avoiding the Radio Mirages

As our radio "vision" becomes progressively sharper, there is a continuing need to fashion lenses (so to speak) to correct deficiencies when that is possible. A major thrust at the present time is on improving knowledge of weather in the troposphere, where invisible water vapor can and does strongly interact with radar beams. For example, electronically steered ballistic-missile-warning and satellite-tracking radars, such as the AN-FPS 85, occasionally encounter beam bending and distortion when looking for unknown targets close to the horizon. This is a result of a distrubance of the normal distribution of water vapor with height, and is closely related to the conditions that sometimes cause FM and TV signals to span unusually long ranges. Continuing research on the lower atmosphere with acoustic and radio sounders has given remarkable new insights into the details of these exceptional refractive-index conditions, and satellite photography has made it possible to determine remotely, and in real time, the areas affected by a given event [8].

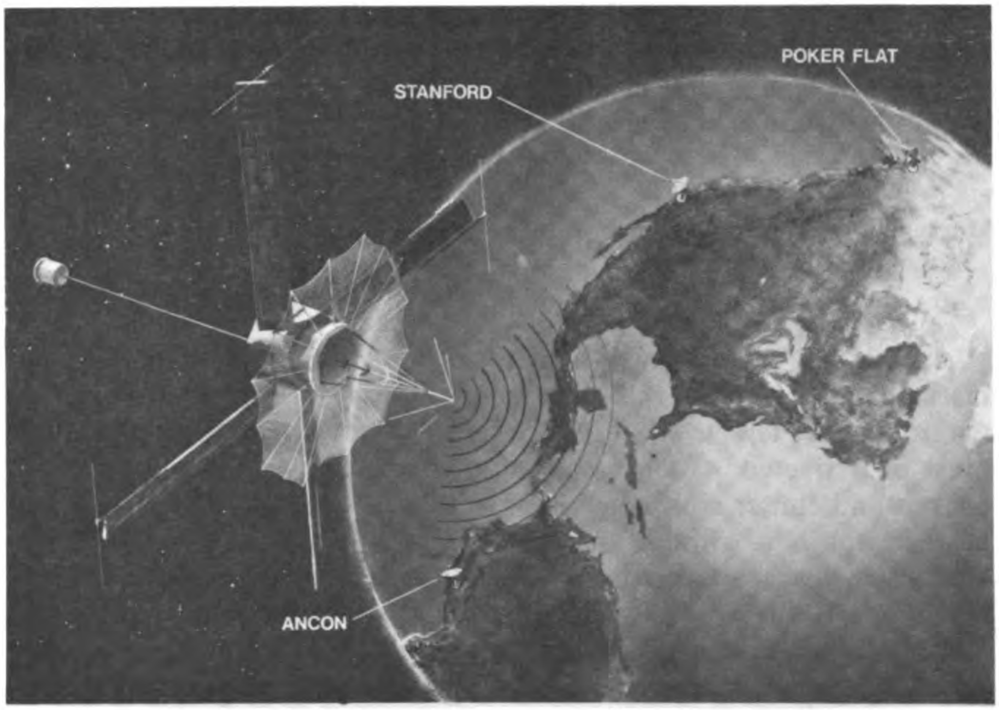


Figure 7 — Artist's conception of the P76-5 payload, launched in May 1976. It carries the most comprehensive experiment yet devised for measuring ionospheric irregularities, including those that produce fading and scintillation of signals from geostationary satellites. A comb of coherent radio frequencies from 147 through 2891 MHz is radiated.

Very long range radars can now correct (at least to some extent) for distorted propagation of this sort, by tracking (as a side exercise) some of the many known satellites that come whizzing by. If a familiar orbiting object is seen apparently to waver in its course when passing through a certain region of the sky, that waver can be recorded and applied to correct the apparent track of an unknown object just coming into view for the first time in roughly that same direction. There are obvious limitations to what can be done here, because the atmosphere is not stationary, but nevertheless quite useful first-order corrections can be made.

Although naval forces afloat may not be able to compensate their radars by use of itinerant objects in space, improved predictions of radar performance are being introduced to good effect. Because atmospheric conditions over water are far stabler than over land, unusual events such as inversions tend both to be larger in geographical extent and longer enduring. They are at the same time more readily predictable.

A carrier task force needs to know how far away its radars can likely be heard (so as to know the intercept range), how far away the radars can detect objects of interest, and whether there exist "holes" in the coverage patterns within which a target would escape detection.

Better predictions and real-time measured data combined with new procedures such as essentially instantaneous ray tracing (made possible by low-cost computers) is bringing about solid improvement, and no end to this trend is yet in sight.

Measuring the Ocean's Moods Without Going to Sea

A line of investigation conceptually rather close to propagation research, but not quite the same thing, is study of the electromagnetic nature both of targets and the background from which target signatures must be extracted. Often propagation characteristics and the details of background clutter are interrelated, so that interpretation of one cannot be accomplished without consideration of the other. Studies of this kind often lead to unexpected and useful results. For example, radar reflections from the sea surface, using a variety of radio frequencies and platforms, have led to what has been called "radio oceanography" [9]. Information on sea state is transferred to radio waves after scattering or reflection and can be observed back at a distant source of illumination. Both high-frequency radar and sounders in satellites can monitor oceanic conditions at great distances in real or near-real time. The former, however, permits continuous "looks" at a given point on the sea surface and is less expensive to establish. A disadvantage is that it suffers outages from time to time. But it can also pinpoint and follow hurricanes. (See for example Figure 8.) HF radar can also indirectly measure surface currents, even localized currents generated by barometric forces and transient wind systems (as contrasted with major oceanic currents put in place by gross features of the global atmosphere circulation).

Real-time remote measurement of ocean currents and sea state is of clear economic importance in ship routing where the object is to minimize elapsed time and fuel consumption by readjusting a ship's course at frequent intervals to avoid regions where higher-than-average waves result in speed loss. Amphibious military operations also need wave and current information. Sea-state data are of further importance to the Navy because underwater sound generated by breaking waves represents a background noise that limits the detection range of sonar systems. Also, of course, high waves limit many kinds of Navy operations. It seems very likely that in the future, sea state will be reliably measured by shore-based means. In addition to improving forecasts, such data should also relieve ships' crews of the necessity to collect and send in oceanographic information as at present. This would be especially valuable in wartime or any other time when heightened tensions make a reduction in radio traffic desirable and mandatory.

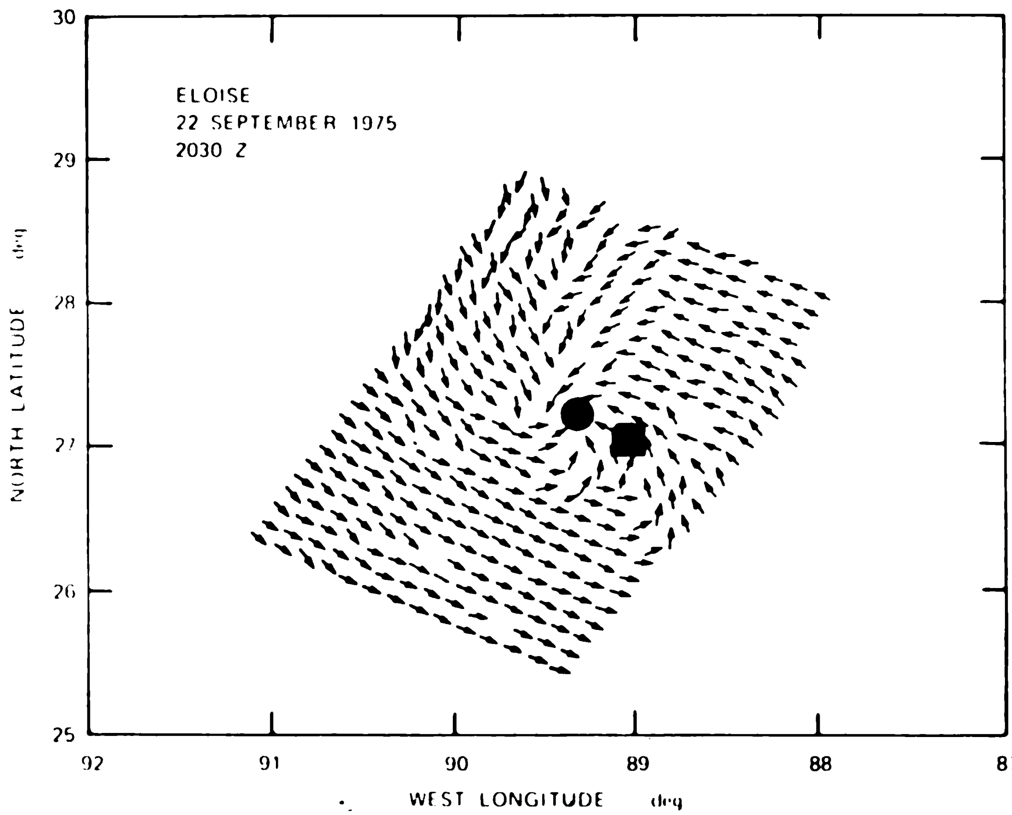


Figure 8 — The black dot represents the position of Hurricane Eloise moving through the Gulf of Mexico at 2100 GMT on September 22, 1975, as determined by an experimental ground-based Hf radar 3000 km distant in California. Arrows represent clutter from water waves. Although this was an ad hoc test, the radar-determined "eye" is only 35 km from the corresponding position (the square) deduced by the National Oceanic and Atmospheric Administration from satellite photographs and reconnaissance aircraft reports. Radar accuracy can undoubtedly be improved further. Storms can be tracked by this means for extended period of time at comparatively low cost.

Doing Something About the Radio Weather

Both ionospheric "weather" and its more familiar meteorological counterpart have been standard conversation starters over the years. Future generations, however, may find themselves deprived of that particular opening gambit as the ability to forecast and even modify our environment grows. At the present time the Navy-inspired Solrad series of satellites continuously checks the sun's output of radiant energy in those wavelength bands exerting the strongest influence on both short- and long-term ionospheric behavior. Since there is a time delay between causative radiation fluctuations and the resulting change in radio-reflecting power, such events can usually be anticipated in time to broadcast warnings to the fleet. Thus communicators can alter transmission frequencies, alter message routings, and take other steps to maintain an orderly flow of traffic. In the past, it not infrequently happened that the only warning of impending trouble was a major circuit failure. The new procedure should be of great benefit to all those systems that in any way depend on the ionosphere.

Since the atmospheric gas above, say, 100 km in height is highly tenuous (about equivalent, for example, to the vacuum of an inexpensive thermos bottle), the possibility of modifying its radio-wave reflecting characteristics to make them more useful is not as farfetched as it sounds. We know that the upper atmosphere is strongly affected by nuclear explosions. We know it is also measurably affected by thunderstorms, large blasts using conventional ammunition, and similar energy-releasing events (including tsunamis and landslides), on the earth's surface. We also know that when low-ionization-potential chemicals such as barium or caesium are released at the right height, the local electron density can be materially increased for a matter of hours, assuming the region to be in sunlight. Conversely, the deliberate or accidental discharge of water into the ionosphere (from rockets or rocket exhausts) is very effective at causing free electrons to disappear; a localized decrease in their density results [10].

Water, of course, is very much a natural part of our atmosphere, so that a question of pollution does not arise. But a clearly nonpolluting technique for ionospheric modification is the radiowave heating method. It can be expected that as knowledge of the details of radio-wave-induced effects improves, additional applications may well be found. Thus far, for example, there have been no studies (to the best of the author's knowledge) of the possibility of combined radio-wave and chemical modification. Extra electrons, released at the appropriate height, could raise the radio frequency at which heating is efficient, thereby significantly reducing the size and cost of the heating installation required.

Modifying the ionosphere to increase reflecting power is of obvious assistance in communication applications. (Such a reflector would have the unique advantage of nearly instantaneous controllability.) However, there are many other conceivable applications, many of them in the electronic warfare area, that have not yet been fully explored.

Another radio-wave modification of importance would be to *decrease* the amount of ionization in a given region, since ionospheric electrons represent a not-inconsiderable source of clutter for earth-borne or spaceborne radars and communication systems which must transmit signals all the way through that region. This includes high-resolution side-looking radars, precision location and navigation systems, and the like.

Atmospheric nuclear weapons tests, and to some extent the natural aurora too, can create extra electrons in the ionosphere capable of making the targets of space-tracking radars appear to scintillate in position and grow either weaker or stronger. To dissipate these extra electrons by means of a powerful radio beam, which in effect "burns through" the affected region, has often been proposed. But the estimated energy requirements have thus far dampened prospects for this technique.

Can Induction be Substituted for Radiation?

Radio waves of really enormous lengths have never been of interest in commercial communication, because much more information can be transferred at lower cost in the MF and HF range. Geophysical prospecting does use this wavelength regime, but prospecting is normally concerned with analytical measurements at a particular location, rather than information transfer over long distances. Thus, communication technology in the 1-to-100-Hz range can hardly be said to be a mature art. Many of the concepts are relatively unfamiliar. For example, the normal variation in electron density resulting from changes in gas pressure with altitude takes place over a distance that is a tiny fraction of a wavelength in the case of superlong waves. The ionosphere, in effect, is a very thin shell. In addition, the effect of both electrons and ions needs to be taken into account, whereas at higher frequencies only electrons need be considered in calculating refractive index.

Although it is tempting to apply in this wavelength regime concepts and simplifications that have proven useful elsewhere in the frequency spectrum, such extrapolation is very risky. It may be preferable, for example, to abandon the concept of "radiation," implying as it does a decay of signal strength inversely as the distance, and to make use instead of a field component whose strength decreases with the square of distance. Optimum launching and retrieval of this field component might well lead to structures scarcely resembling conventional transmitting and receiving antennas at all. Whether these structures, when performing a given function, will be adequately low in cost remains to be established, but there is that hope.

Although the point is not immediately obvious, extremely long waves also have potential for detection and localization just as do their shorter counterparts. One can think, by way of illustration, the longest "wave" of all is a static or d.c. magnetic field. Let it be perturbed at a given point by (for example) a magnetic object. By measuring the detailed spatial distribution of the total field over some aperture at another location, it is possible to deduce the position of the object, but only if the measurements can be made with sufficient precision. If this is feasible with a static field, it can also be done with a time-varying magnetic field, even when the time variation is comparatively slow. This procedure is greatly aided by digital recording techniques that make possible both easy storage and rapid processing.

Conclusion

Only a few of the more challenging electromagnetic propagation matters of potential interest to the Navy have been touched upon here. For example, the many intriguing problems associated with laser communication and weaponry have been omitted. Propagation is a research field that offers a delightful mix of physical effects, spanning as it does the frequency spectrum from 1 to more than 10^{10}Hz, and dealing as it does with transmission through materials as diverse as salt-water and the near vacuum of outer space. As electronic systems grow more complex and as the precision required of them grows ever greater, research must keep pace if the Navy is to retain its leadership in harnessing and exploiting the environment.

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TITLE INDEX 1977

IX. **A Special Issue on the Navy Personnel Research and Development Center (January)**

Selection Procedures at the Naval Academy
Applying Psychobiology
Models for Planning Manpower Requirements and Personnel Resources

AUTHOR INDEX 1977

Removing Surfactants from Waste Water

A Naval Research Laboratory scientist, Dr. Ralph C. Little reports that the well-known aluminum hydroxide floc method of removing surfactants (oils, dirt, detergents) from waste waters can be enhanced by certain additives discovered in recent experiments. Such additives promote hydrophobic bonding of surfactants to the floc surface resulting in the quantitative removal of many surfactants from the treated water.

The application of this technology to shipboard laundry waste, industrial waste and others is quite evident, but further work will be required to test his laboratory results in the field.

U. S. GOVERNMENT PRINTING OFFICE : 1978 O - 255-808

Surfactants in waste waters constitute a significant problem today in waste water treatment because they impede the re-use of treated water in closed systems or render the water unsuitable for return to the environment or to sanitary sewer systems.

The use of recycled water in ship's laundries would naturally avoid the potential of pollution and would eliminate the expense of producing distilled water for that purpose.

The surface tension of the treated waste water, using the additive-enhanced aluminum hydroxide floc, increased the surface tension to 70 dynes per centimeter. For pure water the surface tension is 72 dynes per centimeter.

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VOL. XXX, NO. 12

Cover Caption

This satellite tracking station is part of Navy Navigation Satellite System (NNSS) (See page 8).

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