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Satellite Communications in the Navy -A Look Back and A Look Forward

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SATELLITE COMMUNICATIONS IN THE NAVY--A LOOK BACK AND A LOOK FORWARD

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Summary

It is the purpose of this paper to review the Navy's efforts in the field of Satellite Communications up to the present time, to indicate some of the problem areas, and to suggest some current and possible future trends. Most of the early Navy work in the 50's and early 60's involved use of "passive" satellites such as the moon, reflecting balloons and the like. The moon was used to bounce communications signals between places as far away as Washington and Hawaii. Since the early 1960's emphasis has steadily shifted to the use of "active" satellites which receive, amplify, and re-transmit signals, thus providing a much stronger signal at the receiver than the extremely faint signals reflected from the surface of the moon. As better boosters have become available, large and sophisticated satellites can be put into high altitude orbits. There is a strong trend toward "synchronous" orbits which cause the satellite to appear motionless over a point on the equator. From such a vantage point a satellite can see over 40% of the earth's surface.

Although much early work was done independently by the services, the present programs are, for the most part, joint efforts within the Department of Defense. The Navy's primary area of unique responsibility is in development of satellite communication terminals suitable for use aboard naval combatant type ships. Some difficult technical problems are involved such as finding suitable room for the antennas aboard crowded ships, electromagnetic interference with other systems, etc. Also, there are system problems to be worked out together with the other services such as best modulation methods, multiple access schemes, bandwidths and other important parameters. These problems are being solved. Satellite communications shows great promise of a major improvement in the Navy's vital long distance communications.

Part I Navy Experience in the Field of Satellite Communications

To support its complex mission, the Navy has always been at the forefront of scientific research. Early in the "space age" the Navy recognized Astronautics as a vital new technological field offering significant returns of great consequence to the Navy in Navigation, Communication, meteorology and geodesy. Long range plans were laid for a Navy integrated space program with objectives in three general groups:

First, those areas offering significant improvement to Navy combatant capability. Included were weather, navigation, sea surveillance, communication, and geodesy.

Second, countering the threat from enemy space effort.

Third, those areas where the Navy's natural environment and "know-how" can assist national programs, such as sea launch and sea recovery.

It is the purpose of this paper to review the past Navy effort in just one of these areas, that of satellite communications and to suggest some possible future trends in this area.

The past few years have seen far-reaching and exciting satellite communications developments in the Department of Defense, NASA, U. S. commercial, and overseas. This paper will review the Navy program and will touch on these other outside developments only to the extent necessary to show their influence and impact on the Navy effort.

In 1954 the Navy started experimental communication transmissions between Hawaii and Washington, D. C. by bouncing signals off the moon. This system went operational in 1959 and for years provided reliable communications for the few hours a day (from about 4 to 10 hours depending upon the moon's declination) the moon is mutually visible to both ends of the link.

Much early work was done in perfecting the components and techniques for such "moon-bounce" communications and a shipboard system was successfully put aboard the USS OXFORD in 1962. The Navy also experimented with the "ECHO" balloons launched by NASA in early 60's.

In addition to the Navy's strong early interest in passive communications of the "moon bounce" variety, a watchful eye was kept on the advancing active satellite technology. Because of the tremendous losses, large antennas and very high transmitter powers were required to bounce signals off the moon. Active satellites that received, amplified, and re-transmitted had obvious advantages if they could be made to approach the reliability and flexibility of the passive ones.

In late 1962 the Defense Communications Agency was charged with the responsibility for creating a satellite communications system for the Department of Defense, with the Air Force responsible for the space portion, the Army for the ground portion and the Navy the shipboard portion.

In 1964 the Navy was given the opportunity to conduct experiments with the "SYNCOM" satellites which had been launched by NASA in 1963 and 1964. These highly successful satellites (SYNCOM II and SYNCOM III) were of very special interest because they were placed at the particular altitude (22,300 statute miles) at which they orbit the earth in 24 hours. Thus they are called "synchronous" satellites. They either appear to stand stationary over a point on the equator, or perform a figure eight over such a point if launched in an orbit inclined with respect to the equator. Synchronous satellites greatly simplify the function of pointing a high gain communication antenna at them. From this great altitude over the equator a single synchronous satellite can "see" over forty percent of the earth's surface. As few as three can give world-wide coverage except for small polar areas. For these reasons the Navy was anxious to obtain shipboard experience with such satellites and set to work on a crash program to develop suitable terminals. In February 1965, two combatant type ships, 6,000 miles apart, the USS MIDWAY and the USS CANBERRA established communications via the SYNCOM III satellite, an historic occasion. The terminals used had been hurriedly developed and built by Hughes Aircraft Company under contract from the Navy Bureau of Ships.

Meanwhile the operational requirements of the services for Defense Satellite Communications Programs were being established and validated. As part of the Initial Defense Satellite Communication Program, the Air Force in June 1966 launched seven satellites into a near-synchronous orbit. These have since been supplemented by additional launches and this initial system is now operational. To operate with these satellites, the Navy, in addition to operating certain shore terminals, developed shipboard terminals for ship-ship and ship-shore communications. One of these terminals, designated AN/SSC-3 and built by Hughes Aircraft Company under Navy contract, was demonstrated publicly in August 1966 at the Western Electronic Show and Convention (WESCON). The AN/SSC-3 terminal consists of a six foot diameter parabolic antenna with its pedestal (which also houses elements of the receiver and transmitter) and an equipment shelter which houses operating controls, power supplies, etc. The AN/SSC-3 terminal is shown in Figure 1.

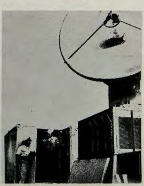

Figure 1. Shipboard SATCOM Terminal AN/SSC-3

It can operate in a voice mode or provide several teletype channels to another ship or to a shore station. The frequency bands employed are those set aside by international agreement for satellite communications exclusive use in the 7-8 GHZ region. Much operational experience at sea has been accumulated with the AN/SSC-3 which clearly indicates the great potential benefits of satellite communications to the Fleet. However, we have not yet attained adequate reliability of the hardware for operational use in the difficult environment aboard Navy ships, and we are engaged in an extensive reliability improvement program prior to any widespread use of this type terminal.

The Navy and Marine Corps are actively involved, together with Air Force and Army, in the Tactical Satellite Communications (TACSAT) Program. This program was initiated by the Department of Defense in late 1965. As the name implies, TACSATCOM is intended to serve the needs of the many highly mobile tactical users in Army, Air Force, Navy and Marine Corps. The distinction between TACTICAL and STRATEGIC communications is not clear cut in a modern military force. Either may include the requirement to communicate over distances of hundreds of miles. Suffice it to say that the TACSAT philosophy is something like this; since many mobile terminals are expected to be involved, they must be as reliable, simple, and economical as possible. If complexity is required, it is generally more cost effective to add it to a few satellites than to many airplanes, ships, and transportable ground stations. This would not necessarily be the case, or at least not to the same degree, in a system primarily concerned with trunking type communications between a few fixed locations.

The first phase of the TACSAT program is now underway. Army, Air Force, Navy, and Marine Corps have a first generation of R&D terminals under development. The Navy and Marine Corps will use ship, shore, and air terminals in a comprehensive test program with the TACSAT 1 satellite, to be launched by Air Force in 1969. This satellite includes repeaters in both the military UHF (250-400 mhz) band and in the SHF frequency band (7-8 GHZ). The Navy already has some satellite communications experience at SHF through the previously mentioned involvement in the Defense Satellite Communications Program. We also have UHF experience, not only in conventional line-of-sight communications, but with satellites. Fortunately, when the TACSAT program was authorized, the Air Force already had a program underway at Lincoln Laboratories of MIT under which a series of experimental satellites was designed and launched. The Navy Electronic Systems Command procured six modified off-the-shelf UHF transceivers and installed them in Navy ships, airplanes and ashore. These terminals performed remarkable well in communicating with each other and with the other services over great distancesthrough LES-5 (Lincoln Experimental Satellite) launched on 1 July 1967 and LES-6 lauched 26 September 1968.

Part II <u>Some Present Problem Areas</u>

We have reviewed very briefly the Navy involvement in satellite communications over a period of several years. Now lets look at some of the problems before us at the present time. The following is not a complete list but is representative:

<u>Frequency Problem</u>: In the early days of satellite communications the question was raised as to the optimum frequency band in which to operate. Above about 10 GHZ (10,000 megahertz) attenuation of signals in the atmosphere increases rapidly, and below about 1 GHZ galactic noise increases. Thus, it appeared that operation somewhere between 1 and 10 GHZ would be desirable and, in fact, frequencies within this range were designated for satellite communications by international agreement, and are used in the present operational satellites. These frequencies allow antennas to be built with high gains and narrow beamwidths. On the other hand, pointing a highly directional antenna at a

moving satellite (or even a stationary one) from a maneuvering aircraft or small ship can be a difficult problem involving complex and expensive stabilization systems. At UHF frequencies the antennas are not so directional so the pointing problem largely disappears. Of course, their gain is lower than at SHF, but this is offset by the lower space loss between the terminal and the satellite. For large fixed terminals SHF appears to have clear advantages, but for small mobile terminals UHF remains attractive.

The Shipboard Antenna Problem

In order for a shipboard satellite communications antenna to communicate through a satellite, it must have an unobstructed line of sight to that satellite. Since the ship must be free to operate in various ocean areas and at all different headings, this means the antenna must cover the entire hemisphere, 360 degrees in azimuth and from the horizon to the zenith All this is plus additional freedom to move to compensate for the ship's roll and pitch.

If a ship's primary function was to carry such an antenna, it would be fairly straightforward. As a matter of fact, there was just such a ship, the USNS KINGSPORT (Figure 2), the

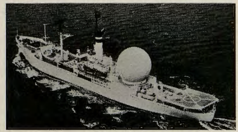

Figure 2. SATCOM Aboard USNS KINGSPORT

world's first Satellite Communication Ship. The KINGSPORT was a converted victory ship originally intended to be used as one of the satellite communication terminals in the Army "ADVENT" project which was terminated in 1962. The ship, with Army, Navy, and NASA support, was completed and operated by the Navy in support of the already mentioned NASA SYNCOM program. The KINGSPORT had a 30-foot antenna under a 54-foot radome and performed vital tracking, telemetry, and communications functions in connection with launch and use of the SYNCOM satellites.

The KINGSPORT was a special case and has little bearing on putting satellite communications aboard Navy fighting ships. The tracking and recovery ships used in support of NASA and DOD programs are also special cases. Anyone who has ever seen a modern Navy combatant ship such as a heavy cruiser must be impressed with the profusion of antennas. This is illustrated in Figure 3 which shows the six-foot diameter AN/SSC-2 antenna almost lost among other antennas aboard the aircraft carrier USS MIDWAY.

Figure 3. SATCOM Aboard USS MIDWAY

All or at least most of these antennas (search radar, fire control, navigation, etc.) have visibility requirements in varying degrees, and all are important. Therefore, there is competition for good locations and compromises must be made. The situation is difficult even on a new ship being designed, but is even more difficult when one is considering adding satellite communications to existing ships. Many older ships are weight and moment critical. It is very difficult to obtain locations aboard combatant ships for a 6-foot (or even a 3-foot) SATCOM antenna of the parabolic dish type where more than 270° out of the desired 360° of visibility can be obtained. Various solutions are under study (including dual antennas) but no completely satisfactory solution is in sight. Considerations which enter into the shipboard antenna problem include: cost, interference to and from other systems, radiation hazard to personnel and to ordnance, and accessibility for maintenance.

The Reliability Problem

In order for intelligence to be transmitted from the originator to the end user, all links in the chain must perform their function. This includes not only hardware (The end instruments, such as teletype machines, the power supplies, modulation/demodulation, receivers, transmitters, antennas, etc.) but it also includes the transmission medium, the satellite itself, operator error, system synchronization, and other considerations. If one can avoid operating with the shipboard antenna pointing too low on the horizon (say above 7 1/2 degrees elevation angle) the distance the signal travels through the earth's atmosphere is not great and (except for heavy precipitation) the losses in the path to and from the satellite are very stable and predictable. The satellites have proven highly reliable. All this puts a very heavy premium on reliability of the shipboard terminals. The shipboard environment is hostile, involving salt spray, shock, vibration, heat, and cold, difficult accessibility for maintenance, and long supply lines for replacement parts. The situation for satellite communication terminals for Navy ships is closely analogous to shipboard radar which required a number of years to achieve an acceptable degree of operational reliability. A shipboard satellite communications terminal is a relatively complex and sophisticated piece of equipment and obtaining the required reliability is not an easy task.

The Modulation and Multiple Access Problem

Given two satellite communications terminals, the type of information to be transmitted and the characteristics of the satellite to be used, a choice of method of modulation would be relatively easy. The problem facing the Department of Defense is vastly more complicated. Obviously, the Navy must be able to communicate with the other services. The type of terminal involved and the type of information to be transmitted vary widely. Various combinations of terminals must communicate through a single satellite as efficiently as possible without interference and cross-talk. Timing and synchronizing requirements must not be beyond the capability of the small mobile terminal. Large powerful ground terminals must not unduly suppress signals from weaker terminals in the satellite and, if a requirement for power control is imposed on the large terminals it must be a simple and if possible an automatic procedure. Complex scheduling and bothersome circuit discipline procedures must be avoided and flexibility to change must be retained. Various methods of modulation and multiple access through the satellites are under study and test to determine quantitatively their performance under various sets of circumstances.

Part III Trends

Aside from nostalgia, of what use is looking back at past happenings? As it says on one of the government buildings in Washington, D. C., "what is past is prologue". The past puts the present in proper prospective. While no one can predict the future of satellite communications with any accuracy, certain trends now appear evident. The following represents merely one personal opinion as to some of these trends. Another writer could, with equal validity, present a completely different list. It should be recognized that these changes will not come about just within the Navy or even, in many cases, under Navy control. However, they do impact heavily on the Navy use of satellite communications. This further points up the multi service aspects of the satellite communications programs.

Growth Potential

When predictions are made as to progress of some technology, in the military or elsewhere, there seems to be a tendency to be too optimistic and overestimate what can be accomplished in a few weeks or months and to underestimate what can be done in a period of several years. The improvements in boosters and their ability to place large payloads accurately in orbit have exceeded early expectations. Similarly, the capacity and reliability of satellites have exceeded what would have been believed possible 10 years ago. This progress has been the result not only of work within Department of Defense but by NASA and COMSAT Corporation. For instance, in a few short years COMSAT has gone from a few channels through Early Bird to 240 two-way voice circuits through INTELSAT II, 1200 circuits through INTELSAT III and an expected 5000 circuits through INTELSAT IV. A few years ago the Navy needed up to 20 kilowatts of RF transmitter power and 60 to 80 feet diameter antennas for communications at teletype rates using the moon as a reflector. A hundred watts or so and a two foot antenna could send such teletype traffic through a modern active satellite. There seems to be tremendous growth potential inherent in the satellite communications technology. As the capability becomes available to send not only teletype and voice but all sorts of data, requirements for sending such data will evolve. The time could soon come when the problem is not getting the data from one place to another but efficient handling, routing, and processing of it after it is received.

Shipboard Hardware

All indications are that space for antennas aboard ship will continue to be scarce. Mounting dual antennas of conventional parabolic design may be a partial solution to the problem. Consolidation of satellite functions, such as a single shipboard terminal for operation with communications, weather, and navigation satellites has been considered. To date, because the principal characteristics of these systems are so varied, consolidation has not appeared practical but this may not always be so. A technical breakthrough in light weight phased-array antenna design suitable for shipboard satellite communications use would be a big assist. As to the rest of the shipboard terminal hardware, there is need for continuing improvement in reliability, ease of operation, greater use of solid state construction, built-in self test and monitoring devices, and improved associated equipments (vocoders, etc.)

System Considerations

Because of the rapid development of active satellites, interest in using passive satellites (the moon, echo type balloons, space junk, etc.) for operational use continues to decrease. Early active satellites were at relatively low altitudes (a few hundred miles). As the altitude increases the distance between points on the earth with mutual visibility to the satellite also increases. Above about five or six thousand miles altitude the single-hop distance covered increases more slowly with satellite altitude. The one-way space loss between terminal and satellite increases as distance squared. This must be made up for by higher transmit power, higher antenna gains, more sensitive receivers, or more efficient modulation/demodulation. Thus there is no great benefit to increase in communication satellite altitude above about 5,000 nautical miles except for the one special case of synchronous altitude. Synchronous equatorial satellites with station keeping capability and ability to be moved to a new location in orbit greatly simplify the acquisition, antenna pointing, and tracking problems. For a ship terminal this is particularly helpful and fortunately the trend is to this type of satellite. It is possible that eventually certain points in the equatorial synchronous orbit may become so popular with various satellite systems that we may some day have interference problems (i.e., several satellites within the beamwidth of the ground or ship terminal antenna).

As to frequency bands, near future use seems to be either UHF, SHF, or some combination. However, as these bands eventually get overcrowded, there may have to be increasing use of the region above 10 GHZ where more bandwidth is available, even though considerable margin may have to be built in for the effects of atmospheric attenuation at these higher frequencies.

It is not possible with present systems for a very large number of separate terminals to send simultaneous signals through a satellite without interference. All presently known multiple access schemes have some serious disadvantages. All fall short of the utopian desire to have any mobile terminal be able to be instantly in contact with any other by simply dialing his address or code like a telephone. It is doubtful if this can be achieved or even closely approached. However, advances in multiple access/discrete address schemes over the next few years should provide a partial solution.

Reliability

The Navy will solve its reliability problem with shipboard satellite communications equipment because it must, and as it has in the case of other new technologies introduced to the Fleet. It will not be done easily nor overnight. Increased use of solid state devices will help, but many problems are with mechanical devices and with high power klystrons and other devices not subject to solid state construction in the near future. Use of redundance in key parts of the equipment, improved quality control, better performance monitoring and self-test features, improved accessibility for maintenance and better trained personnel all will help. As more experience is gained, features may be found unnecessary and dropped, simplifying the equipment. In short, no one simple solution seems in the cards to suddenly achieve high reliability. Instead, hard work and application to proven techniques will do the job.

Outlook

If the foregoing paints a somewhat pessimistic picture, such is not intended. Although there are problems, and some which are troublesome, none are beyond solution. Feasibility has been clearly established and it now remains to find optimum system parameters, mesh satellite communications smoothly with other types of communications and learn how to best use the new capability. Satellite communications promises relief from line-of-sight limitations of present UHF systems, and from the propagation problems at lower frequencies. It offers tremendous growth potential. It seems abundantly clear that the new satellite communication capabilities will revoluntionize global communications and military command and control.