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TACTICAL SATELLITE COMMUNICATIONS

IN THE 1990s

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ABSTRACT

The rapid advancements in electronic technology over the past few years indicate both the need for vastly improved communications capability and the means to provide that capability. Use of the EHF frequency bands allocated for satellite communications and the development of signal processing capability for communications satellites will allow the next generation of military communications satellites to overcome the capacity and interference resistance limitations of today's systems. These improvements will also allow the use of small, highly mobile earth terminals, a capability that is highly significant to the combat forces.

INTRODUCTION

Today we have the most sophisticated and capable military command and control communications systems the world has ever seen. Military commanders can receive information from, and send direction to, widely dispersed forces through a variety of media under almost any condition. As capable and sophisticated as today's systems are, they are rapidly becoming obsolete. The explosion of the capability to gather and process information has put a huge strain on the communications systems needed to transfer that information. The frequency bands in use today are becoming increasingly crowded and the capability of an enemy to effectively jam these bands is growing. There is little that can be done to mitigate these problems for terrestrial communication systems, especially those systems that provide beyond line of sight

service. Fortunately, there are frequency bands allocated to military satellite communications (MILSATCOM) that can overcome the frequency crowding and difficulties with interference and, at the same time provide a new level of mobility and flexibility to the communications equipment for the combat forces.⁽¹⁾ These frequency bands are in the vicinity of 20, 30 and 44 GHz and are commonly referred to as the EHF MILSATCOM bands. The 20 GHz band, actually in the upper range of the SHF frequencies, is allocated for downlink service and the 30 and 44 GHz bands are allocated for uplink service. In this paper we will investigate the enhanced operational effectiveness of combat forces through the use of modern satellite communications, review the evolution of the architecture for MILSATCOM systems, and discuss the motivation for a move to the EHF bands. We will then discuss the technology needed for such a move and the status of that technology development. Finally, we will discuss the tasks which lie ahead of us in defining the detailed requirements for tactical satellite communications, securing agreement to those requirements among the services, and obtaining the resources necessary to pursue the development of a tactical satellite communications system.

ENHANCED OPERATIONAL EFFECTIVENESS THROUGH MILSATCOM

The function of a communications system is to provide a means for the flow of information and direction to and from a decision maker. In the military, the unit commander is the decision maker. The communications system handles incoming status information and orders from higher echelons and outgoing orders and status reports to higher echelons. The flow of orders is "downward"; the flow of outgoing status reports is "upward"; and the flow of incoming status information is from all directions. Information is only useful if

it is in the hands of the decision maker. Information that is extraneous to the decision being taken will only delay the decision and can be viewed as noise in the system. Information in a useable form must be in the proper hands in sufficient time for a decision to be taken and orders distributed to exploit the information. This exploitation of "real time" information can be viewed as a three step process:

- (1) locate targets with sufficient accuracy to fall within the engagement envelope of friendly forces.
- (2) provide target information to a decision maker in a usable form.
- (3) provide orders to friendly forces before targets have left their engagement envelopes.

This process requires effective communications between a sensor and a data processing facility; between the data processing facility and the decision maker (commander); and between the commander and his forces.⁽²⁾ If we view the whole process as a feedback control system we can see that there is an absolute dependence upon effective communications to make the system work. The required characteristics for effective command and control systems include several that are inherent to a modern satellite communications system; these are: availability, mobility, timeliness, jam resistance, flexibility and survivability.⁽³⁾ The MILSATCOM systems of today have orbital parameters that ensure communications availability anywhere in the world. The frequencies used by MILSATCOM systems tend to minimize the effects of ionospheric disturbances allowing communications day or night any time of the year. Projected future MILSATCOM systems will even further reduce the propagation losses. As these systems move into the higher frequency bands,

smaller earth terminals become possible, increasing mobility. The proposed tactical satellite communications system will include the ability to interconnect earth terminals operating in different frequency bands - a feature that will significantly enhance operational flexibility. The combination of worldwide coverage and highly mobile earth terminals allows the timely establishment of communications with any trouble spot. The increased bandwidth available at the higher frequencies allows the incorporation of techniques to negate the effectiveness of enemy jamming attempts. Finally, the location of communications satellites more than 35,000 kilometers out in space provides a level of physical survivability not found in terrestrial communications systems. These features, in combination, lead to communications capabilities that can provide extremely effective command and control of our military forces.

There are many approaches to the measurement of the effectiveness of improved command and control capabilities. Effectiveness can be measured in terms of weapons saved, lives saved, objectives obtained and so on. These measurements must be qualitative rather than quantitative. We can only estimate the resources required to attain an objective with, and without a particular command and control system. For example, we can estimate the number of weapons saved if we can redirect second strike sorties once confirmation of successful first strike is attained. We can improve the accuracy of the estimate through the use of computer simulation of the scenario with, and without, communications for redirection. But we can never experience the alternative not adopted. We can look at history and point out the successful operations that had effective command and control and the failures that did not. (When we are advocating effective command and control) we obviously do not point out

the successful operations that did not have it or the failures that did).

The American soldier has enjoyed the reputation of an independent thinker capable of innovative approaches to unforeseen problems. This reputation is partially the result of the "citizen soldier" concept wherein the bulk of the fighting force is drawn from the ranks of a democratic society that highly values self reliance. Another important factor in this reputation is the historical ability to operate with minimum information because of a clear logistics superiority. When Japanese General Yamashita was asked to rate the Americans as jungle fighters he is reported to have replied "They are not jungle fighters-- first they shoot away the jungle, and then they fight". Americans have long enjoyed the ability to use massive fire power to achieve military objectives. From carpet bombing by B-17s in Europe to air strikes on sniper positions in Viet-Nam, the philosophy was to heavily strike an area occupied by the enemy, even when specific targets could not be identified. Today that philosophy cannot be followed. The logistics superiority we once enjoyed simply no longer exists.(4)

In recent years we have moved to replace our superiority in fire power with a superiority in command and control systems. Reconnaissance by fire is being replaced with a variety of new and sophisticated sensor systems that can locate and identify targets in almost any environment. One drawback to this new situation is lack of acceptance by field commanders. No one likes to be dependent on resources beyond his control; yet maneuver elements cannot be encumbered with large and delicate data processing centers. The problem becomes one of education. First, the distinction between data and information must be drawn.(5) Then the field commanders must be led to understand that systems that reduce data

and provide information are not making decisions for them; but rather are merely providing the basis for rational decision making.

Once battlefield acceptance of remote data processing is obtained, a new realm of operational effectiveness can be entered. Mobile units will no longer depend upon fixed or cumbersome command and control assets. Prepositioned communications for command and control will be unnecessary. With satellite communications, effective command and control of forward elements of units, such as the Rapid Deployment Force, can be accomplished by a CONUS battle staff until forward command elements can be established. The danger lies in allowing a drift from adequate control to overcontrol. The degree of control that is correct varies with the situation. The Mayaguez rescue benefitted from real time control from the Pentagon. The Israeli staff only monitored the communications among elements of the Entebbe rescue.(6)

A delicate balance must be maintained between providing too much command and providing too little control. Too much "help" from higher headquarters is viewed from the field as micro-management or worse. The day to day decisions must be made by the field commanders. The purpose of the command and control systems is to provide adequate information upon which to base a decision. Then the time comes when a field commander must be overruled. After the fall of Tobruk it was the obvious choice for Rommel to pursue and destroy the fleeing British - from Rommel's point of view. This decision should have been overruled (as Kesselring attempted) until the German position in the Eastern Mediterranean was secured by taking Malta.

The examples are endless. For every Jack D. Ripper running out of control there is a Charles Forbin trying to centralize all decision making.(7) The communications

system provides the ability to give information and direction. Its proper use or abuse is a problem the design engineer cannot solve.

Satellite communications can enhance military operations in several other areas. Once the battlefield commanders have accepted the concept of a data reduction center that is not under their direct control, then such a center can be located at great distances from the sensor systems and command elements it supports. The remote location will greatly enhance the survivability of the data reduction center by removing it from the enemy's engagement envelope and release combat elements that would otherwise be dedicated to its defense. Communications with long range aircraft and naval units at sea require long range, reliable jam resistant communications that can be provided only by satellites. Modern satellite communications systems also provide an effective means of maintaining contact with special military operations. The combination of small antenna size and narrow beam pattern achievable at the EHF frequency band allows communications with units, such as Airlift Combat Control Teams operating in enemy territory, without detection by enemy forces.

THE EVOLUTION OF MILSATCOM ARCHITECTURE

For the last several years the military services have been pursuing a MILSATCOM architecture consisting of three segments based upon the unique requirements of three user communities. The first segment provides communications for the nuclear capable forces who need the highest degree of physical survivability, ability to operate in an intense jamming environment, and world wide coverage with high availability. Most of the communications needs of the nuclear capable community can be satisfied with low data rate (75 baud) service. The second segment serves the wideband trunking community. This

community includes the Defense Communications System, the Diplomatic Telecommunications Service and other users characterized by high data rates and large fixed earth terminals. We use the term Earth Terminal to identify the terrestrial end of a satellite to earth communications link. The third segment of the MILSATCOM architecture provides service to the Tactical/Mobile user community. This community requires world wide coverage, the ability to operate in an intense jamming environment, often very close to the source of jamming, and low to medium data rates, typically voice grade service from small mobile or transportable earth terminals.

Today, the nuclear capable forces are served by the Air Force Satellite Communications System (AFSATCOM). The AFSATCOM space segment consists of dedicated Air Force UHF channels on the Fleet Satellite Communications (FLTSATCOM) satellite and transponders on other host spacecraft. Earth terminals are installed on SAC bombers, missile launch control centers, airborne and ground command posts and Navy radio relay aircraft.

The wide band trunking community is presently served by Phase II of the Defense Satellite Communications System (DSCS - II) which provides SHF Satcom service to a world wide network of fixed earth terminals under the management of the Defense Communication Agency (DCA).

The FLTSATCOM system currently serves the tactical/mobile community. The FLTSATCOM satellite provides fleet broadcast and fleet relay service as well as the AFSATCOM service previously mentioned. The fleet broadcast channel uses an SHF uplink; the remaining channels are UHF. Earth terminals are located on ships and aircraft of the fleet, mobile platforms such as trucks and jeeps and even back pack radios.

The three segment MILSATCOM architecture included a near term follow-on system for each segment of the architecture. AFSATCOM was to be followed by the Strategic Satellite System; DSCS II by DSCS III; and FLTSATCOM by a leased UHF system known as LEASAT. The far term included an improved Strategic Satellite System, an upgrade to DSCS III or a DSCS IV and a new tactical satellite communication system called TACSATCOM - II.

The three segment architecture began to run into trouble in the summer of 1979 when Congress deleted funds for the development of the Strategic Satellite System space segment, a new satellite intended to operate in polar orbits at super synchronous altitudes. At the same time the services were continuing their planning for the development of TACSATCOM-II. The TACSATCOM II planning was fragmented and discordant as each service concentrated on its own needs. Little consideration was given to the development of operational concepts explaining the role of satellite communications in the command and control of combat forces and the needs of joint forces were given practically no consideration.

Over the next year much attention was given to the strengthening of the case for the Strategic Satellite System. The planning for TACSATCOM II also began to take shape as the differences between the services were resolved. However, Congress was still not convinced and the funds for the Strategic Satellite System space segment were again deleted. Now the services were faced with a new problem. The time phasing of the two developments with the TACSATCOM development following the strategic satellite development could no longer be followed if the operational need date were to be met. It was clear that another look at the MILSATCOM architecture was warranted.

Last October representatives from the military services and the Defense Communications Agency, under the direction of Doctor Van Trees, Principal Deputy Assistant Secretary of Defense (communications, command, control and intelligence), initiated an intensive reevaluation of the MILSATCOM architecture. The prime goal of this effort was to develop an architecture that would be responsive to the needs of the military and acceptable to Congress. This goal can be met by developing the concept of truly a joint mission satellite. A satellite communications architecture based on satellites with mixed user groups can effectively indicate a unified DOD that strives for the cooperative exploitation of space.

After an extensive review of the requirements of each user community, it became apparent that there is a great deal of similarity in the needs of the nuclear capable forces and the tactical/mobile forces. Both user groups require world wide communications among small, highly mobile earth terminals. Both user groups need to operate in an intense jamming environment. Both user groups operate at voice rate and slower data rates. The basic elements of functional commonality of these communities has led to the consideration of a two segment architecture for the long term follow-on to the existing and programmed MILSATCOM systems. The two segment architecture will provide service to the wide band trunking user community just as was planned in the three segment architecture. The nuclear capable and the tactical/mobile communities will be served by a new tactical communication satellite (we use tactical here in the broader sense of the word--supporting the maneuver elements). The remainder of this paper will focus on the tactical segment. Details of the new two segment MILSATCOM architecture have yet to be fully developed. We expect that the concept of

a joint mission satellite will lead to a generic communications satellite. A family of common, shuttle compatible spacecraft with joint communications payload electronics is feasible. Regardless of the orbital scheme to be pursued, a common payload design is practical. The only differences between spacecraft would be those dictated by the peculiarities of the orbit selected.

We also expect the membership in the tactical user community will expand beyond the combined membership of the nuclear capable and tactical/mobile communities of the old three segment architecture. The tactical MILSATCOM system should serve, in addition to the current AFSATCOM and FLTSATCOM users, some elements of the Defense Communications System, the Rapid Deployment Force, the Ground Mobile Forces, and any other users who need a robust communications capability among small mobile platforms.

THE CASE FOR EHF

While many of the features of the next generation MILSATCOM system remain uncertain, one is becoming increasingly clear. The MILSATCOM system for tactical communications in the 1990's will include substantial capacity in the EHF bands. There are several advantages of EHF over the UHF and SHF bands now in use. Perhaps the most important of these is the wide bandwidths available in the allocated EHF bands. These bandwidths are available for increased capacity as well as spectrum spreading techniques for interference resistance. Unlike the UHF and SHF bands which are crowded with terrestrial users the EHF bands are not presently occupied. Systems operating in the EHF bands also offer the advantage of small high gain antennas and correspondingly small earth terminals--a factor that is particularly important to tomorrow's highly mobile tactical forces. Because there are no existing entrenched systems to satisfy, we

can pursue new, more efficient modulation techniques, applicable to all users and a standard building block set of earth terminal modules. (8)

The precise antenna patterns achievable at EHF, even with relatively small antennas, is another advantage of these frequencies. The narrow beamwidths that can be obtained help make an EHF system more covert. This covertness will allow communications to take place with units operating behind enemy lines and in other situations where they previously had to maintain radio silence to avoid detection. The precise patterns available also allow a reasonable sized spacecraft antenna to steer antenna nulls in the direction of interference sources further reducing the effectiveness of jamming attempts. To effectively accomplish this at UHF or SHF in a tactical scenario would require impractically large antenna arrays in space. The advantages of EHF do not come without cost. The EHF frequencies are affected by propagation losses, particularly at the higher frequencies, due to rain. These losses can be overcome by power, but more power is expensive--especially on spacecraft. The spacecraft power question is a prime reason for selecting a lower frequency (20GHz) for the downlink. Electron devices tend to be less efficient at EHF frequencies further aggravating the power/cost problem and adding a heat dissipation problem where none previously existed. These problems present some engineering challenges but they can be solved. The advantages of EHF in a combat environment far outweigh the disadvantages.

Other features are needed of a future tactical communications satellite if full advantage of the EHF frequency is to be taken. One of these is on-board processing to the base band level. This means that the satellite will despread, demodulate and decode the uplink signal;

direct the signal to the appropriate downlink channel; and then reencode, remodulate and respread the signal into a format compatible with the equipment at the message address. This places the downlink power in signal transmission rather than wasting downlink power by retransmitting system interference.

Another feature of the next generation tactical communications satellite system is the use of satellite-to-satellite crosslinks to avoid the need for multiple hop relays. This feature will allow any earth terminal to contact any other earth terminal without passing through an intervening earth terminal.

The EHF related features described here will be combined with more conventional UHF features and perhaps some SHF capability. The combined spacecraft will be designed for shuttle/IUS launch in the latter part of this decade. A constellation of approximately four to six spacecraft will provide the necessary worldwide coverage.

TECHNOLOGY FOR FUTURE MILSATCOM SYSTEMS

The preceding description of a new generation MILSATCOM system with a substantial increase in capability may seem like a lot of wishful thinking. Even with the advancements that we have seen in electronic technology, these capabilities are a radical departure from the capabilities of today's systems. We might be concerned that the state of technology may not be ready to support such an advanced system. In fact, all of the major technologies needed to implement such a system have been demonstrated or are now under development.

The Lincoln Experimental Satellites 8 and 9 demonstrated the feasibility of several new technologies including the use of EHF for satellite communications and satellite to satellite crosslinks. A LASER

communications system suitable for high data rate crosslinks has been developed and tested. In air to ground tests, operating in an environment much more severe than would be expected of a crosslink, the LASER communication system demonstrated a Giga bit per second (10^9 bits per second) data rate with a bit error rate of less than one per million. Satellite communications systems installed in large aircraft have been operational for several years and, in 1978, the feasibility of satellite communications with fighter aircraft was demonstrated using a B-52 AFSATCOM terminal installed in an RF-4C. Thus, all of the concepts for the new generation MILSATCOM system have been demonstrated. The specific items of hardware needed to implement those concepts are now under development.

Probably the most critical hardware item under development is the EHF transmitter which will operate in the 20 GHz band on board the satellite. A large percentage of communications satellite failures in the recent past have been attributed to transmitter failures. This is particularly true in the higher frequency bands where only Traveling Wave Tube Amplifiers (TWTAs) were capable of providing the required output power. The military experience with TWTAs has been less than satisfactory. To date we have been unable to obtain TWTAs with long-term reliability commensurate with the reliability of other spacecraft components. This has made the desired ten year lifetime difficult to achieve. Solid State technology is now reaching a level of maturity where it can compete with TWTAs at the lower power levels. Solid State transmitters show promise of significantly higher long-term reliability than TWTAs. Solid State transmitters are not without their own set of faults, however. The low efficiency of the current Solid State transmitter designs requires much more spacecraft prime power than equivalent TWTAs designs and also

presents some difficult thermal dissipation problems, particularly at the higher frequencies. (9)

Because the TWTAs and Solid State technologies each have advantages to consider, we are proceeding with development of EHF power amplifiers in both areas. We are currently developing an advanced TWT for operation in the 20GHz band. This development is a joint effort with NASA Lewis Research Center which will produce a proof of concept dual mode tube capable of linear operation at either of two output power levels 10db apart. This tube would normally operate at 2.5 watts but could be commanded to operate at 25 watts when higher power is required. We are also developing two types of solid state power amplifiers in the 20GHz band. The first type uses IMPATT diodes as a low risk approach to achieve 20-25 watts of saturated power output. The second type uses GaAs Field Effect Transistors (FET) to achieve a linear output. This type is currently capable of about half the power of the IMPATT type and is viewed as a higher risk venture. At present we are in device development and expect to begin GaAs FET transmitter development in 1982.

The engineering of Solid State transmitters differs from the engineering of TWT transmitters because the combined output of several Solid State amplifiers is needed to equal the output of one TWT. The conventional approach to Solid State transmitter design has been to combine the output of several amplifiers in a resonant cavity, or other similar circuit, and then feed an antenna in the same manner as a TWT would. As we move into the EHF frequencies the physical size of these circuits becomes increasingly small. Because the efficiency of the devices is also decreasing as the frequency increases, the thermal gradient and heat dissipation problem becomes severe. If we are to achieve an output power comparable with that obtainable from a TWT at EHF,

another approach is indicated.

One approach is to place an amplifier behind each element of a phased array antenna. The output power is thereby combined in the far field of the antenna. This approach reduces the thermal gradient problem by dispersing the heat sources. It also raises overall efficiency of the transmitter by lowering the combining losses. Finally, this approach leads to a graceful degradation upon failure, since the loss of an element only slightly reduces the effective output power.

Another critical item of hardware under development is the laser crosslink system (LASERCOM). The LASERCOM system, which is capable of handling a Giga Bit per second data rate, is ideally suited for the satellite to satellite crosslink application and under favorable conditions, can be used for satellite to aircraft or even satellite to ground applications. Aircraft to aircraft communications by LASERCOM could also be handled using a relay satellite.

We have recently completed a series of field test of the LASERCOM system at White Sands, New Mexico. A high data rate LASERCOM transceiver was installed in a KC135 aircraft and a similar unit was installed in a ground facility at Cowan site on the White Sands Missile Range. These tests fully demonstrated the capabilities of the LASERCOM system in a dynamic environment. Acquisition and tracking were demonstrated under conditions far more severe than those found in space. In addition, some atmospheric and propagation effects were studied. The tests were highly successful indicating that the technology for space laser communications is mature and ready for operational deployment.

WHERE DO WE GO FROM HERE

We have shown that all the critical pieces

of technology needed for the next generation tactical satellite communications system have been demonstrated. What remains to be done is the integrate of that technology into a system and convince the Congress that the system merits development and deployment. To do so we must demonstrate that the DOD finally has its act together in the MILSATCOM arena. This is a task that cannot be accomplished by the technologists alone.

Whole new concepts for the conduct of tactical warfare need development. We, once again, have a situation where technology is racing ahead of operational concepts. We must avoid Maginot Line thinking. The operational concepts for the use of satellite communications systems at the turn of the millenium must be consistent with the operational concepts for the employment of new weapons systems in that time period. Finally, we must present an integrated system, responsive to the needs of all the services.

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