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Satellite Communications to Mobile Terminals -A Forecast of Needs and Techniques

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SATELLITE COMMUNICATIONS TO MOBILE TERMINALS A FORECAST OF NEEDS AND TECHNIQUES

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ABSTRACT

Economic pressures and technical developments lead to an international satellite communications and surveillance system satisfying the needs of many mobile users, especially aircraft. The dominant need is to provide three-dimensional surveillance of air space around airports. The large number of carrier and general aircraft requires the satellite system and its ground control facility to carry the burden of providing adequate link margins and position computation.

INTRODUCTION

Economic pressures and recent technical advances will lead to an international satellite communications system satisfying the needs of many mobile users, especially aircraft. It is timely to encourage designing complete and competitive systems in order to provide guidance to the ITU World Administrative Radio Conference for Space Communications which will convene by early 1971 to make treaty regulations for frequency allocations.

Competitive designs will also provide guidance to the Department of Transportation for satisfying air traffic control needs and navigation needs of many users. The previous DOT administration has already requested the aid of industry to this end. Vigorous design efforts are needed now to prevent a drifting policy detrimental to efficient and safe use of national air space. System design is a vehicle for conducting intelligent dialog within the technical community and is a prerequisite to sound budgetary estimates. A complete statement of system performance (including an implementation plan) can be matched against the most critical needs as well as against existing systems that may eventually be retired and proposed systems of limited utility.

Designing a system to meet these needs will be an exceedingly complex political, economic, and technical problem with many intersystem and interorganizational relationships. Several substantial studies have shown a specific utility of satellite communications for navigation and mapping, administrative traffic to air carriers, Atlantic air traffic control, and world-wide weather data systems. The plan for satisfying all these needs is a jig-saw puzzle not yet assembled. However, air terminal congestion takes precedence as the greatest need. Air traffic controllers have demonstrated in a dramatic and responsible way that they are overloaded. The FAA has attempted to find suitable relief in automation and display without making progress against the tremendous increase in traffic. Proliferation of airports and systems of the present kind will push the FAA budget alone above one billion dollars and push a larger burden onto local communities. A better system seems to be promised by further automation.

Contemporary radar defies simple automation. An air traffic control computer should track every target. But radar was designed to track single targets with the aid of an operator who can discriminate a real target from clutter, atmospheric reflections, multipath, etc. The basic limitation of radar is that the returned signal decreases by the 4th power of the distance. Transponders on aircraft cause jamming because of the poor geometry of ground-based radar. Satellite-based radar can overcome these faults.

Fortunately, the technical base for a system which provides a surveillance function for many users has resulted from military and space efforts. Inexorable economic pressures of air transportation will forge an effective union of organizations to use these techniques. By attempting to forecast the economic pressure and the most likely technical solutions, the author hopes to stimulate extensive dialog.

HISTORICAL BACKGROUND (TECHNOLOGY SEARCHING FOR A NEED)

Many studies have explored the feasibility of using satellites to satisfy specific needs. Some studies propose system designs. Their general shortcoming is parochialism. Satellite communications shows promise at considerable expense. By attempting to satisfy limited needs, the studies leave doubt that the effort is worthwhile. Thus, the characteristic flavor of the recent past has been technology searching for a need.

However, needs are not lacking. In fact, the air traffic control problem is so big that it appears to impede organization by intimidation. At last year's annual meeting of the AIAA several authorities suggested diverse political organizations that should or can do the system design. New political unions are being explored in order to bring the effort to a workable administrative level. All of these activities are indicative of the pressures to form union that will implement a useful system.

Synoptic Weather Data System Requires Little Capacity

Many studies have considered implementing a weather data system using satellites. Comparisons with aircraft interrogation systems show an economic advantage to satellite systems. HF radio interrogation suffers from diurnal variability and irregular performance. Buoys designed for long life in the ocean have been under development and testing for over five years. Missing elements appear to be a data relay network, a position-fixing capability, and reliable mooring.

The benefits of long range weather prediction are really not known in fiscal terms. The efforts of DOT to present a substantial case before Congressional committee have met questioning indicating that need priority is assessed relatively low. Actually, data capacity requirements are so low as to encourage waiting to see what may develop in other satellite communications experiments or system proposals.

Marine Navigation Users Show Interest

The Navy Navigation Satellite System called "Transit" (NNSS) has proven itself useful for ships and research vehicles as well as for Navy requirements. Commercial receivers are now available for about $50,000. This passive system depends on the doppler shift of a signal from a low altitude polar satellite. Ephemeris data is broadcasted to users. The use of only four satellites at low altitude limits position updating to every 108 minutes. The use of low UHF frequencies ultimately limits accuracy to tenths of a mile. The measurement time is the time for the satellite to pass over the user.

ATS VHF satellites have communicated with a merchant ship[1]. A NASA (ERC) study is compiling the needs of the marine community for satellite navigation. These experiments and studies show the feasibility of satellite communications for marine use.

NASA Has Best Systems Capability but Appears to be Withdrawing

NASA has conducted experiments and studies of wide scope directed towards satellite air traffic control. The Joint Navigation Satellite Committee provided comprehensive intra-governmental guidance towards system design[2]. However, their limited budget has been directed primarily to the race to the moon. Futhermore, Mr. Harper, NASA deputy associate administrator for aeronautics has said that system design should be done by FAA, while NASA should concentrate on hardware. Recent research funding cuts on air traffic control research and ATS F and G satellites show that Congress is not sympathetic to allowing NASA to take a more active role in air space problems. Even rather modest efforts to experiment with the 1540-1660 mHz band have been stopped. Industry has noted that weak fiscal position and is seeking opportunities elsewhere.

An example of the type of system design that NASA has sponsored is given in the TRW NAVSTAR report[3]. It recommends a passive navigation system coupled with position reporting by the aircraft back to the controller. The aircraft provides position computation. Maritime users are not excluded.

History shows that NASA is endowed with the management capability to attempt to do new and difficult things in full view of the nation. This contrasts with the philosophy of an operating organization such as FAA which has such immediate difficult operational problems that changes must be evolutionary. The solution to the air traffic problem is going to require innovation. Although several organizations could do the job, only NASA has recently demonstrated this type of gut effort.

RTCA, ARINC, and COMSAT Proposed a System of Limited Capability

The combination of the RTCA community, ARINC, and COMSAT provides considerable interest because it puts quantitative numbers on certain needs. These three groups hoped to solve the problem of air traffic control over the oceans as well as to provide administrative communications to aircraft. If FAA had joined the union and accepted a limited capability of ocean air traffic control (positions reported back from the aircraft over the satellite circuit) funding may have been under way by now. However, the domestic airlines did not feel that the capability of VHF satellite communications was that great an improvement over present capability to warrant picking up a 10 million dollar yearly bill. Thus the aviation community represented by RTCA has given some indication of the value of satellite communications to its operations and the FAA has indicated the value of ocean air traffic control in light of its budget and political position on direct surveillance.

COMSAT Over-Capitalization Seeks Relief from Charter Limitations on Opportunities

The union is also interesting because it illustrates complex organizational problems. COMSAT by its Congressional charter cannot sell services to individual users; it must be a carrier's carrier. An exception (obtained later) is that it can sell directly to NASA or DOD. This and other expansions of service are under fire from INTELSAT. Thus COMSAT has national and international constraints to look to in joining a union. ARINC provides a carrier interface between COMSAT and the individual users. The interface between COMSAT and FAA is presumably more difficult in that it may require Congressional action when the concept expanded to provide control over the national air space. In the 88th Congressional Senate Committee on Aeronautical Space Services, Mr. Jaffe of NASA objected to COMSAT activity towards providing navigation and air traffic control to ships and aircraft. COMSAT has surplus capital and an aggressive management to help overcome these interorganizational difficulties.

The implementation of a VHF communications capability providing four voice channels on three satellites was admittedly not very ambitious but would establish early precedence for a workable union. A preliminary study for COMSAT by Philco-Ford[4] anticipated that the eventual system could be in the 1540-1600 mHz band (so that it could provide position-fixing capability to 0.2 mile using two satellites). Oceanic needs were assumed so VHF provided sufficient accuracy. Actually, a VHF implementation would probably have affected the WARC meeting which will be held in 1971 to study allocations for space communications. COMSAT has filed with the FCC a request that the WARC allow the 1540-1660 mHz band to include maritime mobile service.

ICAO Takes a Long View

ICAO is the international equivalent to RTCA. Last year it convened the ASTRA panel to study satellite communications technology. During the RTCA Fall Assembly in 1968, comments were made by RTCA and ICAO members on the relative positions of the two bodies. RTCA favored VHF without question, while ICAO felt that it was too early to make a recommendation. (In fact, France has already recommended an L-Band system). ICAO says that the problem is international and requires careful comprehensive study so as to not commit the world to an inadequate solution. The slow acceptance of VORTAC by smaller nations can be put in jeopardy by mention of a new system.

The RTCA discussions indicated the many subtle considerations that are required to obtain general international acceptance of a system for the world air fleets.

DOD is Not Directly Involved

U.S. military development has often influenced navigation of the civilian and commercial air transportation industry. DME went through extensive dialog before proving its suitability for general aviation. Now news releases indicate that DOD is investigating satellite communications under programs called TACSATCOM and ICNI. These public announcements do not suggest that the proposed concepts or systems will be useful to civil aviation. In fact, Dr. Finn Larson made clear at the RTCA Fall Assembly that the DOD does not consider this area to be within its jurisdiction. It is probably safe to say that the tremendous resources of the military will not be applied directly to solving air traffic control problems.

FAA and DOT Have Little Congressional Support

The FAA continues to fight its fiscal and operational battles with courage and honesty if not inspiration. Perhaps operational responsibilities of operations vital to public safety are burden enough for one organization. Nevertheless, FAA documentation and reports directed to the FAA continue to give good account of the situation. Direction seems to be lacking because of conflicts in opinion within the FAA and between FAA and NASA and industry. The question is surveillance vs position reporting.

Several years ago, the growing load on air traffic controllers led NASA and industry to say that more responsibility should be given to the pilots[5]. Air collisions dramatized the need. The momentum carried several companies to cooperate with the FAA in a Collision Avoidance System which would use a major portion of the 1540 to 1600 mHz band. These are now nearing test. Meanwhile, in-route traffic control has been sufficient to stop collisions between air carriers. So far the results of the CAS activity are systems which will cost each aircraft over $50,000 for a need which does not seem to be as urgent as terminal control. Furthermore, the system competes for a major part of the most desirable frequency for position-fixing.

Actually, surveillance which depends on aircraft-derived position information is inconsistent with positive control of the National Air Space and is not accepted by the FAA. CAS seems to be an independent safety system which cannot in the long run relieve terminal congestion. A surveillance system which depends on aircraft reporting their positions obtains its strongest proponents among those responsible for supersonic trans-oceanic safety. Some supersonic aircraft will use triple-redundance inertial-guidance units costing about $300,000. Cannot this capability be coupled with a satellite communications reporting circuit to provide the necessary air traffic control ? Those in the FAA who disagree feel that terminal control remains the significant problem, especially for the many aircraft without accurate navigation aids.

The FAA is commendable in its reporting of experiments [6]. Both the FAA and its many critics give a clear indication of the limitations of radar as the prime sensor of the controller. Critics emphasize the poor reliability of radar while the FAA reports a struggle with the display interface as well as with automation of the tracking function. The FAA has found to its chagrin that transponders introduce interference. Angels and bad weather also confuse the display. Thus automation of the tracking function is not going to be complete or comfortably reliable.

Meanwhile, the air traffic controller continues to be overworked and even irritated by attempts to help ease his burden since any system test imposes further strains on an already tense operation situation.

The FAA clearly points out that automation is the least expensive way to relieve terminal congestion [7]. Proliferation of airports can provide the greatest potential improvement but at tremendous expense to the community served . The impact of this observation is weakened by the credibility of the promise of automation. Considering the limitations of the present billion dollar radar system, automation is only a partial aid.

ASSIGNMENT OF RESPONSIBILITY LACKING

The DOT, through the FAA, obtensibly has responsibility for our future air space,Fiscal control is in the hands of the President and Congress. The FAA has been criticized for not vigorously fighting for funds to do its job. No comprehensive and detailed long-range plan is visible in the documents of the FAA or in its record before the BOB or Congress. Since the necessary programs are costly, funding really cannot be expected without showing the Administration and Congress that an improvement is needed and is possible at reasonable cost. A spokesman with a detailed plan is wanting.

Dr. Seiffert of MIT [8], Dr. Cherrington of Harvard, and others who despair of the lack of directed activity suggest that a super agency of private form will become the chosen instrument chartered by Congress to handle air traffic control. COMSAT itself has proposed to build a limited system. COMSAT is over-capitalized and also limited by charter to few investment opportunities. Personnel within the FAA are sympathetic to COMSAT. Members of the aviation community will give support. Therefore, the possibility of another COMSAT activity is a distinct possibility if the Congress does not choose to solve the problem.

Congress will Limit U. S. Government Participation

However, control of the air space is a function which cannot be passed on to private organizations without rending the fabric of the governmental authority since regulation is implied. There are proponents for either NASA, intra-governmental unions, or not-for-profits to do the system design for FAA. So far the most interesting system design proposals have come through NASA efforts. Congress, however, has cut NASA funds towards this end. The R & D funds of the FAA have steadily dropped. Thus, it appears that Congress repudiates the responsible government agencies.

The international aspect of the system will lead to the development of regulatory laws through treaty agreements of ITU and ICAO members, and to system development through an international consortium. International cooperation would broaden the fiscal base while permitting the least expensive satellite configuration . Congress will enjoy release from the responsibility of difficult management decisions while retaining a maximum of funds for defense spending. COMSAT capitalization will start development.

NEEDS
PRIMARILY AIR TRAFFIC SURVEILLANCE

Automation is the least expensive way to minimize termial congestion [8]. High speed ground transportation will be limited to very dense centers such as between New York and Boston and Washington. Since the U. S. is committed to air transporation for long distance travel, congestion is a fundamental limitation on our capability to do business. Therefore, the bottleneck will be attacked directly. Fortunately, the FAA has been giving careful attention to the causes and possible remedies to terminal delay. No compromise with safety is apparent in their deliberations. Organizations such as RTCA [9] and MIT [10] also give insight into our domestic air traffic problem.

What then prevents automation ? The many studies of the FAA lead to the conclusion that the judgment of air traffic controllers is necessary to overcome the inherent deficiencies of the radar system which is the primary sensor of the controller. No significant improvement can come from improving the control center or the display system. Radar transponders do not increase reliability as expected because they jam the display system. It is necessary to look at this limitation in more detail.

Air Traffic Control Limited by Radar

Radar does not give the terminal controller sufficiently reliable position-fixing data. The terminal area may include over 100 targets. Radar depends on repeated reflections to display these targets. The display often shows clutter and angels from clouds, birds, and multipath reflections. Omnidirectional aircraft antenna patterns have deep nulls. Often MTI circuits and aircraft maneuvers cause the target to disappear. The controller must compensate these deficiencies by mentally tracking the aircraft during holding or landing. The strain during poor conditions is great. Futhermore, the shortage of controllers leads to extra duty. Automation of the radar tracking function is expected to help.

The ARTS program for providing this tracking function, while also tagging the display with identification and altitude information, is now being installed in several locations. The addition of the third dimension, altitude, comes from the aircraft altimeter. The acquisition of track still depends on operator selection. The transponders have introduced a jamming problem since the transponded signal is strong enough to hide a passive target. It can even be reflected into the backlobes of the radar antenna. Automation has not relieved the operator of concern for the correctness of his display.

There are many minor airports which do not have a radar facility at all. Several accidents have occurred to aircraft off-course while landing. The possibility of altitude error has been often indicated. A need for extending two dimensional radar coverage to these areas has lead to FAA and industrial development of low cost systems. Three dimensional radar is needed.

The number of voice transmission between aircraft and ground overload the available channels and require frequent channel switching. RTCA has proposed a digital message entry device for automating and speeding up the communications process by at least cutting down identification time[11].

The mechanism for assuring safety is spatial separation. Separation distances are based on radar accuracies and aircraft closing speeds. If anomalous conditions such as bad weather interfere with operations, increased separation is scheduled. Unfortunately, the peak traffic loads at several airports are overloading the traffic control system even in good weather. Bad conditions cause the controllers to stack aircraft in holding patterns. Thus the slowdown increases the load on the controller and an excessive delay builds up. The present solution is a FAA limitation on the number of flights during peak periods. Adequate safety is translated into a limitation on the revenue of carriers.

Other Solutions will also be Needed

Several alternate solutions are being studied. Ground transportation such as high speed trains in the Northeast are being encouraged by DOT. Alternates to travel such as telephone communications have led to facsimile and picturephone experiments. New airports are being planned. No doubt all will be needed; nevertheless, our nation's commitment to air for long distance transportation will require in addition a workable air traffic control system.

New Airports are not the Whole Answer

New airports cause problems. Land acquisition is often very difficult because of the political strength of the large number of affected people. Furthermore, if the new airport is close to the old, interference between air traffic compounds the controller's job or limits the increased capability. Finally, the cost of one large airport is about the same as a world-wide satellite facility. The FAA has indicated that new airports are going to be the most costly solution. The major burden of that solution will fall on the local community. Therefore airport development leaders should be very interested in air traffic control development.

Geometry is Important for Good Radar Performance

Why does radar perform so badly ? Two geometric factors (the signal strength decreasing with the 4th power of range, and the multipath and atmospheric effects on a signal which propagates nearly parallel with the earth) cause the most trouble. A radar on a satellite avoids these problems for elevation angles greater than 20 degrees. Of course, this type of radar requires several satellites to be visible simultaneously to transponder-equipped aircraft. Angle sensing can no longer be done by steering a dish. In fact, this radar looks more like a navigation system working in reverse. The advantages are : a three-dimensional radar which has nearly constant range (signal strength) to all aircraft, several orders of magnitude more surveillance area, reduced clutter and interference from multipath from a transponded signal, and no signal returns from weather targets such as clouds.

Costs of Related or Comparitive Systems

Some quantitative indication of the need can be found by looking at the present air traffic control plant, the aviation industry, proposed system costs and other large programs. Table I lists these cost estimates. The table indicates that proposed systems are appropriate for the expected benefits and are similar to present air traffic control expenditures. In fact, the size of the industry will be a potent pressure towards a usable system.

Table I -- Costs in Billions of Dollars

Satellite System with Control Facility[12]. (5 years)	0.6
Automated Air Traffic Control (ARTS)	1.0
National Air Space Program	0.3
FAA Radar System	0.6
FAA Yearly Operational Budget	0.6
New Airport for Boston	0.5
New Carrier Aircraft Sales per Year	2.5
Sentinel System Authorized Expenditures	1.8

Subsidiary Needs

Several important subsidiary needs are marine navigation, buoy weather systems, oceanic air traffic control, and collision avoidance aids. These are fortunately not as demanding on satellite capacity as a system for control of air space. In fact, oceanic control is assured by a domestic system. These needs require a small fraction of the prime power requirements of the satellite system because of their low data requirement.

Long range marine navigation is aided by Loran, Omega, and Transit systems. All of these aids have especially useful characteristics to different users. On what basis is a competitive system needed ? The need could be based upon the long range retirment of Loran stations (but probably not Omega stations which use very low frequencies in order to obtain long range even to submerged vehicles). The Transit satellite system uses a relatively inexpensive polar satellite system and puts the burden of navigation computation on the user. The basic reason for considering a new system is to get wider use from these systems by making the receiver simple and doing the computation at a central facility.

A toll-type communication system, available to users for emergencies and business as well as for requesting a position-fix, satisfies the need. Present navigation aids are similar to position-fixing by sextant in that it takes time to obtain the measurements and reduce them to a position. Sometimes bad conditions interfere with Loran and Omega and occasionally Transit. The availability of Transit for updating is limited by the few number of satellites in low polar orbit. What is needed is a system in which a user requests a position-fix by satellite communications and the request automatically is reduced to a position-fix after passing simultaneously through several satellites to a ground-based computer facility. The return answer contains the position-fix.

The above need is similar or even identical to what is needed for an oceanic buoy system. A position-fixing capability helps solve one of the most difficult mooring problems of a buoy field. Buoys need constant attention because they loose their moorings in a few months. Even untethered buoys become possible if they can be tracked.

The cost benefits of a satellite system for oceanic air traffic control is based on the narrow flight path variations for economical supersonic flight. The forecasts show that congestion is likely by 1979. These aircrafts are scheduled to have three inertial navigation platforms. Using this reliable system to obtain the aircraft position for transmission to the control facility over a dependable communications system is the heart of several proposed systems. However, the cost of this navigation surveillance package eliminates the less sophisticated user since the navigation system alone costs about $300,000. Implementation would provide good communications to many users but would not satisfy the basic needs of air traffic control in the USA. On the other hand, the implementation of an air traffic control system for general use would satisfy both needs for a community of users at least two orders of magnitude larger.

WATERSHED IDEAS

Initial assumptions have controlled the style of proposed systems. This section states several ideas which seem pivotal if all needs are to be met. Since needs exert pressure on the system design, this section is a forecast of how satellites will be used to provide air traffic control and other functions for the civilian population.

Surveillance and Communications Service Not Passive Navigation

While past proposals have been based on passive navigation, the future system will use active radar surveillance with transponding targets. The transponders also will provide communications. All computations and message-routing will be done by a satellite control facility. These services will be offered to private users through organizations such as ARINC, to military users through DCA, and directrly to governmental departments. The service organization will be capable of dealing with national and international relationships. The service organization will be (or be similar to) COMSAT. There will be no direct military participation requiring passive navigation.

Between 10,000 and 100,000 Users

The large number of users radically drives the system design to minimum-cost user terminals. This single consideration will select the type of modulation , the frequency for transmission, and the radiated power of the satellite system. It will cause the position computations to be done by the service organization. The large number of users eliminates the possibility of free access : toll service will be available to subscribers on demand. Each message unit will be quickly handled to avoid system saturation; therefore, the type of operation will not resemble the processes of Omega, Loran, and Transit which require human judgment or manipulation. The reliability of the service will be like that of the telephone.

Many Satellites at all Latitudes

System reliability will come from having many satellites. Position-fixing depends on having several satellites available to every user at angles greater than 20 degrees elevation but distributed around the user's horizon. This minimum elevation angle minimizes the effect of atmospheric and ionospheric conditions which lay parallel to the surface of the earth and plague present radar and communication signals. Furthermore, the user's omnidirectional antenna can be designed to have relatively lobe-free performance over this fraction of a hemisphere. The large number of users makes the satellite system cost a small fraction of the total system cost. In fact, the estimated satellite system costs are comparable to costs of our present unsatisfactory system. In any case, the satellite costs will not be provided directly by U. S. funding.

The Air Traffic Surveillance will be Automatic

An automatic surveillance system depends on air tubes with fixed schedules, like a railway, to assure safe separation. The satellite system will interrogate aircraft transponders as needed to assure separation and will advise air traffic control and the effected aircraft of deviations. This service would permit positive control of the air space for carriers and others equipped with sufficient on-board navigation to fly area navigation routes. General aviation, at lower altitudes (as well as marine users), would use the system as navigation aid available on request. The air traffic controller in the terminal area would be relieved of the task of using a radar scope as the prime sensor for watching carrier and business plane s. Furthermore much of the controller's present communications traffic will be accomplished automatically by the radar interrogation system.

SUPPORTING TECHNOLOGY

Today's technology supports the type of system which will satisfy the needs listed above. Several companies are already entering the breadboard testing phase on company-sponsored activities anticipating satellite communications and navigation systems. The type of system that is satisfactory for the larger community and for quick position-fixing will use frequencies around one gHz. Furthermore, the user terminal will use a rudimentary fractional-hemispherical antenna which does not introduce a significant drag penalty to supersonic planes. Consequently, the dominant problem is how to obtain the required satellite radiated power to satisfy the link equations. Phased array antennas on satellites having about 1000 watts prime power are within the weight capability of several of our operational launch vehicles. The present activities are to determine the best type of array for this type of system. The question is really a system synthesis trade-off which also includes the selection of modulation and orbit configuration. Finally, input/output technology will be utilized by user terminals to assure that the system does not saturate.

TDM for the Satellite Phase Array

The phased array competes directly with solar arrays in providing high radiated powers. The phased array can also be used by the satellite in its receiving mode so as to minimize user transmitter power. If the organization of the phased array depends on linear power amplifiers in order to generate simultaneous beams , a 3 dB amplifier penalty effectively doubles the satellite weight over a system which steers a single beam. Time Division Multiplexing (TDM) permits steering a single beam to many users. Experiments have been conducted by COMSAT demonstrating TDM modulation[13]. The implied wide bandwidth signals do not need to use high accuracy oscillators in the user equipments. These arguments suggest that the final system will use burst signals much like the response of a IFF transponder to radar interrogation.

High-Altitude Inclined-Circular Orbits with Phase-Phase Array

A few satellites in synchronous orbit do not satisfy navigational accuracy or coverage requirements. Such satellites could use a high gain frequency-scanned array. Instead the satellites must have earth tracks which reach at least middle latitudes. However, the moving satellite cannot easily use a frequency scanned antenna because the user would have to change frequencies according to the position of the satellite. Investigations of inclined synchronous satellite orbits are available[14]. These orbits and polar orbits have earth tracks which cross. Two satellites in close proximity only provide the position-fixing triangulation of one satellite.

Other orbits will overcome this doubling and also reduce the crowding expected at synchronous altitudes which shall be reserved by the IT for fixed ground stations. As an example, a subsynchronous orbit causes the figure-eight earth track to open up into a sinusoidal track having no cross-overs. Four or five cycles around the earth at 45 degrees inclination requires less ETR launch vehicle capability than a stationary satellite. Station keeping is only necessary relative to the other satellites and does not depend on geospheric irregularities. Futhermore, position-fixing implies simultaneous paths to several satellites. Therefore, a phase-phase antenna array is indicated.

Digital Input/Output Devices

Simple automatic digital input/output devices will be used to eliminate system saturation. A request for a position-fix should only require a push of a button. The answer should go only to the requester as a printout, alpha-numeric display, or the prerecorded voice from an enunciator. Transmission of a message should occur after the message has been composed. These digital devices eliminate the time required for human communications which now burdens the aircrew and the airtraffic controller. Fortunately, several types of equipments are now being investigated by the airlines, RTCA [11], the police, and computer terminal vendors.

SUMMARY

Automation of air traffic control will require a satellite system to provide position-fixing and communications. Navigation, communications, and telemetry needs of ships, aircraft, and buoy networks will also be satisfied. The system will result from a bold application of space technology; it will not be an evolutionary development. The design will minimize subscriber equipment costs. Nevertheless, the system costs will be less than the present system for air traffic control and will provide for forecasted air transportation growth.

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