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DEVELOPING A GLOBAL AERONAUTICAL SATELLITE SYSTEM

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ABSTRACT

Airlines have long recognized the crucial role of reliable communications to better secure a safe and profitable service. Arinc, an airline industry-owned and operated company in the United States, has taken steps toward establishing a global aeronautical satellite communications system. Plans call for initiation of a thin-route data operation in 1989, upgrading to establish voice communications via shared spot-beam transponders carried on other satellites, and finally deploying a worldwide network using dedicated satellites by 1994.

BACKGROUND

The concept of aeronautical communications via satellite began in the 1960s with NASA's VHF experiments, and at L-band during the mid-1970s in experiments using the ATS-6 satellite. AEROSAT, designed to cover Atlantic routes, was planned in the mid-1970s as a joint project among the U.S. FAA and NASA, Canada, and the European Space Agency, but for several reasons it was not pursued. Recently, interest has strongly revived. By 1987, voice and facsimile tests were being conducted over both the Pacific and Atlantic, and manufacturers and users are formulating a specification for avionics suitable for universal use.

TECHNOLOGY READINESS

Principal supporting technologies have matured and now can readily support initiation of commercial aeronautical satellite service. First, very thin conformal phased-array antennas with an electronically steerable beam now can be made for aircraft, having sufficient minimum gain to support very substantial communications capacity. Even mechanically-steered reflector antennas under a radome have already been put into service, and smaller ones are being considered for larger commercial aircraft. Implementation of a small, low-gain, hemispherical-coverage aircraft antenna for low-rate data service to a global satellite beam is practical. It may be used by an operator desiring a modest cost single antenna, and as a backup to a high-gain antenna.

The microchip processor will provide for in-flight compatibility with several possible signal characteristics from different service providers, without physical change-out. Digital voice is maturing, as codecs in the 9.6 and 8 kb/s area now are producing near-toll quality voice and are being evaluated. An accommodation to ISO rates (2000n) such as 8 kb/s is important for transparent ground terminal operations of the future.

USER MARKETS

Aircraft operators appear to have a unique opportunity for operational enhancements and cost reductions by using satellite communications. Savings in fuel costs from improved routing and bad weather avoidance are now being quantified as very significant. Also very important to costs may be near-real-time monitoring of engine performance.

Air traffic control is likely to benefit strongly from over-ocean position reports, timely weather knowledge, more rapid response to altitude clearance requests, and a corresponding increase in flying safety. Rapid reporting of accurate aircraft position could permit separation reductions that are predicted to bring major time and fuel savings because of improved routing.

Passengers will enjoy new services and improved efficiencies, principally via voice communications through any public switched network in the world. Until recently, voice service between aircraft and ground has been the province of crew communications. High-quality, distance-insensitive voice circuits worldwide through satellite earth stations will revolutionize the air-travel experience.

New passenger data services such as continuously available national and international news and other reports; inter-computer communications; and traveler support, such as reticketing, car rental, and special services, will further enhance the air travel environment.

The operational savings provided through reduced flight time, rapid clearances, reduced fuel reserves, improved weather information, and other benefits will offset satellite costs for data systems and crew voice services. Combining crew and passenger communications within a common avionics suite and system signal structure can provide for cost-effective delivery of both.

SPECTRUM AVAILABILITY

Recently, developers of aeronautical and land-mobile satellite systems have clashed because of direction of regulatory bodies that would require accommodation of both services in the same band. The 1987 WARC reduced the aeronautical satellite spectrum from 28 to 20 MHz (now 1545-1555 MHz down, 1646.5-1656.5 MHz up), but retained the exclusivity of this allocation and authorized countries to permit aeronautical communications in the remaining 4 MHz with land-mobile space stations. This WARC also clarified the rules that permit passenger communications in this band.

The Federal Communications Commission (FCC) is working to reconcile its domestic rulings for the U.S. -- which tend to unify AMSS and LMSS --

to the outcome of the international WARC, which retains these services' partitions.

Aeronautical mobile feeder links to and from the satellite and earth stations are being sought to operate at a portion of the C-band separate from domestic satellite uses. This will permit a global plan for aeronautical satellite orbital locations and coverage which is optimized for air traffic routes without conflict with other satellites.

SYSTEM DEFINITION ACTIVITIES

Characteristics of aircraft transceivers for satellite communications are being developed by system suppliers and manufacturers together with airline engineers in the Airline Electronic Engineering Committee (AEEC). Avionics form and fit are nearly complete, and functional specs are under development. Throughout, they follow closely the ISO standards, utilizing the "layer" concept to enable transparency to future global networks with a universality of protocols both in the RF (satellite) regime and within the system processors.

REQUIREMENTS AND CONSTRAINTS

In addition to requirements for maximum coverage, a global aeronautical system must assure the highest reliability because it often carries safety-related traffic.

Satellite links at low aircraft elevation angles must contend with four simultaneous impacts: fading; decreased G/T from off-boresight scanning, reflections, and potential blockage; power and sensitivity loss at the satellite antenna edge-of-coverage; and maximum satellite-aircraft range. Link fading that requires significant power margins in the land and maritime cases is less severe for aircraft at altitudes of tens of thousands of feet, amounting to about one dB for most cases. All these link impairments improve rapidly and largely disappear at aircraft elevation angles above 20-30 degrees.

Satellite RF link design choices have been made in the direction of robustness and spectrum efficiency while minimizing control complexity in the earth stations and avionics. The need for high reliability at lowest cost has led to use of the simplest technologies in both the aircraft and the satellite transponder, and to the use of all-digital techniques in network control and earth stations. These concepts are not in conflict when a TDMA (time division multiple access) system architecture is specified.

The satellite power assigned to any one user generally is a compromise among many factors. Class C operation of high-power RF amplifiers (HPAs) provides for efficient use of raw power -- an advantage both for the aircraft: small size, modest cooling, with multi-channel capability for six channels of high-quality voice plus wideband data to and from each aircraft; and for the satellites, making possible cost-efficient HPAs while maximizing capacity for the high EIRP required.

In combination with Class C HPAs, a TDMA operations architecture is ideal to realize these efficiencies because it (1) employs a single, wideband, multi-channel carrier and (2) avoids intermodulation distortion and interference, while conserving spectrum. It also promises

orderly growth to a large future network of thousands of channels using known controller designs.

SYSTEM DESIGN CONSIDERATIONS

A viable mobile satellite system requires a careful balance in sizing, because the satellite per-channel power output and system capacity, -- and therefore user cost -- depend strongly on the mobile unit's G/T.* System noise temperature is generally set at an irreducible minimum, so the mobile's receive antenna gain is the basic determinant of the required satellite EIRP.** But the need for maximum gain conflicts with a tolerance for only the smallest mobile antennas.

Similarly, because of limited spectrum allocations, the needed frequency reuse depends on each mobile unit's discrimination among same-frequency satellites. Therefore, the mobile units' beamwidth and sidelobe levels will determine overall system capacity. Yet obtaining narrow, clean patterns from small antennas mounted on indeterminate conducting surfaces is not a predictable task, and compromises must be made. Through AEEC activities aircraft operators have agreed on a steerable transmit/receive antenna system with minimum gain of 12 dBiC.

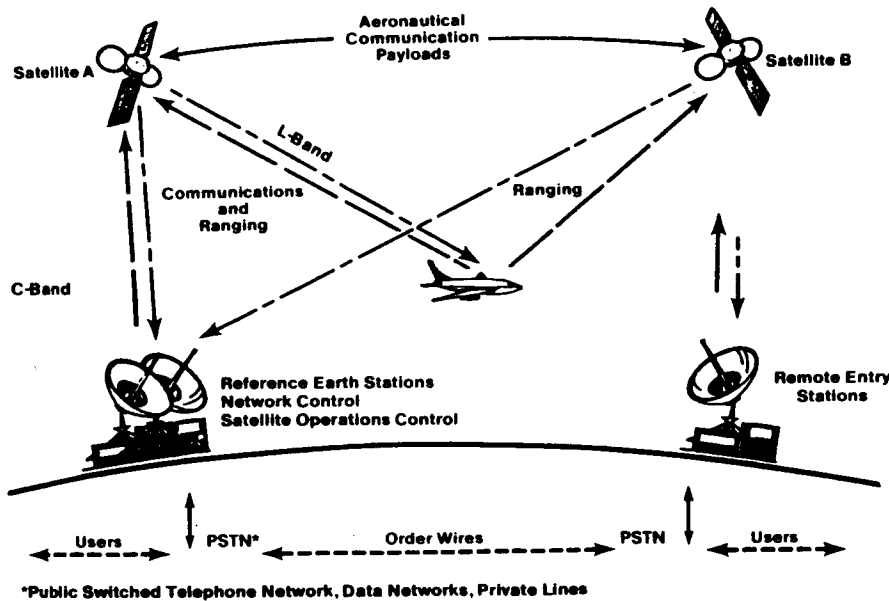


Fig. 1. Basic AvSat System

On the receive side, the achievable G/T for the mobile unit (using $T_{sys} = 320K$) is about -13 dB/K . For the satellite L-band transmission ("outbound"), the desired multi-channel data rate in a 25 dBiC spot beam has been set -- based primarily on available satellite HPA size -- at 320 kb/s. This carrier makes available 32 voice channels at 8 kb/s each, plus some considerable data capability (synchronous and slotted Aloha).

The aircraft transmission ("inbound") plan for spot-beam satellites uses a hybrid FDMA/TDMA approach called Multi-Carrier TDMA. In this sys-

* Gain-over-Temperature, a measure of receive sensitivity.

** Effective Isotropic Radiated Power.

tem, each aircraft transmits in a TDMA mode at 64 kb/s -- a fraction (1/5) of the incoming data rate (320 kb/s) -- which constrains the output power requirement while meeting multi-channel needs of six voice channels plus data. These rates are based on achievable satellite G/T of about -4 dB/K and an aircraft HPA limit of 40-50 RF watts.

In MC/TDMA, the satellite L/C transponder operates linearly in FDMA, each RF carrier containing bursts from up to six voice and several data channels from one or more aircraft. As a result, the TDMA "burst time plan" actually becomes a burst time-frequency plan. This scheme also reduces the number of earth station receivers by a factor of six, and has been successfully implemented in other applications. Detailed avionics MC/TDMA specification preparations are now well under way.

DEVELOPING A GLOBAL SYSTEM

Phase One: A Test Program

ETS-V, Japan's first three-axis stabilized satellite, was launched to 150 East in August 1987. It carries an L-band 20-watt solid-state HPA and a 1.5-meter reflector antenna, producing dual 10.5-degree spots with approximately 36 dBw maximum EIRP. Voice and data tests are now under way. Preliminary plans have been discussed among the Japanese JCAB, the FAA, and Arinc which would permit test of aeronautical satellite transmissions primarily for position reports.

INMARSAT test programs are also under way. Data transmissions to and from aircraft were tested in late 1985, and voice tests now are being conducted with Japan Air Lines over a Pacific route. Further tests are planned by several countries during 1988.

Phase Two: Initial Data Operations

The operation of aeronautical mobile satellite service is expected to begin as soon as sufficient avionics are mounted to comprise a significant user population. INMARSAT's second-generation satellites will operate within the aeronautical band, and are expected to provide for a new service, titled "International ACARS." This service will extend over oceans and remote areas an air-ground packet data service called ACARS, now operated by Arinc. The messages will interface with the ACARS network through INMARSAT satellite terminals equipped to provide the service.

Phase Three: Shared-Satellite Transponders for Voice and Data

The development of significant multi-channel aeronautical satellite services with full connectivity to all ground stations in view awaits the launch of higher-EIRP transponders. One concept is to provide to a "host" FSS (fixed-satellite service) satellite having a mutually desirable orbital location a set of transponders for aeronautical use. Such host satellites have been identified, preliminary business and technical arrangements have been discussed, and satellite manufacturers have cooperated in conceptual designs. Necessary IFRB actions have been completed by the host operator for the Pacific Ocean coverage area and are under way for other areas.

Using one or more Class C HPAs per spot beam operating at a 30-40 watt level, and a spot size of about seven degrees, the EIRP of 39 dBw at edge of coverage will provide adequate E_b/N_0 for a data rate of 320 kb/s. This data rate will enable at least thirty-two 8 kb/s voice channels, plus high-rate synchronous and asynchronous user data channels, and TDMA system overhead data.

Phase Four: Dedicated Aeronautical Satellites

System design requirements that (1) minimize the number of satellites while providing for maximum frequency reuse and position-location coverage and (2) minimize transitions between satellites during an aircraft flight segment result in a six geosynchronous-satellite constellation. Frequency reuse also is enhanced by the use of an interlaced inter-satellite frequency plan for the complete worldwide system. Orbital locations near to four of Arinc's selections were submitted by the FCC and Advance Published (AP) by the IFRB on November 17, 1987. The remaining two locations to serve the U.S. are to be coordinated with the FCC based on spectrum allocation developments.

An important system design requirement is to permit expansion to a large global system of thousands of channels with minimal or no disruption to aircraft over decades of operation. This requirement has driven a plan that permits similar transponders to be added on both host and dedicated satellites, raising the data rate and EIRP by means of smaller spot beams while operating within the same basic architecture.

Satellite technology of today completely supports these near-future needs. Using less than two watts of satellite conditioned power per voice channel, today's larger satellites could enable 2,000 voice channels. Antenna sizes to fit within launch vehicle shrouds without unfurling are adequate even at L-band for the needed EIRP and G/T.

A five-fold increase in the system data rate (from 320 kb/s to 1.544 Mb/s) would need less than a five-meter satellite antenna and could use the same satellite HPA. The additional spot beams would provide the system operator with more flexibility to fit power density to changing user traffic areas. For this upgrade, the necessary changes to avionics are in the filters, modems, and parts of the processors, all of which need only to be reprogrammed.

By upgrading with integral multiples of data rates, expansion of the system retains use of the avionics and the Phase Three shared-satellite transponders, permitting orderly transitions to dedicated satellites and utilizing all resources to their full lifetimes. Spectrum coordination and planning for all the world's aeronautical band users is a major requirement for integration.

CONCLUSION

Satellites for aeronautical communications are not only needed today, but have become essential because there is no alternative for remote-area voice and data so vital to efficient and safe aircraft operation. Supporting technology and radio spectrum allocations are ready, and a phased development plan for implementation is now under way. Shared and dedicated satellites for aeronautical communications are certain to play a large part in providing satisfactory service in the near future.