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Technologies for Future INTELSAT Satellites

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Satellite systems generally require a 6- to 8-year cycle from planning to operation. Changes to the present INTELSAT system, based on the use of INTELSAT V, are being evaluated with respect to research and development requirements. Three technologies emerge as important to the next generation; these are multibeam antennas, onboard satellite switching, and intersatellite links. This paper makes a technology assessment of these three areas.

Introduction

INTELSAT is now providing the transmission paths for two-thirds of the world's international communications. With a traffic growth rate of about 20% per year, it is prudent to plan a new generation of satellites each 5- to 6-year period.[1] Currently, planning is underway for the generation of satellites beyond the developing INTELSAT V. In addition to the study of future requirements, an assessment of the availability of certain technologies which will allow the achievement of projected capacities is important. Three key technologies were selected by INTELSAT for evaluation: 1) multibeam antennas (MBA's), 2) satellite-switched time-division multiple-access (SS-TDMA), and 3) intersatellite links (ISL's). This paper will assess the availability of these technologies for the generation of INTELSAT satellites beyond INTELSAT V. The three technologies are the keys to major growth. Traffic capacity can be increased three to five times by the addition of available bandwidth through frequency reuse. The high antenna gains associated with narrow spot beams also provide the increased power to support larger communications capacity. However, frequency reuse requires interconnectivity, which can be supplied efficiently by SS-TDMA.[2] Alternatively, increased capacity can be achieved with multiple satellites, using global or zone coverages and interconnected by intersatellite links.

Two operating modes are presently used in the INTELSAT system: primary—any user in the geographical coverage area, defined by the 5 deg elevation viewing angle to the satellite, can be interconnected; and major path—specific high-capacity users are linked with carrier pairs.

Maintaining a primary mode of operation with frequency reuse emphasizes the need for an efficient interconnectivity arrangement.

Multibeam Antennas

Two main coverage concepts are being studied by INTELSAT: 1) 6- and 4-GHz dual-polarization global coverage, dual-polarization spot beam at 14/11 GHz, and a large number (approximately 65) of high-gain spot beams at 6 and 4 GHz, which overlay the global beams and are combined to form eight beam groups (frequency reuses); and an alternate concept, 2) a pair of 6/4-GHz hemispheric beams and a set of reconfigurable spot beams overlaid to form six zone coverages, as shown in Fig. 1. This concept covers the Earth with 80-90 high-gain 6- and 4-GHz single-polarization spot beams with variable excitation to the elements which can be controlled by ground command.

Significant progress has been made in the last decade in the development of software and hardware techniques to realize multiple-beam antennas. A large number of elements are needed to generate multiple complex coverage patterns, and with coverage-to-coverage isolations >30 dB, computer-aided analysis tools must be available to evaluate performance of candidate antenna designs. Also, computer-aided synthesis tools are essential to determine the optimum excitation for the elements and to achieve small sidelobe amplitude and high-polarization purity performance. These design tools should show agreement to about 1 dB to measured patterns of high-gain beams (40-50 dB) to levels at least 40-50 dB below beam peak. In addition, the ability to measure and accurately process data from experimental model measurements is required. Several organizations interested in antenna technology have been developing analysis software techniques and automated measurements. Synthesis programs are not quite as well developed, particularly with respect to including the effects of scattering and multifeed mutual couplings.

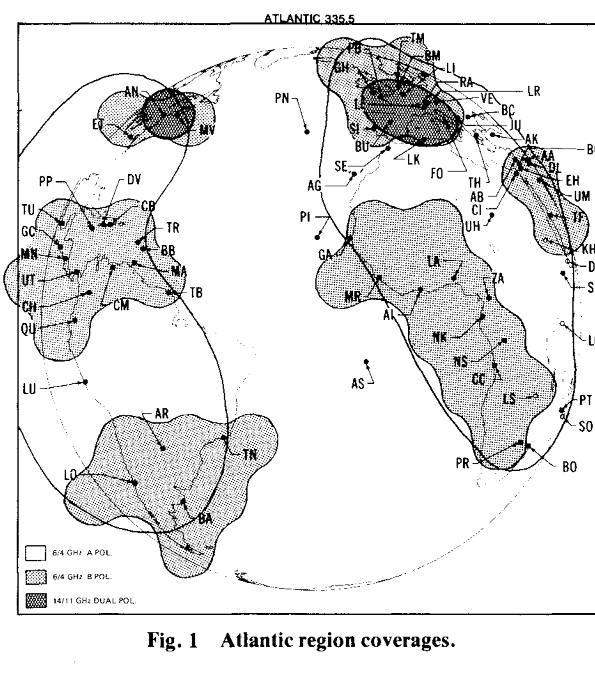

Fig. 1 Atlantic region coverages.

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In the hardware area, as a result of comparative parallel development of lens, reflector, and phased array approaches to complex antennas, the offset fed reflector has been given primary emphasis for the 6/4-GHz band.[3] This emphasis is based on the least weight, overall greater radiated power to prime power efficiency, and ease in folding and deploying large apertures while retaining low sidelobes (<30 dB) and high-polarization purity [(carrier to intermodulation ratio) C/I>27 db].

The realization of large reflectors (>7-m diameter), which can be deployed accurately and maintain their surface shape during at least seven years of -70°C to +150°C temperature variations encountered in space, still remains to be demonstrated. Multiple feeds coupled with beam-forming networks exhibiting low loss (<1 dB) are required. Extremely lightweight and long-term structural stability must be maintained. This combination of properties for fixed patterns, set before launch, is now available. However, reconfiguration of the coverages to accommodate satellite position changes as well as traffic distribution modification is required. These more complex antenna beams will require development of low-loss, lightweight variable power dividers and phase shifters. Although these subsystems are being developed, the level of complexity envisioned for an INTELSAT VI is greater than that of any presently known system.[4]

Associated with the variable power dividers are control circuitry and logic for commanding the specific configuration. This technology is similar to that being developed for the SS-TDMA switches, which will be described later. The major development here is improved reliability and a meaningful way to incorporate redundancy.

SS-TDMA Technology

In addition to the multibeam antenna and receivers which translate the signals to a common intermediate frequency, the dynamic microwave switch matrix (MSM), controlled by a distribution control unit (DCU), and an acquisition and synchronization unit (ASU) to provide the necessary reference for each of the TDMA terminals in the system are the major elements of an SS-TDMA system.[5]

The MSM provides the beam-to-beam interconnection among the multiple up- and down-beams. During normal operation, all beams carry traffic simultaneously, and each up-beam path will be connected sequentially to each of the down-beams according to the switching patterns stored in the DCU. For the reference burst transmission, a single up-beam is connected to multiple down-beams simultaneously. In all other transmissions each up-beam is normally connected to only one down-beam. Typically, a beam-to-beam interconnection may continue from 12-100 μs; the actual time depends on the traffic distribution among the beams.

The basic operational parameters of the MSM are listed in Table 1. The common intermediate frequency is 4 GHz with a flat (<0.5 dB variation) bandwidth of at least ±250 MHz. For flexibility, each switch point may operate in either a continuous connection or a dynamically switched mode. Figure 2 is a schematic diagram of a 4×4 MSM. However, present INTELSAT developments utilize an 8×8 MSM as a basic building block. Two or more of these units can be used for redundancy or for providing more interconnected beams.

The DCU provides a programmable cyclic sequence, stored in a memory, and the on-off control for each switch of the MSM. An alternate sequence memory is usually incorporated to systematically change switch connections without service interruption. A remote command and telemetry link supplies the input control from the ground and verification of the control. Figure 3 is a simplified block diagram of the DCU.

The principal characteristics of the DCU are given in Table 2. The onboard clock is a stable free-running oscillator which establishes both the frame rate and time phase of the SS-TDMA system frame. With a basic programmable 6-μs frame unit size, the complete stored sequence will be read once each 750 μs, thus providing a unit time interval per switch operation of slightly less than 1% of the total frame.

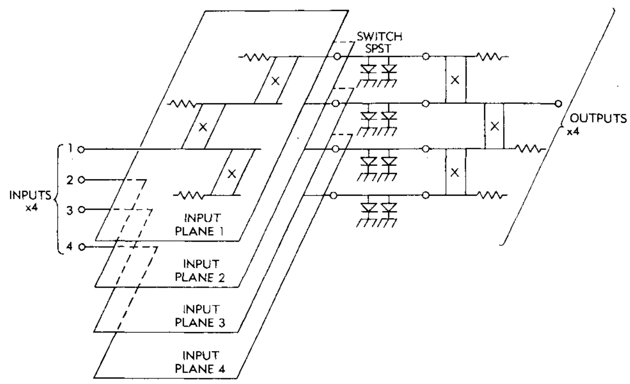

Fig. 2 Schematic diagram of the simplified microwave switch matrix.

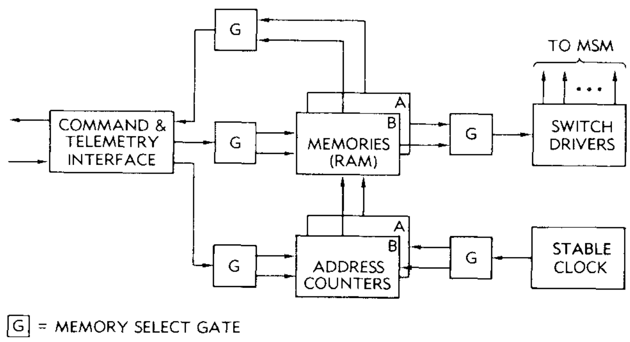

Fig. 3 Simplified block diagram of the distribution control unit.

Table 1 MSM operational parameters

Matrix type	Crossbar 8×8
Switch type	Single pole, single throw, bias-on
Switch element	PIN diode
Switched signals	
Input	±15 dBm
Output	−10 dBm
Insertion loss	<30 dB ± 0.5 dB
Path-to-path variation	<1 dB
Path isolation	>50 dB
Switch time	<50 ns

Table 2 DCU characteristics

Long term stability	1×10^{-8}
Minimum burst time	6 μs for a 750-μs frame
Memory and program	4 kbit, reprogrammable without interruption of service
Memory check	a/b check

Acquisition and Synchronization Unit

The ASU enables an Earth station to systematically acquire and maintain the frame period and synchronization phase of the onboard microwave switch, thereby enabling the transmission of a TDMA reference burst at the start of each frame, to which all TDMA terminals are synchronized.[6] Table 3 lists the primary operational parameters of the ASU.

The acquisition pulse, which has a length of 500 μs, is modulated first by one tone and then by a second tone. This divides the frame into equal distinguishable length parts. A coarse binary acquisition scheme is used to center the switch

Table 3 Operation parameters of the ASU

Acquisition mode	
Modulation	FSK[a] burst
Power	– 20 dB below normal TDMA burst power
Received bandwidth	800 kHz
Acquisition time	< 3 S
Synchronization mode	
Modulation	4-phase PSK[b] burst
Burst time	6 μs for 750-μs TDMA frame
Burst power	Normal TDMA burst transmission level
Synchronization accuracy	± 1 symbol
Minimum E_b/N_0	9 dB or 10^{-5} error rate

[a] FSK = frequency shift keying.
[b] PSK = phase shift keying.

time between the two modulation tones corresponding to the sync window. This is followed by vernier adjustment at full power, using the measured time phase of a short burst four-phase PSK modulated carrier with a predetermined symbol pattern.

For a number of years, SS-TDMA technology has been developing which has resulted in a microwave integrated circuit (MIC) implementation of an 8×8 crossbar switch operating in the 4-GHz region. A special three-position T-switch to provide redundant operation of the paths is being developed.[7] It will be utilized as shown in Fig. 4. DCU's have been developed using special purpose logic chips. A third-generation DCU is being completed which will realize the control of a row of switches in the matrix in MOS large-scale integrated (LSI) technology.

The ASU design is in its second generation; an earlier version has been under test since 1975. The newer unit will be fully compatible with the operational requirements of the INTELSAT TDMA system specification. Figure 5 is a simplified block diagram of this unit.

Simulated SS-TDMA tests have been conducted using the COMSAT Labs Unattended Earth Terminal (UET) at Clarksburg. Since it was convenient to use the switching unit on the ground, the TDMA transmission links were routed through the satellite and back before being switched. Hence, the transmission signal-to-noise and path delay variations in the Earth-satellite path were accurately simulated, with the Doppler approximating the worst case condition. The completed series of tests demonstrated that the system can be synchronized to an accuracy of 100 ns or better. The capability of rearranging the switching sequence of the MSM and TDMA terminals without interrupting voice channel service was also successfully demonstrated.

Several organizations are conducting studies and/or development activities on SS-TDMA components. The microwave switch technology is well along in development. The DCU technology has been carried to the furthest extent in terms of reducing size and power consumption, and an LSI is feasible. Individual devices such as PIN diodes and FET's are well developed and reliability histories are available. The basic technology for a DCU includes well understood logic and memory elements, plus switch drivers. Although these elements can be realized in LSI form, their reliability in this construction must be established. Although no new technologies are required, important development tasks must be accomplished before an SS-TDMA package can be incorporated into INTELSAT VI.

The requirement of maintaining all possible connection paths over the lifetime of the system dominates the design of the MSM/DCU package. Therefore, further development must emphasize: 1) establishing a high order of reliability for the switch and DCU configuration and incorporating a sound

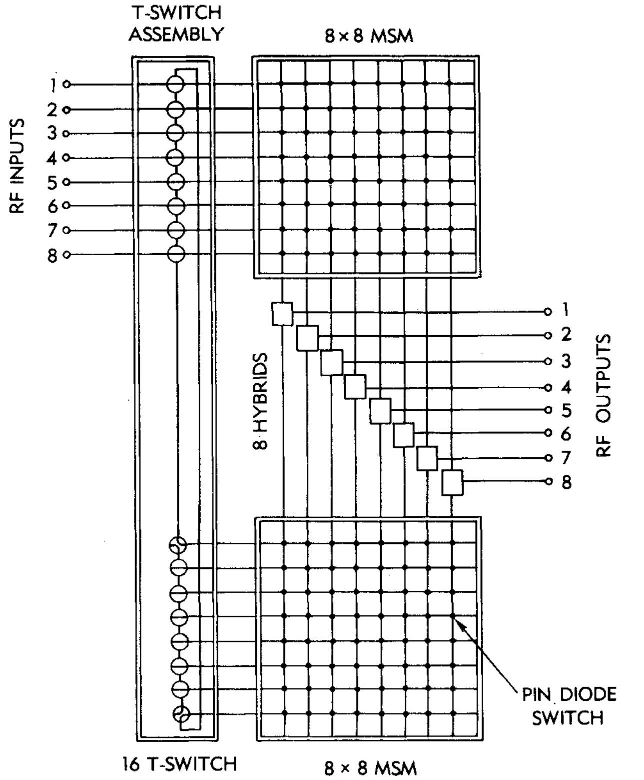

Fig. 4 Use of three-position T-switch for redundant matrix connection.

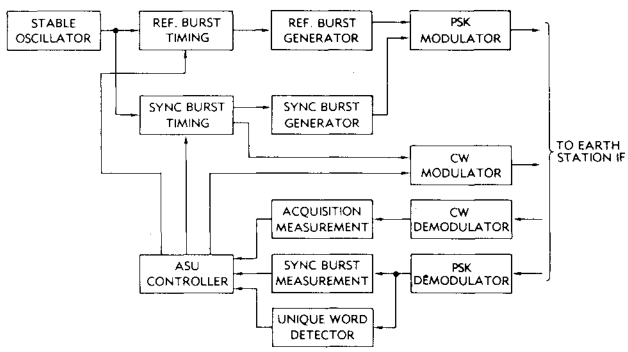

Fig. 5 Automatic acquisition and synchronization unit.

redundancy method; 2) minimizing the weight and power consumption; and 3) improving the mechanical construction of the MSM and DCU to ease fabrication, assembly, and testing of large switch arrays.

It should be noted that the most likely use of SS-TDMA will be with a multiple transponder configuration. The wideband receiver associated with each receive beam will be connected to a frequency multiplexing filter dividing the band into approximately 80-MHz increments. Each increment will be separately amplified to the outgoing beam, where the amplifiers will be combined to the outgoing feeds. A switch matrix will be required for each 80-MHz segment of the band for each beam.

Intersatellite Link

Intersatellite links (ISL's) can be implemented at microwave frequencies, infrared or visible light. An ISL for analog FDM/FM/FDMA transmission of about 3600 channels over a 10 deg longitude separation can be designed at centimeter to millimeter waves, with less total impact on the spacecraft than at optical frequencies. Microwave technology is preferable, since it is more readily available. A study of

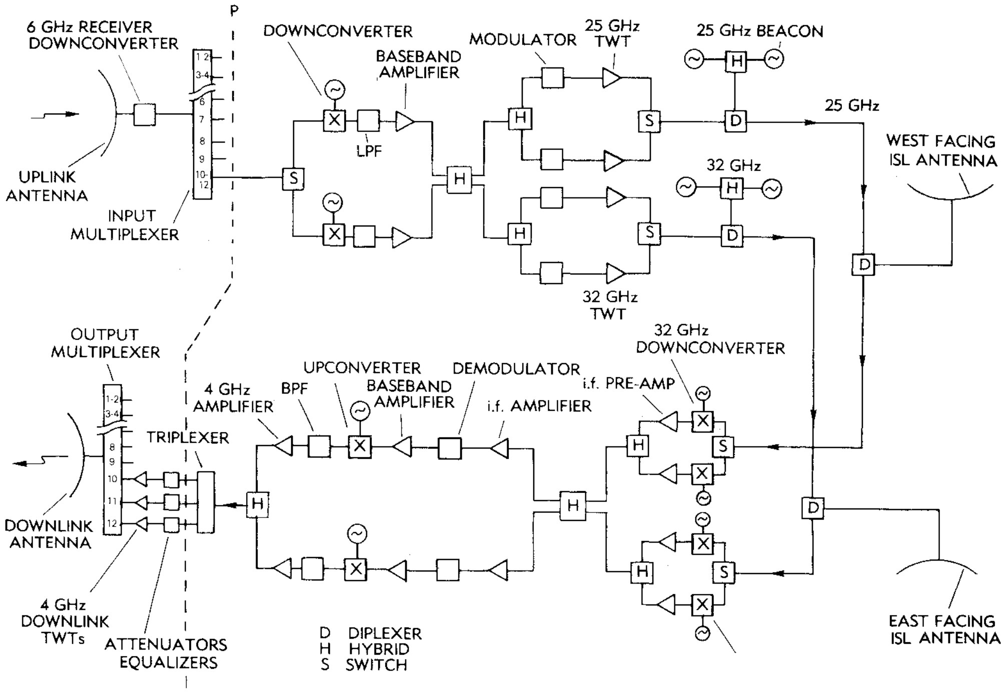

Fig. 6 Communications schematic of ILS-equipped satellite.

INTELSAT requirements for ISL's concluded that two 1-GHz bands located in the 24- to 32-GHz region would be desirable.[8] Microwave technology in these bands has been developed, and it is adaptable to space use. However, the available components must be investigated further to establish their detailed performance and reliability.

Modulation techniques which are compatible with current or planned modulation/multiple-access techniques were investigated. These studies determined that retransmitting several carriers from two or three 40-MHz transponders from satellite to satellite will be influenced by either the linearity of the final microwave amplifier or the modem of a remodulation scheme. Since linearization of the modem would consume less power, this approach is being developed. The FM remodulation approach will accept the output of the group of transponders to be interconnected and translate the frequencies to the low baseband range such as 10-300 MHz. This band of frequencies will then frequency modulate a carrier in the 20- or 30-GHz band. At the far end, a demodulator will recover the baseband; this group of signals would then be translated to 4 or 11 GHz for retransmission to the ground. Although such a modem is entirely feasible, wide bandwidth and required linearity ($C/I < 40$ dB) have not been demonstrated. Development is clearly in order.

Intersatellite Link Configuration Implementation

A model of an ISL transmitter/receiver is shown in Fig. 6. The majority of elements in this block diagram are available with present technology. The three major subsystems requiring development are the modulator previously mentioned, the output power amplifiers, and the tracking antenna systems. An antenna gain of 52 dB at 25 GHz can be realized with an aperture of 2 m and 55% efficiency. With an antenna approximately 200 wavelengths in diameter, the Cassegrain configuration offers advantages in this application.

Acquisition and tracking are critical performance considerations; however, these functions can be accomplished with available technology. A three-level tracking system may be considered: tracking by command from the ground, programmed pointing, and closed-loop tracking. Since the satellite attitude and position will be known with sufficient accuracy, manual acquisition is possible. After the pair of satellites is acquired by ground command, the received signals of the two-way link may be maximized by switching on the progammed pointing or the closed-loop tracking system. Reliability may dictate use of all three methods.

Spacecraft attitude control precision and power requirements are increased by incorporating an ISL; however, the impact is not dramatic. An ISL system such as that described above will weigh approximately 70 kg and require about 120 W from the spacecraft bus. Output amplifiers using TWT's in the 10-W range would provide an adequate carrier-to-noise ratio. Although TWT's in this power range are feasible, a development program to achieve the reliability and lifetime desired is essential. During phase 1, the design will be evaluated to determine if a single tube can cover the 25- to 32-GHz band, or if two designs are required. Phase 2 will encompass prototype implementation and extensive testing to confirm the life and reliability.

In parallel with the development of the wideband FM modem and TWT, computer and experimental simulation is desirable to investigate the sources of transmission impairments, e.g., the effects of modulator-demodulator nonlinearities, channel filtering, signal variations with attitude misalignments, and the dynamic range required to accommodate signal variations and sun interference.

Conclusions

Three important technologies have been discussed for possible impact on an INTELSAT VI. The major pacing technology which would yield significant increase in satellite communications capacity is the multibeam antenna technology. This creates the need for high-speed switching for interregion connections. In addition, satellite-to-satellite links can augment interconnectivity among satellite coverage regions. A vigorous research and development effort is being pursued in these areas.

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