DESIGN OPTIONS FOR FUTURE COMMUNICATIONS SATELLITES

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Summary The INTELSAT global system of communications satellites in operation today is a development covering four generations of satellites. Starting with the INTELSAT I or "Early Bird" satellite launched in 1965, each succeeding satellite series has provided more capability by the introduction of new coverage areas or increased telephony and television capacity Today with the INTELSAT III and IV satellites in operation, service is being provided between earth stations around the world of a quality that meets all appropriate CCIR and CCITT requirements. In this paper, the global network is examined with a view to determining those technical factors that impact on the design options of communications satellites of the future.

The factors and trends expected to influence future satellite designs and configurations are discussed. Specifically these are derived from analyses of the volume and the distribution in each ocean area of the system traffic, from analysis of the available modulation and multiple access techniques, from estimates of possible traffic growth rates for the time frames of interest, as well as from considerations of the availability of launch vehicles, of the present and future state of technology, of reliability and continuity of service requirements and of impact on earth station design and modifications.

Introduction The INTELSAT global system of communications satellites was inaugurated with the INTELSAT I or "Early Bird" satellite. This satellite, launched in 1965, was capable of transmitting 240 voice circuits or 1 TV channel between two earth stations and it initiated commercial communications services via satellite. It was subsequently followed by the INTELSAT II, III, and IV series of satellites. The latter two types are today providing service throughout the world. The introduction of the INTELSAT IV satellite into service in 1971 provides INTELSAT with a large space segment capability, and ,.this satellite with its versatile multi-transponder flexibility is expected to provide satisfactory service well into this decade.

INTELSAT satellites to date have all used the band of frequencies of 5.925 to 6.425 GHz for the earth-to-space link and the 3.700 to 4.200 GHz for the space-to-earth link. This 500 MHz of bandwidth has been made available internationally for commercial communications services and it is shared in many parts of the world with terrestrial communication networks. Early satellites did not utilize the full 500 MHz bandwidth allocated because of the limited power available from the satellites. With the advent of the INTELSAT III, and subsequently, the INTELSAT IV satellites with their despun or earth oriented antennas, the full bandwidth became usable.

Since the earlier satellites were in effect power limited, frequency modulation (FM) was used, since by exploiting its .bandwidth expansion properties a profitable bandwidth for power trade-off could be made. FM has continued to remain the major operational mode in the system to date, although in the case of INTELSAT IV with its significantly larger carrier-to-noise ratios (C/N) in both the spot beam and global beam mode of operation, a bandwidth limiting condition is being reached. Consequently other modulation techniques, i.e., digital modulation as used in Time Division Multiplexing (TDM) in particular, are beginning to have certain attractions in the quest for increasing channel capacity in the allotted bandwidth. FM will, however, remain the predominant transmission mode in the foreseeable future in spite of no longer exploiting its bandwidth/power trade-off capabilities in the spot beams because of the large amount of equipment presently in use, and the fact that after many years of development it is both reliable and relatively inexpensive. In addition, in certain modes of operation, e.g., single carrier per transponder operation, its capacity is equivalent to that obtainable by digital transmission.

The present earth station network is based around each operating entity, as authorized by INTELSAT, accessing the satellite through the facilities of a “standard” earth station. More than one antenna may be located at an earth station complex, depending on requirements, and it may be utilized either as a spare for back-up purposes or alternatively put into service operating over another satellite to provide diverse routing facilities. The majority of “standard” earth stations now operating in the system utilize 97' diameter antennas in conjunction with wide-band (500 MHz) cryogenically cooled parametric amplifiers having a minimum gain-to-noise temperature ratio of 40.7 dB/°K. This earth station network today encompasses approximately 62 earth stations in the three ocean areas. By far, the largest region is the Atlantic where there are approximately 31 earth stations and where six countries now are planning to operate with dual antennas in the near future. Interconnectivity between earth stations in this network is based on specified traffic requirements.

The services carried by INTELSAT satellites are primarily international telephony and telegraph services, television, data, etc. The qualities of all services are provided in accordance with appropriate CCIR and CCITT recommendations.

Systems Considerations International communications by satellite has experienced rapid and steady growth since its inception, and a continued annual growth rate of 15 percent to

25 percent is indicated for the foreseeable future. The capacity available with the presently used 6/4 GHz bands can be expanded by the use of frequency re-use techniques, but additional bandwidth will soon be required thus necessitating the use of the recently authorized 14/11 GHz and/or 30/20 GHz frequency bands.

In order to establish a valid basis against which all future satellite configurations can be evaluated in terms of determining their responsiveness to meeting system requirements, a systems model must be postulated. Using the present system as the base line requires that there be at least one operational satellite providing full coverage in each major ocean area, i.e., the Atlantic, the Pacific, and Indian oceans. Within each area all stations accessing the satellite can establish telecommunications services with each other depending on their individual requirements. In addition, in the Atlantic a second operational satellite is utilized to provide additional service facilities over heavy traffic links to those countries utilizing second antennas.

The global system in its present stage of development already shows some interesting variations in terms of traffic requirements and distributions in the three ocean areas and these are outlined in further detail below. Since the introduction of the INTELSAT IV satellite into service many studies have been carried out, (and are continuing) in an effort to determine the potential saturation date of this satellite. This is necessary (even though it appears to be at least in the mid 1970's even on the heaviest usage route - the Atlantic) since this date sets the timetable requirements for the next INTELSAT satellite series.

Traffic Growth and Distributions Figure 1 shows the present forecasted traffic requirements for each ocean area for the next few years together with extrapolated annual growth rates of 15 percent and 25 percent projected into the 1980 time frame. For system planning purposes the useful life of the INTELSAT IV satellites is estimated to be about seven years and consequently some should still be available for service at the end of this decade even though their capacity may be inadequate for certain heavy usage links.

The major distribution paths of this traffic in each area is shown diagramatically in Figure 2.

Analysis of these figures indicate that forecasted traffic volume for the next few years in the Atlantic, Pacific and Indian Oceans is approximately in the ratios of 4:2:1. For example, the 1975 projected Atlantic traffic level of 12,000 channels may not be reached in the Indian Ocean until 1982 even with a 25 percent growth rate. Referring to the distribution it can be seen that the major traffic links in each ocean area differ in terms of geographic location as well as the relative capacity requirements of the various links.

To satisfy these differing requirements was relatively easy on a straight forward multiple access satellite such as INTELSAT III where all signals were received and re-transmitted through a global antenna connected by wideband amplifiers and no routing was required on the satellite. In the case of INTELSAT IV with its two directional spot beam antennas some on-board routing is required. Where multiple spot beams are utilized employing frequency re-use, the on-board routing becomes an extremely complex network, which ultimately can dictate the method of modulation used since some forms such as time division multiple access (TDMA) lend themselves to being electronically on-board switched.

In determining the channel capacity requirements for future satellites, the time frame over which it is to provide service must be considered. For example, based on the data of Figure 1, the following capacities could expect to be handled over possible periods of interest. Also of importance is the manner in which service is to be provided, i.e., whether it is to be a single satellite or a two-satellite configuration. The use of multiple satellite configurations can be expected to increase as capacity requirements rise since it provides increased overall reliability if links are operated over two separate facilities which includes both the satellites and earth stations.

TABLE 1 Examples of Capacity Requirements

	Typical Time Frames of Interest					
	1975 - 1982		1980 - 1987		1983 - 1990	
Growth Rates	15%	25%	15%	25%	15%	25%
Atlantic Ocean	31,000*	57,000	63,000	175,000	96,000	340,000
Pacific Ocean	14,000	25,000	28,000	78,000	42,000	150,000
Indian Ocean	7,800	14,000	15,000	43,000	23,000	80,000

*Channel Requirements

Examination of Figures 1 and 2 indicate that utilizing one model of satellite for all ocean areas at the same time may not provide for the most efficient utilization of the satellite. However, to date, this single satellite approach has proved to be most advantageous. In the future, it is possible that satellites will be developed around the need to meet a more generalized requirement such that different satellites might be used in the different ocean areas.

Other Considerations A number of other factors play a prime role in determining the ultimate selection of the characteristics of a communication satellite. Some of the more important are discussed below.

A. Impact on Existing Earth Stations

The present earth station network has developed a degree of stability in terms of operational methods and equipment standardization. The basic method of transmission for telephony service is FDM/FM, although SPADE (a PCM/PSK/FDMA method of transmission) is expected to become operational in early 1973. The present method of FDM/FM transmission generally requires one or more multi-destinational carriers to be transmitted and on the receive side a separate down chain is required to receive each separate carrier. Thus, even when a station may have a small total channel traffic load but communicates with a number of other earth stations, the investment in equipment is quite significant.

Considering the impact on earth stations in service today, any new satellite should be capable of appearing transparent to the earth stations, or at least, requiring a minimum upgrade program to bring them into fully operational service. Conversely of course, the satellite should also be capable of handling any improved mode of transmission that could be brought into service throughout its operating lifetime. The effect of the satellite may range, for example, from the relatively small requirement of most earth stations having to transmit more carriers if a multi-beam satellite is introduced (a separate carrier being required for each beam), to the more complex modifications required to improve performance if cross polarized beams are introduced.

In order to handle this wide range of requirements, some provision is normally considered necessary to be made in terms of extra switching facilities, additional functional units, separate bandwidth allocations, etc., which, while providing a very flexible and viable satellite, tends to use part of the limited resources of the satellite for non-revenue producing functions. Consequently, a very careful systems analysis must be made in arriving at a final satellite configuration that provides a balance between maximizing the satellite's capability over its useful lifetime, while also considering the impact on the present and future earth stations in the system.

B. Launch Vehicles

INTELSAT communications satellites have up until now, and will probably continue to be launched by existing vehicles of proven capability requiring few special modifications to accommodate the communications satellite pay load. In the past the actual vehicle selection has not completely dictated the spacecraft's design since, e.g., the INTELSAT III spacecraft characteristics were determined principally by communications system requirements and the design was expected to be suitable for a single or a multiple launch. INTELSAT IV was planned to utilize all the capability of the Titan-Agena which was later changed to the Atlas-Centaur without significantly affecting spacecraft design.

Nevertheless, when considering future communications satellites specific launch vehicles must be kept in mind in order to develop optimized spacecraft designs whose communications capability can be evaluated against the requirements of the system. The matter of choosing between a single or multiple launch for a satellite is a complex one. Basically though it is centered around analyzing the generally more economical but higher risk of losing more than one satellite at a time multiple launch, against the individually more costly but only a single satellite loss probability single launch. To date, all INTELSAT satellites have been single launches, but multiple launches have been made in the past by other entities.

When considering the 1975 to 1985 time frame it is not possible to obtain a precise commitment concerning the maximum pay load capability of any specific launch vehicle, but a range and variety exists today which could be expected to be maintained into this time frame. As anexample, Figure 3 shows some near term projections demonstrating that variety does exist to carry payloads in a wide range of weights.

C. State of Technology Development

One of the most critical items in assessing the capability of a new model spacecraft, to be available within a specified time frame, is the state-of-technology that will be utilized. Normally, this can fall into two general areas that can be grouped under the headings of “extended technology” and “advanced technology.” “Extended technology” as used here refers to items which are considered to be a reasonable extension of the present state-of-the-art without special R & D. “Advanced technology,” on the other hand, refers to items that require R & D effort and possible in-orbit tests before they would be considered acceptable for operational use.

Commercial communicaitons satellites are designed to operate with high reliability over their design lifetime which today ranges over approximately 5 to 7 years. Communications services provided by these satellites are comparable in performance to that of high grade terrestrial microwave systems, and any anomalies in performance, e.g., signal level variations due to unstable amplifier gains, degraded pointing accuracy of antennas due to malfunction of the antenna pointing mechanism, etc., would be regarded in a serious light, if not actually total failure of that portion of the satellite affected.

In a broad generalization, technologies can be broken down separately into those related to the spacecraft and those related to the communications package. Thus, one consideration for a future satellite might be to retain a proven existing spacecraft with only minor modifications and incorporating a completely new communications package utilizing “extended” or “advanced” technology. Obviously this approach cannot be carried too far before an imbalance arises and limitations of the spacecraft reduce the effectiveness of the advanced communications package. Alternatively, a completely new spacecraft and communications package can be developed and placed into operational use after a longer time period. but its reliability and capability would be based on different criteria.

Another factor to be considered in this area is that of the communications facility available at the higher 14/11 GHz and 30/20 GHz frequencies. Components for use at these frequencies are still under development and their reliability/ redundancy requirements, together with the as yet unproven performance and propagation effects at these frequencies, impact on the capacity available in this band. Table 2 shows examples of typical technology improvements that might be made and their resultant impact on spacecraft performance and capacity.

D. Transmission Techniques and R.F. Frequency Utilization

As stated earlier, the primary method of transmission in use today is FDM/FM, with Frequency Division Multiple Access (FDMA) being utilized. Utilizing digital modulation techniques now under development (TDM/TDMA) on the INTELSAT IV satellites would provide for a possible 30 percent to 50 percent increase in satellites capacity, and thus from a space segment efficiency point of view this would appear to be an attractive way to go. However, as pointed out in (A) above, the impact of such a general change over on the earth stations would prove to be quite considerable.

It is expected that digital modulation techniques may be introduced gradually in the INTELSAT IV time frame and undoubtably a successor satellite would also have to be able to accommodate both modes of transmission. The introduction of the higher frequency bands would probably be limited to TDMA techniques with operation at transponder saturation; since due to the considerable magnitude of fading at the higher frequencies, extensive forward transmit power control or other such technique would have to be implemented in order to achieve a stable FDM/FM/FDMA system operation.

	EXTENDED TECHNOLOGY Example 1	 Example 2	ADVANCED TECHNOLOGY Example 3
Freq. of Operation	6/4 GHz	6/4 GHz & 14/11 GHz	6/4, 14/11 & 30/20 GHz
Transmission Mode & Modulation Access	A. FDMA & TDMA employing frequency re-use with spatial separation B. Limited inter-connectivity through switched filters	A. FDMA & TDMA employing frequency re-use with spatial separation and orthogonal polarization B. Enlarged filter bank	A. FDMA & TDMA with facility for introducing PSK-TDMA, with multiple spot beam operation and orthogonal polarization B. Filter bank and/or electronic beam switching
Propulsion System	Hydrazine thrusters	Hydrazine thrusters	Hydrazine thrusters and ion engines (optional)
Energy Storage	Ni-Cd batteries	Ni-Cd batteries	Rechargable fuel cells (optional)
Earth Pointing	Earth horizon senors	Earth Horizon sensors	Radio beacon sensors
Solar Array	Body mounted solar cells	Body mounted solar cells	Deployable, oriented rigid panels
Antennas	Fixed mounted reflector, nonsteerable	Multiple positionable beams, non-deployable	Multiple steerable beams, deployable
Possible Channel Capacity (useable channels)	13,000 chans. and 1 TV channel	26,000 chans. and 1 TV channel	35,000 - 50,000 channels including TV chans.

TABLE 2 POSSIBLE TECHNOLOGY IMPROVEMENTS

Spacecraft Design Considerations In the above sections, the system and technology aspects that impact on the selection of a particular spacecraft design were presented. In this section, the factors influencing the satellites' communications configuration will be examined with the discussion pointed towards identifying options available and the particular characteristics that each option would impose on the system.

On comparing the relative usefulness of any new satellite one of the main criteria is its channel capacity. In addition, the relative ease of introduction of this satellite into service must be examined, operational aspects considered and all transitional problems defined. The advantage of a larger capacity satellite is that fewer second antennas are required at earth stations so that only those stations desiring this facility for diverse routing and increased reliability need obtain the additional antenna. In addition, the increased capacity prolongs the time period, whereby a two satellite configuration is workable in the Atlantic, and single satellites in the other ocean areas.

As stated earlier the bandwidths available to communications satellites in the 6/4 GHz and the 14/11 GHz bands are 500 MHz wide. Wider bandwidths are available at yet higher frequencies e.g., 30/20 GHz band, but exploitation of these frequencies will most likely have to await further technology development and more experience with propagation effects before systems operating at these frequencies can provide the same reliability and cost effectiveness of systems operating at the lower frequencies. Since the present global system is exclusively based on the utilization of the 6/4 GHz band, it is considered most likely that future satellites will be developed around maximizing the use of this band, with the higher frequencies being introduced gradually, and on a selective basis in those areas where the 6/4 GHz band is operated at saturated capacity.

Channel Capacity vs. Bandwidth Considering the utilization of the 6/4 GHz band, the INTELSAT III series of satellites used two 225 MHz wide transponders each with a 10 watt TWT amplifier. Thus, 20 watts of R.F. power was concentrated by a directive antenna onto the visible portion of the earth, corresponding to an 18° beamwidth. INTELSAT IV satellites went a step further by the addition of two 4.5° spot beams to complement its global beam to provide increased power on selected portions of the earth's surface. This satellite with 12 transponders, each approximately 40 MHz wide, used 72 watts of R.F. power over the 500 MHz bandwidth.

The use of narrow beam high gain antennas associated with the transponders increases the channel capacity per unit of bandwidth, but as shown in Figure 4, in a substantially nonlinear manner with respect to the increase in channel capacity as a function of the increase in power made avalla e.

Figure 4 shows the number of telephone channels available as a function of the transponder e.i.r.p. in a 36 MHz bandwidth and indicates clearly that the incremental increase in channel capacity obtained as the e.i.r.p. is raised becomes proportionately smaller at the higher e.i.r.p. values. In effect, the transponder is bandwidth limited, and ultimately a saturated capacity value would be reached. Scale (A) shows the satellite transponder e.i.r.p. expressed in dBW while in Scale (B) the satellite e.i.r.p. expressed in watts has been divided by the corresponding channel capacity to provide the watts per channel as a function of the number of channels.

These calculations were made for a standard INTELSAT station, i.e., one having a G/T of 40.7 dB/°K and utilizing an FM carrier modulated with frequency division multiplexing. For the case of a multiple access PCM/PSK transmission as would be used in a time division multiplexing system, the capacity would approximate that of the FM single carrier per transponder case.

The significant points to be noted here are:

(i) In doubling the capacity from 500 to 1,000 channels the power required is increased approximately four times, where as when going from 1,000 to 2,000 channels the power is increased approximately eight times. If this sixteen-fold increase in power was put into sixteen separate beams a sixteen times increase in channel capacity would occur rather than the doubling obtained when using a single beam. This is one of the basic premises around which future satellites will probably be designed - the extensive utilization of frequency re-use through multiple beams.

(ii) While there is obviously no single channel capacity number that is an optimum, the figures would indicate that about 600 to 900 channels per 36 MHz of bandwidth appears to represent a good choice in the power/bandwidth trade-off. However, there is not normally sufficient isolation available between beams to allow a large number to be used, and as described below just the addition of extra beams does not increase the usable capacity significantly. Therefore a compromise situation will normally develop where a trade-off will be made between the number and size of beams and the amount of e.i.r.p. allocated per beam. With 12 such transponders covering the full 500 MHz of bandwidth, based on typical traffic distributions and volumes and the mixed use of single carrier per transponder and multiple carrier per transponder operation, a channel capacity of about 7,000 to 10,000 channels will be representative of 500 MHz of bandwidth.

Communications Configuration The use of multiple beams employing frequency re-use is the obvious manner to achieve increased channel capacity from a satellite operating within present bandwidth constraints. The question to be answered then is what is the minimum number of beams necessary to provide the required communications capability. In addition, if some higher frequency capability is to be provided, e.g., operation at the 14/11 GHz or 30/20 GHz bands, what is the optimum proportion for the division of spacecraft capability between these bands. Since all of these factors reflect back onto the spacecraft structure, power, and weight requirements, a number of interactive trade-off studies are required before a final decision can be made.

The starting point in attempting to arrive at a satellite configuration is to determine how much usable capacity might be achieved on a satellite. It is quite clear that extensive use will have to be made of spot beams in both the 6/4 GHz and 14/11 GHz bands if service is to be provided to meet even the lowest forecast growth rate of traffic into the 1980 era. one of the most important aspects to recognize in the design of a communication's subsystem involving a large number of spot beams, is that just adding more spot beams does not dramatically increase the usable capacity once a certain point is reached. In fact, a point of diminishing returns is reached when the additional power and weight required for an extra spot beam outweighs the benefits of the extra channels picked up. As an illustrative example referring to Figure 2, it can be shown that although a spot beam located over Central Africa has the capability of adding up to 10,000 channels to the system, since the actual traffic in this area is relatively small compared to traffic in the other spot beams, at saturation this beam may be only 30 percent full.

One approach used to determine the best spacecraft communcations configuration is to over-lay various beam configurations onto a traffic distribution model (similar, but in greater detail than that shown in Figure 2), and determine the resultant channel capacity at saturation. The results of one of these studies is shown in Figure 5.

Referring to this figure, curve (A) shows the satellite channel capacity realizable by the use of spot beams of 4° beam widths at 6/4 GHz only in conjunction with a global beam capability. The introduction of the first two spot beams placed over the obviously high density routes expands the usable capacity 60 percent. The addition of each subsequent spot beam, however, over a lesser dense traffic area, while providing the same capability as the earlier spot beams services fewer earth stations generally of lower capacity and thus the actual used channels is lower than for the earlier beams. Curve (B) shows the channel capacity realizable when two beams at 14/11 GHz are added to complement those at 6/4 GHz, but no interconnection is provided between bands. Curve (C) shows the resultant capacity when interconnection between bands is provided. Curve (D) shows the satellite capacity when 3 beams at 14/11 GHz are provided.

A number of similar studies are performed for the different ocean areas and also for changes in parameters, e.g., the beam widths at each frequency band may be varied and the beam locations moved, to encompass either the maximum number of earth stations or the highest traffic earth stations (or both depending on the geographic area and traffic distributions). Prom this it can be seen that an analysis of the actual traffic distributions to be encountered in service must be made to ensure that a balance is achieved between the 6/4 GHz and 14/11 GHz bands as well as the number of spot beams that are used in each band to arrive at a configuration that, at saturation, has all beams most effectively loaded. This of course must also be carried out within the weight and power budget constraints.

Another important feature in the consideration of frequency re-use techniques is polarization isolation. By this means the available bandwidth is effectively doubled but at a cost of increased performance requirements of both satellites and earth stations antenna assemblies. -A number of studies are presently being carried out for both linear and circular polarization to ascertain the practical limits of polarization isolation that can be achieved with both current and future antenna assembblies, the result of which will form the basis of future system designs.

When viewing possible systems employing frequency re-use techniques through either multiple spot beams spatially separated or orthogonally polarized beams, the amount of isolation achieved will probably determine the ultimate channel capacity obtainable. This is because interference between signals using the same frequencies will now most probably become the limiting factor, i.e., interference constraints will. now move more into the forefront of considerations rather than the power or bandwidth limitations of the earlier systems.

The provision of multiple spot beams, each serving distinct geographic areas brings with it the problems of how to provide the necessary interconnectivity between stations located within these respective beams and possibly those few stations geographically dispersed and thus, still remaining within a global coverage beam. With the continued use of multidestinational FDM/FM carriers with Frequency Division Multiple Access used in the satellite a filter matrix could be provided where filters of specified bandwidth, (dependent on traffic requirements) would provide the necessary interconnection paths between the beams. Some filters would be hard wired between the beams, while others could be made switchable and controlled in orbit by ground command, to provide the necessary flexibility to meet changing traffic distribution patterns over the lifetime of the satellite.

This method is generally considered to be feasible when the number of beams is small but as the number of beams to be interconnected rises this method becomes cumbersome and in practical terms the physical size inflexibility and weight aspects detract from its acceptability. One alternative approach now under consideration is an electronic beam switching devise that provides interconnection between all beams on a time sequential basis. This method does, however, require that the earth stations be transmitting Time Division Multiplexed (TDM) signals which are not expected to come into general usage until 1978-1980 time period. Consequently, it can be expected that both methods of providing interconnection will be seen on communications satellites in the future.

Conclusions Many factors will influence the design of future communications satellites. There is already a worldwide well developed earth station network providing exceptionally reliable and excellent quality telecommunications services of all forms. The capability of future generations of satellites introduced into this service must consider the present requirement of this network, its future development and growth and any potential new services that might be introduced. The design of these satellites while making use of the latest technology must continue to provide assurance of maintaining the high reliability and long lifetimes expected of satellites in this service.

New modulation and transmission techniques will be introduced as well as the latest frequencies allocated to these services as they become viable and the satellites will be expected to accommodate these changes as the develop.

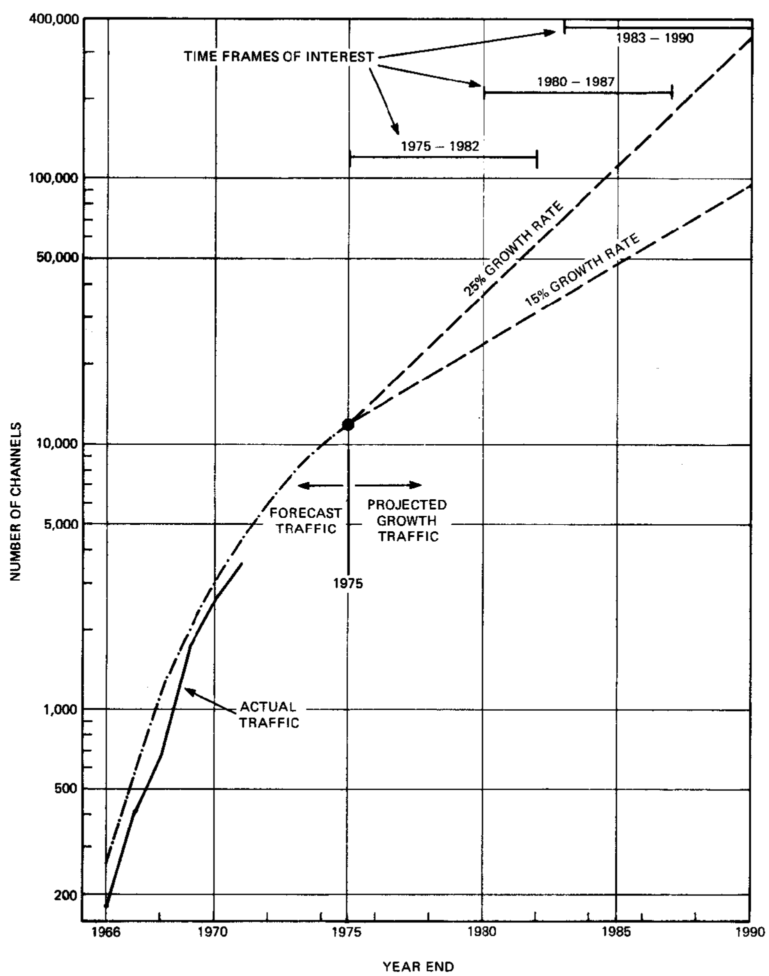


FIGURE 1 (a) ATLANTIC REGION POTENTIAL TRAFFIC GROWTH

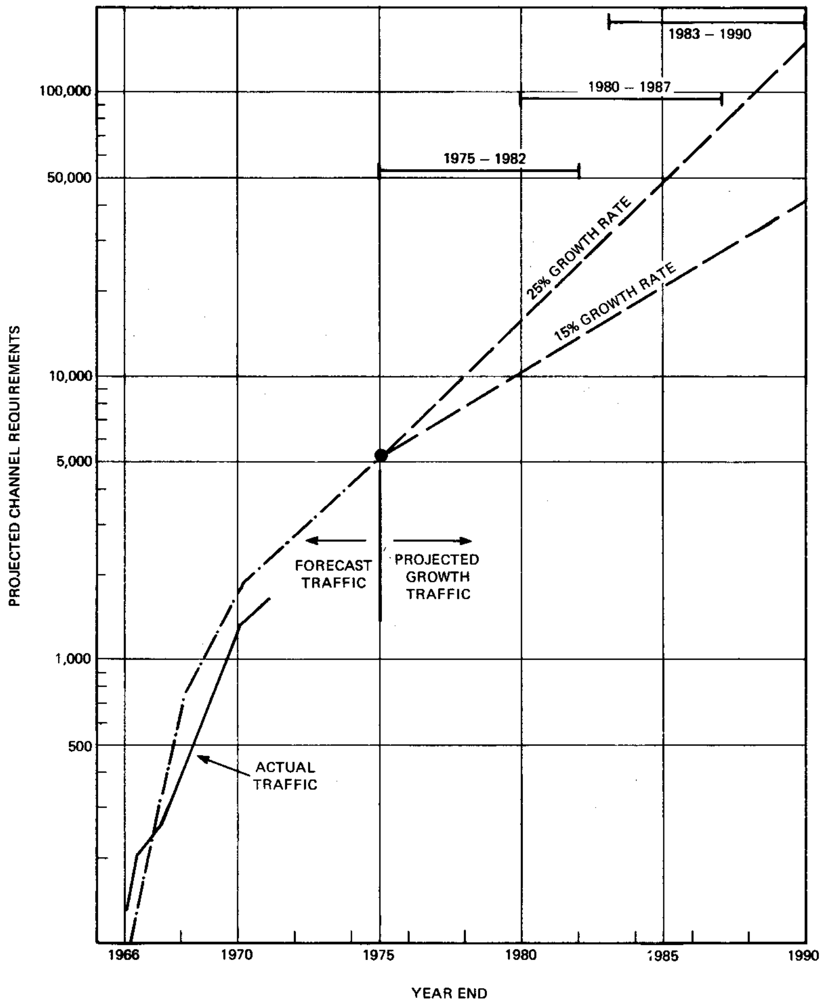


FIGURE 1 (b) PACIFIC REGION POTENTIAL TRAFFIC GROWTH

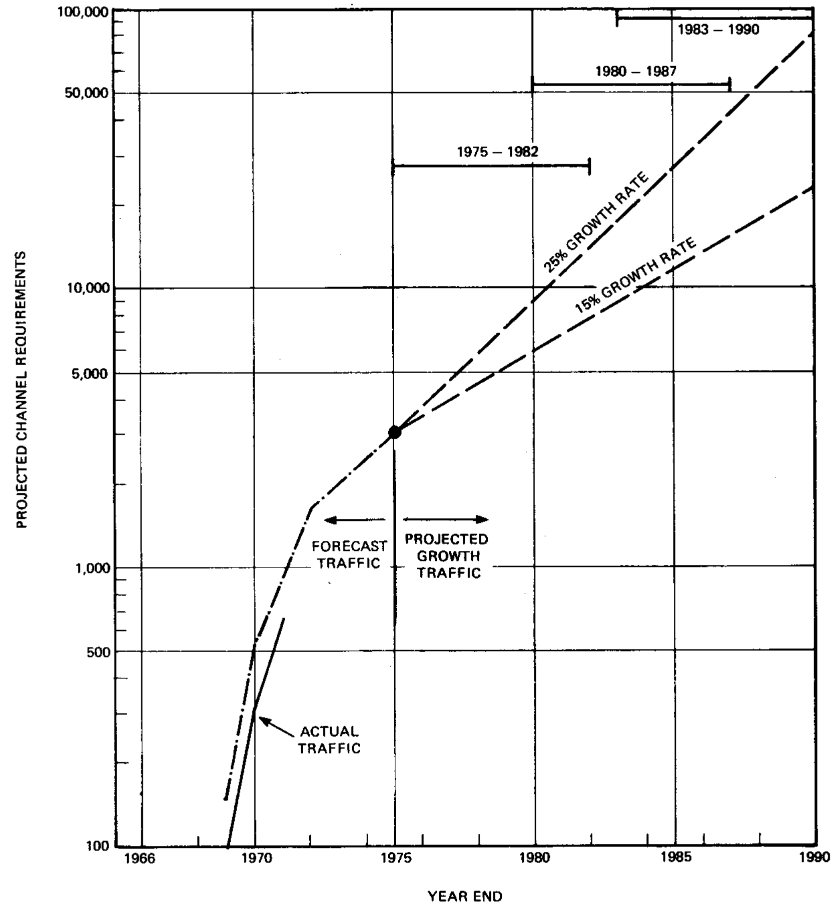
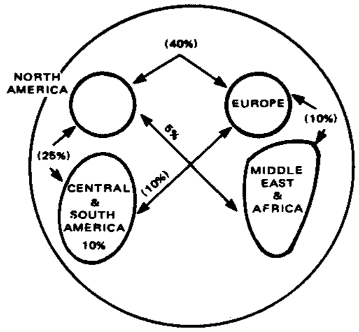
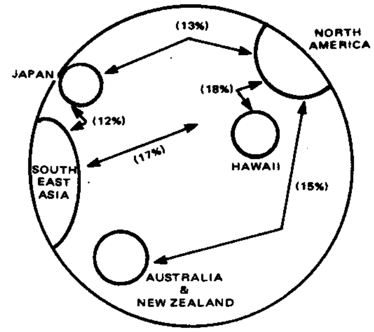


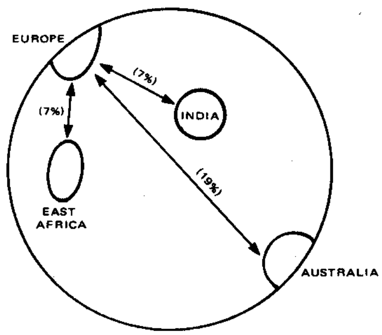
FIGURE 1 (c) INDIAN OCEAN REGION POTENTIAL TRAFFIC GROWTH



(a) ATLANTIC TRAFFIC DISTRIBUTION



(b) PACIFIC TRAFFIC DISTRIBUTION



(c) INDIAN OCEAN TRAFFIC DISTRIBUTION

FIGURE 2 MAJOR TRAFFIC DISTRIBUTION PATTERNS

	PAYLOAD ENVELOPE DIAMETER
DELTA	86 INCHES
ATLAS–CENTAUR	106 INCHES
TITAN III–C	110 INCHES
TITAN–CENTAUR	150 INCHES

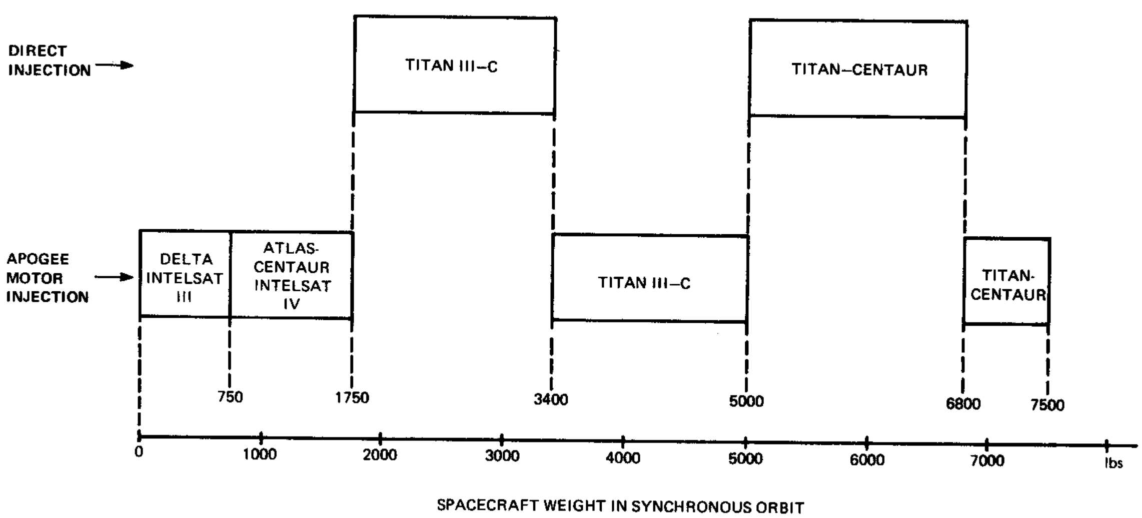


FIGURE 3 LAUNCH VEHICLES AND INJECTION METHODS

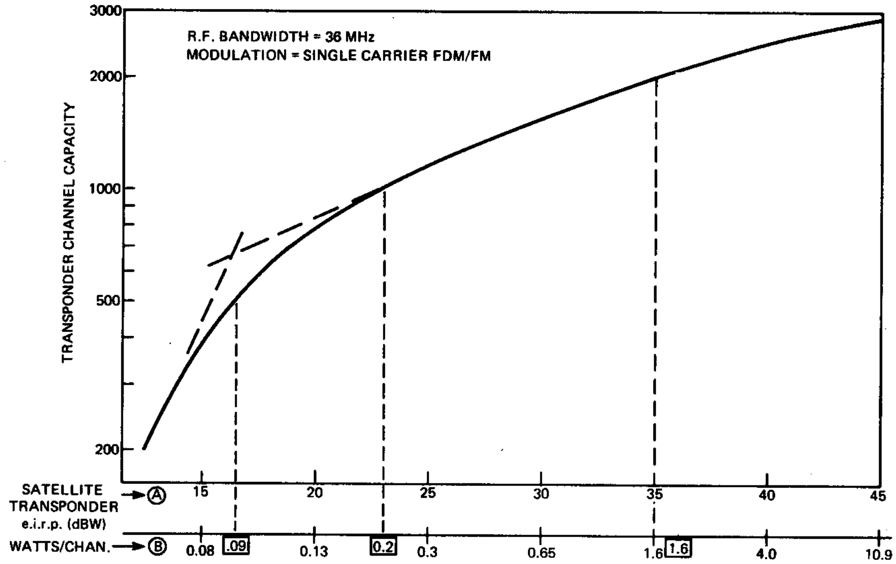


FIGURE 4

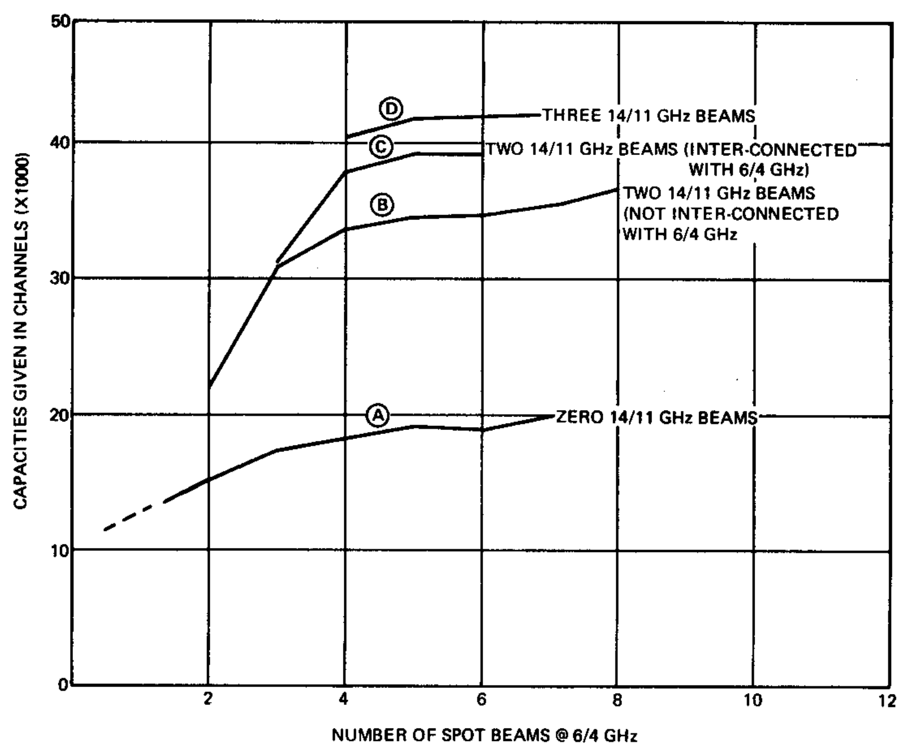


FIGURE 5 SATELLITE CAPACITY AS A FUNCTION OF THE BEAM CONFIGURATION

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