COMMUNICATIONS SATELLITE CONFIGURATIONS FOR THE 1990's

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ABSTRACT

Continuing growth in domestic and international communications traffic indicates a need for expanded communications satellite capacity. The size of spacecraft for the 1980's has been established and design concepts to meet the increased capacity of the 1990's are under consideration.

Launch vehicle capability permits alternatives to single-purpose spacecraft for the new era. Multipurpose spacecraft platforms and clustered satellites are concepts with unique advantages. Platform concepts will be seen in the 1990's, and growth in technology will permit dedicated spacecraft to achieve new levels of capacity.

Technical advances in the 1990's will include extended spacecraft lifetime possibly enhanced by refurbishment of payloads. Technical capability may well exceed the ability of institutions to utilize it, and innovative arrangements, including participation of financial institutions, may be required to fully exploit the improved technology.

In this paper, influential factors, such as multiple narrow-beam antennas coupled with precise pointing, are appraised in terms of design consequences and their impact on spacecraft subsystems is identified.

INTRODUCTION

Over the few years that satellite communications have been commercially available, traffic growth has made the provision of adequate capacity a continuing challenge. Reuse of

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This paper is based upon work performed at COMSAT Laboratories under the sponsorship of the Communications Satellite Corporation.

allocated frequency bandwidth is already required, and techniques such as polarization of radiated energy and formation of many narrow antenna beams are already in general practice. The latter technique, in which narrow beams require large antenna structures, is causing new generations of communications satellites to become “space antennas” that carry along supporting communications and housekeeping equipment, rather than spacecraft buses that carry along a few antennas. This trend influences the design of cost-effective, resource-efficient commercial communications satellites. Coupled with the ability of the new launchers (especially the STS “shuttle”) for boosting more mass and greater volume into orbit, the new technique will direct the configuration of future communications satellites away from familiar forms.

To support the greater capacity and higher pointing precision expected to be required of communications satellites in the 1990’s, new challenges must be faced in the design of supporting spacecraft subsystems. High accuracy deployment, thermally stable structural elements, and attitude control precision are among these challenges. An additional technology that will require attention is thermal control. It is likely that more advanced techniques will have to be employed to provide acceptable temperatures for higher power and more exposed critical elements. This paper presents some aspects of these new directions and speculates on configuration trends.

COMMUNICATIONS NEEDS

The thrust of communications system design is for more frequency spectrum and, for some missions, higher signal strength at the earth terminal. Increased frequency spectrum can be achieved by opening up new bands for communications satellites. But the usable spectrum is a finite resource and there are practical limits to what can be accomplished. Frequency reuse, the common solution to this problem, is achieved by polarization and spatial diversity. Spatial diversity permits reuse of a frequency band by illuminating only a portion of the earth with a narrow beam. Several beams having the same frequency, but carrying different traffic, can then be used to illuminate the desired user locations with consequential capacity increase.

The trend in commercial spacecraft antenna design has been toward increased size and sophistication. This is best seen in INTELSAT spacecraft (Table I) which have evolved through several generations, beginning in 1965 with INTELSAT I and culminating with the recent launch of the first INTELSAT V in December 1980 (Figure 1). The series will continue with INTELSAT VI, whose design and development are expected to begin in early 1982. The simple antennas of INTELSAT I through III provided virtually full earth coverage at 4 GHz. That coverage was supplemented in INTELSAT IV (1971) when narrow beam antennas were added. INTELSAT V extended the trend with narrow beam antennas at 11/14 GHz and polarization diversity added to the 4/6-GHz service. The antenna and communication subsystems for INTELSAT VI will continue the trend with even greater frequency reuse through more complex antennas. This spacecraft will be larger, heavier, more complex, and more demanding of spacecraft bus services.

The size of the antenna grew sufficiently large with INTELSAT V so as to exceed the launch vehicle shroud and thus to require on-orbit deployments to accomplish the required geometry. The larger antenna reflectors are characteristic of narrow beam antennas having carefully architected patterns. Antenna beam pointing accuracy becomes more stringent as the beam width becomes narrower or as isolation from adjacent beams becomes a dominant design driver, as is the case with INTELSAT VI. This beam pointing accuracy requirement imposes severe constraints on spacecraft antenna mechanical design as well as on the spacecraft’s attitude control system. In some applications these requirements lead to R.F. beam steering.

DEDICATED SPACECRAFT VERSUS MULTIUSE SPACECRAFT

Growth in traffic requirements has lead to an increase in spacecraft mass with each succeeding generation. INTELSAT VI will be ARIANE IV-compatible with a transfer orbit mass of approximately 3500 kg. Nearly 45 times larger than INTELSAT I, this new spacecraft will require approximately half the capacity of a shuttle. It is clear that with this growth rate, a full shuttle capacity payload is not far off. Table II shows at least one version of a growth extrapolation. Much attention has been given to low-orbit assembly of multiple shuttle payloads into platforms that are then raised to geostationary orbit, and to multiple satellites operating as a cluster with inter-spacecraft communications.

PLATFORM CONCEPT

A communications platform is a large spacecraft which, at a minimum, is a full shuttle payload. A larger version involves in-orbit assembly of elements brought up by several shuttle launches requiring subsequent orbit raising to synchronous altitude. Figure 2 shows a possible configuration of such a platform. The platforms are usually envisioned as providing multiple services, e.g., direct TV broadcast and telephony, with interconnection between services or service areas done on board the platform rather than by current terrestrial interconnects. Platform switching eliminates the up- and down-links required for terrestrial switching, providing greater economy in spectrum use, among other benefits. No mission in the 1990’s is foreseen as requiring more than a single shuttle launch; hence, the potential for establishment of platforms in this era is dependent upon integration of two or more missions that can be more efficiently performed with the platform concept.

The size inherent in the platform concept does permit the spacecraft designer more latitude for integrating the large antenna arrays of future communications missions. In-orbit assembly of the platform will allow corrective intervention, if necessary, during deployment of platform elements, such as antennas and solar arrays.

CLUSTER CONCEPT

Satellite clusters are made up of several spacecraft, some of which are identical and some with unique capabilities that are sufficiently proximate to resemble a platform when viewed from the earth. Interconnection and service switching are performed within the cluster by communication links between spacecraft, which could be microwave, optical laser, or fiber optic cable. The only difference between the cluster and a platform is in the area of spacecraft operations; i.e., control and monitoring of six spacecraft within a kilometer of one another represents a challenge. Figure 3 illustrates a cluster in the loop configuration.

The cluster concept does allow for smoother growth in communications capability, since new services can be added by supplemental launches. The distributed capacity of clusters as opposed to the concentrated capacity of a platform may have advantages, one being that financial requirements may be spread over a greater period of time. Also, the cluster concept does not restrict spacecraft size. Often described in terms of Delta class size spacecraft, the concept could utilize larger spacecraft or a mix of sizes. But the cluster is an interim step before the establishment of platforms. The optimum configuration is determined by cost effectiveness, and clusters of platforms may be the final solution.

INDIVIDUAL DEDICATED SATELLITES

The two preceding concepts are possible ways of meeting projected needs, but the current approach will not be superseded unless it becomes technically unacceptable or an overwhelming cost benefit emerges. The dedicated spacecraft is optimum because its technical requirements are derived from mission needs only, without compromise. Growth in spacecraft capability has been accompanied by growth in launch vehicle capability. Historically the situation has been one in which small increments of vehicle growth were driven by new payload requirements. Vehicle growth pushed by payload is reversed by the shuttle whereby more capacity is available than is required by any current single mission. Unfortunately, shuttle capacity, in terms of geosynchronous orbit payload, is not a continuum but rather incremental, since it is limited by the availability of suitable perigee stages.

Spacecraft programs during the 1980’s will largely rectify the situation for the 1990’s. These programs will drive the development of a variety of perigee stages, each suitable for a modest payload range, but in total covering the entire range of interest. For a full shuttle payload, no perigee stage currently exists. Hopefully, with adaptation and growth of the

Centaur, this need will be met. The shuttle launch cost equation encourages the designer to equalize the mass or length fraction of shuttle capability that the payload consumes while seeking to minimize the fraction. The foregoing and the increasing demand for larger antenna subsystems are leading to greater conflict between simplicity and reliability, and complex deployments necessary to minimize payload length. Table III presents the advantages and disadvantages of the new concepts.

PROPULSION NEEDS

The current shuttle manifest is populated with a variety of communications satellites. The largest fraction of this population consists of the lowest mass, DELTA class, spacecraft. These spacecraft use PAM-D as the perigee stage. In a unique configuration, they are stowed with their longitudinal axes transverse to the cargo bay's longitudinal axis, thus occupying a minimum of the cargo bay length. The PAM-A perigee stage is currently the next step up in capability and is sized for satellites of the INTELSAT V class. PAM-D and PAM-A payloads are solid propellant motors and, prior to ignition, are ejected from the shuttle after being spun up. After PAM-A, the IUS is presently the next step up in capability. Also a solid stage, it is more complex and includes the apogee motor. The large payload increments between stages do not permit design of optimally sized spacecraft without special perigee stage development within the spacecraft procurement program. This development is expected during the 1980's for some programs in which optimization produces sufficient cost savings to accommodate the additional costs of perigee stage development. The solid motors developed for IUS have long been considered candidates for alternate perigee stage configurations. Payloads beyond the IUS capability must rely on new stage development. The Centaur stage has the best prospect for adaptability to shuttle use. It utilizes a liquid propulsion system, making it quite versatile. Centaur increases payloads to the order of 12,000 lb in synchronous orbit, and must be considered a prerequisite for orbital platforms.

While shuttle payload capability is incremental due to perigee stage availability, it is far more elastic than the capability offered by expendable vehicles. The user can develop a perigee stage because the costs are within reach for some missions. This elasticity of payload mass leads to increasing interest in liquid propulsion for the apogee motor function. The liquid propellant systems can accommodate relatively wide variations in payload mass by simply adjusting fuel loading if the tanks are sufficiently large. The increased I of bipropellants represents an additional attraction beyond the increased flexibility. A natural consequence of the use of bipropellant apogee motor is to consider an integrated propulsion system that provides bipropellant spacecraft attitude control and stationkeeping thrusters. The dynamics associated with large quantities of fluids will be demonstrated during the 1980's, as with the INSAT launch, which uses such an integrated bipropellant system. The ion thruster waits in the wings as a highly effective alternative to chemical systems, but provides only low thrust levels. It also requires further development to achieve the required mission lifetimes. Since the ion thruster's principal benefit is reduced propellant mass requirements, the shuttle's large capacity relieves the urgency of using such thrusters.

POINTING ACCURACY CONSIDERATIONS

As noted earlier, the trend in RF performance requirements is increasingly demanding of spacecraft bus systems. RF beam pointing accuracy is becoming the paramount design driver for many of the bus subsystems, as well as a major influence on satellite operations. The on-station beam pointing accuracy of each antenna must be assessed individually and combined with spacecraft bus errors. The principal contributors to error are:

a. Mechanical alignment,
b. Thermal distortion,
c. Attitude control system precision,
d. Orbit imperfections.

Categories a through c are spacecraft design considerations and are affected by category d, which has to do with spacecraft operation and how precisely the orbit is controlled by onboard thrusters. Usually, ±0.1° is budgeted for north-south and east-west stationkeeping errors. Tighter beam pointing accuracy requirements will inevitably require reduction of this range with consequential increase in operational work load.

Mechanical alignment factors are becoming more difficult to address as the antenna subsystem becomes larger. Various parts can no longer be installed on a single rigid portion of the structure, but rather are distributed over the spacecraft structure, making their alignment and testing more difficult.

Greater exposure to the orbit environment, which in some cases includes higher concentration of heat, will likely require techniques for transferring heat that are more sophisticated than the conventional passive approaches. Heat pipes and circulating fluid loops may become the dominant technique for temperature control.

Control of thermal distortion has already led to an entirely carbon fiber antenna subsystem on INTELSAT V. Further progress in designing zero coefficient of thermal expansion structures will be required for the 1990's. Improved analytical, design, and manufacturing techniques will be mandatory for the very large structures foreseen in platforms. Better, and probably heavier, thermal control on-orbit will be necessary, including perhaps active temperature control of critical structural elements. Adaptive contour control of reflectors may be required for more demanding missions.

Further improvements in attitude control system accuracy will be necessary. Techniques appear to be available for the 1990's, but may be costly. Sensor accuracy improvement has always been a profitable path. The attitude control system will be required to handle the flexible body dynamics of large deployable structures, antennas, and solar arrays for future configurations. As spacecraft size increases, the beam pointing errors associated with the structural flexibility and thermal distortions will reach the point where RF beam tracking/steering will be required. In this regard, antenna technicians can help by developing folded optic designs that provide the required focal length, but in a more compact package. These designs can also relieve the trend toward an increasing number of deployable elements.

ANTENNA CONSIDERATIONS

The full earth coverage antenna of INTELSAT I has yielded to the offset-fed narrow-beam antennas typical of INTELSATS IV-A and V. These narrow-beam antennas lay down patterns on the earth that are carefully configured shapes required to avoid adjacent beam interference and to more efficiently use RF power to provide the energy levels needed at the earth terminals. Domestic or regional systems may have additional constraints with respect to illumination of adjacent nations, as might be the case with direct TV broadcast. The peculiar and precise beam shaping is achieved by a large reflector fed by a multiplicity of feed elements. INTELSAT V has 88 feeds, which are not all used simultaneously, but permit in-orbit beam reconfiguration for the Atlantic, Pacific, and Indian Ocean regions. The size of the feed assembly requires an offset-fed geometry to eliminate feed blockage effects. Future trends are for still larger reflectors with arrays employing hundreds of feeds. Circular aperture reflectors beyond a 4.4-m diameter must be deployable because of shuttle bay limitations. While much work has been done on center fed deployable reflectors, e.g., ATS-6 had a 9-m reflector, almost nothing has been done to demonstrate RF or mechanical performance with deployables having offset geometry. Recently, a modest step in that direction has been taken by some organizations, but much more needs to be done, including flight demonstration. The focal length to aperture diameter ratio, f/D, for these antennas is usually 1 or greater. For the larger apertures, this makes spacecraft configuration design for launch stowage and on-orbit quite difficult. The launch stowage of the large structural elements can require multiple articulated joints that increasingly contribute to antenna beam pointing error. While reduction in aperture size does not appear to be technically possible, long focal lengths may be made more practical by use of folded optical paths and subreflectors. This allows the antenna subsystem to be more compact and aids in error control as well as in reducing waveguide losses. The growth trend in feed and reflector size, and in number is towards the antenna subsystem becoming the spacecraft, with bus systems fitted where possible. The interaction of large reflectors with attitude control thruster plume impingement is another issue that must be addressed, since configurations with a substantial degree of interference are on the horizon.

While folded optics will help in extending the application life of conventional reflector antenna systems, phased arrays are becoming a more likely prospect. The requirements of increasingly narrow beams, and dynamic beam mobility, dictate such a direction. The improvements in both size and performance will allow implementation of highly capable phased arrays as both direct radiators and as feed arrays in conjunction with reflectors. The compactness of a phased array feed, together with the active RF components in the feed assembly necessary for RF performance, can present major thermal control problems. Relatively inefficient devices that will improve the RF components in the feed will dissipate up to 80 percent of the DC input power as heat. This heat must be transported to appropriate radiator surfaces that may be some distance from the feed. The area required will be large in comparison to the area of the feed assembly. Heat pipes or pumped fluid loops may be the only effective solution. Figure 4 shows such a spacecraft.

Large-aperture, direct-radiator phased arrays may be an alternative for some applications. The spacecraft becomes a “billboard” in orbit, as shown in Figure 5. Spreading out the RF components over a larger area should help the thermal situation. The mechanical precision required with the multiple radiating elements is certain to be most demanding. Carbon fiber composite material is expected to be the primary choice for future antenna structures, with Kevlar used in some areas where RF transparency is needed.

TRADE-OFFS

Spacecraft life expectancy was only one or two years in the early 1960’s. As technology improved, component quality and reproducibility were achieved, and improved redundancy strategies permitted extended life. INTELSAT III had a five-year life, and INTELSAT IV a seven-year life; other spacecraft have life expectancies of up to ten years. Launch vehicle limitations have inhibited life extensions because additional orbital life requires additional mass, more propellant, and more component redundancy. The shuttle launch capability largely eliminates that restraint and may provide for life extension of up to twenty years. Increased lifetime reduces the annual unit cost. Communications satellites are launched with severe underutilization of capacity, because they are designed to be saturated at end-of-life. They earn revenue only for utilized capacity; but capacity tends to encourage use, as seen by the popularity of SATCOM in TV broadcast distribution. Nevertheless, financial considerations require careful balance between cost to place a spacecraft in orbit, including development costs, and the revenue to be generated over the spacecraft’s lifetime.

The considerations above are secondary to the question of technology changes. Technological growth is quickly making obsolete spacecraft that are young in terms of terrestrial equipment lifetime. Furthermore, these spacecraft are considered today to be inefficient users of scarce resources, RF spectrum, and orbital slots. INTELSAT II, now long defunct, will be 19 years old when INTELSAT VI is launched. INTELSAT VI, while not fully free from the inhibitions imposed by expendable launch vehicle limitations, will be capable of handling 60,000 telephony channels compared to the 480 of INTELSAT II. Similar technology growth is seen in smaller spacecraft, where DELTA class spacecraft are performing what was once a Centaur class mission. Technology, consumer needs, and new markets are moving so swiftly that exceptionally long-lived spacecraft are not yet advisable although technically feasible. If per-channel cost reductions stop declining with each new generation, then long lived spacecraft will be a method for further cost reductions. That time is not foreseen, although a limited “used spacecraft market” appears to be developing.

While few commercial organizations have yet retired a spacecraft series, it is time to consider how best to do this, what effect this should have on design life, and how to introduce the new concept of “graceful retirement.” If there is a statistically significant number of spacecraft in use, a certain proportion will survive beyond their design lifetime, perhaps with reduced capacity (for example, 6 transponders versus the original 12). While such capacity degradation is intolerable for the original purpose (e.g., primary path service), and the system operator has already provided a new generation substitute, the spacecraft may have some residual value. For example, the customer may see no difference between using a 12-year-old transponder or a 2-year-old device, considering only communications performance and reliable availability.

The primary system operator has a tendency to view old degraded spacecraft as crippled while looking forward to the new “problem-free” generation. Older spacecraft are carefully maintained only to the degree that they serve as backup to primary capacity. Older but still serviceable spacecraft are often retired to a higher orbit. They are considered service burdens because the secondary transponder market has not yet become financially attractive. As the population of degraded but serviceable spacecraft increases, such a market may mature as it has with aircraft. If this market has potential, then adaptations to spacecraft design in the areas of propellant loading and thermal control design are indicated. These adaptations are well defined and can be evaluated against the statistical probability of residual transponder capacity available beyond the design lifetime.

REFURBISHMENT

In-orbit refurbishment of communications systems is not a matter for the future; in a broad sense it exists today. Spacecraft communications capability is routinely replaced with new spacecraft providing enhanced capacity and new services. For example, beginning with INTELSAT V F-5, maritime services will be provided to INMARSAT. Implicit in clustered satellites is the need for replacement of failed units and technological updating when appropriate. The question is whether to replace an entire spacecraft or to replace portions because of wearout, consumables, technology improvements, and new services. It is thought that large orbiting platforms can have extended life and the technological obsolescence intrinsic in long life can be ameliorated by providing in-orbit servicing and refurbishment. In-orbit servicing is envisioned as an intelligent (or perhaps manned) vehicle that transports equipment and supplies from the shuttle orbit to geosynchronous orbit where docking and refurbishment take place. Return of the vehicle to shuttle orbit for reuse is optional, but probably cost effective. It is necessary to plan for servicing in the original platform design, but since some features required for servicing will also be required for low-orbit platform assembly, this may not be as great a requirement as initially perceived. The communication payload is approximately one-third of the total in-orbit mass of a contemporary communications satellite. It appears desirable to reuse the bus subsystem, which is two-thirds of the mass, rather than to replace it every seven to ten years. With this concept, the platform's bus subsystem would be designed for long life while the communications modules, which are more technologically perishable, would have more modest lifetimes.

Platforms should lower the cost threshold for new services. Only design and development of the module would be necessary, which is far less costly than design and development of an entire spacecraft. While in-orbit refurbishment is considered exotic today, it will not be considered so by the late 1980's. A multitude of shuttle flights (including EVA's to correct payload problems) will provide a new perspective from which to view in-orbit assembly and servicing.

INSTITUTIONAL CONSIDERATIONS

Communications satellite services are provided by private companies, national government agencies, and organizations of governments such as INTELSAT and INMARSAT. Each entity identified a single communications service need and launched a spacecraft to fulfill that need. INTELSAT is the most mature of these endeavors, so it is not surprising that the in-orbit mass of the INTELSAT system during the 1980's will be far greater than that of any other enterprise. Fifteen INTELSAT V's may be launched in this decade. Other systems are younger and most are still on their first spacecraft generation. For systems embarking on new services, the universal choice is a PAM-D class spacecraft. This initial increment of capacity is well suited to the birth of new systems. These systems will mature and require subsequent generations of spacecraft with increased capacity to match traffic growth. While advancing technology will continue to improve the communications capacity derived from a unit mass in orbit, subsequent spacecraft generations will no doubt outgrow the PAM-D class payload. The domestic and regional systems typically do not require procurement of a substantial number of spacecraft; two to four usually suffice. The low number will make it difficult to procure a uniquely new, large spacecraft because of the development costs that must be allocated to each unit. This fact will tend to limit such systems to existing spacecraft buses that may not be completely suited to the mission requirements.

An alternative is to join several technically compatible missions, resulting in more numerous spacecraft or perhaps even in larger spacecraft in which two or more missions coexist. The coexisting missions/payloads might be interconnected on the bus to the mutual benefit of each, possibly yielding new service combinations. This reasoning makes possible still larger spacecraft platforms or clusters. The proliferation of individual spacecraft serving small markets cannot continue because of the scarcity of spectrum and desirable orbital slots. While the current diversity of systems is characteristic of a dynamically expanding and competitive industry, the future may involve fewer but larger systems. The early history of the telephone, for example, was characterized by hundreds of individual telephone companies often with incompatible equipment. But technology and forces of the marketplace slowly encouraged the emergence of a national system with total inter-connectivity.

Organizations, whether domestic or international, that aggressively pursue the path of large hybridized payloads will bring new levels of efficiency to satellite communications. There will be considerable risk in stepping beyond the narrow boundaries of their primary service function. This risk can be moderated by proper planning and discussion among the users of satellite spectrum. Some of the most compatible systems may be expected to join by mutual consent to achieve more efficient operation, particularly as orbital slot scarcity becomes more acute.

The capital costs associated with such large multipurpose facilities require new financial arrangements. The airlines industry is also capital intensive and many of the aircraft are owned not by the airlines but by banks which lease to the carriers. Possibly some future spacecraft could be financed in a similar manner and leased to the system operator.

CONCLUSION

In the commercial communications satellite industry, it is clear that the limited resources of frequency bandwidth and orbital slot locations must be used with ever increasing efficiency if the traffic demands of future years are to be met. The trend of spacecraft configuration will be towards larger, higher precision antennas and, very likely, towards sharing of common support services. For the spacecraft designer faced with problems of packaging for launch, precision of deployment, and compatibility among mission payloads, the 1990’s present formidable challenges.

ACKNOWLEDGMENT

Thanks go to George Welti for the tables presented herein.

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Table I. INTELSAT Satellite Evolution

	Year							
	1965	1967	1968	1971	1975	1981	1983	1986
Series	I	II	III	IV	IV-A	V	V-A	VI
Innovation	-	-	Despun Antenna	Despun Platform	E-W Reuse	Pol. Re-use K_u-Band	Global B	N-S Re-use SS-TDMA
Capacity (ch)	480	480	2,400	8,000	12,000	24,000	30,000	60,000
Bandwidth (MHz)	50	130	460	480	800	2,280	2,480	3,360
Number of Beams	1	1	1	3	3	7	8	10
Maximum Reuses	1	1	1	1	2	4	4	6
Number of XPDRs	2	1	2	12	20	29	34	46
BOL Mass (kg)	30	67	152	730	790	967	1,100	1,800

Table II. A Projection for Future INTELSAT Satellites

	Year				
	1986	1989	1992	1995	1998
Series	VI	VI-A	VII	VII-A	VIII
Innovation	-	New Bands, Linearization	K_a Band	Scanning Beam	Cluster of 2
Capacity (ch)	60,000	120,000	240,000	480,000	960,000
Bandwidth (MHz)	3,360	6,720	13,440	26,880	2 x 26,880
Maximum Reuse					
C Band	6	6	8	8	2 x 8
K_u Band	2	2	4	8	2 x 8
L_a Band	-	-	4	16	2 x 16
Number of XPDRs	46	46	96	144	2 x 144
BOL Mass (kg)	1,800	1,850	2,500	5,000	2 x 5,000

Table III. Advantages and Disadvantages of Satellites, Clusters, and Platforms

	Large Satellite	Cluster	Platform
Advantages	Simplicity Single Antenna System	Phased Introduction Cheap Spare	Single Antenna System
Disadvantages	Large Investment No Diversification	Antenna Duplication Duplication of Housekeeping Function	Large Investment No Diversification Space Docking Required

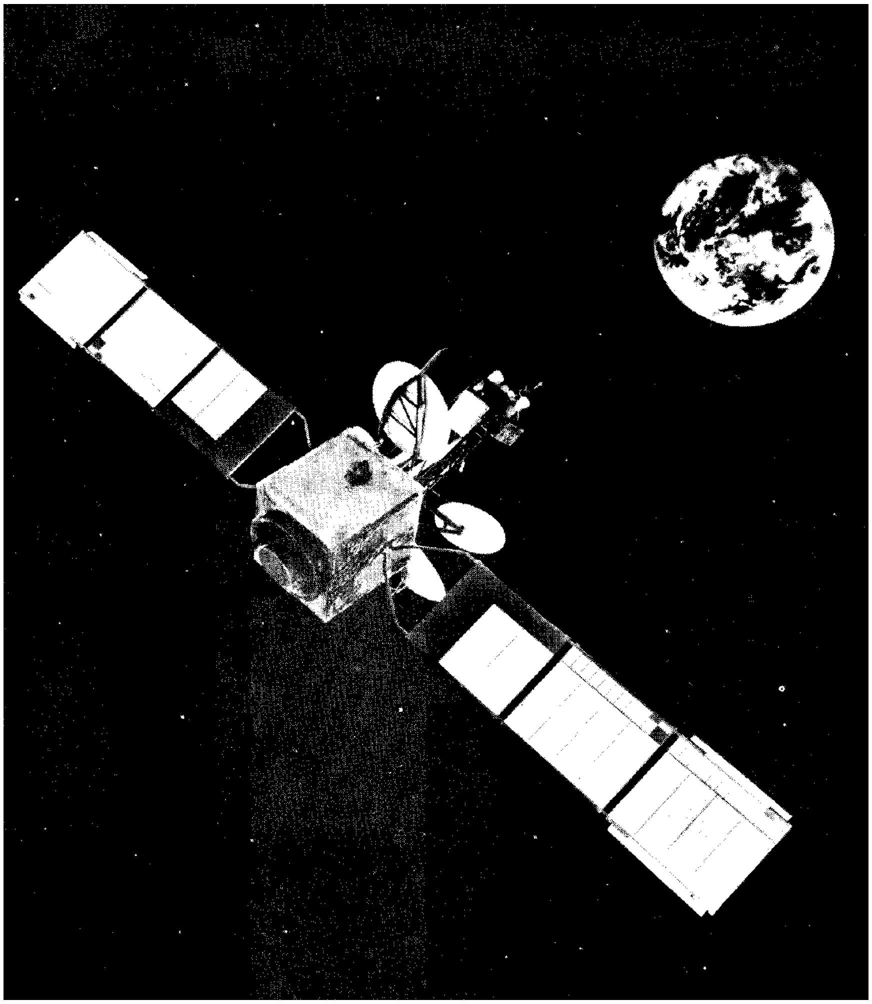

Figure 1. Intelsat V in Orbit

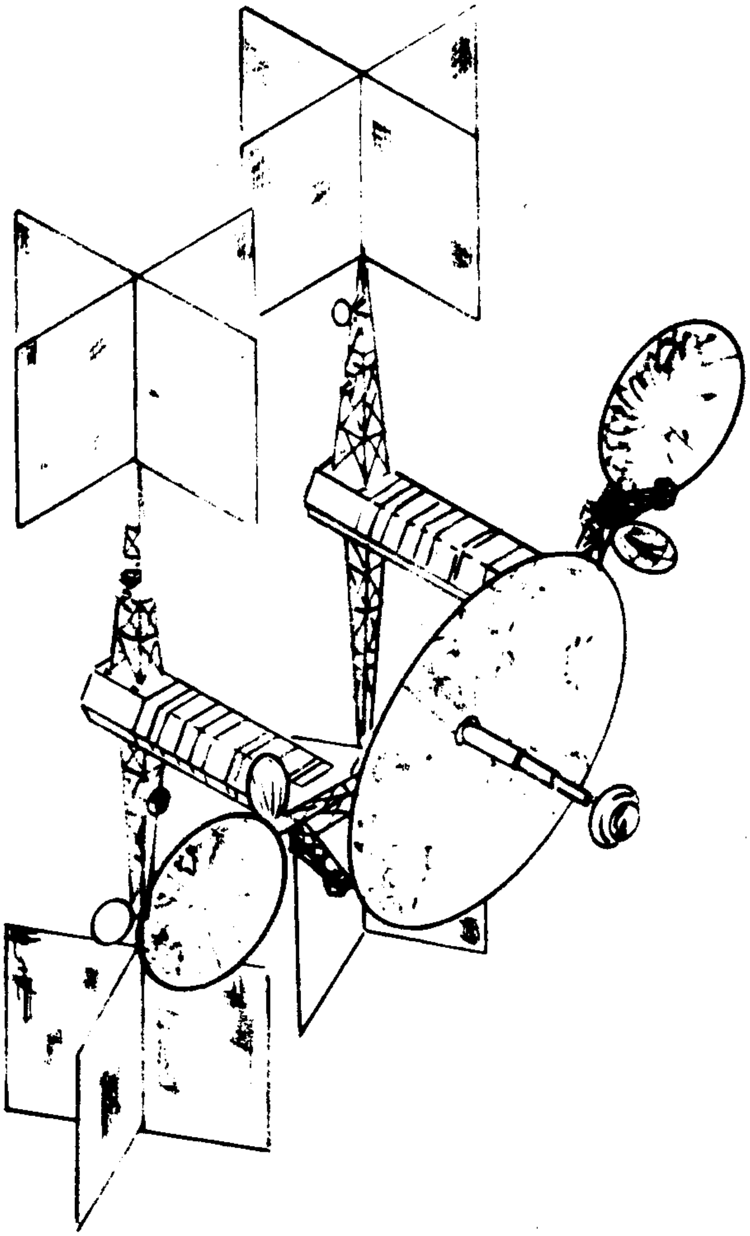

Figure 2. Geostationary Multiple Service Platform

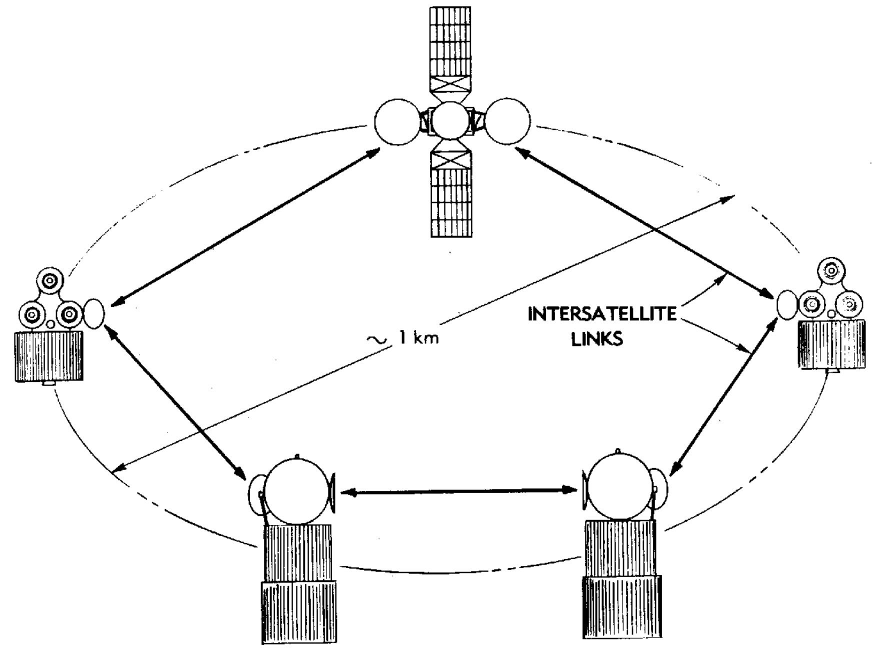

Figure 3. Clustered Satellite Configuration with Intersatellite Links

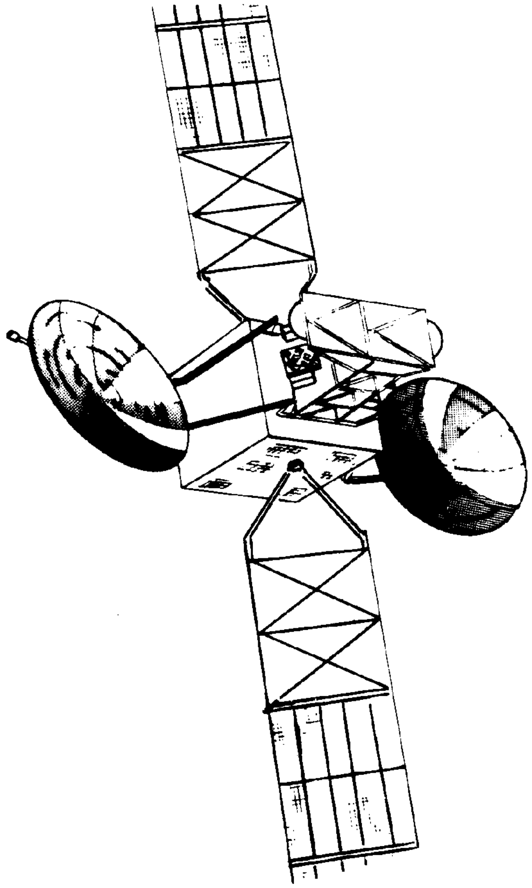

Figure 4. A Spacecraft Using Folded Optics Antenna Design with Phased Array Feeds

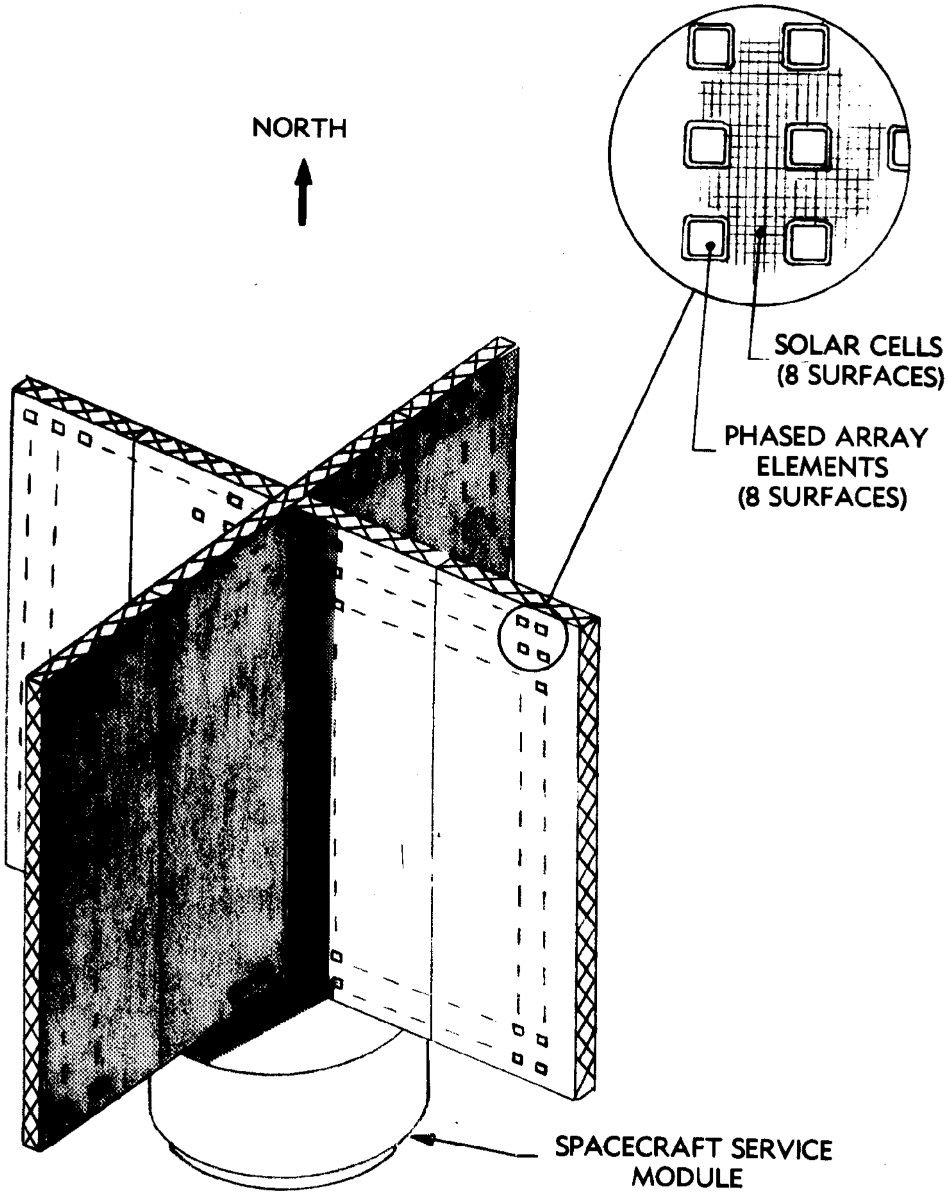

Figure 5. A Phased Array Spacecraft with Solar Cells Sharing the Cruciform Surfaces with Radiating Elements