



journal 38
university of liverpool engineering society

Communication by Satellites

by Mahendra M. Shah,
Final Year Electronics.
University of Liverpool 1967

Man has been trying to improve his methods of communication ever since the beginning of time. However, with the start of the Technological Age, more than a revolution has occurred in the field of communications. During the last hundred years or so telephony, radio, microwave and cables have been developed and perfected to a great extent; but unfortunately, these methods, though excellent, will not be able to cope with the increase in communications as the present trends indicate.

1. The Need for a New Communication System

Communication by cables is at present the cheapest and the most reliable method between two not too distant places however, for two distant places this system becomes expensive because of the difficulty of laying cables under the sea and over rough country. This same difficulty applies to building Booster Stations for microwave links. Microwaves cannot be bent and, moreover, because of transmission losses, these Booster Stations are essential. It appears possible to use microwave relays for a world-wide line (connecting the Asian and the American land masses via the Baring Straits) but this scheme does not appear to be politically or economically possible.

With the V.H.F. ground waves, there isn't enough bandwidth to meet current and increasing demands, nor is the standard of transmission of the required quality. Similarly in the case of radio, one has to use high frequencies in order to increase communication capacity and difficulties arise since high frequencies are not reflected by the ionized layers of the atmosphere. Moreover, the system is unreliable, since the ionosphere is at times put out of action by solar eruptions and nuclear explosions.

Therefore for reasons of high performance, large capacity and increased reliability, it has been necessary to find a suitable communication system.

2. The Growth of an Idea

Satellites have tremendous potentiality for the establishment of a world-wide high-capacity telecommunications system, but they have remained a challenge for some years. In 1945, Mr. A. C. Clarke envisaged the basis of a world-wide system of communication by three satellites spaced around the world at a height of 36,000 km. At that time space rocketry consisted of only a few experiments with V.2 Rockets. Satellites had to be accurately positioned in space and this could only be possible with suitable launching rockets. Furthermore, all the satellite components had to be specially designed since the satellite environment would be completely different from that on the earth. This environment is a very complicated and changing system and our knowledge of it is far from complete. Many of the space phenomena described here were not known or even suspected three years ago; and so for the present engineering projects for space systems, the best we can do is to make an estimate on the data of satellite environment.

Most satellites work on the line of sight principle according to which communication via a satellite between two Earth Stations is possible if the satellite is visible from both the stations simultaneously. Therefore, the higher up a satellite, the larger the surface of the Earth it can serve, but at the high altitudes, engineering difficulties are encountered as metal surfaces tend to weld together in extreme vacuum. And moreover, according to the present data, it is essential that for longer lifetimes, satellites be placed outside the Van Allen Radiation Belts which extend from a height of 1,600 km. to 18,000 km. These belts are the most intense penetrating-radiation flux regions, now known to be present in space, and were not even suspected before their discovery in 1958 by Explorer I satellite system, which actually penetrated well into the radiation belt. This radiation consists of high-energy charged particles (both electrons

and protons) trapped in the Earth's magnetic field. The belt consists of a hard-proton and an electron component. Both these high energy particles (50/1,000 MeV) are capable of penetrating at least a few milligrams per square centimetre of material and hence can interfere with the solid state equipment within the satellite system.

In addition to the Van Allen Radiation Belts, the environment is made hazardous by Solar-flare, Cosmic and Auroral Radiations. The solar-flares eject high energy protons and electrons, and in fact, Rothwell and Millwain in 1959 detected protons having energies in the region of 200 MeV and electrons up to 100 MeV on the Earth's surface. Calculations and experimental data showed that these flares die away with a time constant of 1 to 3 days. Cosmic Radiation also consists of atomic nuclei moving with velocities near the relativistic range. The composition of cosmic radiation is roughly similar to that of matter in the Universe as a whole principal constituents being hydrogen and helium elements.

As with solar-flares, the Auroral Radiation consists of high energy particles. Such an environment has led to the search for metals and structures which could withstand such intense radiations. An important factor that has affected this search has been the importance of minimising the weight of the satellite since this determines the necessary launching power.

3. The Choice of Satellite Orbit and Position in Space

Satellite power requirement also depends on the choice of orbit which can be either circular or elliptic. With an elliptic orbit higher altitudes at the extreme of the orbit can be achieved with less launching effort. Furthermore, at apogee the satellite is travelling relatively slowly and is hence longer in position to handle the traffic between two stations. The main disadvantages of elliptic orbits are that the strength of the receiver signal varies with altitude and also that the elliptic orbit passes through the most intense of Van Allen Belts. On the other hand, circular

orbits can be attained outside the Van Allen Belts at higher altitudes, but this needs large launching effort, thereby increasing the cost of the satellite. One of the advantages is that with circular orbits, the strength of the signal does not vary with position. Satellites can be put into circular orbits at altitudes below 1,600 km., but in this case their life time is shortened. This occurs because of the deviation of the Earth's gravitational field from an ideal spherical field and also as the gravitational pull is large at lower altitudes, eventually the satellite would be pulled into the Earth. The choice of the satellite orbit eventually depends on such factors as what area of the Earth's surface it is to serve, etc.

The orbit can further be synchronized or subsynchronized with synchronized equatorial orbit at 36,000 km., the satellite is stationary and this considerably simplifies the ground stations tracking problems. In this case, three satellites in the latitudes 75°N and 75°S , would be sufficient to maintain a world-wide communication link (or six satellites if standby are provided). One of the difficulties with this system is that because of that vast distance the signal must traverse between the earth and the satellite, there is a time delay of 270 ms. (one way) and this would be unsuitable for telephone subscribers if very low time delay land circuits were connected to the satellite link. Therefore synchronized orbits would appear to be best adapted to providing extensive "regional" rather than full "world-wide" coverage. With subsynchronized orbits, twelve satellites at 14,000 km, would be required for world-wide coverage -- 60°S . / 60°N . latitude. In this case all satellites would follow the same track as seen from the Earth and re-appear at the same local times each day. However, with this system, an additional antenna is required at Earth Stations when switching from satellite to satellite. This system of twelve satellites has the advantage that the time delay is the order 120 ms. (one way) and therefore regional coverage as well as world-wide coverage would be possible. To a great extent, the position and the type of orbits is determined by functions that the satellite will perform.

Basically, there are two types of satellites, namely Passive and Active. These been illustrated in the diagram Fig. I.

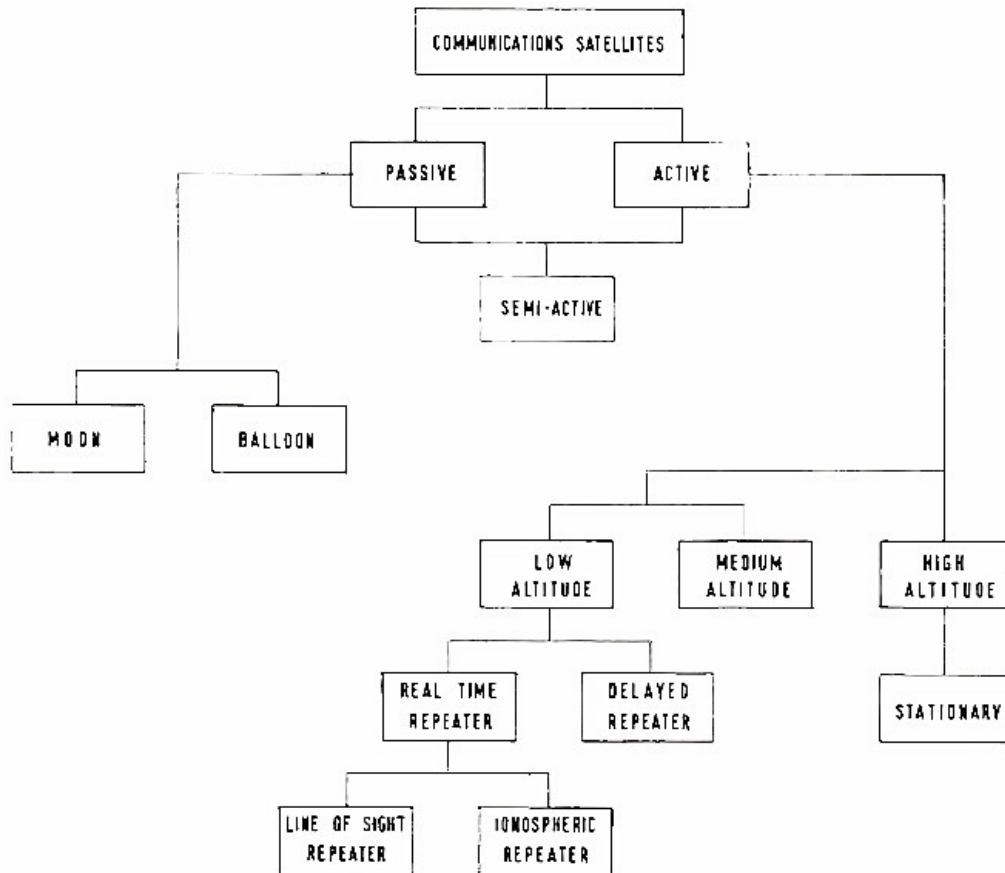


FIG 1 COMMUNICATION SATELLITE SYSTEMS

4.1. Passive Satellite Systems

A passive satellite is simply a sphere, coated with a metallic film and shaped such that it reflects transmitted waves specularly and only reflections from the First Fresnel Zone reach the receiver. The satellite carries a minimum number of components since the transmitter, receiver and associated equipment is excluded. The main principle of a passive satellite is that transmitted signal from station A are reflected towards the

receiver station B. The ratio of receiver power to transmitter power is given by:

$$P_R = \frac{(P_T) G_T A_C A_R Y_R}{(4\pi)^2 D_T^2 D_R^2}$$

- P_R : Power density at Receiver
- P_T : Power density at Transmitter-Earth Station
- G_T : Transmitter Antenna gain
- A_C : Reflection Cross-Section of the Satellite
- A_R : Receiver Antenna gain
- Y_R : Efficiency of Receiver
- D_T : Transmission distance for Earth/Sat.
- D_R : Receiver distance Earth/Sat.

The receiver power is of the order of a few microvolts and for such a small signal level, care has to be taken in reducing noise and other interferences to a minimum.

Passive satellite experiments were carried out using balloons, but it was soon found that because of micrometeorite bombardment the balloon deflated and lost shape. This in turn reduced the reflection coefficient. Stahler and Johnson suggested the use of metalised spheres which had the necessary rigidity and also were much less subject to solar and drag pressures. The use of a wide grid was experimented with and the results showed that grid spheres are useful for wavelengths exceeding ten times the mesh size and that a wire grid sphere reflects five times (7 dB) more power in the defined direction than the smooth spheres. Stahler and Johnson also suggested a sphere coated with lenses over the reflector surfaces. Such a configuration would reflect the received signal back to earth and avoid scattering it into the full solid angle of 4π . In this case gains of the order of 10 dBs were realised. The practicality of this system was first demonstrated by Echo I smooth experimental sphere, which was orbited at 1,000 statute miles on August 12th, 1960. The sphere had a vacuum deposited layer of aluminium 2,200Å thick. The balloon was folded before launch and inflated in space. With Echo I a reflection

coefficient of 98% was achieved. The satellite showed the feasibility of voice, facsimile and data transmission. In 1962, it was used to transmit a picture and a signal contrast of 10 dB was obtained. However, by this time the internal pressure of the balloon had fallen and deep fades and signal scintillations resulted from the surface wrinkles.

Prior to this satellite, the feasibility of Earth-Moon-Earth transmission had been demonstrated in 1954. Moon, Earth's natural satellite, in addition to not being a specularly reflecting body, is not available for communications at all times. Hahn and Randall analysed the peculiarity of this condition and found that the moon's declination varies sinusoidally during the lunar month, and therefore is unreliable for use as a reflector.

Passive satellites have the merit of simplicity but complications arise in that there is a requirement for station-keeping or for continuous control of orientation of say a flat or parabolic reflector. In order to overcome some of the complications, the West Ford experiment was carried out in October, 1961. This was the "needles" experiment in which a large number of metallic whiskers were intended to form a passive reflection belt by spreading out. The first attempt failed because the needles did not disperse. The system was further set back by the criticisms of radio and optical astronomers who thought that the needles would be likely to interfere with the observations of the cosmos. Under the circumstances, the experiment was discontinued.

4.2. Semi-Active Satellite Systems

This type of satellite combines the advantages of both passive and active systems. In the case of a passive satellite a major disadvantage is the high power demand which enforces bandwidth restriction and in the case of the Active Satellite, the factor of component reliability is very strict. One aspect of semi-active satellites consist of placing dipoles on a sphere. Each active dipole (dipole and amplifier) has a larger cross-section

than the area it occupies and moreover if some dipoles fail, this merely degrades the operation. If all the dipoles fail, the satellite is still available for use as a passive satellite. Semi-active schemes seem to have a higher life expectancy than the conventional satellite arrangements, however, they still remain to be experimentally tested and developed.

4.3. Active Satellite Systems

An Active satellite is one which has a receiver and a transmitter in addition to a host of other equipment for storing, amplifying, repeating, remodulating and redistributing messages. By the very nature of the functions that must be performed, the satellites design is much more complicated than that of a passive satellite. Unlike passive satellites, power is an essential requirement in an Active satellite. Strict weight restriction standards have brought about the development of solar cells to produce this power but with larger satellites, even solar cells will not be able to cope and in future it is possible to envisage the use of small nuclear power generators. The power is used to drive the various sections of the satellite. The block diagram shows a 24-hour satellite which is synchronized with the rotation of the Earth. The main sections of the satellite are communications, telemetry and command, control and power. A message from Earth Station A is received via the communications antenna. This received signal is amplified and retransmitted either immediately in which case it is an active repeater system, or else after a certain time-delay. In the case of delayed time system, the information is stored until given the command a frequency signal from the Earth Station to which the message is addressed. The storage system comprises of a series of tape-recorders, but with the rapid advances in computer technology, it will be possible to utilize computer memory systems. Such a computer could also be used as a control procedure storage unit. Accurate positioning in space is made feasible by the Advanced Command and Telemetry Subsystems. There is an altitude antenna

control and this is directly actuated from the onboard sensors. Only if the onboard system fails, then the ground

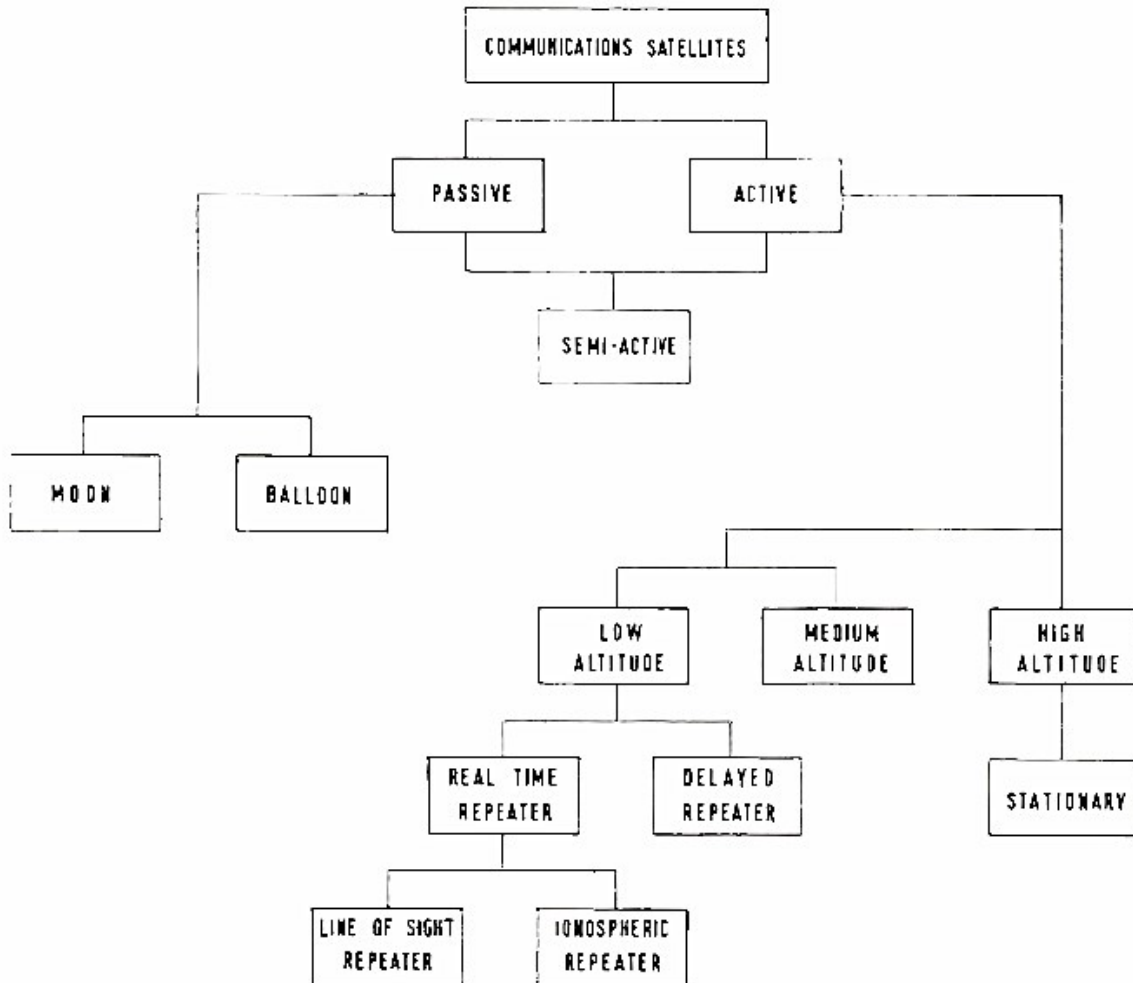


FIG 2 BLOCK DIAGRAM OF A 24 HOUR COMMUNICATIONS SATELLITE

commands can override the onboard sensors. The control section contains the propulsion, inertial wheels and appropriate systems for altitude and orbital positioning.

The components of the various sections have to be of an extremely high reliability. The order of magnitudes will be realized from the fact that for average component failure for a two-year life expectancy of 95% of a system for 1,000 components would be $1.15 \times 10^{-9} \text{ hr}^{-1}$. Our knowledge of solid-state and printed circuit technology has very much advanced in

the last decade and thereby it has been possible to design such highly reliable and complex equipment. The various designs and systems have been tested on various satellite projects. Some of these projects have not been fully successful, but the accumulation of data from such projects will eventually lead to a perfect communication system of satellites.

5.1. Active Satellite Projects

The first of the satellite projects was Project Score launched on December 18th, 1958. This was a battery powered Atlas Missile containing a radio receiver, transmitter and a recorder. The project successfully demonstrated the possibility of voice communications and teletype-write transmission and delayed message repetition was also tested. The satellite failed on December 30th, when the batteries stopped functioning.

The next two years were spent preparing for Project Courier, which was launched on October 4th, 1960. Courier was equipped with V.H.F. and U.H.F. circuits. The V.H.F. circuit was used for tracking and telemetry. Upon acquisition the tracking beacon was switched off and the U.H.F. telemetry link used for tracking. The satellite demonstrated the capability of the active satellite concept. The five tape-recorders on board demonstrated delayed repetition of digital as well as analogue information. As the Courier was achieving success in orbit, plans were already being put in hand for the Telstar satellite. This was a private venture by the Automatic Telephone Co. of America. As such it was a repeater prototype rather than an experiment. The satellite was launched on July 10th, 1962, from Cape Kennedy. Telstar's broad-band amplifiers were able to relay colour T.V. transmission. The project successfully demonstrated the first real time black and white and colour T.V. between the American and the European continents. Tests of wide-band multichannel voice transmission for transcontinental traffic were also successfully carried out. Telstar was put out of action by a nuclear explosion on the Earth.

In the same year on December 13th, 1962, Nasa's Relay 1 was launched. Relay demonstrated a better wide-band, multi-channel voice communications system and also successfully measured the achievable channel quality on many passes. Numerous other satellite projects such as Syncom have been carried out and all these have contributed towards the improvement and perfection of the various systems used. This has resulted in the success of the present Early Bird and Intelsat Projects. These comprise synchronized satellites which will provide the first International Telecommunication link serving most parts of the world—via satellites. Previous to the acceptance of this plan, in 1962, the British Government put forward the plan of utilizing twelve equally spaced satellites on an equatorial orbit of altitude 12,000 km. This system had the advantage that if one satellite failed then the effect would not be as bad as if one of only three satellites broke down. In the latter case, the telecommunications between various countries would become chaotic. However, the Hughes Aircraft Co., to whom the Early Bird and Intelsat projects have been awarded, have suggested the use of three further standby satellites. In fact, these are already under construction.

5.2. Present-Day Satellite Projects

Early Bird, the first of the commercial satellites was launched, on 6th April, 1965. The construction was similar to the Active 24h satellite described previously. The plane of the Early Bird orbit is slightly inclined to the equator and therefore appears to trace out a thin figure of 8 once a day. The tracking speed is therefore low and this has considerably simplified the tracking problems. The tracking is done via Cape Kennedy, Goonhilly and a station in Europe. The Goonhilly station has had to be modified to provide an optimum functioning high gain, narrow beam steerable aerial. To do this a new high tolerance stainless steel surface was built on the 85 ft. parabolical aerial. The result of the stringent requirements of accuracy is that the loss in gain has been limited to a factor of not more than 0.3 dB at 6,000 Mc/s and 0.1 dB at 4,000 Mc/s. The station aerial is steered by an automatic control system which has a

computer programme consisting of a 300 ft. control tape to provide 12-hour tracking information. This basic control system is further supplemented by an auto-flow mechanism which continuously minimizes the small steering errors caused by wind and gusts or imperfect predictions. In addition, modification had to be carried out to reduce the losses in wave-guide feeders. So far the tracking stations have worked perfectly and this has enabled a continuous telecommunications link between the American and the European Continents.

Early Bird's success has led to the acceptance of the Intelsat system, which should establish a world-wide link within the next three to four years. Early Bird was, in fact, the first phase of the Intelsat Project and the second stage Intelsat II was launched in October, 1966. This satellite had the same channel capacity but twice the radiated power as Early Bird. The satellite was to have been positioned above the Pacific Ocean, but the apogee motor failed to put the satellite in the geo-stationary orbit at 36,000 km. This satellite while temporarily in position above the Indian Ocean accomplished the first Australia/U.K. television link. The apogee motor has since been modified and a replacement for this "rogue" satellite, as well as an Atlantic satellite, are due to be launched later this year. This timing has been planned such that the Intelsat System will be used as a half way link between the Earth and the Apollo Spacecraft which is due to land on the moon in the 1970s. In fact, half the Intelsat IIs capacity will be used by the Apollo Project while the other half will be available for routine commercial communication. Truly satellites will play an ever-increasing part in the conquest of space in being able to successfully accomplish communications between Earth Stations and Spacecraft.

6. Conclusions and Future Satellite Systems

In 1887, Heinrich Hertz demonstrated the feasibility of transmitting and receiving electromagnetic waves. At the beginning of the 20th Century, Guglielmo Marconi initiated the era of long-distance communications by transmitting the letter S between the two continents

of this planet; and seven decades later, communication systems have been perfected to provide terrestrial satellite communication systems and plans are well ahead for planetary communication systems to come into use once man's conquest of other planets is accomplished.

Satellites have already proved the feasibility of high reliability, large capacity and high performance world-wide communication links. Today, within a matter of minutes it is possible to establish a communications link between the European and the American Continents and as soon as the Intelsat Project is completed, this link will be extended to establish world-wide coverage.

In future, it will be possible to have small transmitters which can be directly connected into the world satellite link and hence news of emergencies, etc., in any part of the world can be instantly flashed around the world and help obtained. For a long time, there has been a need of such a link for aircraft in flight. Time and again the position of crashed aircraft is not known and valuable long hours are spent in frantic search for the wreckage. Satellites can be utilized in this field in that an aircraft about to crash can send a distress signal to a satellite link, which would then be flashed to the relevant stations giving the details of position of crash, etc. In this way, a heavy loss of life and effort in search of lost aircraft can be avoided. And with the increasing number of vehicles in space, such a system will be indispensable. A more down to earth application of communication satellites is the possibility of T.V. and Telephone transmission between various parts of the world. This is only the beginning and satellites will play an ever-increasing part in communications in to-morrow's world.

References

1. A. C. Clarke, 1945, *Wireless World*. Vol. 51, 305-308.
2. S. P. Brown and G. F. Senn, 1960. "Project Score." *Proc. I.R.E.* Vol. 48, 624-830.
3. P. W. Siglin and G. F. Senn, 1962. "The Courier Satellite." *Communication Satellites*, L. J. Carter (Ed.), Academic Press, New York.
4. Project Telstar, 1962. *Wireless World*. Vol. 68, 208-209.
5. J. D. Kiesling, 1964. NASA's Relay I, *R.C.A. Review*, Vol. 25, 232-261.
6. Early Bird, 1965. *Engineering*, 199.
7. Intelsat Project, 1965. *New Scientist*, 695-696.