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EARLY BIRD TELEVISION TRANSMISSIONS

INTRODUCTION

IN THE SPRING of 1965 it became possible, for the first time, continuously to transmit live television between Europe and the United States. Furthermore, two programmes could be transmitted simultaneously, one from west to east, the other from east to west. The medium, of course, was Early Bird. Maintained in a stationary orbit over the equator at the mid-Atlantic, the 28-in. diameter satellite can be used 24 hours a day for television, voice and teletype. Although this single spacecraft alone is capable of almost doubling the current trans-Atlantic channel capacity, future systems will carry several television channels and thousands of voice channels simultaneously. The technology is here. Only motivation is needed.

THE SPACECRAFT

In order to understand television transmission via Early Bird it is necessary to understand the spacecraft itself. A photograph taken shortly before launch is shown in Fig. 1. It is 28 in. in diameter and weighed about 148 lb at lift-off. Solar cells provide 45 W of power and the spacecraft spins about its axis of symmetry at about 152 rev/min. Both the transmit and receive communications antennas are included in the mast on the upper end of the spacecraft. Because the satellite is constantly spinning, it is essential that the patterns of both the transmit and receive antennas be symmetrical about the spin axis and also contain the Earth within their beams. This is shown schematically in Fig. 2. By decreasing the width of an antenna beam, the gain becomes greater, but this could result in less of the Earth being covered. A compromise was made in Early Bird by limiting the beamwidth to about 11° for a peak gain of 9 dB on the transmit antenna. Furthermore, in order to place the peak of the beam near the latitudes of the U.S. and European ground stations, the antenna beam was tilted upward by 7°, as shown in Fig. 3.

Two television programmes may be passed simultaneously through the satellite. The r.f spectra and frequencies concerned are shown in Fig. 4. At the ground stations the video signals frequency modulate the respective 6 gc/s carriers. In Europe the carrier centre frequency is 6,301 Mc/s while in the U.S. it is 6,390 Mc/s. Each country beams its carrier at the satellite, where the two 6 gc/s signals are received, separated by two bandpass filters and routed to their respective repeaters. There are two separate and independent receivers within Early Bird. One receiver carries the signals from Europe to the U.S., while the other receiver carries the signals from the U.S. to Europe. Each receiver has an i.f bandwidth of 25 Mc/s and is therefore capable of working with broadband television signals.

A block diagram of one of the two repeaters is shown in Fig. 5. Using the European-bound television signal as an example, it is received at 6,389·97 Mc/s from the U.S., is filtered and then is converted to the i.f frequency of 59·54 Mc/s in the mixer. The signal is then amplified, limited and a beacon frequency inserted. Next, the signals are converted to the 4 gc/s band (4,160·75 Mc/s for the television signal and 4,137·86 Mc/s for the beacon) in the high-level mixer and are fed to the travelling wave tube (t.w.t) transmitter. Note that no processing of the frequency modulation has taken place during these operations in the satellite—only frequency conversion—resulting in a transmitted frequency-modulated signal with the same modulation index as that which was received.

The beacon signal was inserted in order to provide a known stable carrier for tracking and telemetry. These carriers are slightly outside of the main communications bands, as shown in Fig. 4. There are two t.w.t's in Early Bird, but only one is used at a time. The tube is the 215H made by Hughes Aircraft Company and has a saturated power output of 6 W at 4 gc/s, a gain of over 40 dB and an efficiency of about 30%. The effective radiated power (e.r.p) from the spacecraft is developed by both the t.w.t and the transmit antenna. When two TV signals are simultaneously passed through the satellite, the power available in each signal is about 10·5 dBW, or 11 W effective radiated power.

So far nothing has been said about the audio signal which must accompany the video signal. The audio is readily accommodated by frequency modulating it onto another carrier and placing it at one edge of the 25 Mc/s band. The energy distribution in a video signal frequency modulating a carrier (without pre-emphasis) peaks strongly in the vicinity of the carrier and falls off rapidly towards the edges of the 25 Mc/s band. The bandwidth associated with the audio signal is much less than that of the carrier so the two signals may be transmitted simultaneously within the same 25 Mc/s band with negligible mutual interference. The receive spectra when two TV signals are being simultaneously transmitted are shown in Fig. 6.

Significant spacecraft characteristics are summarized in Table 1.

GROUND STATIONS

So much for the spacecraft; now consider the ground stations. Those stations which are currently being used are shown in Fig. 7. Note that Andover (Maine) is the

COMMUNICATIONS CHARACTERISTICS OF SPACECRAFT

Receive antenna gain	4 dB
Receive antenna beamwidth (3 dB)	35°
Transmit antenna gain	9 dB
Transmit antenna beamwidth (3 dB)	11°
Receiver noise figure	8·5 dB
Bandwidth of each of 2 repeaters	25 Mc/s
Effective radiation power (each of 2 carriers)	10·5 dBW

Table 1.

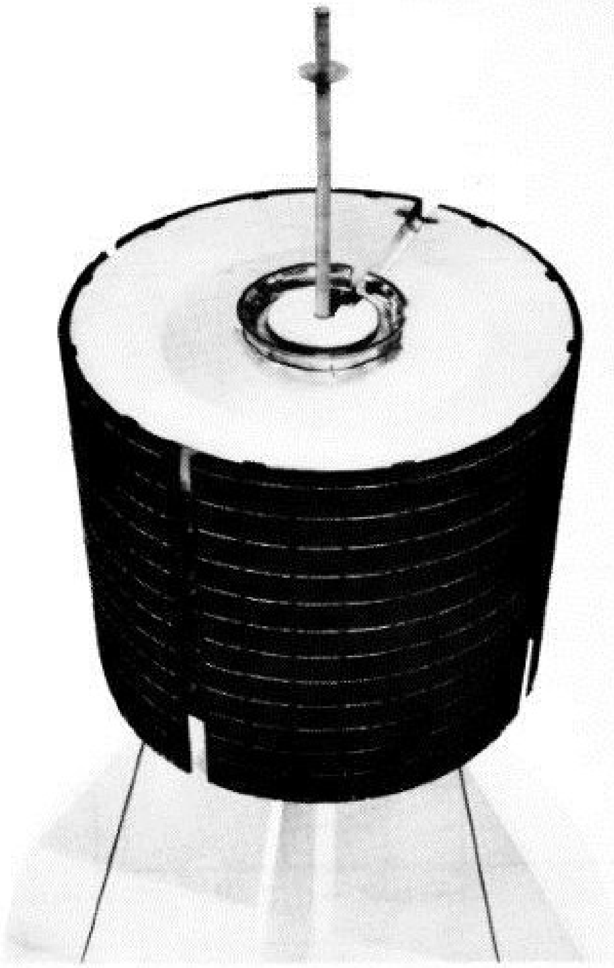

Fig. 1. The 28-in. Early Bird satellite uses solar cells providing 45 W of power for transmission and reception. The total weight of the satellite at lift-off is 148 lb.

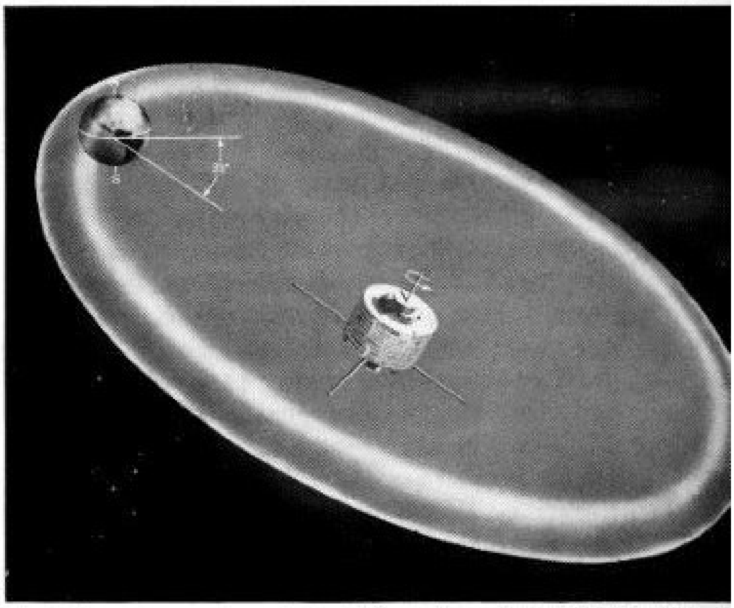

Fig. 2. The antenna pattern of Early Bird providing a beam width of 11° with a gain of 9 dB.

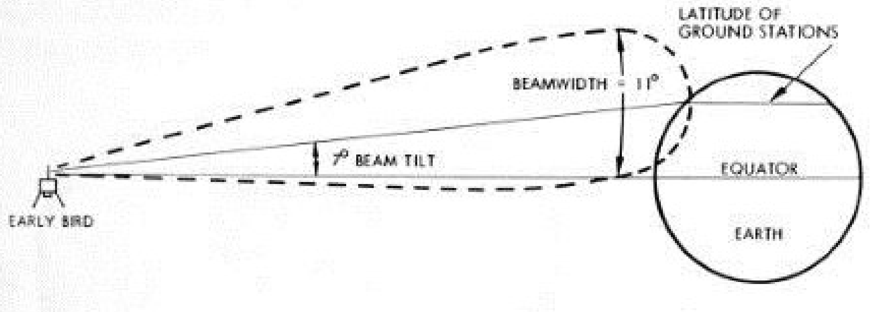

Fig. 3. Antenna beam tilt to favour U.S. and European ground stations.

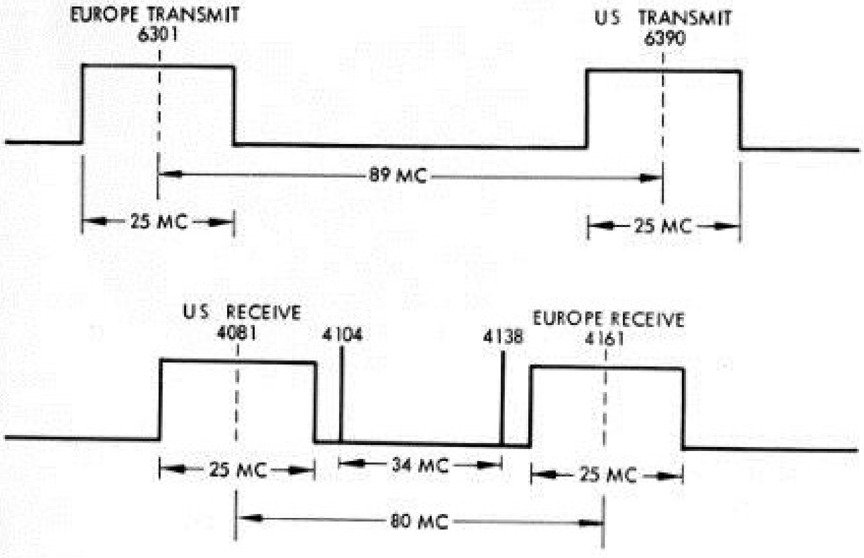

Fig. 4. R.f spectra available for Early Bird transmission.

only U.S. station. All stations except Fucino (Italy) have antennas which are approximately equivalent to 85-ft diameter parabolic dishes. Fucino has a 44-ft dish.

The ground-station transmitters generate between 2,000 and 5,000 W of r.f power at the antenna. Therefore, an 85-ft dish with a gain of 61 dB at 6 gc/s has an effective radiated power of 95 dBW, assuming a 2,500-W transmitter. The space attenuation due to the journey from the ground antenna to the satellite is about 200·5 dB. With 2 dB assumed for miscellaneous losses, the television signal which appears at the terminals of the 4-dB gain satellite receiving antenna is therefore about −73·5 dBm or 45 micro-micro W—a sizeable signal for space communications.

The satellite increased the TV signal level by about 115 dB. In other words, the TV signal power which is transmitted is 250 billion times greater than the signal power entering the spacecraft receiver at the antenna terminals. After all of this amplification, the effective radiated power is only about 10 W. This emphasizes how small the received signal was to begin with.

The signal is again attenuated by 197 dB propagating from the spacecraft to earth but is increased by the antenna gain of the 85-ft dish by 58 dB. The resulting signal level is now −98·5 dBm, or considerably smaller than that received at the satellite before amplification. Only the low noise temperature of the ground receiver—about 35°K—prevents this tiny TV signal from being completely obscured by receiver noise. Next, the signal is amplified and filtered and then enters a discriminator where the frequency modulated signal is converted to a video signal which can be displayed on a television receiver. The audio signal is processed in a similar fashion.

Although the i.f bandwidth of each repeater in the satellite is 25 Mc/s, best television reception is generally obtained if the bandwidth is limited to about 16 Mc/s in the ground receiver. This situation results because it is essential in f.m reception using a limiter-discriminator that the carrier-to-noise ratio in the i.f preceding the limiter exceed about 10 dB. The narrower the i.f bandwidth for a given received carrier level, the higher the carrier-to-noise ratio. However,

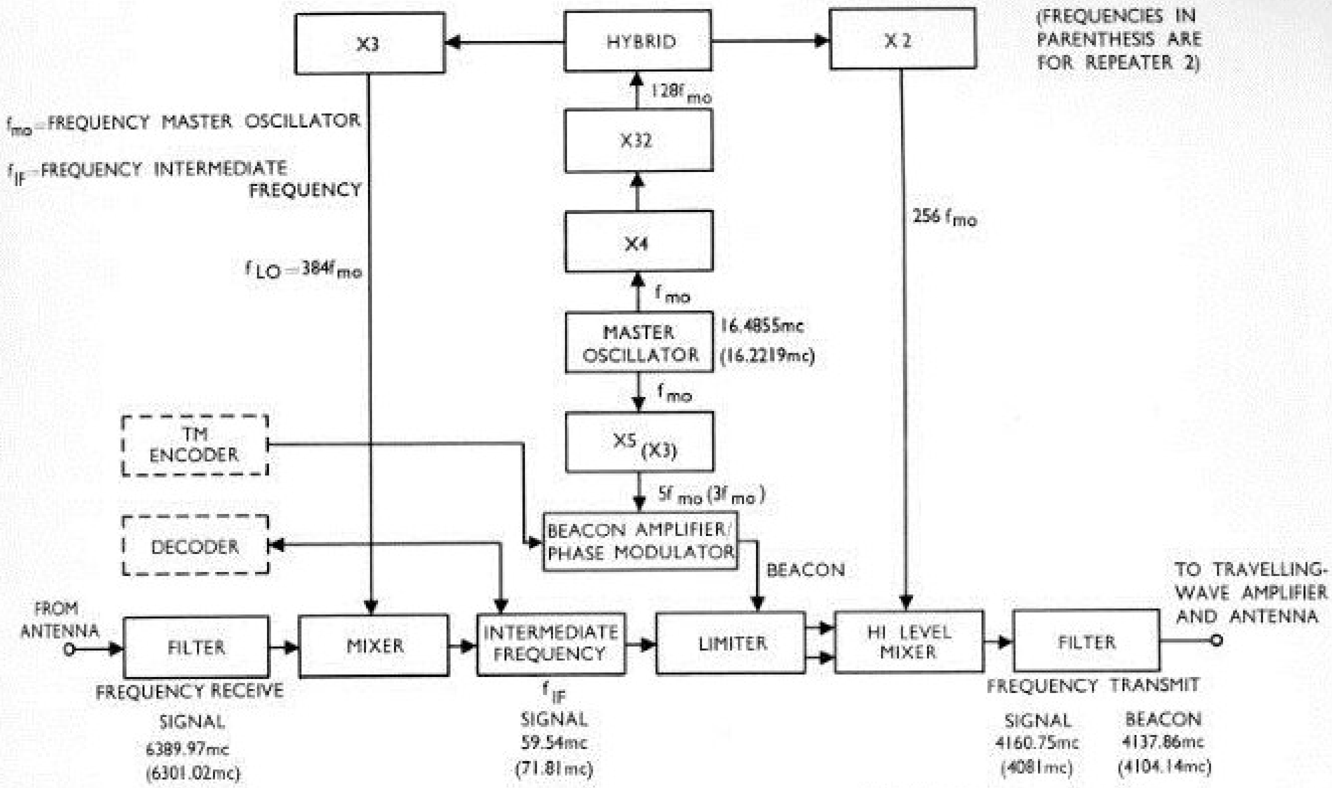

Fig. 5. Block diagram of repeater.

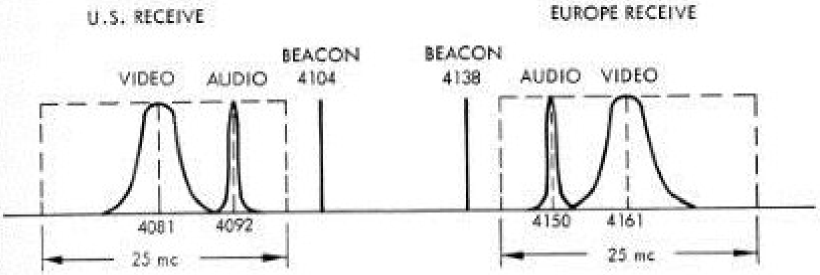

Fig. 6. Receiver spectra when two TV signals are simultaneously transmitted via Early Bird.

if the i.f bandwidth is reduced too much, distortion in the video signal becomes excessive. It has been determined empirically that a 16 Mc/s bandwidth is a good compromise under normal operating conditions.

When it rains at the receiving ground station it is often necessary to reduce the bandwidth in order to maintain a carrier-to-noise ratio greater than 10 dB since the rain causes some signal attenuation. This situation is further aggravated at those stations which use radomes to house the antenna since water on the radome causes the effective noise temperature of the receiver to increase, thus reducing the carrier-to-noise ratio even further. Even greater reduction in the receiver bandwidth may be necessary under these conditions, accompanied by reductions of the frequency deviation and degradation of the video signal-to-noise ratio.

Under normal signal conditions the video band is limited to about 4·0 Mc/s and pre-emphasis and de-emphasis circuits are used. The ratio of peak-to-peak picture signal to r.m.s weighted noise is about 47 dB.

The audio carrier is received at a level about 13 dB below the video carrier and is band limited to about 300 kc/s. Under normal conditions the audio weighted signal-to-noise ratios are on the order of 48 dB.

FUTURE DEVELOPMENTS

Impressive though the accomplishments have been of Early Bird in the international TV transmission field, much more can be done in the next generation of communication satellites. Of the 500 Mc/s bandwidth available in the commercial communications band

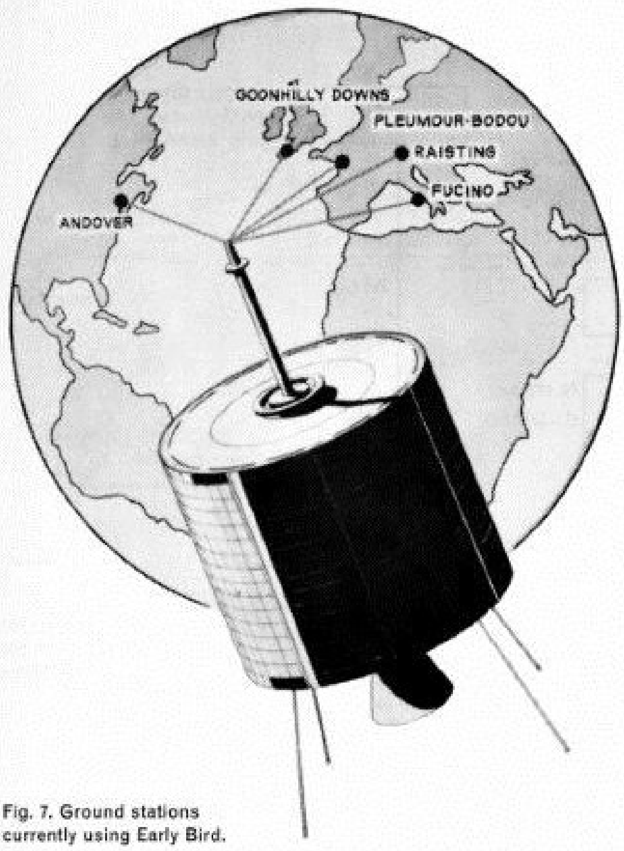

Fig. 7. Ground stations currently using Early Bird.

(5,925 to 6,425 Mc/s transmit and 3,700 to 4,200 Mc/s receive), Early Bird is capable of using only a total of 50 Mc/s. Therefore, in designing a new system the bandwidth would be increased to 500 Mc/s and the effective radiated power of the satellite would be increased to permit the ground stations to receive adequate power per channel. It is evident that this system could carry many TV programmes simultaneously.

A linear repeater in the spacecraft would replace the limiting repeater in Early Bird. The linear system results in less intermodulation distortion when several different carriers are simultaneously passed through the satellite.

The effective radiated power is increased in two ways: first, increasing the transmitter power; second, increasing the antenna gain. The transmitter power may be increased by adding to the number of t.w.t's which drive the antenna. This, in turn, demands greater power and thus requires an increase in solar cell area and a larger spacecraft. Multiple low-power tubes have an advantage over a single high-power tube in that redundancy is inherent and the tubes are already available. Additional antenna gain is achieved by forming a pencil beam which illuminates only the earth, instead of radiating most of the energy into free space, as is done in the current system shown in Fig. 2. At synchronous altitude the earth subtends an angle of 18° as seen from the satellite. Therefore, this establishes the optimum beam width. The pencil beam is shown schematically in Fig. 8. Such a beam may be formed by either an array of elements or a reflector. A spin-stabilized satellite requires that the beam be despun in order that it always point towards Earth. This is accomplished by either electronic phasing of an array or mechanically despinning an antenna.

A communications satellite which fulfils all of these requirements for global coverage is shown in Fig. 9. The spacecraft diameter is 9 ft and the height of the solar panel is about 6 ft. This solar array is capable of providing over 500 W of power. Sixteen t.w.t's provide a total of 100 W of r.f power and the electronically despun antenna develops a gain of 17 dBW, resulting in an e.r.p of 5,000 W. With a repeater bandwidth of 500 Mc/s both multiple channel television and multiple access voice circuits can be transmitted simultaneously. The spacecraft weight at launch is about 1,530 lb and is readily carried by the well-proven Atlas–Agena launch vehicle.

With very little change in the basic spacecraft, a very significant advancement in the field of educational television may be made by using the full spacecraft

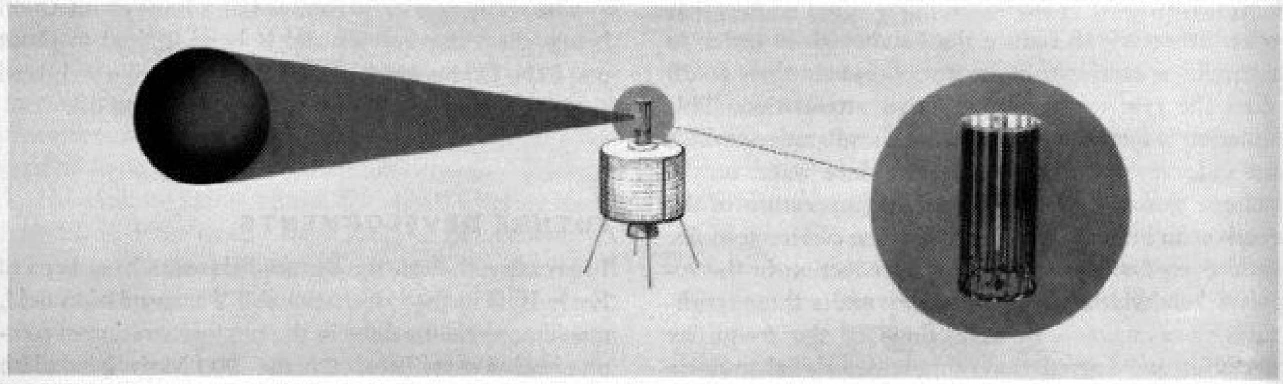

Fig. 8. Pencil-beam illumination of the Earth.

e.r.p to transmit a single channel. By so doing the requirements on the ground receiving station are reduced to a very modest and inexpensive level. High-quality television programmes may now be received using a 6-ft diameter antenna and an inexpensive solid-state converter adaptable to any commercial television set. Every little isolated hamlet or school, regardless of its location, can now be an independent receiving station with access to the most sophisticated level of programming or educational system which the sponsoring country cares to provide. The cost of the antenna and converter is of the same order as the cost of the television set itself.

The technology for these high-capacity communications satellites exists today. No additional research is needed to make the system operational in less than two years. Only motivation is required.

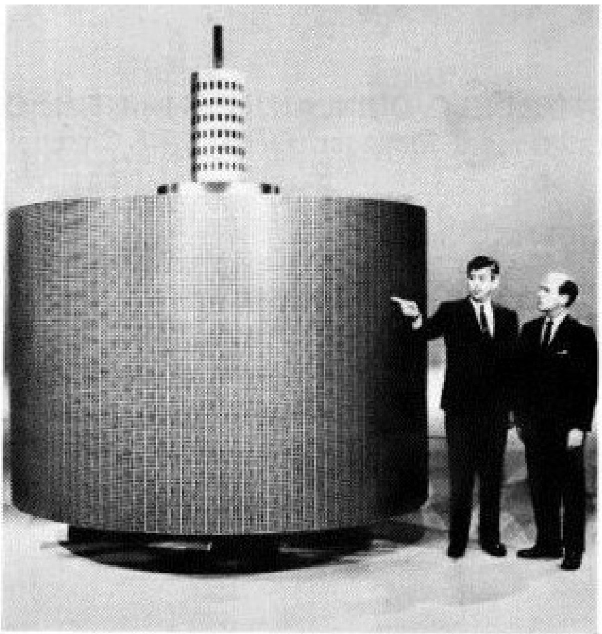

Fig. 9. Global coverage communications satellite.