Great develop's of 20th century reviewed in rec. New Yorker

From + By Harold Rosen



**Syncom**

The story of Syncom begins with the convergence of two events in the late 1950's related to the cold war and the beginning of the space age. These events affected the viability of the radar department at Hughes Aircraft Company, my employer at that time. One of the department's biggest projects -- an advanced radar for an interceptor being designed to counter a fleet of high speed Soviet bombers -- was abruptly cancelled when it was learned that the bombers themselves were to be replaced with ICBMs. Shortly thereafter, the advanced state of the USSR rocketry was dramatically emphasized by their launch of Sputnik, the world's first artificial satellite. My department head, Frank Carver, challenged me to find a new project which would use some of our radar technology to keep our staff gainfully employed. After conferring with my colleagues Tom Hudspeth, a brilliant communications engineer and avid radio amateur, and John Mendel, who was leading the development of advanced traveling wave tubes for our radars, both independently suggested to me that the new project be a communication satellite. Both pointed out the then sad state of international communications -- telephony was hard to schedule and very expensive, and transoceanic television was impossible. These problems, they said, could be overcome with a properly designed communication satellite system. This excited me. I began to learn all I could about what appeared to be an important and relevant field.

Don Williams, another brilliant colleague whom I had lured into my small advanced development group with the promise of working on space projects, had been thinking independently about satellites and was already developing a concept for a navigation satellite. I wasn't thrilled with that objective, but was intrigued with several features of his design: first, it was in a geostationary orbit; and second, he had analyzed the mechanics of the orbit sufficiently to show how little impulse was needed to change from one orbit location to another in a reasonable time.

My most valuable reading was of a seminal paper in the March 1959 IRE Journal titled "Transoceanic Communications Via Satellites," written by John Pierce and Rudy Kompfner of the Bell Telephone Laboratories. I knew of John Pierce's reputation as one of the world's finest communication scientists, who among many other accomplishments had tamed the traveling wave tube's propensity to oscillate thus making it a valuable wideband amplifier. The paper, which was very instructive, contained a link budget which showed how little satellite transmitter power was needed to provide a useful communication link to a ground terminal. I was struck by this: compared to our department's radars, which had to transmit powerful signals in order to detect weak reflections from the target, transmitting a signal from a satellite seemed relatively easy. The paper discussed many different possibilities for satellites: active repeaters, passive reflectors, fleets of satellites in low altitude orbits, and a system using geostationary satellites. Of these options, the authors favored the low altitude fleet equipped with active repeaters. To them, the geostationary solution was deemed too complex to be practical. (Unbeknownst to me at that time, there was an ongoing government program, Advent, to design a geostationary satellite that was proceeding as smoothly as the biblical Tower of

Babel, and I now believe John had based his negative assessment of the geostationary solution at least partly on that program's many problems.) In order to have the reliability and long useful lifetime for a good communication system, their proposed low altitude satellites had neither attitude nor orbit controls to perform their mission. To do this, their antenna patterns were nearly omnidirectional and the orbital spacing between satellites was not maintained. I could see that this system design had drawbacks. It needed a large number of satellites to prevent frequent gaps in service and relatively high power built into the link to accommodate the low gain antenna. On the other hand, the geostationary satellite requires a number of active attitude and orbit control elements that must match the lifetime of the communication system. This, of course, would make the satellite heavier. Not only that, but a geostationary satellite would need to be launched into an orbit that needed an additional 4000 meters per second velocity increment, which would require more fuel, over that of a low altitude satellite. Given the small launch vehicles then available, it seemed to me that the authors considered this to be too difficult a challenge.

I, however, reached a different conclusion, despite my respect for the authors. They were communication experts; I had spent the first part of my career (at Raytheon) in the design of high performance antiaircraft guided missiles, and felt I was a better judge than they of the difficulty of guidance and control for a geostationary satellite. I was inspired to try to find a practical design for a geostationary communication satellite with the technology that was then available or that could be readily developed. I knew that the both the basic communication and control elements would have to be as light as possible.

While pondering various possibilities in August, 1959, I remembered back to a Caltech classroom discussion from years earlier on the dynamics of rotating bodies. The physics course was being taught by Carl D. Anderson, a renowned but modest Nobel laureate. I asked if he could explain in simple terms the powerful stabilizing effect against external influences that spin had on objects such as footballs or artillery shells. He couldn't do so offhand, but together we worked out a comparison of the effects of external torques on similar bodies, one spinning and one not, over a period of time. The effect of the spin was to reduce the angular disturbance by a factor approximately equal to the angle through the body had spun in that period, which could easily be millions of radians.

Using this earlier knowledge, I made a few calculations that led me to an estimate that the spin axis attitude of a spinning satellite could be maintained for a useful period with no active attitude control. In an epiphany, I realized that if the spinning configuration were adopted, with the spin axis parallel to the earth's axis, it would enable spin phased impulses to permit a single thruster to control both the period and eccentricity of the orbit, a major simplification. An obvious disadvantage of spinning was the difficulty of incorporating a high gain antenna for the communication system. However, even with a beam pattern that was a figure of revolution around the spin axis, significantly more gain than omnidirectional could be achieved by narrowing the beam pattern in a plane containing the spin axis, and valuable communication bandwidth resulted despite this less than optimum pattern. I felt that in the future, an electronic or mechanical beam despin system could be employed to provide still more gain, but that it was best to start with the simplest possible approach. A second disadvantage was the relative ineffectiveness of the spinning solar panel compared to a flat, sun oriented array. However, adequate power for the light weight, efficient payload could be obtained with a cylindrical array.

When I conveyed this concept to Don Williams, he enthusiastically jumped aboard and together we started filling in some of the details, such as how to achieve the initial orbit and orientation. Since we were unaware of the Thor Delta booster development program then underway, we selected the low cost Scout sounding rocket as the launch vehicle. We added a small fifth solid rocket to the Scout's four solid stages to achieve the high energy transfer orbit, and incorporated an even smaller sixth stage (an apogee kick rocket) inside the satellite to change from the transfer orbit to the synchronous orbit when it reached apogee. For our launch site we selected a small equatorial island, Jarvis, so that no plane change (removal of inclination) would be needed to achieve the equatorial orbit. Since the upper stage of the Scout was spin stabilized, we retained the spin to stabilize the added stages. Since the booster's spin axis was in the equatorial plane, we required a 90 degree reorientation to get to the operational spin axis attitude. This was done in two steps -- the initial spin was killed by en electric motor reacting against the spent fifth stage, followed by separation and spin in the desired attitude effected by tiny spin rockets.

For attitude sensing, Don invented (and built in his garage!) a V-beam solar sensor that determined both the spin phase and the angle between the spin axis and the sun line. The second attitude sensor that was required to unambiguously determine the spin axis attitude was the polarization of the communication signal.

While Don and I were working these issues, I asked Tom to design a communication payload that would also provide the necessary telemetry and command links. Since ITU frequencies had not yet been allocated for satellite use, we picked our own: UHF (470 MHz) for the uplink, and 2 GHz for the downlink. Microwave transistors were not yet available, so frequency multipliers were used for the local oscillator signal, and a traveling wave tube amplifier for the transmitter. Tom's design turned out to be remarkable for its low weight and excellent performance. He also designed the collinear dipole array antenna that generated the desired communication beam pattern.

For the satellite transmitter, I knew that we would need a lightweight (lighter than any then available) traveling wave tube. For this design, I approached the expert in this area, John Mendel, who worked in a different area of the company. TWTs were then emerging as the preferred microwave amplifiers for many applications, and high power versions were being developed for use in radar transmitters. This ingenious device, invented by Kompfner and made practical by Pierce, was even at the relatively low power of our satellite transmitter simply too heavy for use in our design. The weight was mostly in the focusing magnet used to confine the beam radially. John decided that he could make the focusing structure much lighter by using a field of alternating sign along the beam axis, effected by a multiplicity of very small permanent magnets of alternating field direction replacing the much larger single magnet design then in vogue. To compensate for the less effective focusing than that was provided by a uniform field, he made the envelope of metal rather than glass, with ceramic windows for the input and output leads and the power connections. This construction permitted the tube to be baked out during manufacturing at a temperature high enough to handle the higher beam interception than that occurring in the heavier tube. This metal ceramic, periodic permanent magnet TWT was considered a difficult but doable development whose advantages far outweighed the risks. It has proven to be an extremely valuable product that is the transmitter of choice in most communication satellites even today, nearly 50 years later.

With a paper design of the communication payload now available, Don and I worked together to improve the aforementioned control system. Don was a gun fancier, and had used bullets in his navigation satellite design to provide the control impulses. When we learned of the availability of fast-acting pneumatic valves, we changed to bursts of compressed nitrogen for providing orbit control impulses. I realized that we could now replace the relatively cumbersome despin-respin initial orientation with a reaction controlled reorientation maneuver. I thought that four additional thrusters would be required to minimize the nutation during this reorientation maneuver; Don showed me that the maneuver could be achieved more simply with just a single additional thruster. This orientation thruster would also enable us to adjust the spin axis orientation over the lifetime of the satellite if solar radiation pressure unbalance or other perturbations caused it to precess excessively.

I was now convinced that we had a practical design which could provide substantial transoceanic bandwidth at a relatively low cost. At the going rates for transoceanic telephony, it could be very profitable. There was no established rate for television, since transoceanic service was not available. With the support of Frank Carver, we presented our plan for a communication satellite business based on our satellite design to Allen Puckett, and subsequently to Pat Hyland, our general manager. (Howard Hughes, the company founder, had by then become a recluse but retained the title of president.)

The presentations led to a formal study Sam Lutz, who directed engineering for the Hughes communications division. The resulting Lutz report enthusiastically made the case for the communication satellite venture that would be funded and operated by Hughes. But Hughes upper management was more cautious, and the project did not receive the support needed for the next steps -- developing and demonstrating a prototype of the satellite. Instead, we were encouraged to seek government support for the project. To that end, in January, 1960, Don and I prepared a descriptive brochure summarizing the technical features of the system. We made presentations to high levels at the newly formed NASA, but they dismissed the concept with no sign of further interest. As time passed without this hoped-for support, Tom, Don and I decided to try to do it ourselves. We would pool our resources to the extent of $10,000 each as seed money and to try to find outside investors. We thought that an additional million dollars or so would be needed to get to the project off the ground, literally.

This was not the most auspicious time to propose a commercial space program -- the most vivid impression most people then had of space related activities was of rockets blowing up at Cape Canaveral. The thriving venture capital businesses we have today had not yet been formed -- it would be another twenty years before my brother Ben would become a noted venture capitalist in the emerging personal computer sector. Faced with universal skepticism, we quickly ran out of contacts. In March 1960, in desperation, I called a former colleague at Raytheon, Tom Phillips, who had by then risen through the ranks to become its executive vice president, and outlined our plan to him. He invited the three of us to brief him and the rest of the upper management of Raytheon.

This briefing occurred shortly thereafter at Raytheon headquarters in Waltham, Massachusetts. Among those attending were Raytheon's president, Charles Francis Adams, and the vice president of engineering, Ivan Getting. Tom was sold on the merits of the satellite system, but not on the private venture aspect of our proposal. He offered instead to pursue the system as a Raytheon venture, with the three of us becoming Raytheon employees in Massachusetts. It wasn't all that we wanted, but I felt it was the best we could do.

Upon returning to Hughes the next day, I told Frank Carver I was resigning to accept Raytheon's offer. He wouldn't accept my resignation without a fight, and arranged a meeting with Allen Puckett. Allen told me that he and Pat Hyland had had further thoughts about the project and had decided to invest company funds in a prototype development. When Pat Hyland himself personally assured me of this decision, I felt elated. Even though we would not have a direct financial stake in the enterprise, we could now proceed with my main objective, the development and demonstration of the system.

Frank Carver provided laboratory space for the design of all of the communications electronics (except the for the traveling wave tube, which would take place where John Mendel worked in the microwave tube lab). The skills we had honed in designing state of the art airborne radars were well suited to those needed for our satellite: a greater sensitivity to weight and efficiency issues than those involved in the design of ground equipment. Before long, we were able to demonstrate a communication transponder that relayed a television signal or multiplexed voice signals in the laboratory, using flight-like electronics minus the traveling wave tube whose development as expected took longer. The telemetry and command functions, whose requirements were quite modest, were integrated into the communication system in order to save weight. The antenna that would provide the flattened-doughnut-shaped beam pattern during the satellite's operational phase consisted of a coaxially-fed linear array of dipoles. In order to handle telemetry and command signals while the satellite was still attached to the launch vehicle, the antenna was split into three identical sticks fed in parallel, which were spread out to lay on a conical surface during the launch phase, in order to provide continuous telemetry and command access.

Don demonstrated the smooth precession of a spinning wheel obtained by pulsing a single thruster in synchronism with its spin. He used a toroidal tube to store the gas and provide the spin inertia, the assembly being mounted on a spherical bearing. (Motion pictures taken of this precession later proved to be an important part of subsequent patent infringement litigation, which was eventually settled in Hughes' favor.)

Feeling pleased that most of the major elements of the satellite had been demonstrated, we once again tried to obtain government support. Allen Puckett was now an enthusiastic advocate and presented the concept to the Space Science Panel of the President's Science Advisory Committee. He arranged for Don and me to brief many of the defense agencies within which he had contacts. But the Department of Defense had its own project, the previously mentioned Advent satellite, and wasn't interested in hearing of a practical alternative. Unfortunately, NASA had signed an agreement with DOD which prevented it from supporting a competing synchronous satellite system. So these overtures to the government were all doomed from the start. We also tried to form a venture with the General Telephone and Electronics Corporation (GTE), whose west coast technical staff endorsed our concept only to have their recommendation rejected by their management. We also presented our case to Bell Telephone Laboratories, but we were unable to persuade them to reconsider their objections to the geostationary system. (John Pierce has since written that he regretted his negative assessment at this meeting. We later became friends and shared the 1995 Draper Prize for our work in communication satellites.)

The year 1961 began with neither a government program nor a commercial partner, and the outlook was bleak. When NASA issued a request for proposals for a low altitude satellite, Hughes decided to bid even though no part of our design was appropriate to that orbit. The low altitude system, to be called Relay, was NASA's attempt not to be left out of the communication satellite field – AT&T/ Bell Lab's low altitude system was beginning to move from concept to active program – and, as previously mentioned, a geostationary orbit system was precluded by its agreement with the DOD. I was neither surprised nor unhappy when we lost the Relay competition to RCA. I felt that RCA could become a formidable competitor in this field and was glad to see their able technical staff tied up in a program that I was certain had no future.

The situation was still bleak.

In the spring of 1961, Hughes decided to display our satellite at the Paris Air Show, which had become the world's most important trade show for air and space related products. Tom and I were sent to demonstrate the relay of television signals via our satellite repeater across the display booth. For us, it was an exciting time. The demonstration was quite popular, and generated much interest and press coverage. Company Francais Thompson Houston (CFTH) hosted a demonstration of the satellite on the Eiffel Tower, revealing the system to an even wider audience. Alas, in the end no sales resulted. But things were about to change.

John Rubel, a former Hughes executive who had become Assistant Director of Defense Research and Engineering, had been given a briefing on our satellite program during an official visit to Hughes. At that time, I could tell from his reaction to our demonstration of the communication and control systems that he was extraordinarily excited, but I didn't know why. I learned later that he had become convinced that the troubled Advent program that he had inherited would never work, and saw our program as a possible substitute. In the spring of 1961, working behind the scenes in Washington with both DOD and NASA personnel, he managed to annul the agreement restricting NASA from the geostationary orbit and helped create a joint DOD-NASA program which became known as Syncom. The Syncom satellite development would be contracted for by NASA. NASA would also supply the launch vehicles, while the ground stations, which had been developed as part of the Advent program, would be supplied by DOD. A contract was awarded to Hughes in August 1961 to construct three satellites based on our design. We were, to say the least, exuberant. (I have remained in contact to this day with John Rubel, a vibrant and lively man in his 80s who likes to flirt with my wife.)

Although Syncom was based on our system design, significant changes were nonetheless required. The launch vehicle chosen by NASA was the new Delta which launched from Cape Canaveral. The higher payload capability of the Delta allowed the use of redundancy in all of the communication and control elements, which was of course desirable. The 28 degree latitude of the launch site meant that the satellite could not initially be injected into an equatorial orbit. This resulted in considerable north-south motion as seen by the ground stations, so that tracking would be necessary. But planned improvements in the Delta would make this only a temporary impairment, since later augmented Deltas would permit launch trajectories from which the inclination could be removed by the apogee kick motor. Another significant deviation from our original design was a change in the uplink frequency, required for compatibility with the Advent earth stations. This required another exotic multiplier development to provide the local oscillator signal, not an easy task with the components then available.

Our team grew quickly as we set about building the three satellites. On the NASA side, overseeing the technical compliance was Bob Darcy, who proved to be particularly helpful in resolving technical issues as they arose. Under John Mendel's supervison, completion of the development of the traveling wave tube progressed smoothly since adequate funds were at last available for this essential task.

Another improvement resulted from a visit to the launch site in the fall of 1961. I observed a small rocket on a stand emitting puffs of a white gas and was told that it was steam resulting from a test of its hydrogen peroxide control thrusters. Up to this time, I had not been aware that hydrogen peroxide could be used in a pulsed mode. Since this liquid propellant provided a much higher specific impulse than compressed nitrogen, I convinced NASA to let us use hydrogen peroxide for our redundant control system, which substantially increased our control capability.

By the end of 1962, the first flight model of Syncom was nearing completion and a launch was scheduled for February 13, 1963. After three years of struggle, the moment of truth had arrived.

The launch preparations proceeded smoothly and the Delta rocket lifted off at the appointed time. The Delta performed flawlessly, placing Syncom 1 in the desired transfer orbit during which normal telemetry was received. Five hours later its solid fueled apogee kick rocket was ignited for an expected 22 second burn. But one second before burnout, all signals disappeared, never to be heard again. The disappointment was almost unbearable.

But I knew that we could waste no time on mourning. We had a second flight model to launch. We quickly identified three possible causes of the disaster: an apogee rocket explosion, a burst of one of the nitrogen tanks, or a wiring failure. To be safe, corrective measures were taken to all three areas, and Syncom 2 was shipped to the Cape to prepare for a July 26 launch.

The launch preparations this time were extremely difficult because of heightened concern about the consequences of a second failure. Many imaginary problems were dealt with by our team, and just when it appeared that we were good to go, a real problem arose, or so it seemed -- the communication repeater broke into a hard oscillation. The satellite was by now fueled and mounted atop Delta's third stage, and bringing it down for troubleshooting at that point was almost unthinkable. Instead, we lugged a heavy spectrum analyzer up to the 13th floor of the gantry, the last three without benefit of an elevator, so that we could troubleshoot in situ. Tom Hudspeth then performed some more of his magic -- by placing his fingers between the folded down communication antenna and the receiver he could suppress the oscillation, thus determining that the feedback path was between the antenna and the receiver. Since we had never before tested the communication system with the antenna folded down, which was the launch but not the operational configuration, we felt the system was probably okay in its operational mode, but we had to find a way to prove it. When we reproduced the oscillation on the prototype down below and showed the NASA folks that it disappeared when the antenna was erected, we were finally given a launch go ahead.

Once again the Delta performed flawlessly, and the telemetry was normal during the transfer orbit. The apogee rocket was fired on time, we held our breath and to our great relief, this time we survived the burn. We were in a 24 hour orbit!

A few days later, the reorientation maneuver involving thousands of spin synchronized pulses was performed for the first time on a satellite. With the spin axis now orbit normal, we could communicate with the earth stations 24 hours a day. The new era of continuous space communications had begun.

President Kennedy used Syncom in an historic conversation with the Prime Minister of Nigeria, in August, 1963, beginning its five years of service to the U.S. government.

These five years clearly demonstrated that, despite many predictions that it wouldn't be reliable enough, Syncom proved that a geosynchronous satellite could have the necessary reliability for communications.

With most of the technology for geostationary satellites proven, we started planning modifications in the last of the three Syncoms to achieve the remaining objective, the demonstration of a geostationary orbit. Taking advantage of planned improvements in the Delta, we designed a mission in which some inclination reduction would be performed by the Delta at perigee injection into the transfer orbit. The remaining inclination would then be removed by the improved apogee rocket (already used for Syncom 2), which would finally result in an equatorial (hence, geostationary) orbit.

Syncom 3 was scheduled for launch in the summer of 1964, shortly before the Tokyo Olympics. We received a request to provide television coverage of these events. What an opportunity – never before had the Olympics been seen in real time overseas. In order to improve the quality of the television signal, we increased the bandwidth of one of the satellite transponders and installed a liquid helium cooled maser as an ultra low noise receiver for a large ground antenna at Point Mugu, a naval facility 50 miles to the north of our Hughes plant. (This antenna had originally been installed for the Advent program.)

We and the Delta team were getting good at this. The launch and subsequent operations proceeded flawlessly and the first geostationary orbit was achieved in August, just a few weeks before the opening ceremonies. Even though the effective radiated power of satellite was only about seven watts, the sensitive receiving system allowed continuous transoceanic television of the events.

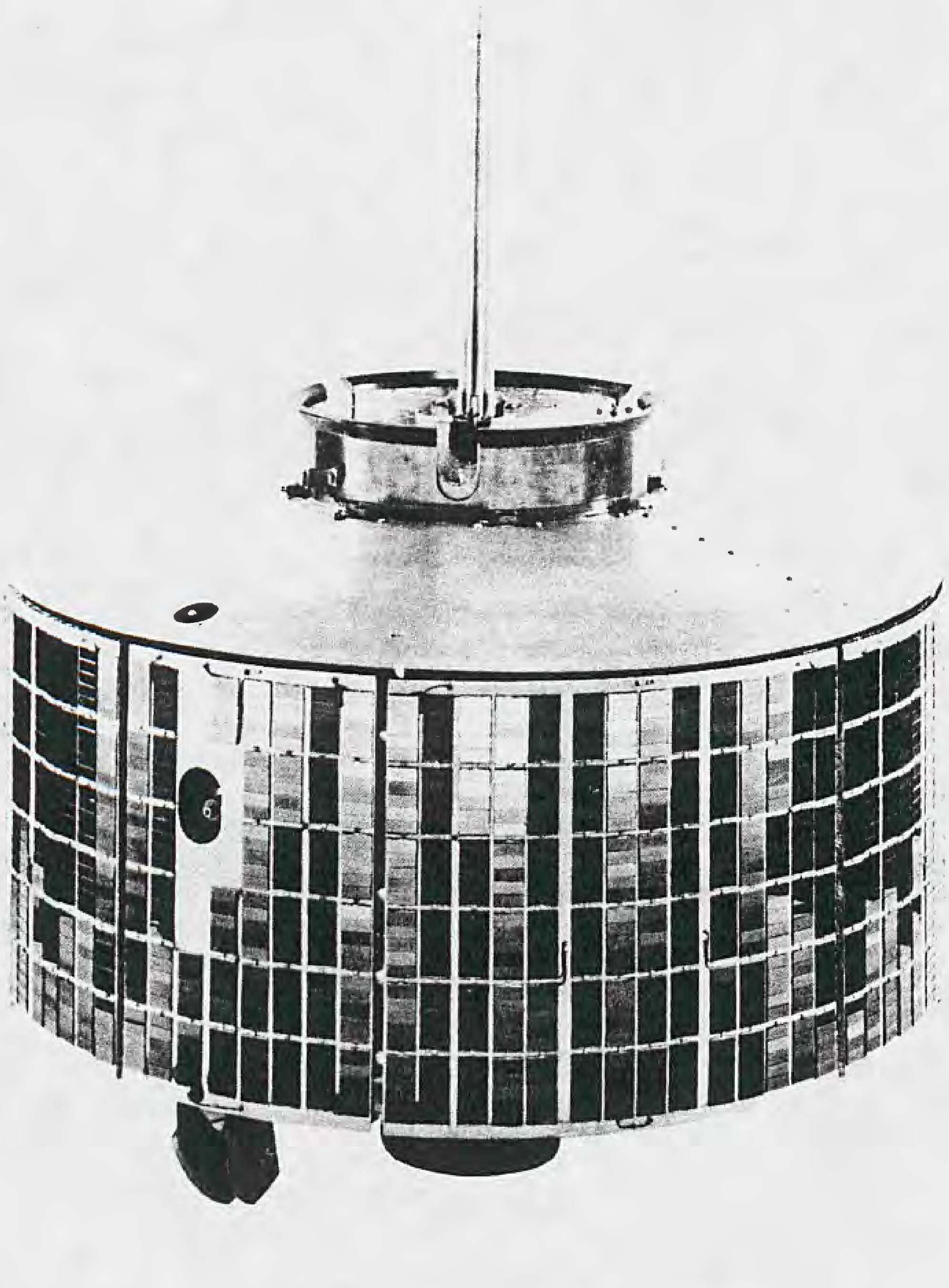
The Communication Satellite Corporation (Comsat) had been chartered by an act of Congress to provide commercial satellite service. Noting the success of Syncom 2, Comsat had contracted with Hughes in April, 1964 for delivery in one year of a commercial derivative of Syncom for its first satellite. This new satellite would later be called Early Bird. The era of commercial satellite communications was about to begin.

# COMMERCIAL COMMUNICATION SATELLITE

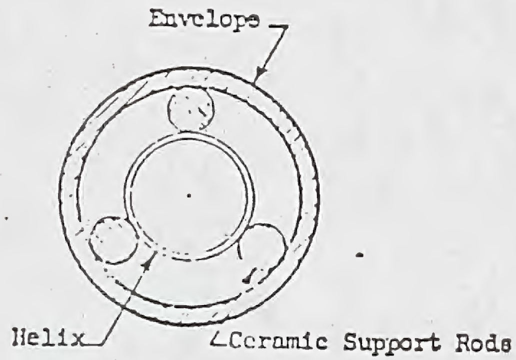
RDL/B-1

H. A. Rosen
D. D. Williams

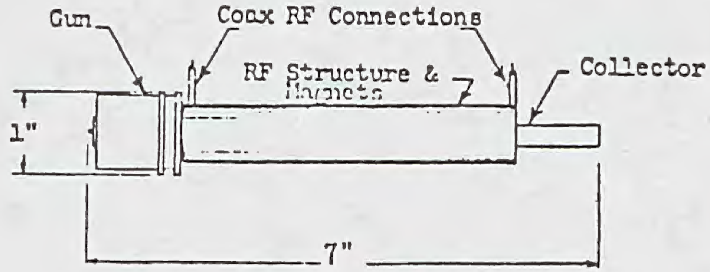
January 1960



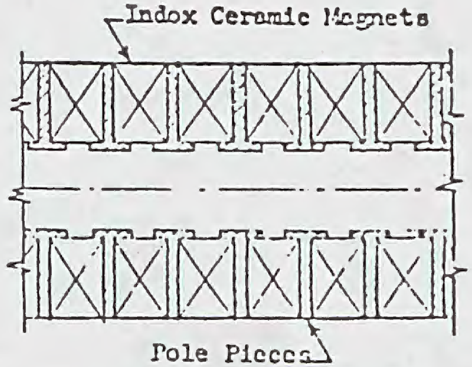
Hughes satellite payload.



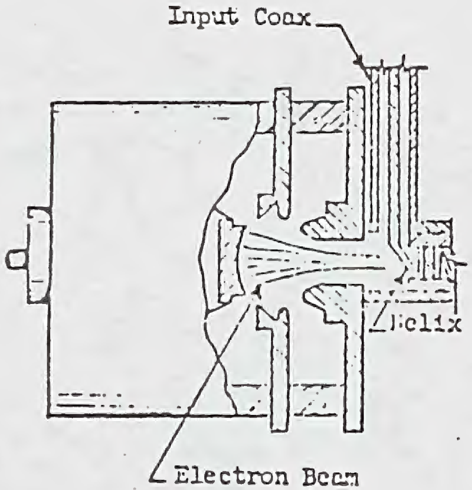

Helix Support Detail




LAL-1 Complete



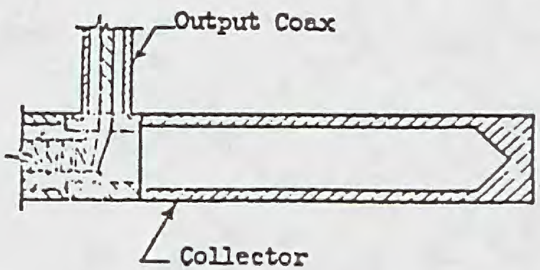

Periodic Magnet Detail




Gun Detail

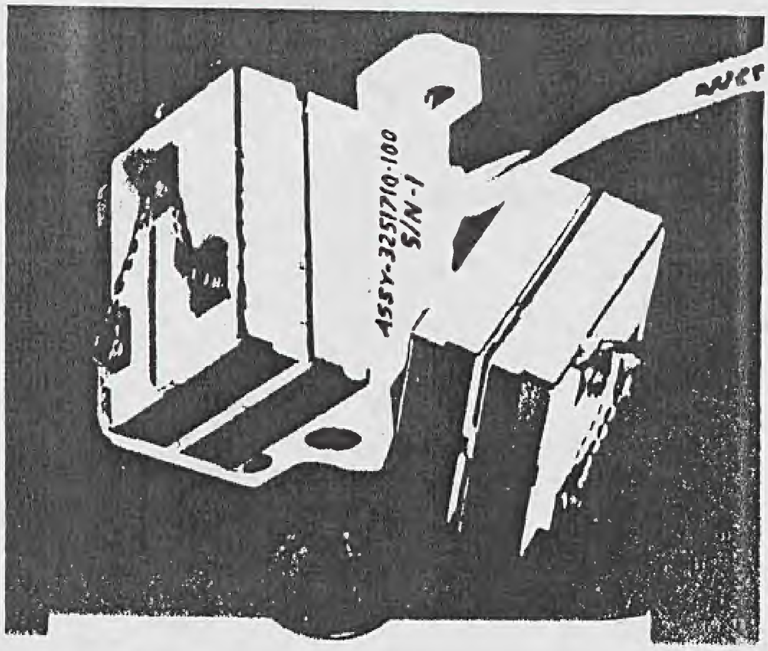
Specifications:

| | |
|---|---|
| Power Output | 2.5 watts |
| Gain | 30 db |
| Efficiency | 33% |
| Weight | 12 oz. |
| Frequency | 1800-2200 mc |
| Filament Power | 2 watts |
| Life | 10,000 hrs. |
| Focusing | Periodic PM |
| Envelope | Metal-Ceramic |

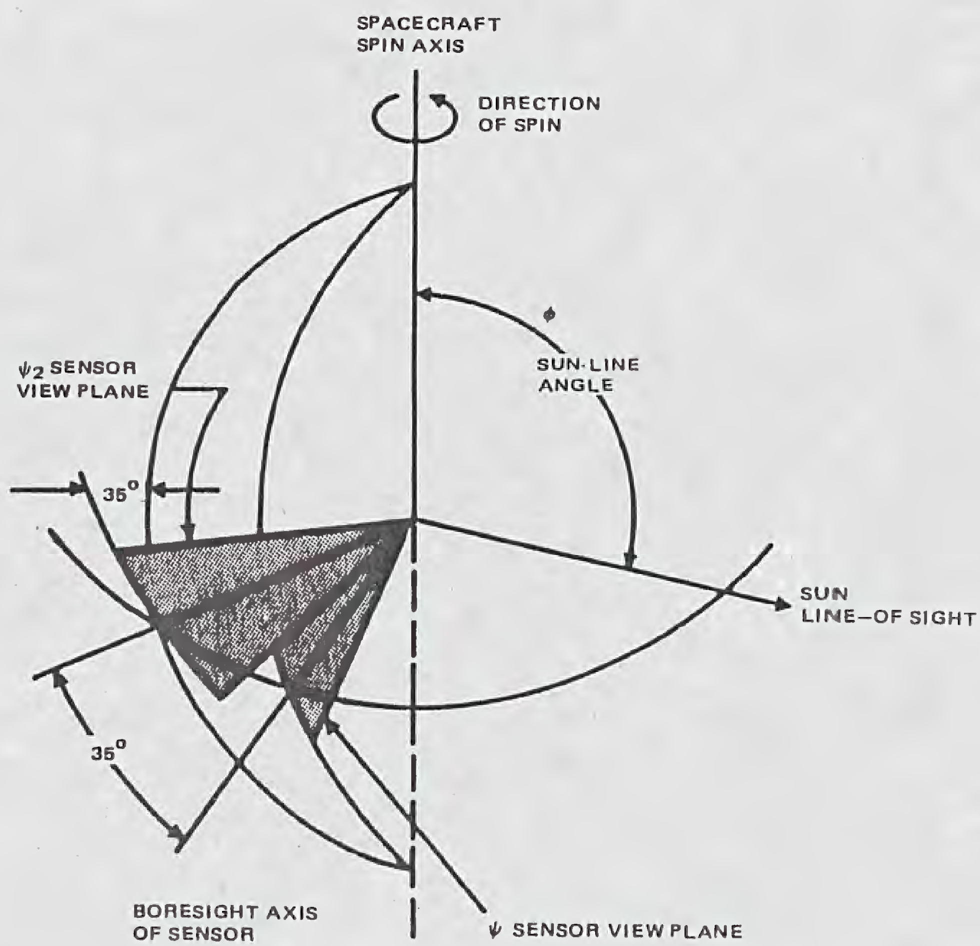



Collector Detail

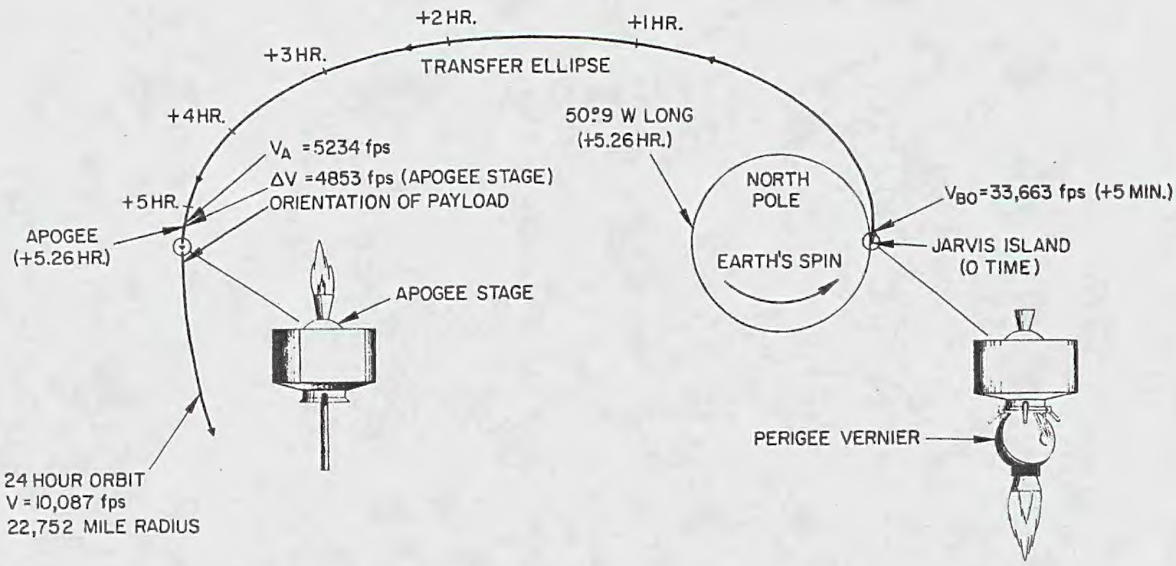
Payload traveling wave tube – LAL-1.



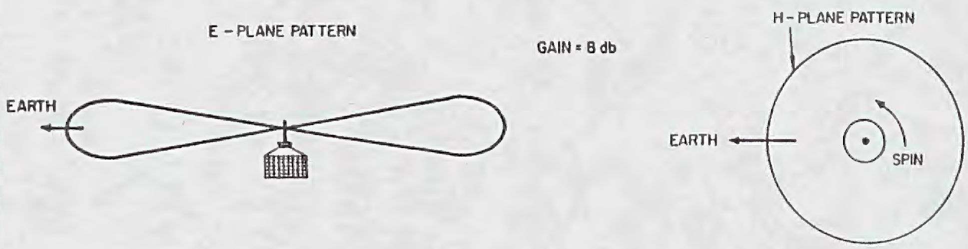
SUN SENSOR



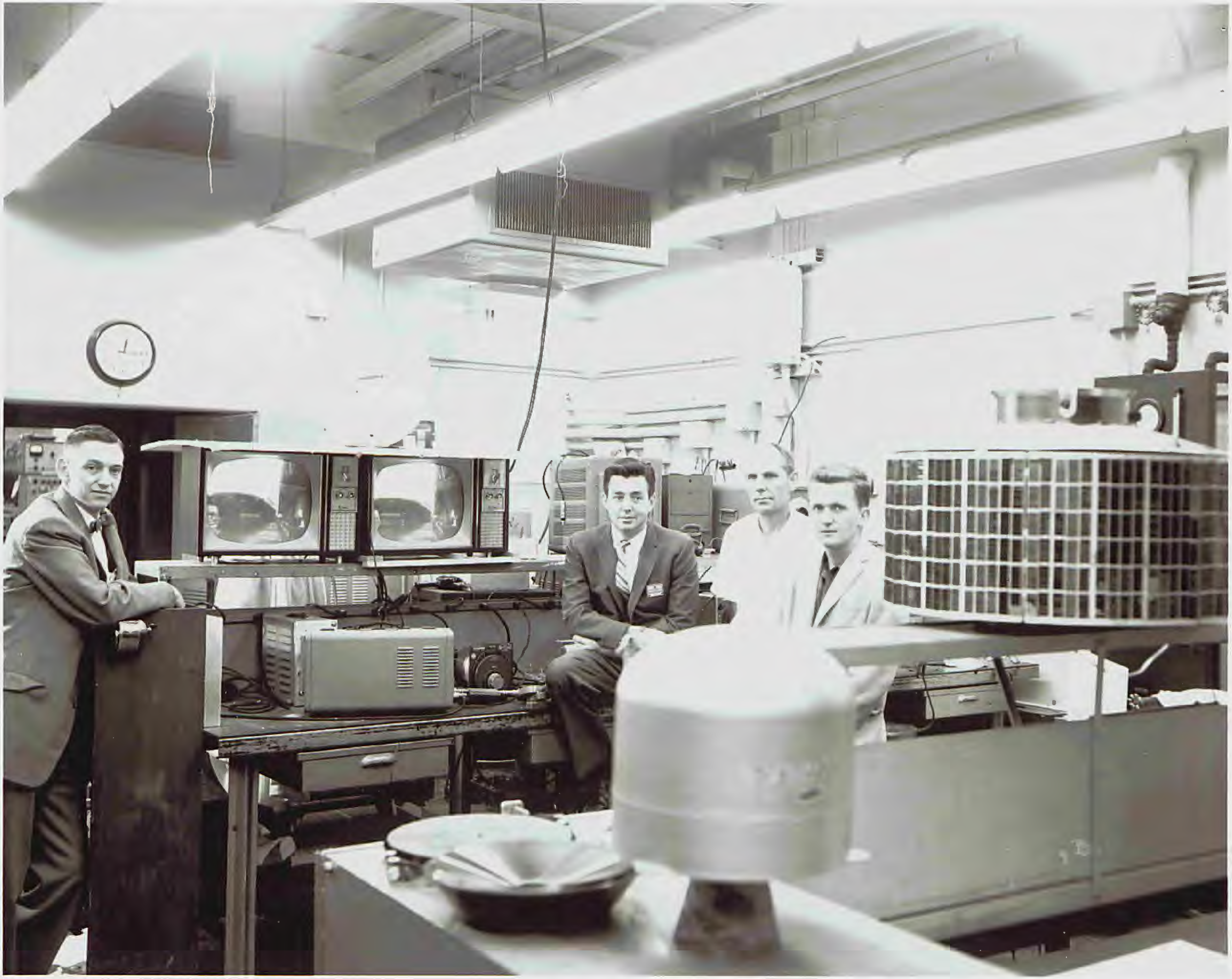

SUN SENSOR GEOMETRY

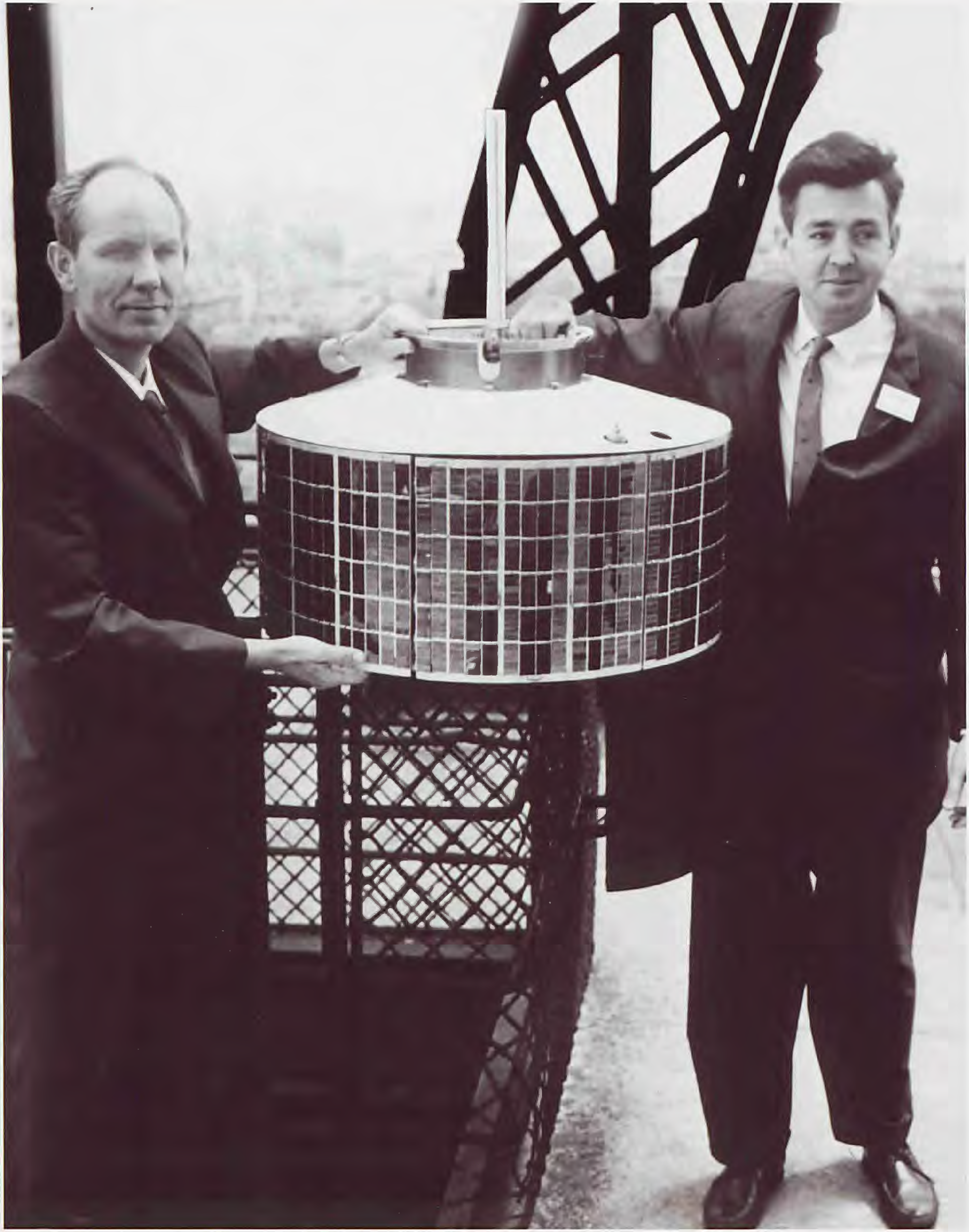


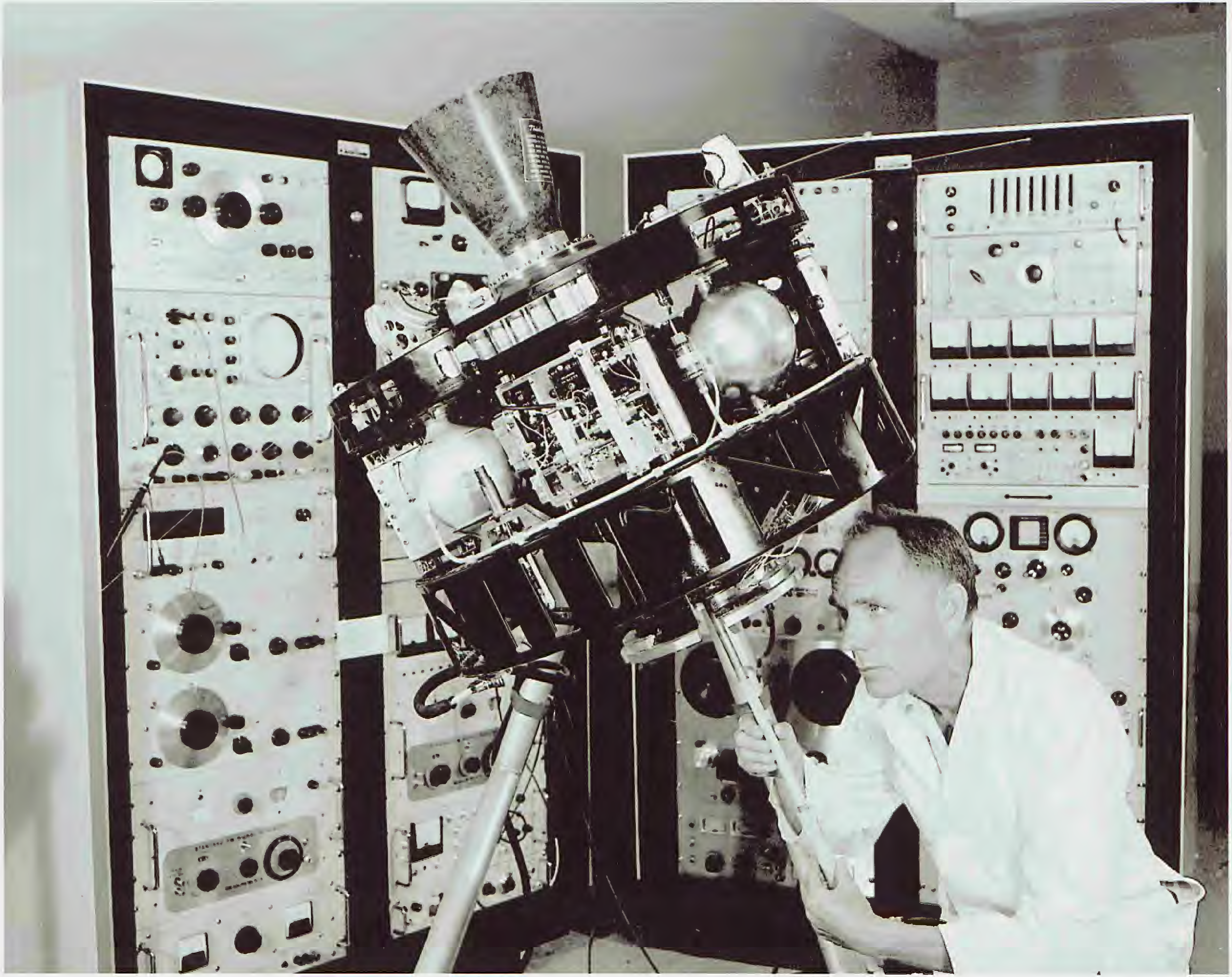

Insertion into orbit.

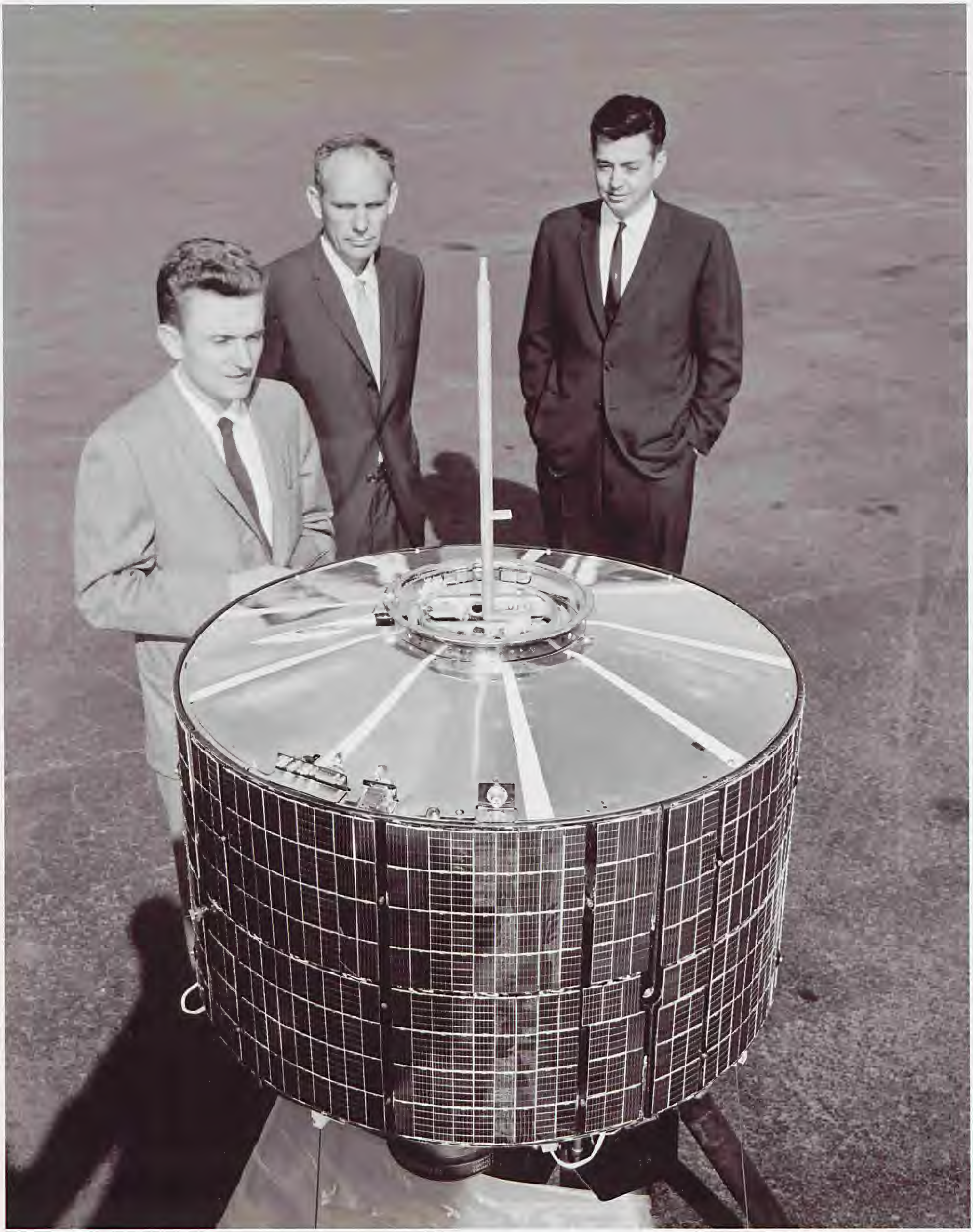



Communication System Antenna Pattern










NHK