Earth Stations for Fixed and Mobile Services

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Earth stations for fixed and mobile services

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This paper discusses the evolution of fixed and mobile stations during the past two decades and extrapolates trends into the future.

It is shown that for the various communications satellite systems discussed, i.e. international, domestic, maritime and direct broadcast, the terminal designs are controlled not only by technical factors but also by economic, organizational and political factors.

The net effect of these combined forces, while yielding less than optimum designs from a technical or economic viewpoint, has made for a remarkable growth in twenty years. From an experimental–operational system of four stations in 1965, which used a satellite with 10 W of effective radiated power, to, by 1990, millions of home television stations using a satellite of 200 kW effective radiated power per channel.

1. GENERAL INTRODUCTION

Commercial satellites communication service began 18 years ago with the launch of Early Bird (Intelsat I). This paper will describe the evolution of the Earth stations used in the Intelsat system, and will focus on the technical, political and operational factors that have influenced their design. The outstanding success of the Intelsat system led to the use of communication satellites for domestic, maritime and direct broadcast use as well. The growth of these systems has exceeded all expectations. From four stations in 1965, there are now 650 stations working with the Intelsat satellites. These stations are either using Intelsat capacity directly for international service or are part of domestic and regional systems that have leased capacity from Intelsat. Domestic systems in the United States of America total over 500 transmit–receive Earth stations, with antennas measuring from 1.2 m to 30 m diameter and traffic per station ranging from one circuit to thousands. There are approximately 10000 stations with four to five metre antennas for cable television receive-only head ends, and about 400000 to 500000 receive-only antennas for 2.5–5 m diameter used by individuals for television reception in the 4 GHz band. The Intersputnik, Canadian, and Indonesian satellite systems have been operating for a number of years with a total of hundreds of Earth stations. Recently, India initiated its own system, and by the second half of this decade, ten other countries are expected to launch national systems.

More than 2000 commercial ships communicate via satellite; by the end of the 1980s, there should be millions of home receivers for direct broadcast satellite television reception.

The major thrust in the design of large fixed stations has been to increase the telephone circuit capacity per station, at a decreased cost per circuit. In addition, new services have been and are being developed to explore the special capabilities of satellite transmission, in particular the development of maritime and aeronautical services, direct broadcast television services, and new business services permitting wideband transmission with small Earth stations.

2. Fixed international service stations

(a) *Overall considerations*

When fixed international-service Earth stations were introduced in the 1960s, they differed from terrestrial radio relay stations mainly in degree rather than in kind. Because of the thousandfold increase in distance between satellite and Earth station, compared to a radio relay hop, the Earth station's antenna had a diameter ten times greater. The antenna facing the cold sky permitted the use of cryogenically cooled receivers with noise temperatures of tens of degrees rather than thousands. The transmitter output amplifier was in the kilowatt range rather than in the few watt range. Fortunately, the 40 dB fading allowance needed for terrestrial relays could be decreased to a few decibels. Also a transcontinental relay system must allow for the build-up of noise in 100 receivers, while a satellite system includes only two.

In all previous communications systems, the owners and operators of the system could balance the design of the various elements of the system to minimize the cost of the system as a whole. But in Intelsat, a unique political problem arose because each country's earth station was owned completely by that country, whereas each country shared the cost of the satellites based on that country's share of the total traffic. About 20 % of the 109 member countries generate approximately 80 % of the traffic. A country with 1 % of the traffic today carries about 650 circuits, but 80 % of the countries have fewer circuits, typically a few dozen. The largest users are the United States, with about 16000 circuits, and the United Kingdom with approximately 8500 circuits.

The major element of cost for the high traffic countries is the space segment, while for the lower user countries, the Earth station cost predominates. The lower traffic countries have no interest in increasing their Earth station costs by purchasing a new multiplex terminal that would use the power and bandwidth of the satellite more efficiently, thereby increasing the satellite telephone channel capacity and reducing the cost per channel. Their space segment cost might be only one tenth the cost of their Earth station, without the addition of the multiplex equipment. The large user would have the reverse problem and would be delighted to make the change. But since the large and small users communicate with one another, they must have the same type of multiplex. Initially, all countries used F.D.M./F.M., but by the early 1970s the differences in traffic were so great that single channel per carrier (s.c.p.c.) was introduced for use in light traffic streams. Beginning with Intelsat IV, a special form of s.c.p.c. was initiated for demand assignment (SPADE), which resulted in still higher efficiencies by making frequencies from a pool available, shared by all on demand.

During the 1980s, a third form of multiplex–modulation will be introduced, T.D.M.A., which is best suited for the moderately high traffic streams shared by a number of countries.

The Intelsat system charges the same price per telephone channel to a country using six circuits as to one that uses 6000 circuits. This situation is at odds with pricing policies in all other businesses. Further, since the heaviest traffic stream in the Intelsat system is across the North Atlantic, it is technically possible to serve this stream with a relatively small satellite of the Delta class, about half the size of the Atlas Centaur or Ariane class used to launch the Intelsat V. By taking advantage of the proximity of the major Earth stations in Western Europe, and of those in Eastern United States and Canada, 2.5° beams might be used. With an efficient multiplexing system, about 135000–180000 two-way circuits could be obtained, compared to the 35000 circuits in an Intelsat VI, satellite, which weighs more than 3.5 times as much and costs that much more.

However, another satellite would be required to tie together all of the above countries with the others of the Atlantic region. With the heavy traffic skimmed off, the remaining traffic would cost more.

The policy for the Intelsat system has always been to emphasize its global responsibilities, especially to the lesser developed countries. This has resulted in the same Intelsat charge per telephone channel to all countries regardless of the number of channels leased. It has also resulted in the design of universal satellites rather than specialized satellites favouring the North Atlantic countries at the expense of those in South America and Africa.

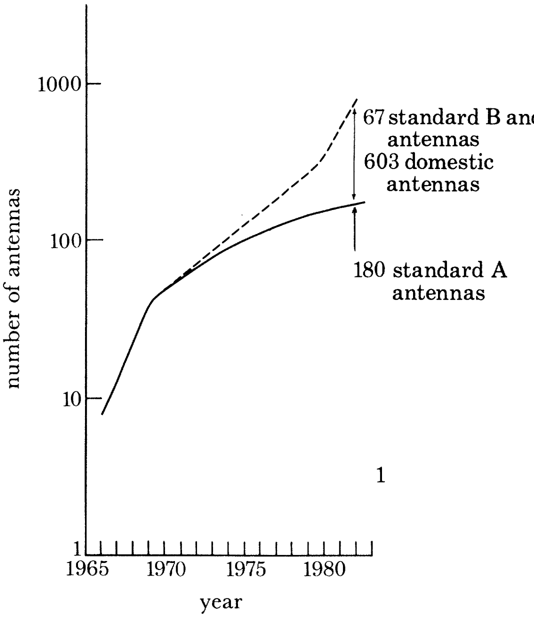


Figure 1. Growth in the number of Earth stations. The numbers shown are for the end of each year.

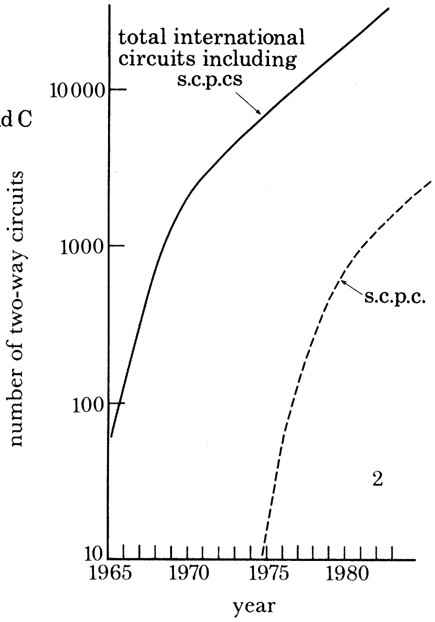


Figure 2. Traffic growth.

Similarly, the decision to adopt a geostationary system for the Intelsat system, rather than one at medium altitude, resulted in Earth stations requiring one antenna (and related equipment) instead of two. The decrease in cost by almost one half was of great significance to the smaller traffic countries to whom Earth station cost is predominant, being many times the space segment cost.

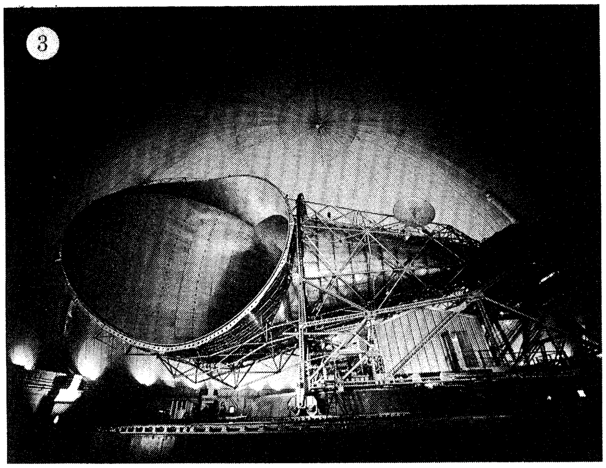
The extensive difference in the amount of traffic has resulted in changing from the initially universal standard A station (about 30 m diameter) to the introduction of standard B station (11 m diameter). Both of these stations are in the C-band, and use the frequencies from 5925 to 6425 MHz for transmission from Earth station to satellite, and from 3700 to 4200 MHz from satellite to Earth station. Standard C is a recent K-band station, with a 14 m diameter antenna (14–14.5 GHz from Earth station to satellite and 10.7–11.7 GHz for the reverse). In addition, two new series of stations for the new Intelsat Business Service have been approved. Standard E-1, E-2, and E-3 operate in the K-band with diameters of 3.5, 5 and 7 m, respectively; standard F-1, F-2, and F-3 operate in C-band with diameters of 5, 7, and 9 m, respectively. Thus the system is gradually evolving to match better the wide variety of new requirements that have developed with the advent of higher powered satellites and the use of new frequencies in bands free from terrestrial radio relay systems.

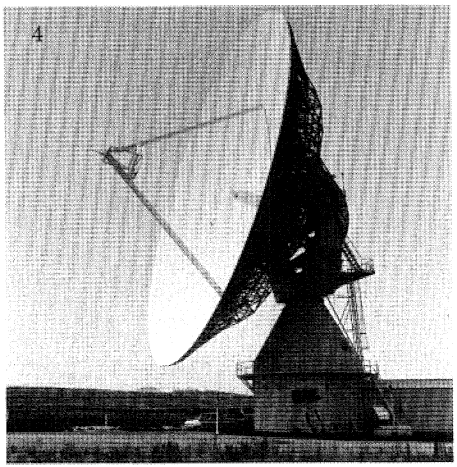
The change in the nature of Intelsat Earth stations over the years may be seen in figure 1, which shows that the initial users were the heavy traffic countries using the system exclusively for point-to-point communications with each other. In the early 1970s, lower volume traffic stations entered the system, and it was more economical for them to use the standard B station By the mid-1970s, transponders were leased for domestic use, for the most part with 5.5–11 m antennas. These now constitute the major part of Intelsat's 800 antennas, but the revenue from these leased transponders amounts to only about 8 % of Intelsat's revenue. Similarly, figure 2 shows the growth of s.c.p.c. circuits in use for international traffic only. It appears to follow the same curve as the growth of Intelsat's total traffic (F.D.M./F.D.M.A.) but delayed by about ten years. However, at present it constitutes only about 4 % of the total traffic.

(*b*) *Antennas*

In early 1964, before the formation of Intelsat, Comsat made a decision to launch an 'Early Bird' satellite, which later became known as Intelsat I after Intelsat was formed in mid-1964. This satellite was the heaviest (39 kg) that could be placed in a geostationary orbit with the Delta launch vehicle available at that time. The satellite could support only a single 6 W travelling wave tube, which, with the two carriers required, one for each direction of transmission, resulted in an effective radiated power of 10 W per carrier. To achieve a worthwhile traffic capacity with this low power, the receiving antenna had to be as large as possible. At that time, that meant a 25.9 m diameter antenna, which, if a 50 % efficiency and a 50 K noise temperature is assumed ($G/T = 40.7$ dB K^{-1}), provided 240 two-way telephone circuits. Comsat had purchased A.T.&Ts Andover, Maine, station, which used a horn antenna (see figure 3) with approximately this performance capability. A.T.&T. had chosen the horn design because it had used thousands of such antennas, but with a 2.4 m diameter, for its radio relay installations. The antenna had a simple geometry, with readily calculable parameters. A.T.&T. had built successfully a 6.1 m version for the Echo project. Therefore, it felt confident that a 20.7 m version could be built. It proceeded to build two antennas of this type, one for Andover and one for the French station at Pleumeur-Bodou, in 1962. The German station at Raisting had a 25 m Cassegrain antenna, and the United Kingdom built a 25.9 m front-fed antenna. Of these three designs, the Cassegrain has been proven to be the best choice, considering performance and price. It is now used almost universally.

Early antennas were copied from designs that did not require maintenance during operation. Intelsat's emphasis on the need for ready access to all equipment at any time stimulated changes in the mechanical design of the antennas from the kingpost (see figure 4, which shows the antenna at Brewster (1966)), which unfortunately required a technician to perform maintenance work on equipment at the base of the feed, doing so at the elevation angle of the antenna. For Comsat's antenna in Hawaii, this entailed working at a 45° angle, a most uncomfortable position. To overcome this problem, the following design incorporated an elevated room that remained horizontal regardless of the elevation angle (see figure 5, which shows the antenna at Etam (1968)). The wheel and track design permitted the antenna to be built on top of the building, which eliminated the concrete pedestal of the previous designs and thereby reduced costs (see figure 6, which shows an antenna in Alaska (1970)). Finally, the thrust to minimize the number of operating personnel and to reduce equipment cost led to the 'beam waveguide' approach of reflecting energy to and from the subreflector to the feed (now located in a building below the antenna) by means of several mirrors, similar in principle to an optical periscope. This permits all equipment to be on one level, eliminates the need for an elevated room, and yet accomplishes this with acceptably low transmission loss.





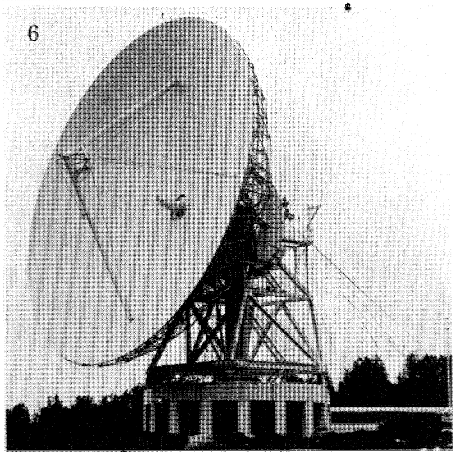


Figure 3. Horn antenna at Andover, Maine.

Figure 4. Antenna at Brewster, Washington, D.C.

Figure 5. Antenna at Etam, West Virginia.

Figure 6. Antenna in Alaska.

The 500 MHz bandwidth required by Intelsat III (1968) could not be obtained by the maser amplifier (150 MHz bandwidth) used for Intelsat II. A parametric amplifier was successfully designed, but at the cost of increased noise. Increasing antenna diameters from 25.9 to 29.6 m offset the effect of greater noise. A similar approach of increasing diameter to 32 m was later used to offset the additional noise introduced when changing from the original, cryogenically cooled parametric amplifiers to the simpler, more reliable, lower cost Peltier cooled parametric amplifiers. Not only did this change eliminate the need for cryogenics, but it also decreased the high power amplifiers (h.p.a.) power requirement by 35 % between a 32 m and a 25.9 m antenna, an important advantage in these days of high fuel costs.

While mechanical changes in antenna design were being made to reduce cost and improve accessibility, the electrical design was also improved to increase G/T (the ratio of antenna gain G to system noise temperature T is a basic measure of system performance). Aperture efficiencies were improved from 50–60 to 60–70 % by shaping the reflector surface to maximize the area illuminated by the subreflector and thereby increase gain. The spillover past the edge of the antenna was minimized as well, to reduce noise.

The costs of two dozen standard A stations, ordered from 1967–83, were studied to determine trends in pricing. The prices were for 'turnkey' contracts, including antenna, foundation, g.c.e., h.p.as, and control console. The extent of auxiliary equipment (standby power, microwave terminal and multiplex) vary among stations, but some interesting conclusions can be drawn.

The number of stations for which contracts were issued in the indicated time periods is shown in table 1, together with the range of 1967 selling prices and their equivalent cost now. It should be noted that three stations are not included, since their costs are significantly disproportionate to the others. The stations listed in table 1 were built by four contractors.

Table 1. Number of stations for which contracts were issued together with their cost

period	number of stations	price in 1967 millions of U.S. dollars	equivalent cost now millions of U.S. dollars
late 1960s	6	5–6.5	5.5–6.5
1970s	9	2–3.8	4–5
early 1980s	5	2.5–3	6–7.2

It appears that the relatively high price of the first generation of stations may have been due to writing off development costs, plus the higher costs involved in entering a new field. Once past this phase, the real costs in the 1970s and 1980s show a marked decrease.

Of the operating costs for the large Comsat stations, the largest element (about 50 %) is for personnel, and the next largest (20 %) is for power. The power costs have risen by a factor of about three in the last decade.

(c) *High power amplifiers*

A unique aspect of satellite communications, as distinct from terrestrial radio relay systems, was the need for multiple access to allow the carriers transmitted from a number of Earth stations, each on a different frequency, to pass through a single satellite amplifier. At the Earth stations, a similar situation arose because several carriers may be transmitted from a single station. To minimize intermodulation among the various carriers, the Earth station power amplifier rating had to be approximately five times more powerful than the sum of the output of these carriers. For the larger Earth stations, this required a h.p.a. of 8 kW to cover the entire 500 MHz bandwidth. Such tubes had never been built at 6 GHz. Therefore, Comsat initiated a development programme to learn how a 2000 h (three month) life might be obtained. The results were successful and later production tubes typically operated for about three years (25000 h). However, these tubes are expensive and require liquid cooling, which is an operational nuisance. To ameliorate these problems, there has been a trend to use several lower powered h.p.as rather than a single 8–12 kW amplifier, and to use air cooled tubes that are available up to 3 kW. While these power levels are far too high for solid state ampliers, the output tube gains are sufficient to permit all low level stages to be solid state, thus simplifying power supplies, lowering costs and increasing lifetime.

In the large U.S. stations, on-the-air availability is about 99.995% on average, but of the corresponding 25 min unavailability per year, the major cause is due to problems with the h.p.as. The second largest contributor to unavailability is due to operator error, which arises from the constant reconfiguration required in these large stations that communicate with dozens of other stations.

(*d*) *Low noise amplifiers*

The earliest stations, in Andover, Goonhilly, Pleumeur-Bodou and Raisting used masers that had an extremely low noise temperature of 4 K but required operation at liquid helium temperature, with liquid stored in a vacuum insulated flask and periodically topped up to replace the liquid lost through boiling. Later, cryogenic refrigerators were designed by the A. D. Little Co. With the introduction of Intelsat II satellites, Airborne Instruments Lab. developed a maser with a 150 MHz bandwidth (in the 4000 MHz region), but for the 500 MHz requirement of Intelsat III in 1968, it did not appear possible to extend further the maser bandwidth. A 500 MHz parametric amplifier was developed for Comsat by A.I.L. with a noise temperature of 15 K. The increase in noise was offset by adding a 183 cm skirt to our 25.9 m antennas.

These parametric amplifiers operated with gaseous rather than liquid helium at approximately 15 K, which resulted in a simpler, more reliable refrigerator than for the masers. This still required care and periodic overhaul. With the development of better diodes and higher frequency parametric amplifier oscillators, it was found possible to use electrical Peltier cooling and dispense with the mechanical refrigerator completely. Here again, this operational gain was bought at the expense of more noise, about 35 K. This was offset by increasing the antenna diameter to 32 m.

Spurred on by the need for lower cost amplifiers for small Earth stations, intensive development has resulted in gallium arsenide field effect transistors with noise temperatures of about 75 K at 4 GHz. These eliminate the need for a pump oscillator, operate at a low voltage and have a long life.

All of the noise temperatures quoted pertain to the low noise amplifier itself. When the noise contributions due to sky noise, filters, switches and waveguides are included, 45 K is typically added.

(*e*) *Multiplex systems*

Initially, Intelsat used F.D.M./F.D.M.A. because F.D.M. was the universal modulation method for cable and microwave relay. It was recognized that passing multiple carriers through a satellite travelling wave tube would provide only half the total capacity possible with T.D.M.A. In 1965, when T.D.M.A. was in its early stages of commercial operation, Intelsat concluded that it would not be desirable to introduce additional untried technology into the system if conventional multiplex could be used, even though the efficiency was decreased. However, the future need for this more efficient system was apparent. In 1965, experiments were started that tested T.D.M.A. This work has continued, and T.D.M.A. will become part of the Intelsat system in 1984. T.D.M.A. has been in use in both the Canadian and United States domestic systems for a number of years.

Intelsat is investigating 32 kbit s^{-1} digital modulation, half the present rate. Digital speech interpolation may further double or triple the number of possible voice channels by using the gaps in a users speech, as well as the larger gaps that occur when listening to the oppcsite party, to interpose pulses from other channels. In the future, perhaps 16 kbit s^{-1} codecs might be built with toll quality. Experiments between the Federal Republic of Germany and the United States are under way using S.S.B./A.M., which has the potential of providing five to ten times the channel capacity per transponder, compared to current methods. This has become feasible because of the availability of compandors on a chip and lower speech power per speaker. The latter has come about because of the higher quality of long distance circuits.

(*f*) *Small Earth stations*

Intelsat V and VI satellites, with K-band e.r.p. from 41 to 44 dBW will permit the use of standard E stations. The smallest of these, E-1, has a 3.5 m antenna and a 64 kbit s^{-1} capacity. This antenna can be readily placed on an office building or plant, provide one or two voice channels, or one high speed data channel. The space segment can be leased full time, part time, or for occasional use. Therefore, this should open up entirely new domestic and international services, even though political problems may arise concerning ownership of such stations and space segment access.

3. Fixed domestic service stations

The success of international systems in the 1960s gave rise to the domestic systems of the 1970s in Canada, the United States and Indonesia, plus the leasing of Intelsat transponders or portions of transponders to countries for their domestic needs. At present, 23 countries are leasing a total of 41 transponders. By the second half of the decade, about ten new domestic satellite systems will be launched. Because the antenna coverage pattern is usually less than the pattern required for international use, domestic satellites typically produce about ten times the e.r.p. of an international global beam, which permits the efficient use of 5–10 m antennas. However, as in international service, large antennas are more cost effective for large traffic cross sections. For example, in A.T.&Ts new Telstar 3 system, composed of three domestic satellites using companded single sideband transmission, the transponder telephone channel capacities are 7800 for 30 m antenna diameter with a 2° or 4° satellite spacing; 4200 for a 12 m antenna with 2° spacing, or 6000 for 4° spacing with the same diameter.

Even with a difference of 1800 channels, as at 4°, at an average charge of $750 per month for a leased line, the use of the larger antenna can produce an increase of $1 350 000 per month. With 24 transponders per satellite, the larger antenna is clearly more cost effective. Further, the new F.C.C. requirement for 2° spacing between satellites along the orbital arc, instituted to accommodate the growing demand for new slots, will favour the use of large antennas. This could increase satellite capacity by 86% over the 12 m capacity for this particular case. For light-traffic stations, the smaller antenna is to be preferred, since the new generations of domestic satellites have more power than their predecessors. To further increase channel capacity, they are operating in both the C- and K-bands. Also, more efficient modulation methods have been introduced, including 32 kbit s^{-1} digital transmission in place of the standard 64 kbit s^{-1} rate, digital speech interpolation to further double the capacity, and companded single sideband, so that a 24 transponder Delta class satellite, with a 30 m Earth station antenna, could carry over 90000 two-way telephone circuits.

A 2.4 m antenna used for early domestic system tests is shown as it would be used operationally, in the parking lot of an industrial plant (see figure 7).

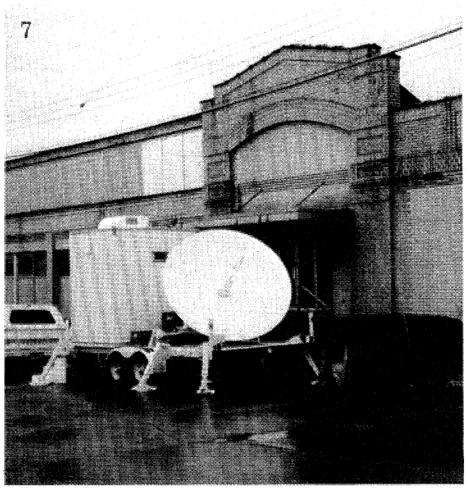


FIGURE 7. Business services antenna.

At present, the United States domestic satellite networks include about 500 transmit–receive Earth stations, with antenna diameters ranging from 1.2 to 30 m. The traffic per station ranges from 1200 bit s^{-1} to thousands of voice channels. A.T.&T. assigns as many as 28000 message telephone circuits to satellite facilities. In addition, the Alaskan domestic system has approximately 200 transmit–receive stations, which use, for the most part, 5 m antennas, one or two s.c.p.c. channels and a television receive channel. About 10000 c.a.t.v. receive-only stations, with 4–5 m antennas, are used to feed programs into cable systems. Finally, 400000–500000 C-band receive-only stations of 2.5–5 m diameter are used for television reception by individuals located in places not served by u.h.f. or v.h.f. television stations, or by those who desire a larger variety of programmes.

4. DIRECT BROADCAST STATIONS

In 1977, the Broadcast Satellite World Administrative Radio Conference proposed a worldwide plan at K-band for the direct broadcast satellite service, assigning every country to one or more longitudinal slots and a number of television channels, usually five, but extending to some dozens of channels for the larger countries. This was a quixotic approach, based on a complete absence of experience with direct broadcast satellites. Events since then have proved that this approach has serious problems. Twenty Arab countries joined together in a common satellite for telephony and direct broadcast. Since they had been assigned a variety of orbital slots, there was no slot common to all the countries involved. This predicament forced them to go to the 2000 MHz region for the broadcast transponders.

The slots assigned to China included 35 separate beams from several slots to cover the country. Since they preferred to initiate their system with a less ambitious programme, one covering the country with only two beams from a single satellite, the resulting patterns did not match the preassigned patterns of neighbouring countries. Canada and Australia wanted their satellites to be used for fixed service as well as for broadcast service, a combination not envisioned by the plan. Finally, Earth station technology at 12 GHz, and television technology have generated significant improvements since 1977. North and South America did not accept the 1977 proposal and, in 1983, chose their own assignments, which resulted in a higher number of channels per country than would have been obtained in 1977. One analysis estimates that the use of the orbital arc was nearly four times as great under the 1982 plan as for the 1977 one.

In the United States, numerous satellites are under construction. This demonstration of active interest has spurred manufacturers to step up development efforts on 12 GHz home receivers. Antenna efficiencies have increased from 50–55 to 65–70%. Improved gallium arsenide field effect transistor devices now provide noise figures of 2.5–3.5 dB, compared to the 6 dB in 1977. Most important, projected home receivers, including antenna, outdoor and indoor electronics with video and audio deciphering circuits and an individually addressable feature, are anticipated to cost $300 if provided in large quantities. While Canada is already using lower powered satellites, with home receiver antennas of 1.2–1.8 m diameter, the Satellite Television Corporation (S.T.C.) satellites, due to come into operation in early 1986, will be much higher powered and operate with 0.75 m antennas (see figure 8). To cover two time zones in the U.S.A. (to serve about half the United States) and have an edge of coverage e.r.p. of 53 dBW (0.2 MW), 200 W travelling wave tube will be used, manufactured by C.S.F. and Telefunken. The signal will be enciphered, and each home will be individually addressable via satellite. S.T.Cs early entry system will start operation with a slightly lower power beam covering the area from Boston to Washington, D.C. By the end of this decade, five to ten million home receivers may be in operation. Future trends will be towards transmission of higher definition television.

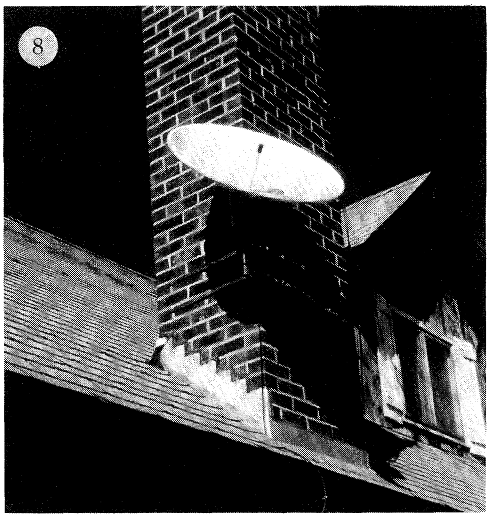
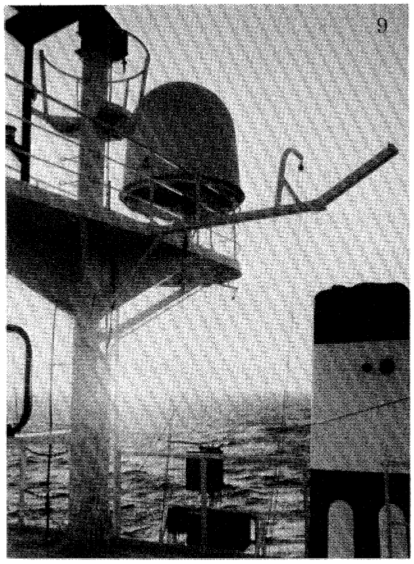
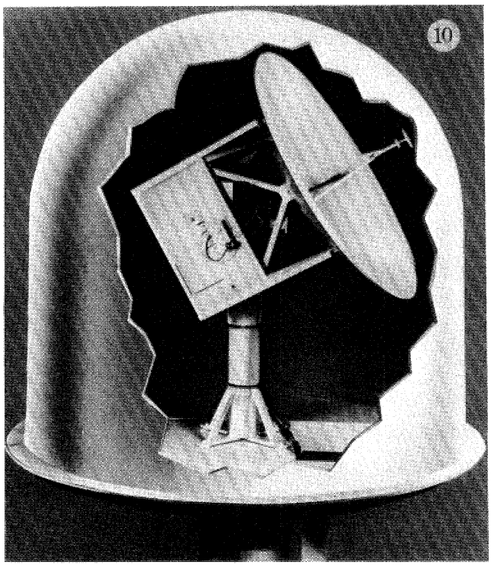


FIGURE 8. Direct broadcast television services.

5. MARITIME SERVICE

Maritime service started in 1976 with the successful launches of three Marisat satellites, one over each of the major oceans. The shipboard antennas were 1.2 m in diameter and automatically steerable to keep pointing at the stellite, regardless of the heading of the ship. The





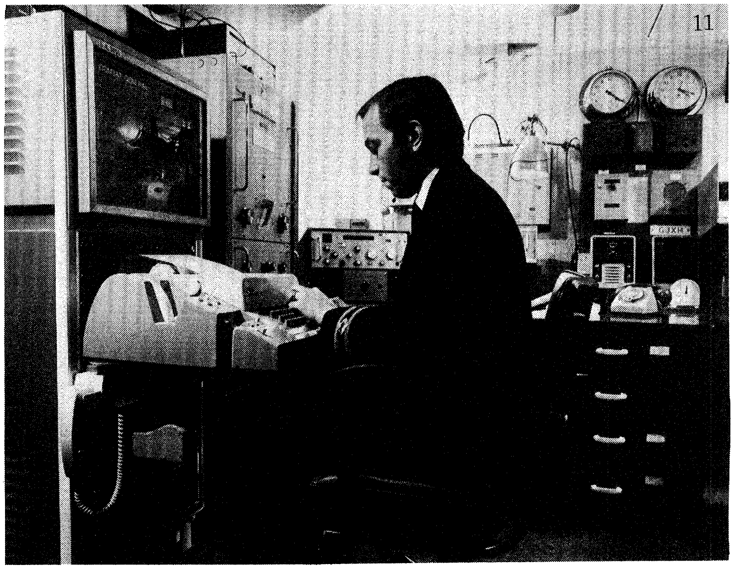


Figure 9. A maritime installation.

Figure 10. A ship antenna.

Figure 11. Below-deck equipment.

ship station could provide one voice and one teleprinter channel. By 1982, these circuits were converted to automatic dialling. They were so successful that over 2000 commercial ships are now so equipped. By increasing the antenna efficiency and lowering receiver noise, it is now possible to use antennas of 0.9 m diameter. Furthermore, even in a period of inflation, the cost per ship station has dropped from $50000–60000 to $35000–40000. Whereas Marisat had a capacity of approximately ten voice channels and 44 teleprinter channels, the next generation of Inmarsat satellites will have a capacity of about 120 voice channels and 300 teleprinter channels. Future trends appear to be in the direction of further decreasing the cost per channel and the cost of ship stations. One approach is to investigate digital transmissions at lower than the present 64 kbit s^{-1} rate to reduce bandwidth and thus the corresponding satellite power or ship station antennas, or both. There is also a search for a much lower cost ship station devoted solely to teleprinter operation. Fifty-six kilobit per second transmission service is now provided from ship to shore, and 1 Mbit s^{-1} service is being considered. Over the years, several proposals have advocated illuminating an ocean with a number of beams, thus permitting use of the smaller ship antennas and frequency re-use, thereby increasing channel capacity.

Figures 9–11 show a maritime antenna installation in a radome, a view of the 1.2 m antenna, and the below-deck installation, respectively.

6. Conclusions

International satellite communications, in less than two decades, have expanded from 60 circuits in 1965 to 33000 circuits today, and from four stations to 650. The Intelsat system now offers a variety of services designed for Earth stations with antennas from 3.5 to 30 m in diameter. The thrust of Earth station design is to simplify equipment and reduce cost per circuit, even at the expense of more complex satellites, including on-board processing, switching between multiple narrow antenna beams, and the use of higher frequencies.

Domestic and maritime satellite systems are heading in the same direction, towards higher powered, higher capacity satellites and simpler, less expensive Earth or ship stations. This will tend to move the complexity of the satellites, using the techniques described above.

Finally, in the direct broadcast systems of the 1980s, there may be a trend toward higher definition television. Since the existence of this service depends on low cost stations, the industry is looking toward the design of receivers and decoders using circuits on a chip and enabling production quantities in the millions to achieve Earth stations at low cost. This will provide programmes to every home in the nation, regardless of location.

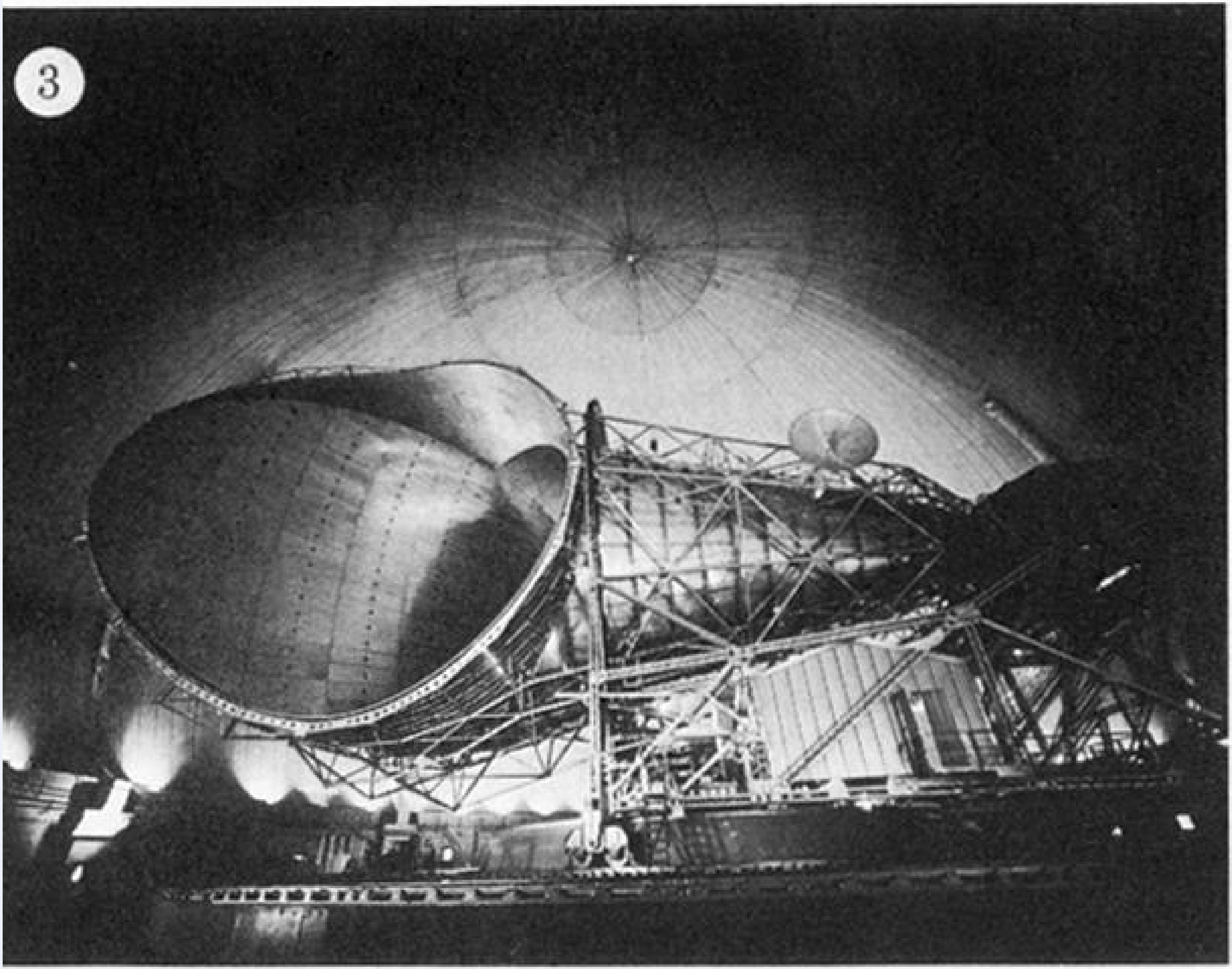
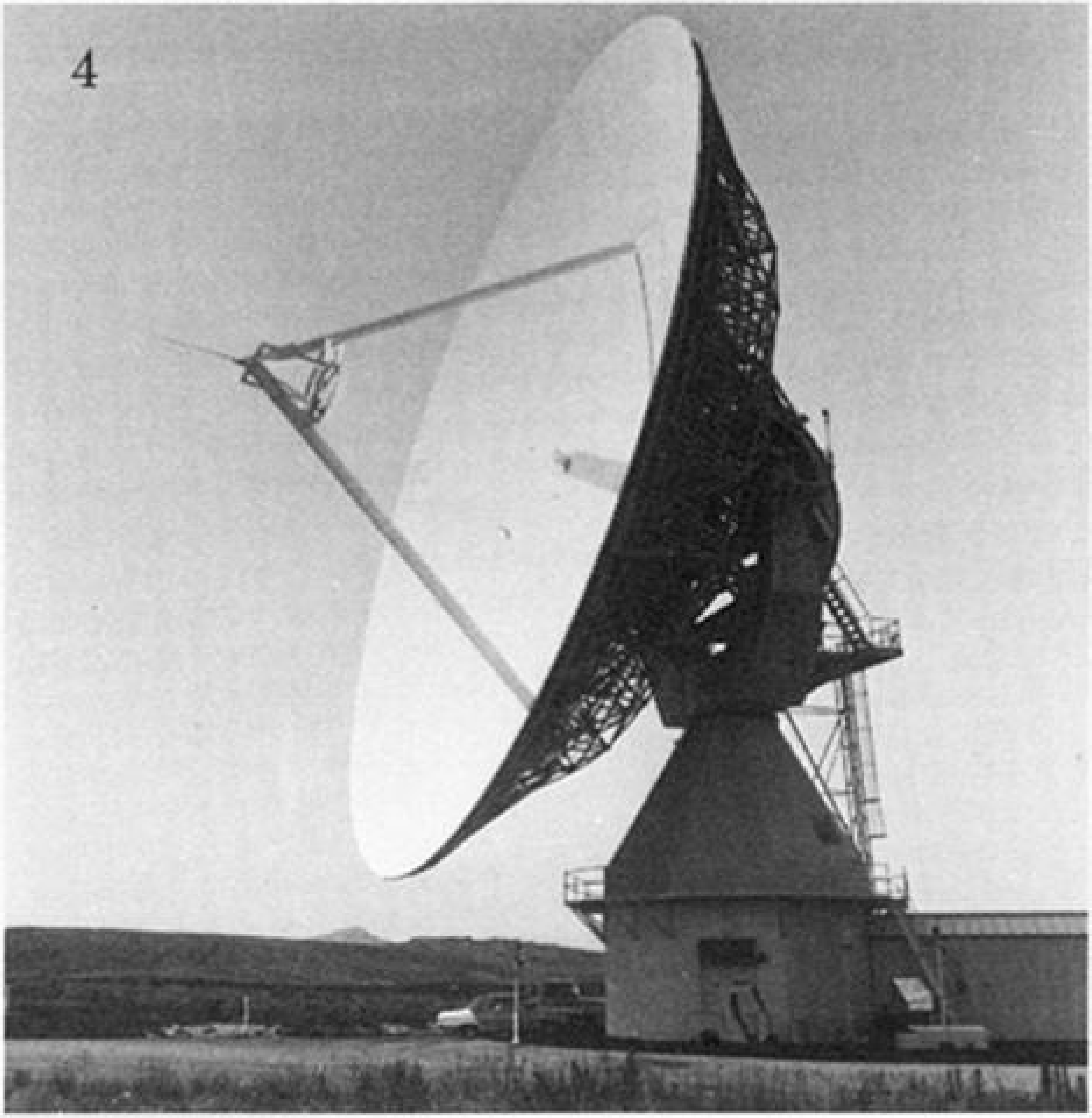


FIGURE 3. Horn antenna at Andover, Maine.



IGURE 4. Antenna at Brewster, Washington, D.C.

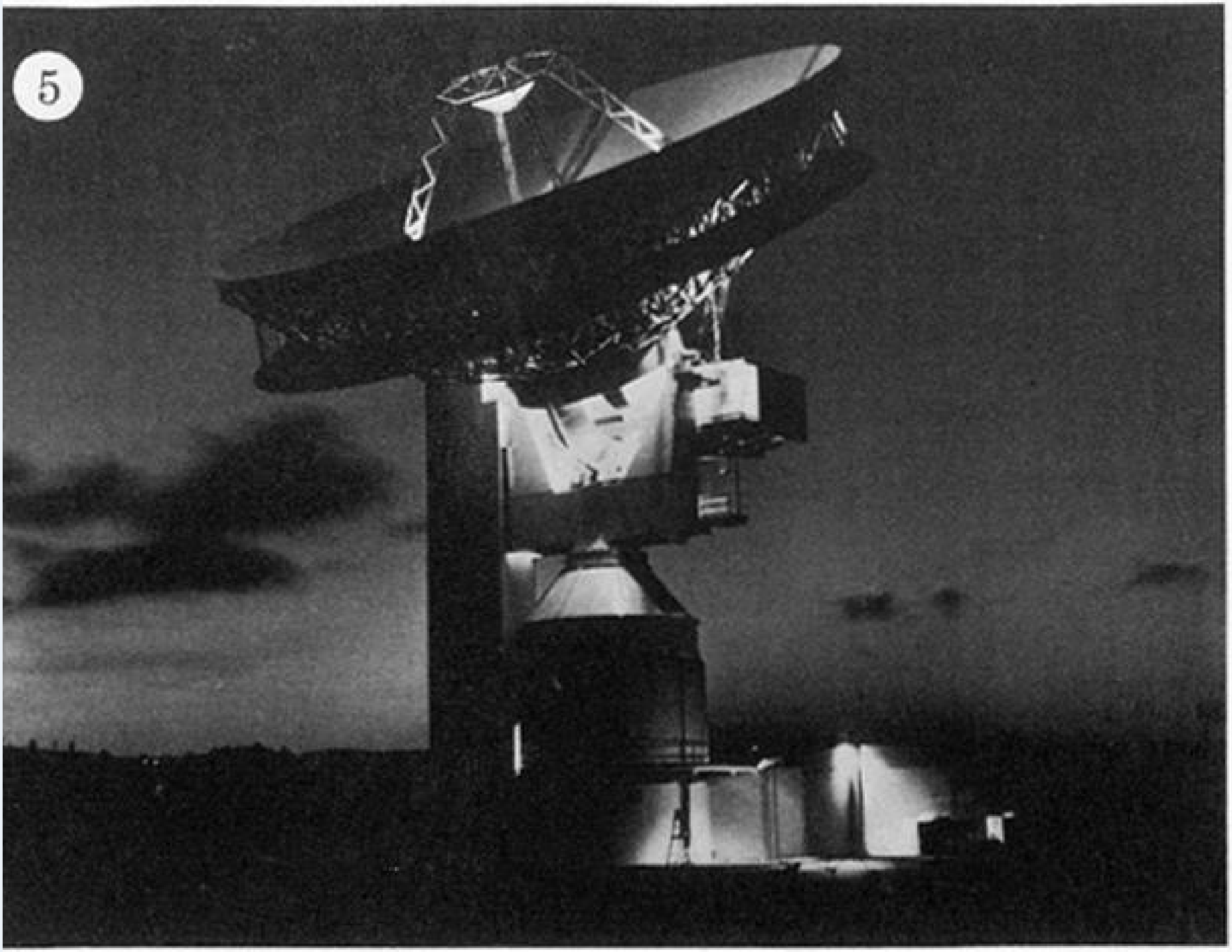


FIGURE 5. Antenna at Etam, West Virginia.

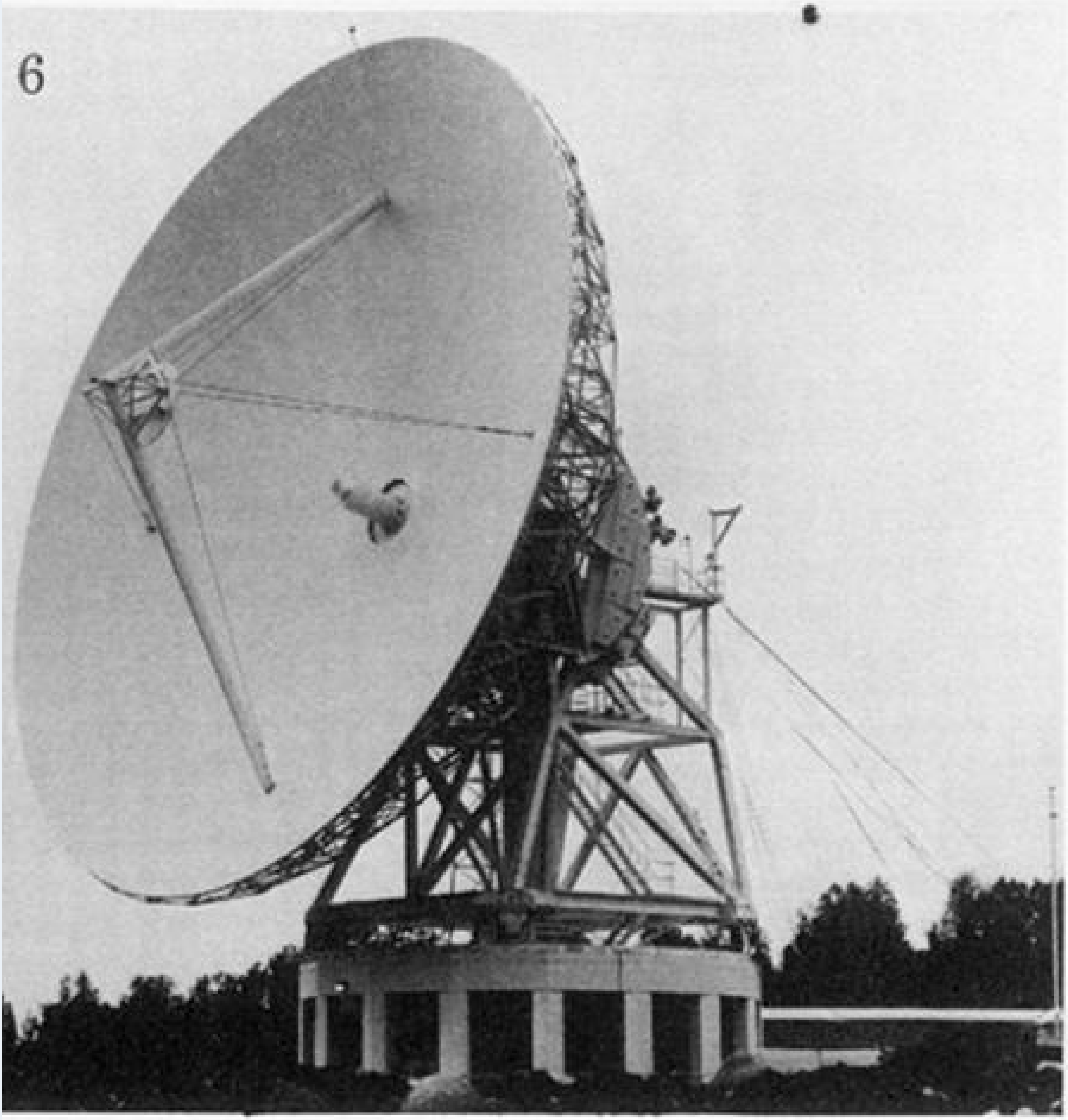
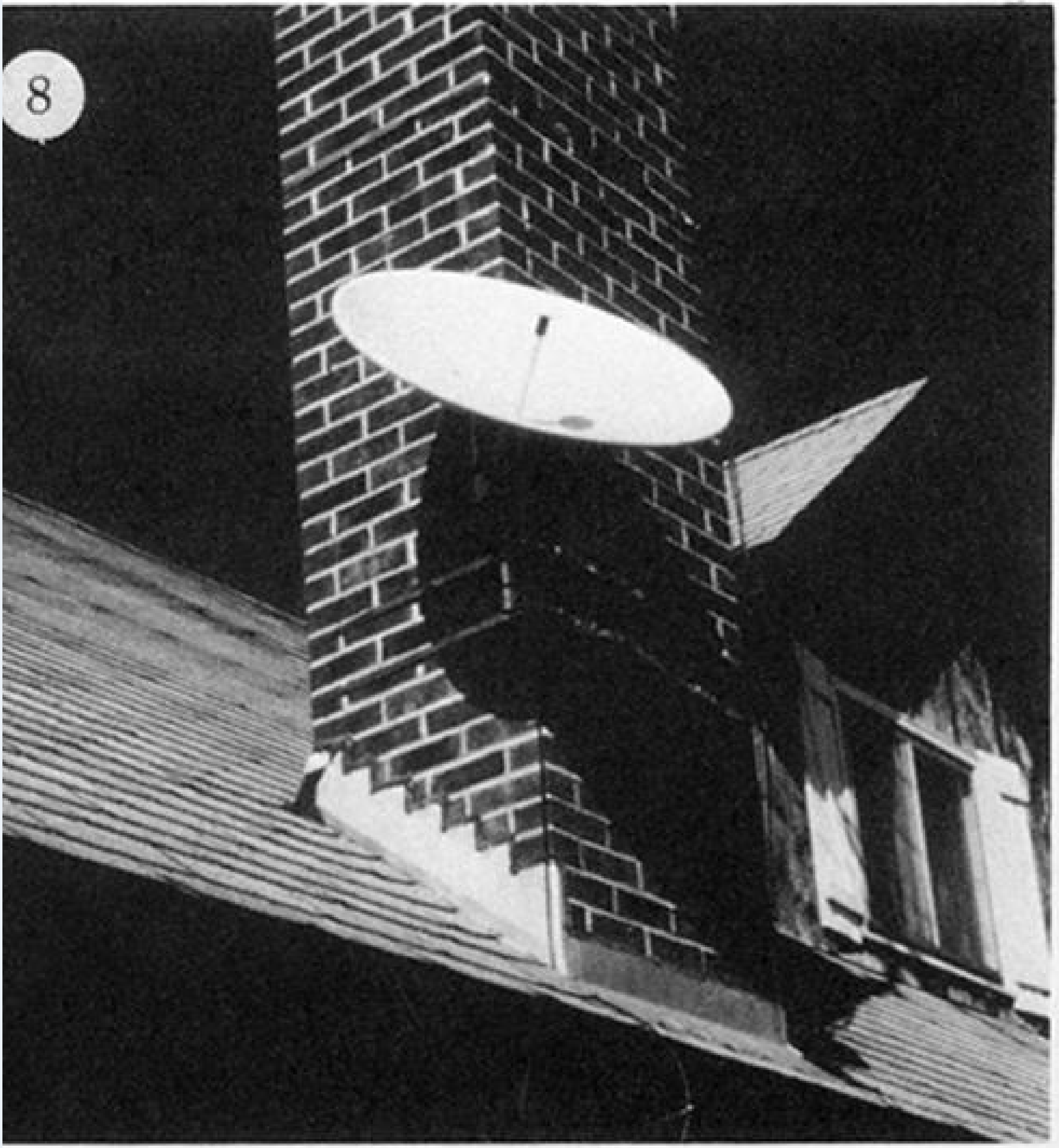


FIGURE 6. Antenna in Alaska.

Figure 7. Business services antenna.



IGURE 8. Direct broadcast television services.

FIGURE 9. A maritime installation.

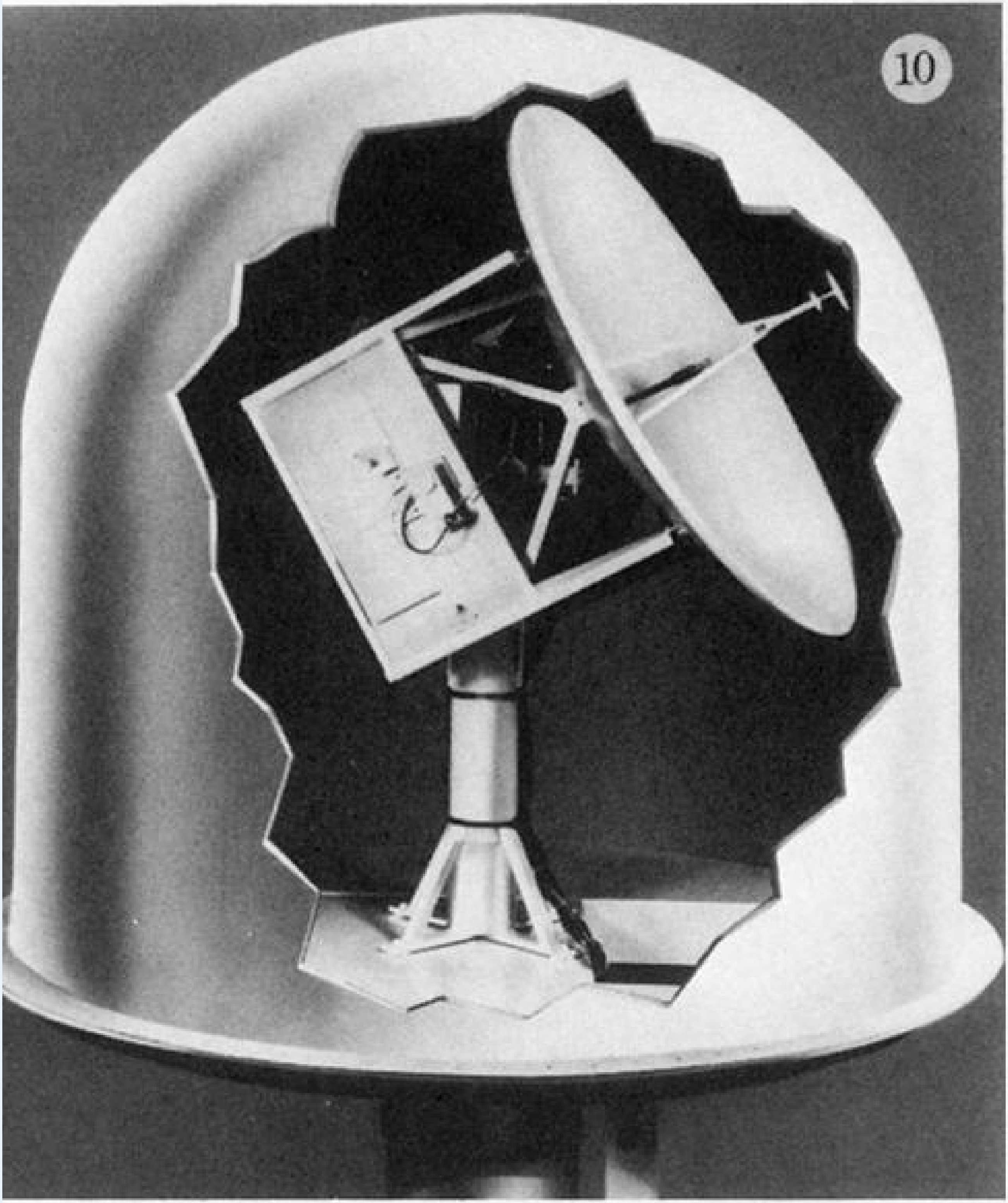


FIGURE 10. A ship antenna.

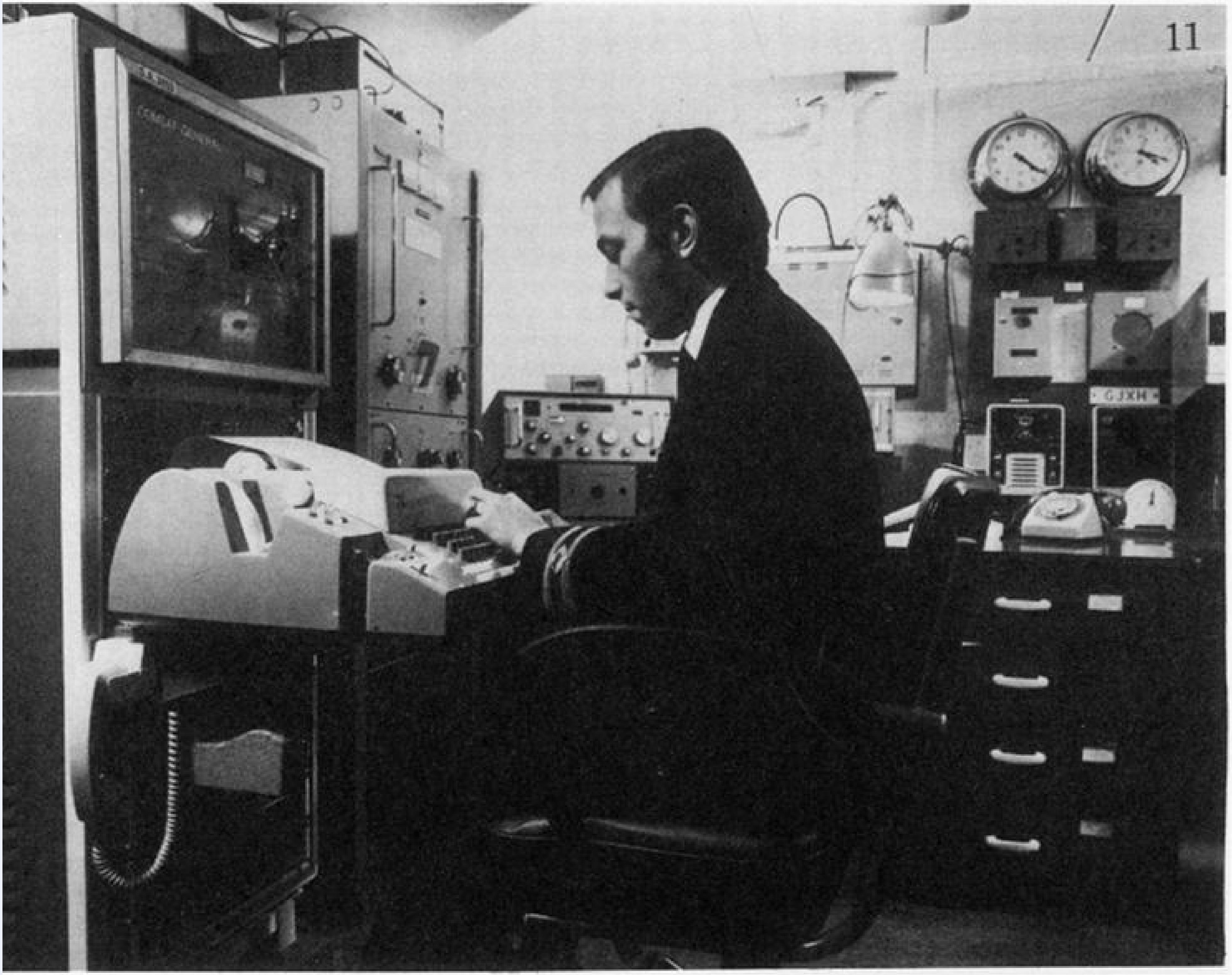


FIGURE 11. Below-deck equipment.