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Reprint from "Siemens Review"
Vol. XXXII · January 1965 · No. 1 · pp. 3 to 13
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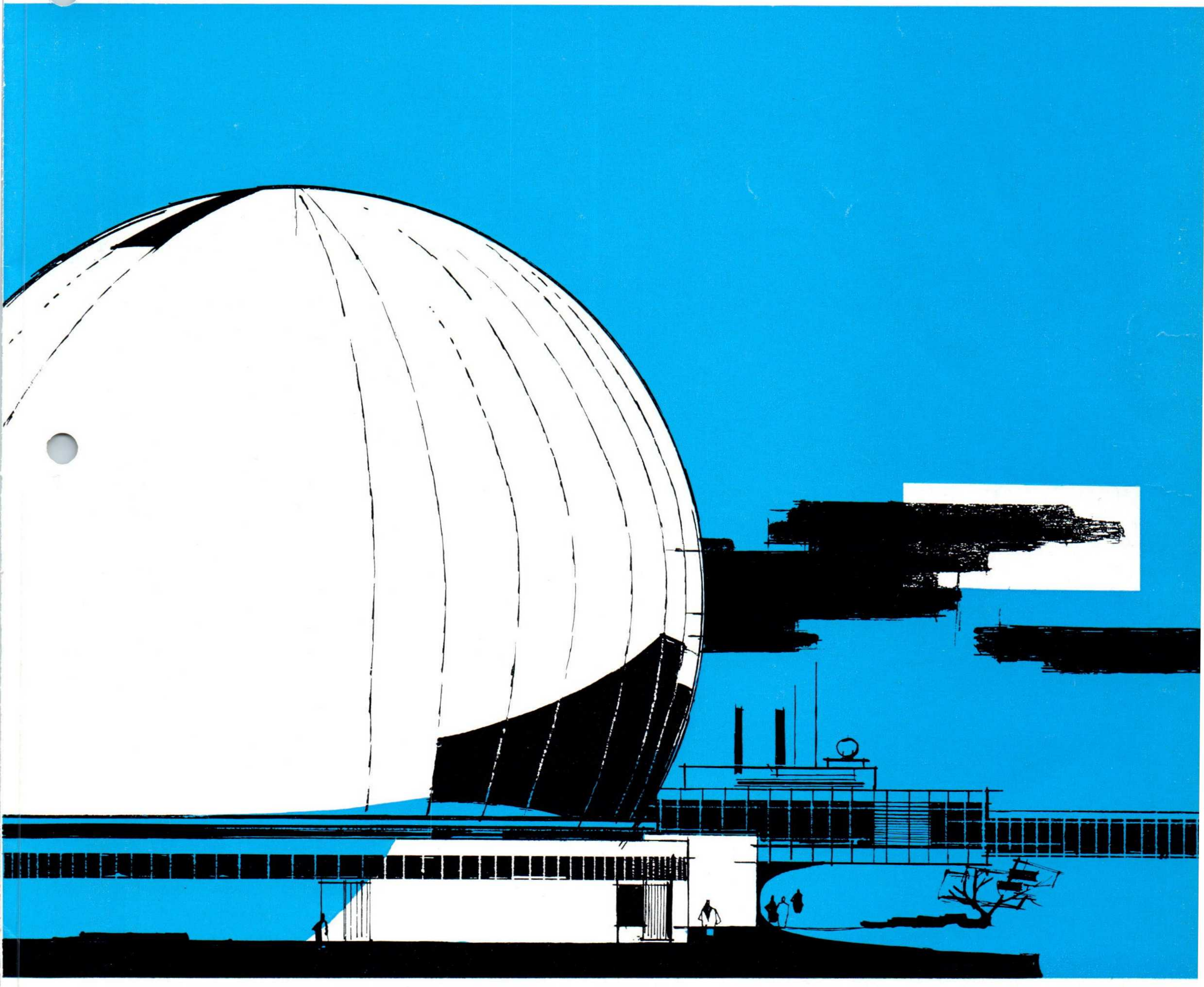
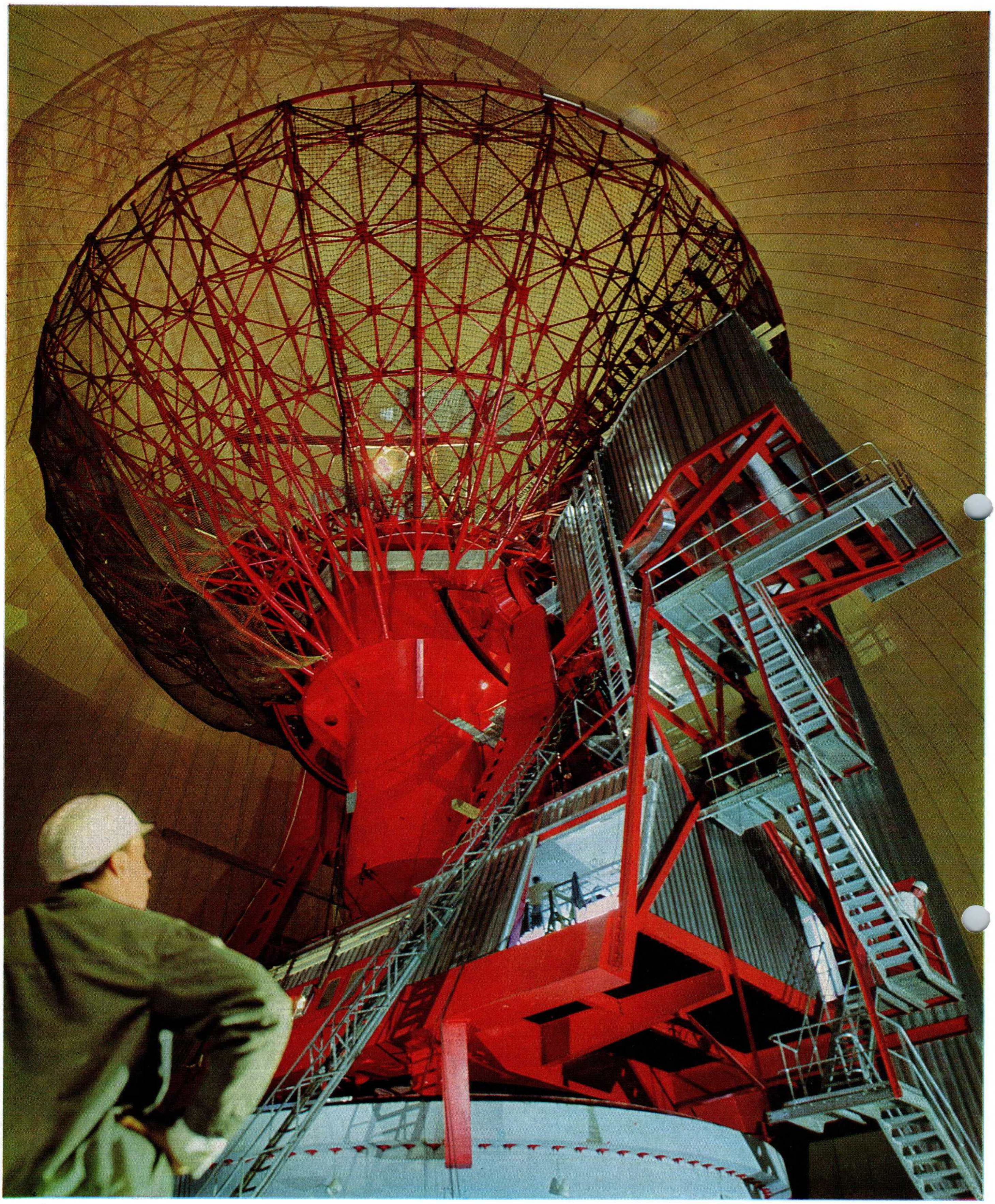




Antenna system of Raisting earth station. Dish diameter 25 m, overall height 32 m.
Antenna can be tilted by 115° and panned by 360° along with receiving room and control and transmitting room for tracking a satellite to within a few thousandths of a degree

Raisting Earth Station for Satellite Relay Communication

By Herbert Kinder and Walter Stöhr

Submarine cables and shortwave radio relay systems, as the conventional transmission media for transcontinental and transoceanic communications, will be joined in the very near future by artificial satellites (Fig. 1). Preparations for the operation of a system of satellite relay stations are reaching maturity in all parts of the world. The West German PTT is taking part in this project with its earth station in Raisting.

Transmission by way of artificial satellite relay stations is technically much the same as with the ground relay stations used in radio relay systems except that the latter, on account of the curvature of the earth, cannot usually be spaced more than 50 km apart (Fig. 2*a*). A single satellite relay station that has been placed in orbit at a sufficient altitude (Fig. 2*c*), on the other hand, can cover distances of almost half the circumference of the earth. The possibility of launching a satellite to an altitude and with an orbit suitable for worldwide communications transmission is now available to communications engineering as the result of the advances made in space travel technology. Without artificial satellites a direct communications link between Europe and America (6000 km) would require a relay station mounted on a tower about 1000 km high (Fig. 2*b*), which would be a completely utopian project. Or, using radio relay towers of conventional height, such a link would require more than 100 relay stations. While this is quite feasible and also conventional for overland links, it cannot be used for transoceanic links.

The suggestion of using artificial satellites as relay stations for transcontinental radio relay systems was first made in the year 1945 by Arthur Clarke in England. Some ten years ago, advances in the technology of communications components and rocketry brought the realization of such a project within tangible reach. Studies conducted by Bell Laboratories on transoceanic satellite relay links disclosed the demands to be met by the various types of equipment installed in both the satellite and the earth stations. On completion of these studies, Bell built the first communications satellite, known as the "Telstar", which was placed in orbit in July 1962. Earth stations were at the same time placed in service by the American Telephone & Telegraph Company (AT & T) and the French and English PTT's. Already the first attempts to relay long-distance telephone calls and television programs by way of this satellite were successful and the results came fully up to expectations.

It is easy to understand that a single satellite will not be sufficient for a worldwide satellite radio network, for whatever its position it cannot provide coverage of more than one half of the earth's surface. In the case of low-flying models such as Telstar I (maximum distance from earth 5000 km), some 30 satellites would be required. Or, if they could be launched to an altitude of about 15000 to

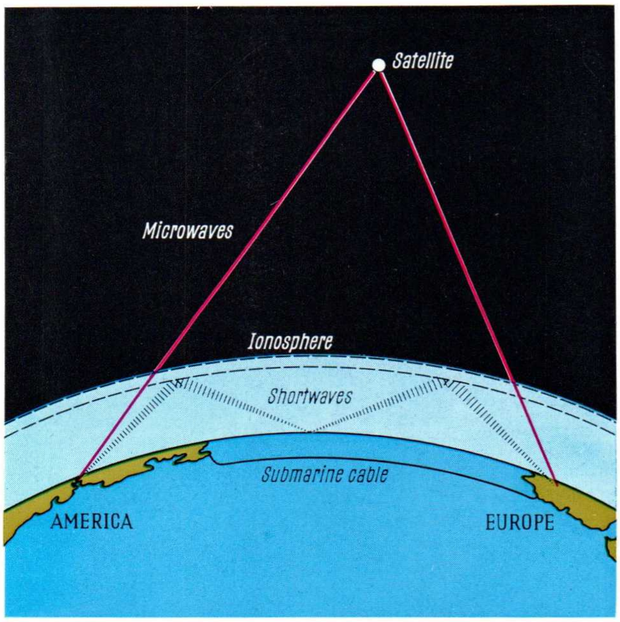


Fig. 1 Submarine cable, shortwave radio and satellite relay station as worldwide communications paths

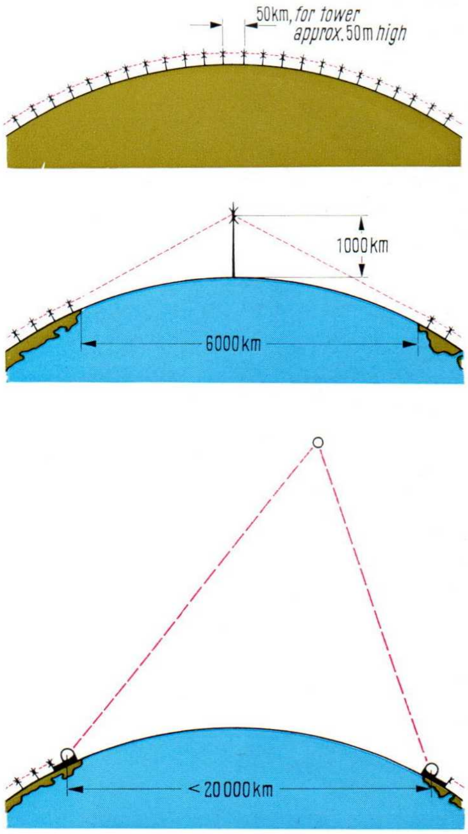


Fig. 2 Radio links with geometric line of sight

a Overland with approx. 50-km radio hops

b Transoceanic with a single (utopically high) relay tower

c Transoceanic with a communications satelite as relay

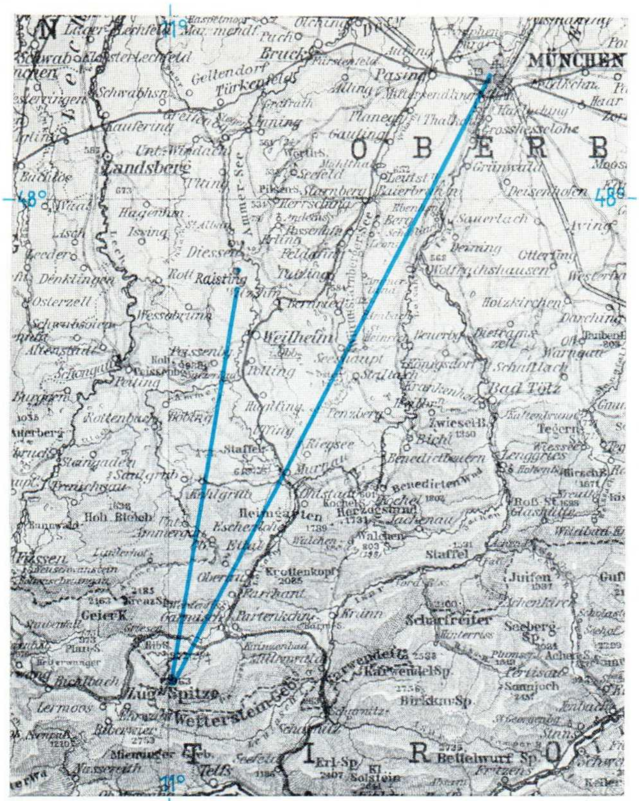


Fig. 3 Location of Raisting earth station with the Bavarian Alps in the background (scale 1:1000000)

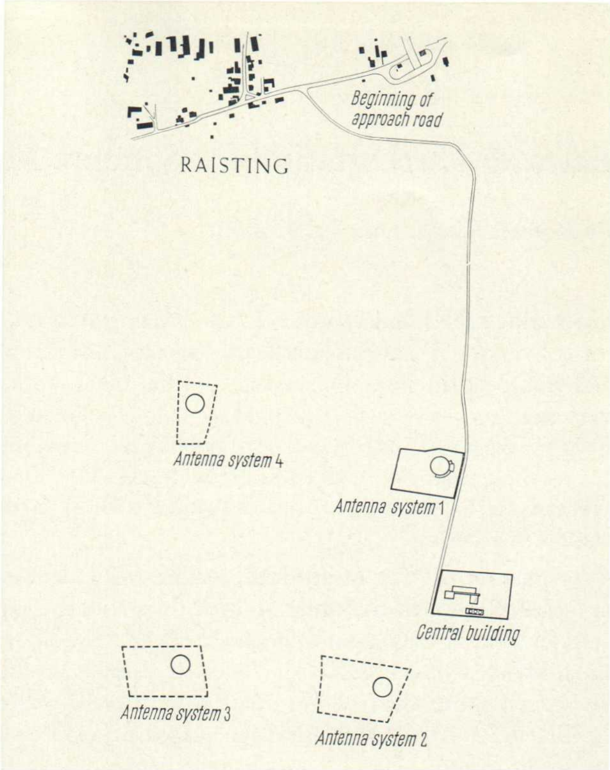


Fig. 4 Antenna systems and central building of Raisting earth station (scale 1:20000)

20000 km, about half as many would be sufficient. If such satellites could be brought to orbit the earth around the equator in such a way that they remain equidistant from each other and so appear to be stationary in the sky, three would be sufficient; their distance from the earth would have to be about 36000 km.

The cost of launching satellites into the required orbit around the earth make it necessary for their weight and volume to be limited to an absolute minimum. Another problem is that, since a satellite cannot be serviced after it has been launched, extraordinarily high demands have to be made on it with respect to reliability, and that so far only relatively low power from solar batteries with an active area of limited size are available for feeding the communications equipment, especially the transmitter. All this means that as much of the technical equipment as possible must be accommodated in the earth stations. These stations must be provided with large highly directive tracking antennas and with high-power transmitters and low-noise receivers of hitherto unknown receiving sensitivity. When satellites are in orbit, each earth station must be able to establish radio contact with any satellite almost as soon as it appears on the horizon and track it continuously in its orbit and then switch to the next satellite as soon as its predecessor disappears over the horizon. Any earth station for a commercial communications system must therefore have at least two antennas for each satellite relay station and a central building which accommodates their power supply plants and control equipment.

Even before the first communications satellite proved successful, the West German PTT decided to build an earth station of its own. For this project they entrusted Siemens & Halske with the following duties as the main contractor:

- Overall planning of project
- Control of all construction work
- Development and supply of a large-size tracking antenna, a receiver with a low-noise input stage, a high-power transmitter, associated supervisory equipment, and a diplexer for separating the transmitting path from the receiving path
- Technical responsibility for all antenna servo groups imported from the USA and their adaptation to the new type of antenna
- Design and supply of the extensive power supply plants.

The site chosen for the earth station was required to be easily accessible and, having regard for the heavy antenna foundations which must be precisely oriented, located

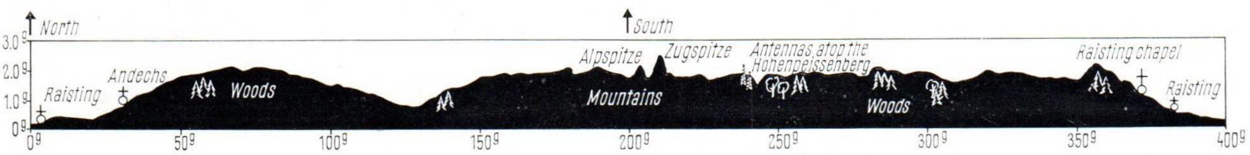


Fig. 5 Elevation angles of horizon around the station (angles indicated in 1/400 of a circle)

on extremely solid ground. R-f decoupling with respect to radio links operating in the same frequency range is of crucial importance. The site should therefore preferably be located in a basin surrounded as far as possible by hills. Such terrain is to be found, for instance, in terminal moraine areas. Also coastal areas are suitable because interference is there possible only from the land side. Terrain elevations should not be too high, however, because it is desirable that radio contact be made with satellites at the smallest possible elevation angles of only a few degrees. The site must also be protected against interference from radar equipment and should be located outside of airlanes.

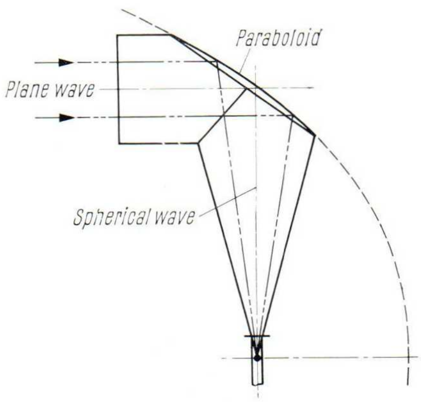


Fig. 6 Underlying principle of a horn reflector antenna

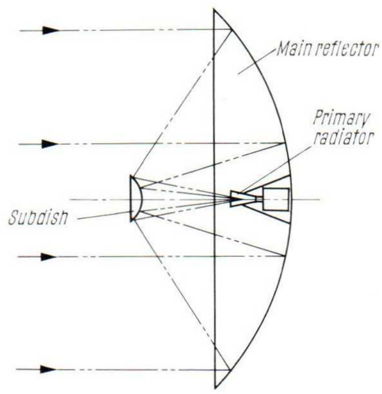


Fig. 7 Underlying principle of a Cassegrainian antenna

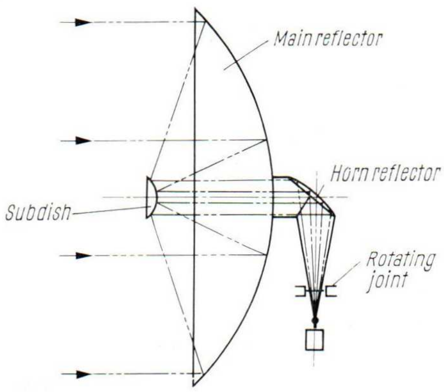


Fig. 8 Cassegrainian antenna fed by horn reflector

Of the many possible sites investigated for building the first German earth station for satellite relay communication, the low country to the south of the Ammersee in Upper Bavaria was finally chosen. Fig. 3 shows the location of the Raisting station with the alps in the background. The various antenna systems – only one has been installed for the time being – are so spaced (Fig. 4) that they will not screen each other at the elevation angles used in sighting and tracking. The smallest useful elevation angle (3°) is determined by the surrounding hills (Fig. 5).

Construction work was commenced in May 1963. The wish of the West German PTT to be able to place the station in service for a trial workout in the fall of 1964 was met.

The typical station equipment will be briefly described.

Antenna System

Preconditions for dimensioning the antenna

The frequency range for the operation of satellite relay stations should be so chosen that both troposhere and ionosphere are positively penetrated by the radio signals. Having regard for the input sensitivity of the receiver, preference should be given to frequency ranges that are unaffected by atmospherics due to electrical discharges or by noise components due to absorption losses in the atmosphere. It is also necessary to avoid frequency ranges in which cosmic interference is to be expected. If all these demands are met, the frequency range available for satellite relay stations will be confined to the region between about 1 and 10 Gc (wavelength 30 to 3 cm). Since adequate r-f decoupling from radio links is secured by limiting the elevation angle for earth stations, the same frequency ranges are used for satellite relay stations as are conventional in broadband radio relay systems, viz. the region around 6 Gc for earth-to-satellite transmission and the region around 4 Gc for satellite-to-earth transmission. As in broadband radiocommunication, frequency modulation is used in the interest of a larger signal-to-noise ratio.

Owing to the large distance of the satellite, the path loss is very high, while the gain of the satellite antenna cannot amount to more than a few decibels. Particularly high demands must therefore be made on the ground antennas. Since the ground antenna must have an extremely high gain (high directivity), its dimensions will be very large in proportion to the wavelength. If the satellite is to be used to relay television programs or a large block of telephone conversations simultaneously, a gain of about 60 db referred to an isotropic radiator should be set as a goal even in the case of optimally high receiver sensitivity and high transmitting power. For the frequency ranges mentioned, this high gain can be attained with an aperture diameter of about 20 to 30 m. Adherence to the desired beamwitdh of about 0.2° between half-power points is only possible if the antenna retains its form with sufficient exactitude in any position, i.e. contour deviations must remain below about $^{1}/_{20}$ of the operating wavelength. An antenna used for earth stations should further exhibit extremely low inherent noise. In particular, the feeders should not supply any significant amount of resistance. In addition, the side lobes should be very small so as to avoid as far as possible the pickup of ground noise.

Since the transmitter and the receiver connected to this antenna operate in different frequency ranges, it must be designed for broadband operation.

The antenna aperture should be movable over the range of a hemisphere. On account of the required accelerations, the rotatable system must have as little mass as possible and a small moment of inertia. Motion should be steady even at low speeds of rotation. The antenna should be adjustable to within a few thousandths of a degree.

Type of antenna

The exacting demands are satisfied by only a few optical types of reflector antennas. The most favorable antenna from the electrical standpoint is doubtless the horn reflector, in which a wave passing from a waveguide into a horn travels in the horn as a spherical wave until it is deflected by 90° by a parabolic dish and so transformed into a plane wave. The principle for the receiving direction is represented in Fig. 6. If the horn is large in proportion to the wavelength, this type of antenna will have a bandwidth of several octaves. The already low side-lobe responses can be further reduced by placing a suitably dimensioned cylinder in front of the aperture. Considering its excellent characteristics, it was only logical to choose this type of antenna for earth stations. Horn reflectors 50 m in length and with an aperture area of 300 m^2 are operating very successfully in the Andover station in the USA and the Pleumeur-Bodou station in France. The only disadvantage of the horn reflector is its great length, which amounts to about two and a half times the aperture diameter.

For a certain amount of outlay it is also possible to satisfy the requirements of earth stations in a first approximation with extra-large rotation-symmetrical parabolic reflector antennas. Such an antenna has been installed at Goonhilly in England. With the conventional type of antenna used thus far, the feeder for the primary radiator is run through a support of the radiator. Additional noise effects develop, however, due to line loss. A far more suitable type of antenna in this respect is designed on the Cassegrainian principle known from optics. It consists of a subdish, the main reflector and a primary radiator arranged near the crest of the main reflector, which is a large parabolic dish. The incoming radiation is focused by the main reflector upon the subdish, from where it is further deflected to the primary radiator (Fig. 7). As a result of this arrangement, the feeder running to the primary radiator can be made considerably shorter. Cassegrainian antennas have been erected for earth stations in several countries, but it has been found that the quality of the horn reflector is superior.

For the Raisting earth station a Cassegrainian antenna has been combined with a horn reflector to produce a new type of antenna (Fig. 8). Instead of giving the Cassegrainian antenna a small primary radiator, a horn reflector that furnishes considerably more favorable radiation than a small primary radiator has been provided. As it further allows a beam deflection of 90°, the composite antenna can be fed like the horn reflector in the elevation axis. In addition to low loss, this form of feeding has the advantage that the sensitive communications equipment can be connected by way of a flexible coupling so that it is not elevated as well. The dimensions of this composite antenna are far smaller than those of a horn reflector antenna.

The antenna (Figs. 9,10) built by M.A.N. for the Raisting earth station has a diameter of 25 m. The relation of the focal width to the diameter is 0.26, the reflector being made this deep in order to minimize spurious radiation.

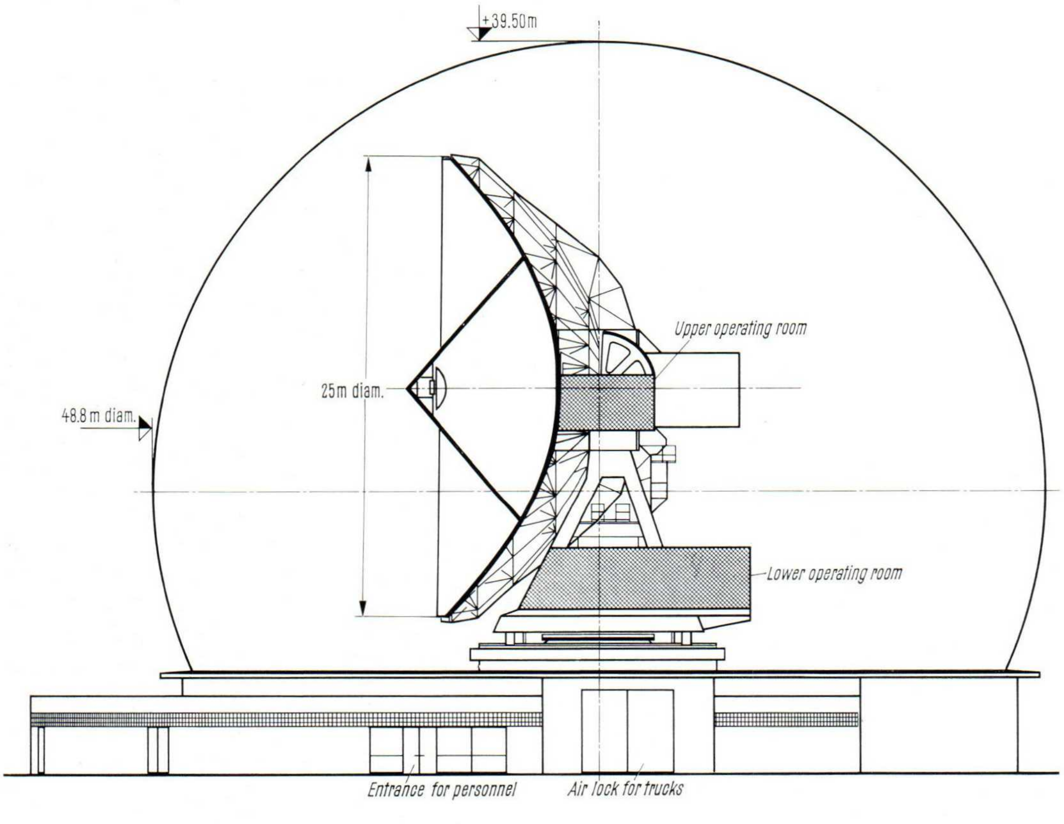


Fig. 9
Elevation drawing of antenna system under radome

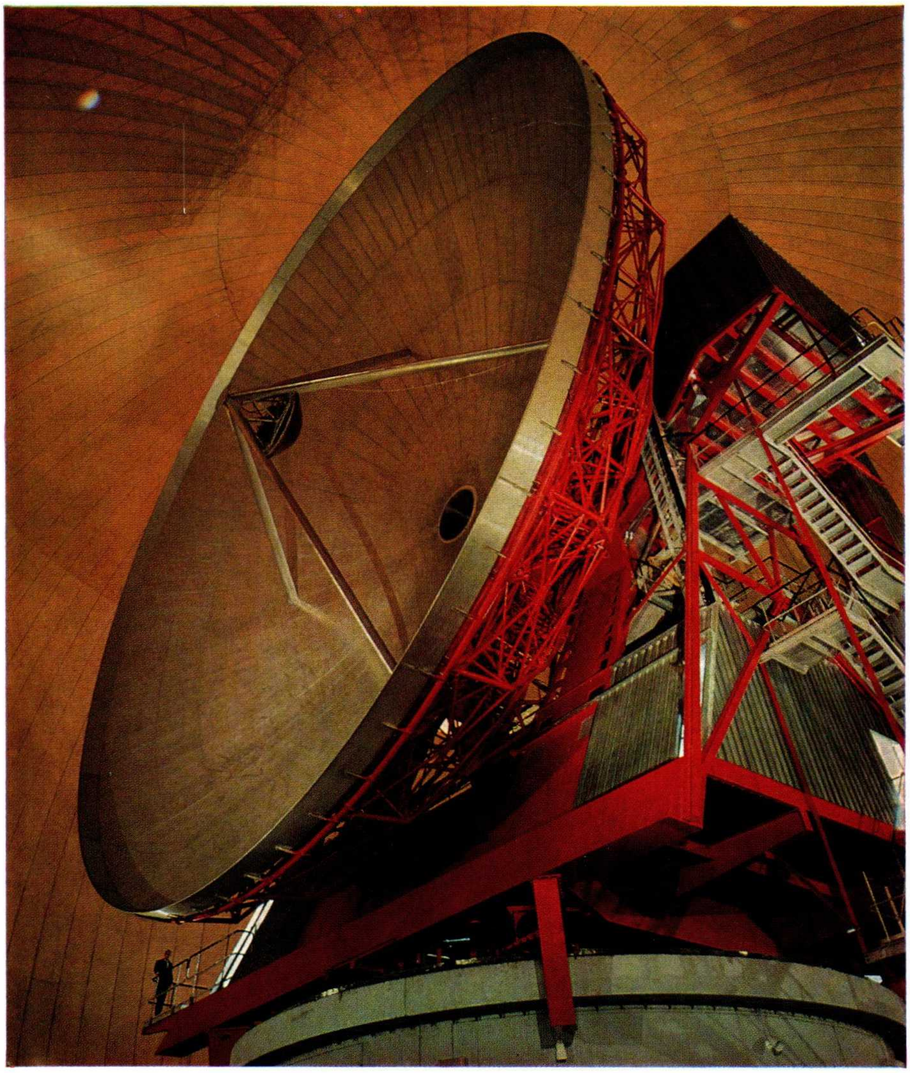


Fig. 10
Parabolic-dish antenna
with subdish

The exciting horn reflector is of about the same size as that of a radio relay antenna. The antenna can be panned by 360° around its vertical axis and tilted about 115° around its horizontal axis by way of its rotating joint. The feeding waveguide of the horn reflector ends in an upper operating room which also accommodates the sensitive receiving equipment. The transmitting and control equipment is accommodated in a lower operating room.

As a result of this arrangement it was possible to keep the mass and hence the moments of inertia smaller than those of equivalent horn reflector antennas. The contour accuracy of the horn reflector is 0.4 mm, while that of the subdish is 0.2 mm; that of the 25-m dish is only 2 mm in any position. A gain of at least 58 db is attained at the receiving frequency (around 4 Gc) and one of about 61.5 db at the transmitting frequency (around 6 Gc). The beamwidth between half-power points averages about 0.2°. The maximal panning speed of the hydraulically driven antenna is 3°/sec in the azimuth and maximal 2°/sec in the elevation. Each of the two hydraulic Vickers motors for the panning motion (azimuth) has a power rating of 25 hp, while the two for the tilting motion (elevation) have individual power ratings of 10 hp.

Radome

The electrical characteristics of antennas for satellite earth stations must be largely insensitive to weather. It is therefore advisable to cover such antennas with an electrically permeable radome. Such a cover prevents temperature differences from developing inside the antenna structure due to the radiation of the sun on one side, and also affords protection against wind, rain and sleet. Smooth antenna motion in reponse to the driving powers that have been stated cannot be guaranteed unless the antenna is installed under a radome. Experience shows that a maximal heating power of 0.1 watt/cm^2 is sufficient to keep the surface of the radome free from snow and frost under all weather conditions encountered in Upper Bavaria.

The air-supported radome chosen for the antenna system in Raisting is of outstanding symmetry. It has a diameter of 48 m, a height of about 40 m, and is made of Dacron manufactured by Bird Air. It has an overall area of 5000-m^2 and weighs 13 tons. The Dacron is 1.8 mm thick and has a tear resistance exceeding 150 kp/cm. The electrical properties of the dacron are entirely satisfactory; the loss tangent is 10^{-2}. The clearance between the radome and the antenna was so chosen that the antenna system could be erected under the radome without any considerable additional outlay. The internal air pressure is automatically controlled in such a manner that deformations due to wind remain within the admissible range. The supporting pressure required at low wind velocities is 40 mm WG and can be increased up to 150 mm WG in the case of wind velocities of 165 km/hr. Experiments conducted with a model showed the radome material to withstand creeping discharges and dielectric punctures so effectively that the provision of a special lightning protection system is not necessary.

Fig. 11 shows the layout of the operating rooms. The antenna system 1 in Raisting with its radome may be seen in Fig. 12.

Antenna control

Various servo groups are provided for contacting and tracking satellites. The antenna can be controlled with the aid of a magnetic tape on which the orbital data of the satellite have been recorded at set intervals of several seconds. Deviations of the antenna setting from the programmed orbit produce error signals with the aid of which the setting of the antenna can be corrected. A versatile servo-control system developed by Bell Laboratories is being adapted by the Telefunken AG to the Raisting antenna. With this control system it will be possible to track a satellite to within an accuracy of a few hundredths of a degree.

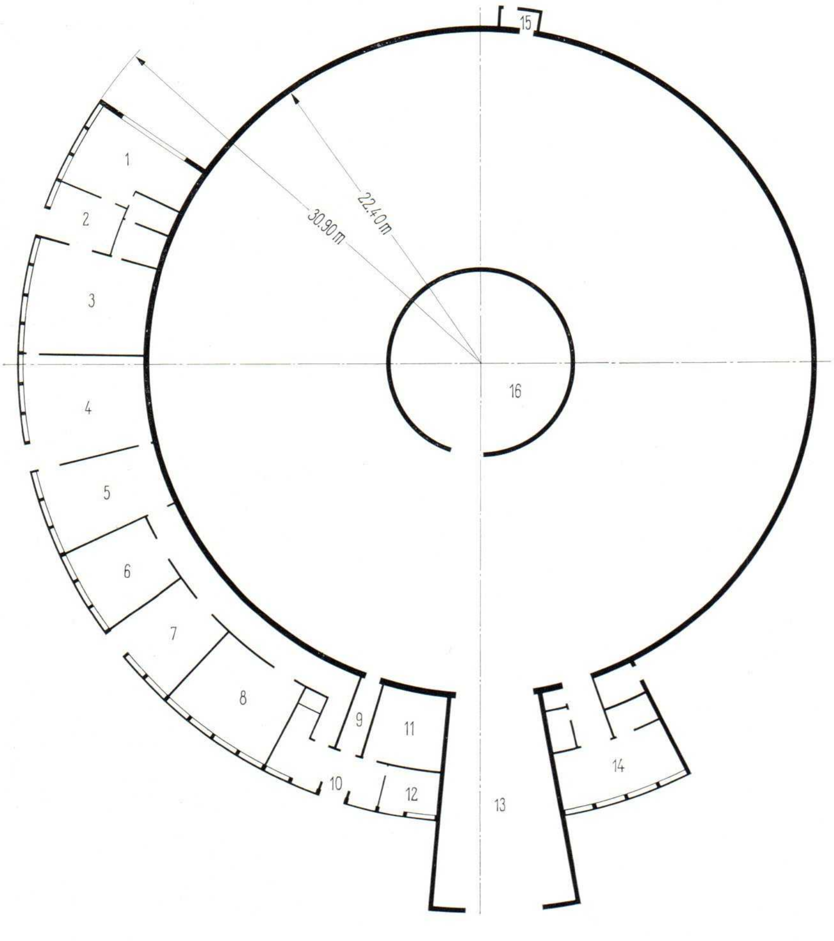
The antenna also embodies a vernier tracking feature with which it is possible to determine the magnitude and direction of tracking errors by comparing two modes in the waveguide according to magnitude and phase. The error signals are applied directly to the control amplifier. This precision method, however, can only be used if the satellite transmits a beacon signal similar to the identification used in radar. Vernier autotrack (VAT) equipment also imported from the USA restricts the tracking error to a few thousandths of a degree. If the point where the satellite appears on the horizon is known to within $^{1}/_{10}{}^{\circ}$, the antenna can be controlled solely with this type of equipment. The new antenna allows the fullest use of this technique.

Extra-high reliability is obtained by coupling magnetic tape control with vernier autotrack. Fig. 13 gives a survey of the interoperation of the antenna servo groups with the communications equipment.

Receiving assembly

The receiving assembly consists of a maser as an extra-low-noise r-f preamplifier for boosting the low-power 4-Gc signal picked up from the satellite, and of a receiver with associated i-f amplifier of the type conventionally used in radio relay systems, followed by a frequency feedback demodulator and the carrier supply. A receiver test cabinet is provided for system tests.

The solid-state maser operates on the traveling-wave principle with rubies as the active element. It is cooled with liquefied helium to about 4°K and requires for operation a constant magnetic field of about 3 kG and a pumping power of 100 mw at 30 Gc. The gain of this maser, which was developed by Bell Laboratories,



1 Recooling system
2 Diesel generator room
3 Blower room
4 Refrigerator room
5 Heating and ventilation
6 Servicing
7 Storage depot
8 Cable distribution room
9 Air lock for personnel
10 Entrance
11 Reception room
12 Porter
13 Air lock for trucks
14 Helium liquefaction
15 Emergency exit
16 Cable wrap and slip-ring system

Fig. 11
Floor layout of antenna system

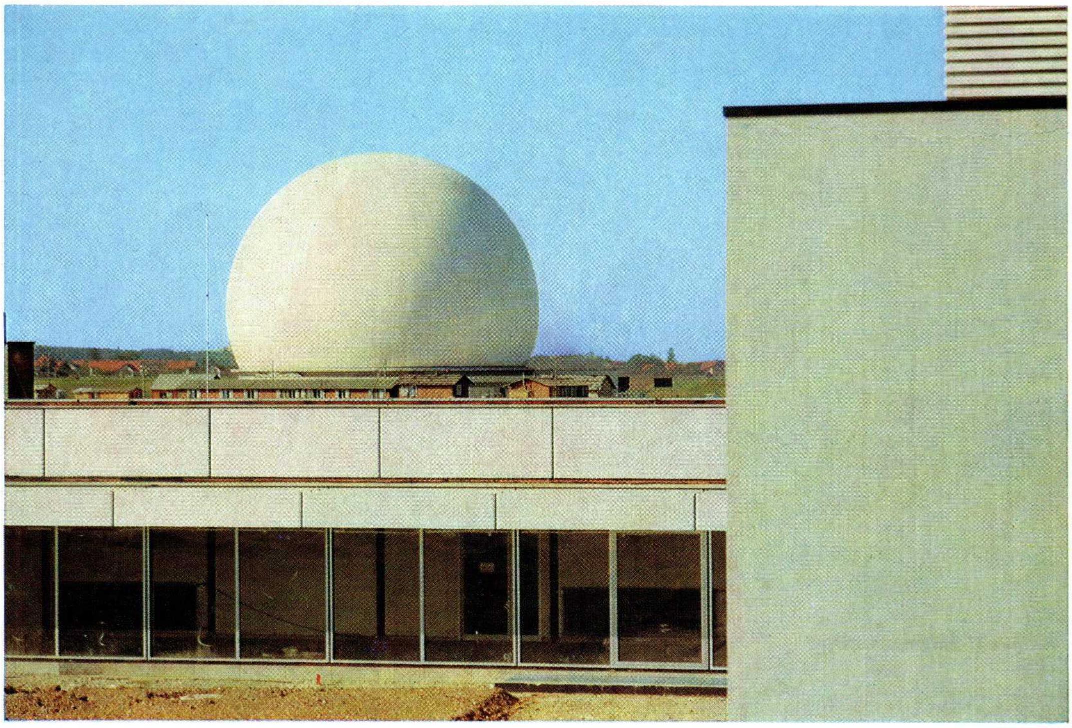


Fig. 12
Antenna system 1
as seen
from behind
central building

is 40 db, while its bandwidth (for a drop of 3 db without an equalizing filter) is 16 Mc. The noise temperature is about 4°K. The bandwidth of the receiving circuit is extended to 25 Mc by equalizing the maser frequency response in the following i-f circuit.

Fig. 14 shows the comb-like delay line and also the rubies of this maser. A circulator combined with the delay line restricts amplification to one direction only. The f-m degenerative demodulator improves the threshold value of the f-m receiver by several decibels. Degeneration in the receiver reduces both the frequency deviation and the bandwidth. The noise temperature of the receiving circuit, including the antenna, will prospectively amount to 30 °K on clear days with the antenna in its zenith position. About 40 °K was measured at 10° elevation, about 50 °K at 5° elevation. The highest value so far measured during rain was 85°K at 5° elevation.

Transmitting assembly

The transmitting assembly consists of a traveling-wave preamplifier and the power stage, for which a water-cooled traveling-wave tube has been developed by the Tube Division of Siemens & Halke. On account of its broad frequency band and high efficiency, the traveling-wave principle has found wide acceptance in designing transmitting tubes for broadband radio relay systems.

The preamplifier, for which the carrier supply and the transmitting modulator were also developed, delivers in the region around 6 Gc a driving power of 2 watts to the power stage which, given a gain of 30 db, delivers an output power of 2 kw and a saturated power of 3 kw. In order to improve reliability, the power stage is provided with two tubes which can be cut in alternately. The output of the power stage is regulated as a function

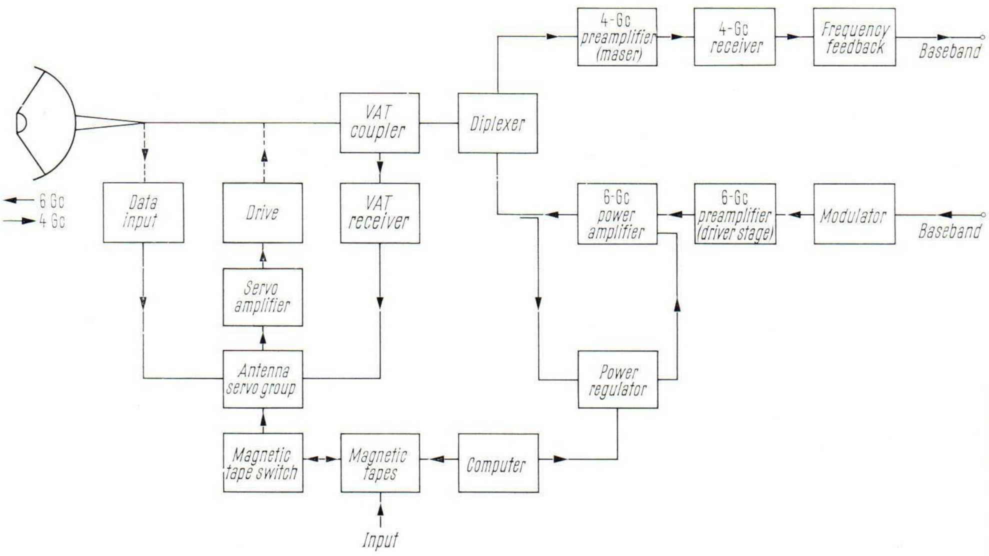


Fig. 13
Block schematic of the servo-control groups along with the transmitting and receiving equipment of antenna system 1

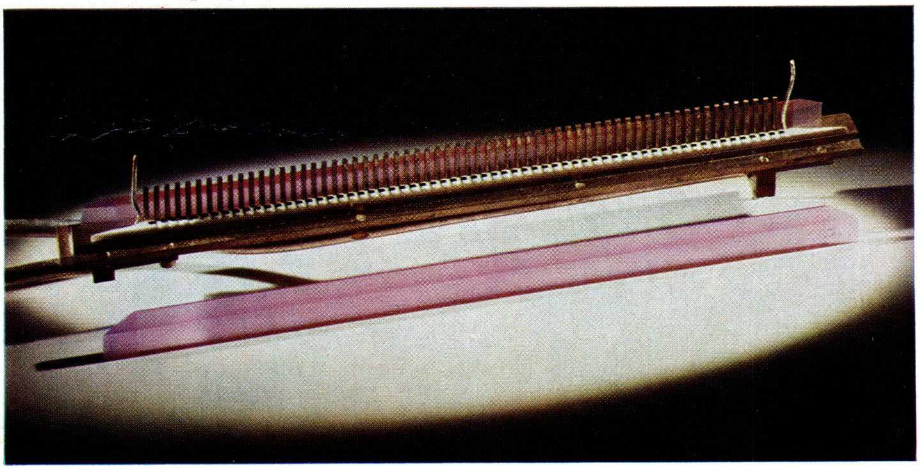


Fig. 14
Elements of a traveling-wave maser: ruby rods and comb-like delay line with circulator

of the distance of the satellite. Automatic supervisory control equipment has been developed for both the exciter transmitter and the power amplifier.

Diplexer

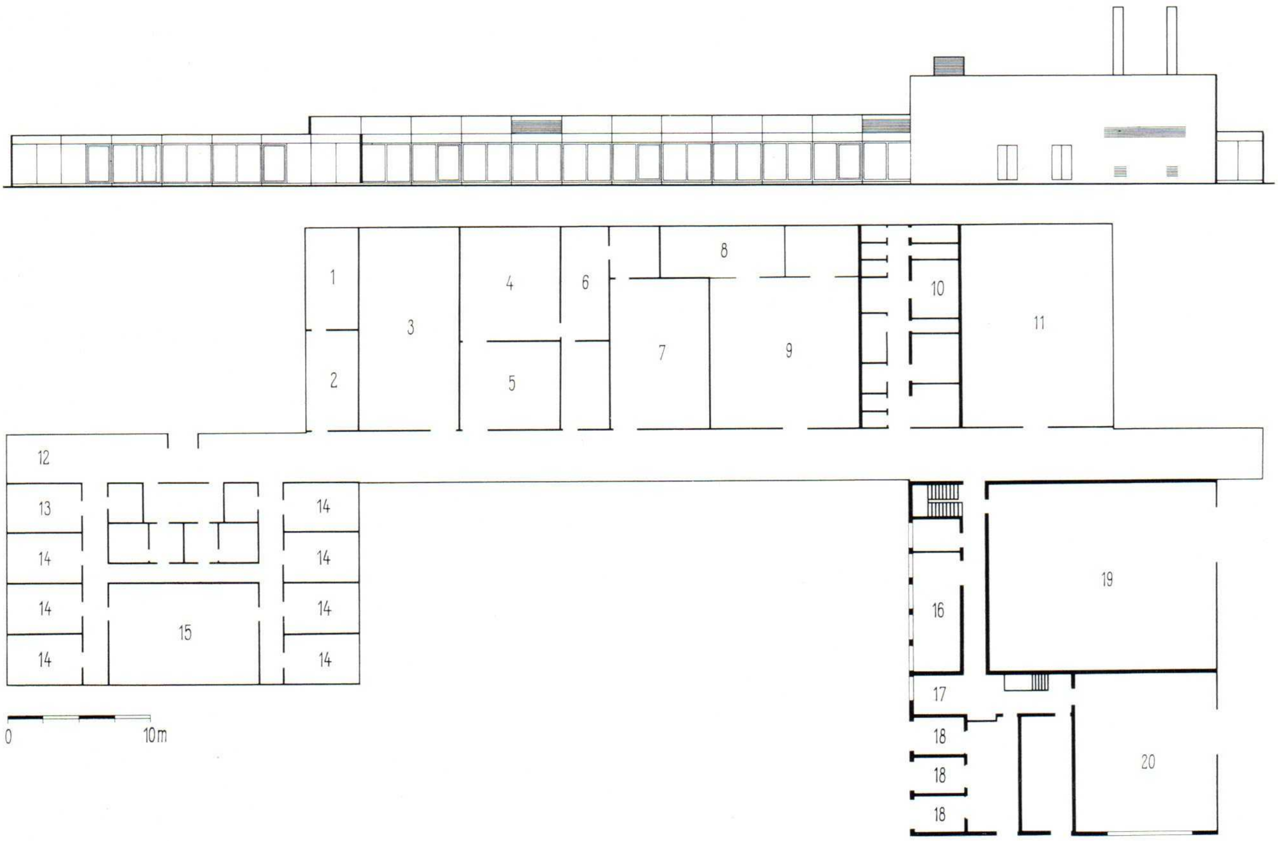
Since both receiver (receiving power $\sim 10^{-12}$ watts) and transmitter (transmitting power $> 10^{3}$ watts) use the same antenna, a diplexer is required in order to allow simultaneous operation and to effect the necessary changes in polarization in the transmitting and receiving circuits. The losses of the diplexer must be extremely low so as to prevent any serious increase in the noise temperature of this system.

Satellite simulator

A manual/remote satellite simulator with a 6-Gc receiver, a 4-Gc transmitter and, like the satellite, a beacon transmitter, has been developed for testing the earth station. The simulator is mounted along with a directional antenna on a measuring tower located in the far field of the antenna at an elevation angle of about 2°.

Central building

The U-shaped central building has three sections: one for the communications dropping and processing equipment, one for the offices and lounges of the station, and



Section 1:

1 Switch room
2 PABX
3 Lecture room
4 Radio room
5 Servicing room
6 Measuring rooms
7 Supervisory room
8 Filing and programming room
9 Computer room
10 Air-conditioning rooms
11 Switching control room

Section 2:

12 Porter
13 Senior engineer
14 Office rooms
15 Lounge

Section 3:

16 Recooling system
17 Meter room
18 Transformer rooms
19 Heating room
20 Diesel room

Fig. 15 Side and floor plans of central building

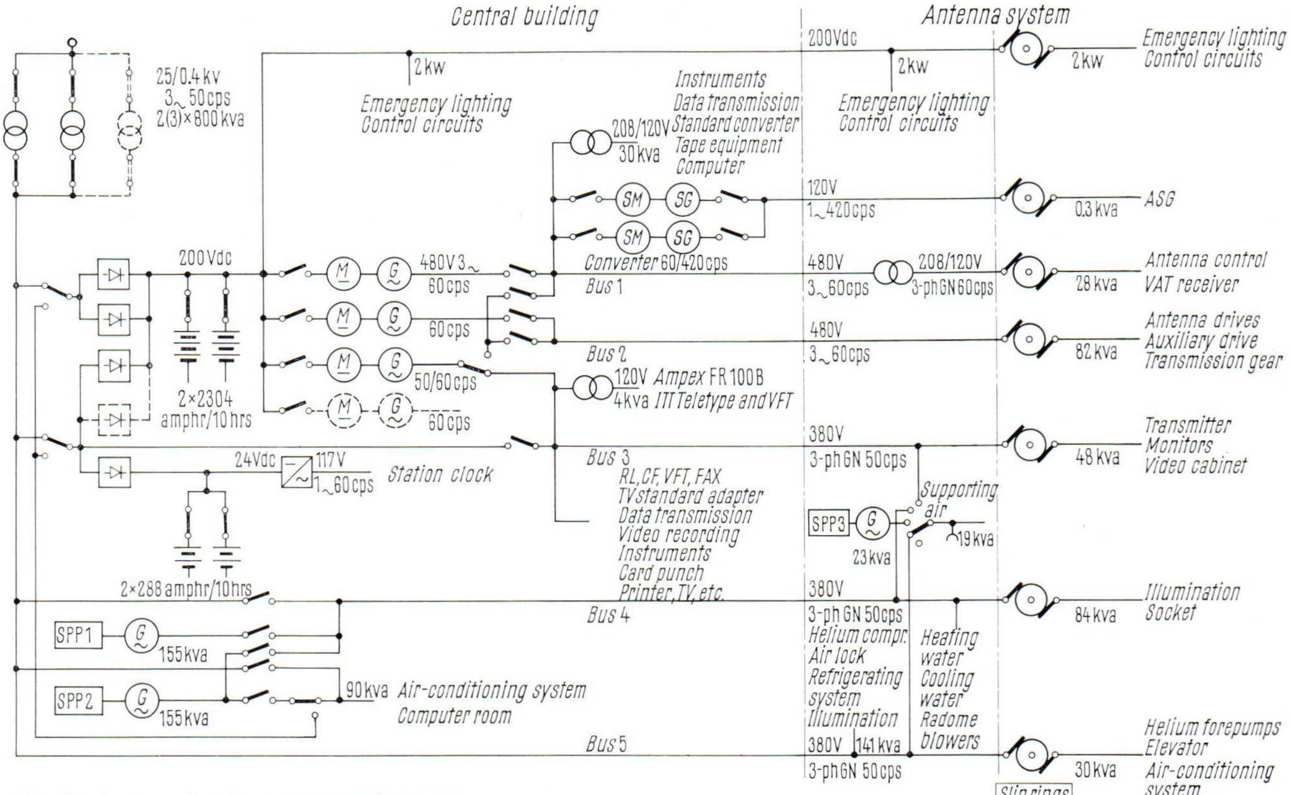


Fig. 16 Survey of station power supply system

one for the heating and power supply plant. Fig. 15 shows the side and floor plans of the building.

In the control room of the central building the engineer in charge of the station supervises the functioning of the communications equipment at a console at which all classes of trouble that may develop in the system are instantly indicated. The console also has controls for initiating the changeover operations required for the transmission of television programs, including adaptation of the scanning line standard.

Since the power supply equipment is of particular importance it will be described more closely.

The power supply system had to be so dimensioned that neither short voltage dips lasting a few milliseconds nor long-term breakdowns of the power supplied over the rural power grid will affect the operation of the station. Short power outages will pass unnoticed because even during normal operation battery-fed converter units supply all the voltages required for the communications equipment. The standby power plant, consisting of a battery, a dc/ac converter plant and diesel generators, was dimensioned to insure full operation of the station over power outages lasting up to one hour. As outages lasting longer than this are heardly to be expected even if the rural power grid breaks down, they were not allowed for in planning. With a view to the subsequent addition of further antenna systems, due provision has been made for the easy expansion of both building and system. Furthermore, in the interest of improved reliability, all major power supply groups are subdivided so that, if a unit breaks down or has to be shut down for preventive maintenance, operation will be continued until a standby unit is started.

Since the non-communications plants impose far less exacting demands with respect to voltage and frequency stability of the power supply than the communications equipment, the outlay for feeding these plants was kept reasonably low. However, since the American equipment is designed to be fed from a 60-cps power grid, a 60-cps bus had to be provided in addition to the 50-cps bus.

The general circuit diagram (Fig. 16) shows how the various requirements have been met. The equipment associated with the central building is divided from that of the antenna system by vertical dash-dot lines; subsequent system expansion is indicated by dashed lines.

Floated from the rural power grid, the battery feeds three converter units that deliver a 60-cps voltage to buses 1 and 2 and a 50-cps voltage to bus 3. All communications equipment is connected to these three buses. Buses 4 and 5 are fed directly from the rural power grid and supply the non-communications plants.

In the event of a power outage, buses 1 to 3 are supplied through the battery-fed converters. Standby power plant 1 (SPP 1) feeds bus 4, while bus 5 is disconnected; standby power plant 2 feeds the air-conditioning plant of the computer rooms; standby power plant 3 feeds the blower plant for the radome. Being a vital part of the overall system, the blower plant can also be fed from the battery by way of one of the converters. If standby power plant 1 breaks down, standby power plant 2 then supplies bus 4 and the air-conditioning plant is shut down. In the event of a lengthy rural power outage, the battery can be recharged by way of the standby power plant.

The present rating of the power supply system is 2 × 800 kva.

Conclusion

The Raisting station is connected to the radio relay network of the West German PTT by way of a link with the Zugspitze and connected from there to München (see Fig. 3). Experimental communication with the orbiting Relay and Telstar satellites began in the fall of 1964. Television programs were picked up by way of the satellite relay for the first time on October 9th. The picture quality was excellent. The current objective is to determine whether the equipment will operate with the same reliability as in other long-line communications systems. The equipment will afterwards be adapted for communication with the Early Bird synchronous satellite, which is to be launched in the spring of 1965.

Raisting will prospectively commence commerical operation as early as in 1965.

Issued by Wernerwerk für Weitverkehrs- und Kabeltechnik,
8 München 25, Postfach 704

SIEMENS AKTIENGESELLSCHAFT

Order No. 2-4114-015-101
Printed in Germany
7681. (0135)