Antennas of vehicles landing on a planet surface

Kira K. Belostotskaya

Abstract — **The antenna systems designed under the international projects "Mars-96" and "Phobos" are described. The antenna system of Small station landing on Mars, in flight is packed under protective petals of the station and is opened on a surface with the help of flexible legs. The original scheme of excitation in the form of compact strip-geometry is described. The antenna system of the mobile vehicle landing on Phobos, provides the omnidirectional pattern on the basis of the combination of antenna methods with methods of processing of the received signal. The high efficiency of the antenna results from its construction in the form of an active antenna.**

Keywords — *antenna system, omnidirectional pattern, active antenna.*

The small vehicles which are landed on a surface of planets, must have, as a rule, very limited sizes and weight. At a phase of overfly in a transport position the antenna devices should be packed inside the vehicle and in working position it is appropriate to use the elements of the vehicle in a design as components of the antenna. The radio system of Small automatic station landed on a surface of Mars (international project "Mars-96"), was equipped with receiving system. The system received a command from the orbital spacecraft to switch on the equipment for the scientific information transmission.

The communication was realized by transmiting-receiving antenna. The antenna provided a reception on a frequency of 437.1 MHz and transmission on a frequency of 401.5272 MHz. The requirements to the pattern were determined by communication angles with the orbital spacecraft. The antenna should have a radiation characteristic in the upper half-space (on azimuth – omnidirectional, on an elevation – $\pm 70°$ from a direction in zenith). The field of radiation – circular right hand with elliptic coefficient not worse then 4 dB in a zone of working angles.

The external outlines of the upper hemisphere of the station and system of legs in the form of flexible contoured metal ribbons for the lift of the antenna and installation it into working position were determined during the designing of the antenna. Besides, the scientific devices were placed above the antenna and on the elements of legs.

The antenna system represents a dipole antenna of turnstile type (Figs. 1 and 2). Four arms of dipole assume the position at which the pattern on two frequencies is satisfactorily formed. The metallized top of a station surface served as the reflector for the antenna, forming its radiation in the upper hemisphere.

The height of dipole above a station surface, and also their inclination to a vertical axis of station was selected from conditions of synthesis of maximum gain within working angles on two operational frequencies. The increase of the antenna bandwidth was reached by selection of strip width
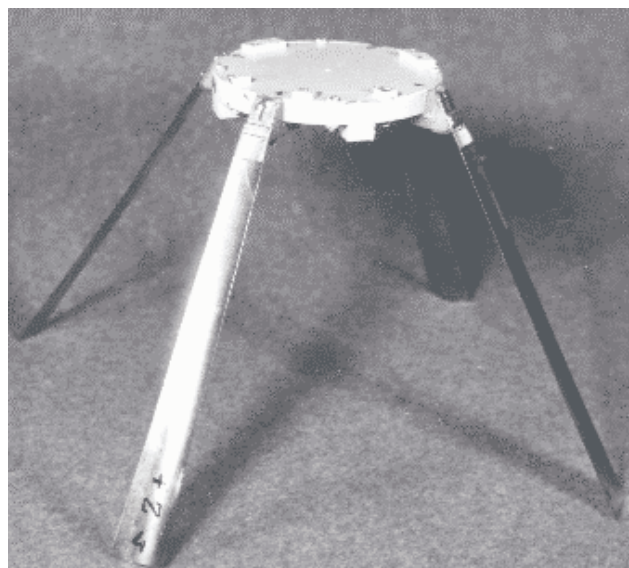

Fig. 1. Mars Small station.

Fig. 2. Antenna system of Mars Small station.

of dipole. As dipoles are for long in a folded bent condition in notches of protective dielectric coating of station, the plates have a special configuration and special limiter. The material of a plate – bronze with special thermal treatment. Four dipole were excited with shift of 90°, providing the

circular polarization field which is omnidirectional in an azimuth plane.

The essential problem has arisen at working out of the device of excitation, phasing and matching. The necessity of the installation of scientific devices practically in "body" of the antenna was the reason of this problem. As a result the dipole lost its ordinary point of a feed, because the arms of dipole have been strongly removed one from the other. From the diplexer of transponder to the antenna could be made only one flexible cable along the one of four legs and whole beam-forming network (BFN) should be placed in a small volume under the scientific device occupying the center of a symmetry of the station. The height of this volume was limited also. As a result the beam forming network and design of a feeding unit became complicated and required fine turning. The scientific devices and flexible legs change the input impedance. The input impedance has a sharp frequency response because the arms have nonresonance sizes on working frequencies. As a result, matching could be fulfilled on two separate working frequencies only (Fig. 3). The scheme of excitation and matching of turnstile antenna are made as a three
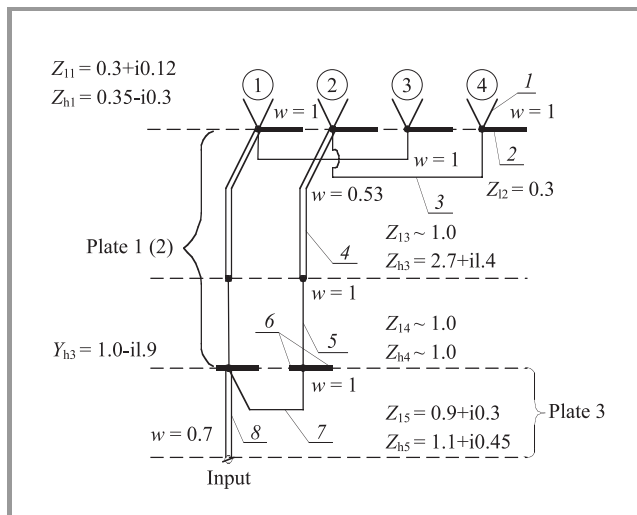

Fig. 3. Excitation and matching scheme of turnstile antenna. Explanations: 1 – dipole; 2 – symmetrizing section $1/4(\lambda_1 + \lambda_h)$; 3 – matching stub for f_1; 4 – $\lambda_1/4$ transformer; 5 – shift transformer for f_h; 6 – resonant stub $\lambda_1/2$; 7 – $\lambda/4$ phasing section $1/8(\lambda_1 + \lambda_h)$; 8 – matching transformer $1/2(f_h + f_1)$.

plate set of symmetrical microstrips of a complex configuration on disks with a diameter of 78 mm. There is a $180°$-phase shifter on the first plate for first pair of opposite arms (Fig. 4). There is a $180°$-phase shifter on the second plate for identical matching of the second pair of arms. At first the antenna matching is made on low frequency with the help of a transformer and a stub. Then after transformation on the low frequency the stub which provided the matching on the upper frequency is connected. The phasing on $90°$ and final matching is executed on the third plate. The scheme is terminated by the connector such as SMA, to which was connected cable mounted on a leg. The antenna

system must operate with high reliability in conditions of low temperatures ($-100°C \ldots 140°C$). For this reason conductors connecting the dipoles with BFN as well as the connectors between plates must had redundant length. The feed points of dipole are protected by a polyurethane compound. The full losses in the antenna system are evaluated in 1.7 dB.

The antenna system gain with polarization losses in 95% in the zone of working angles had values: -4.2 dB on $f = 401.5272$ MHz and -3.9 dB on $f = 437.1$ MHz. Weight of the antenna system with a cable 1060 mm long was 240 g. The tests in conditions of statistical, dynamic and impact accelerations, and also at reduced temperature were conducted on the antenna system which was a component of a technological experimental model of Small station. After these tests the parameters of the antenna were kept.

Other example of unique development is the antenna system of the vehicle landing on the surface Phobos. The multipurpose international space project "Phobos" provided the activity of mobile vehicle on a surface during a long period (Fig. 5).

The vehicle was equipped with radio telemetry system for transmission of the data of ground research to the spacecraft and also command radio link for periodic turn on of transmitting system of vehicle. The orientation of the mobile vehicle on a surface could be any. The task of formation of the omnidirectional characteristics of radiation requires a combination of antenna means with certain circuit designs. Here double-frequency transmission and two-channel signal reception was used. By this principle two independent patterns were added so that the zones of a low gain of one pattern were filled by radiation with a high gain from the another. The number of antennas in a system is selected from a condition $n \geq 1.5 \ldots 1.8$ ka, where ka-electrical radius of the vehicle. Depending on processing methods the synthesized pattern is equal either sum, or envelope of large values of the pattern of separate channels. On the vehicle two antennas on sphere surface separated on $90°$. The small frequency separation of antennas (about 7%) has allowed to use the antenna devices of the identical sizes in channels $f_1 = 280$ MHz; $f_2 = 300$ MHz. It is necessary to mark, that of the double-frequency principle provides an actual hot-standby operation of a system, the failure of one channel does not result in a full communications breakdown, and only limits a zone of working angles.

The requirement concerning absence of outstanding antenna elements over a shell of the mobile vehicle has determined the size of antenna vertical parts. The size of outstanding parts must be not greater than 0.025 wavelengths. This task was decided by designing the antenna system of an active type. The antenna was made as the Γ-shaped quarter-wave oscillator of a shunt feed directly incorporated with a transmission device (Fig. 6).

For selection of an optimum regime of an antenna matching with the transistors the power diagram of the transis-
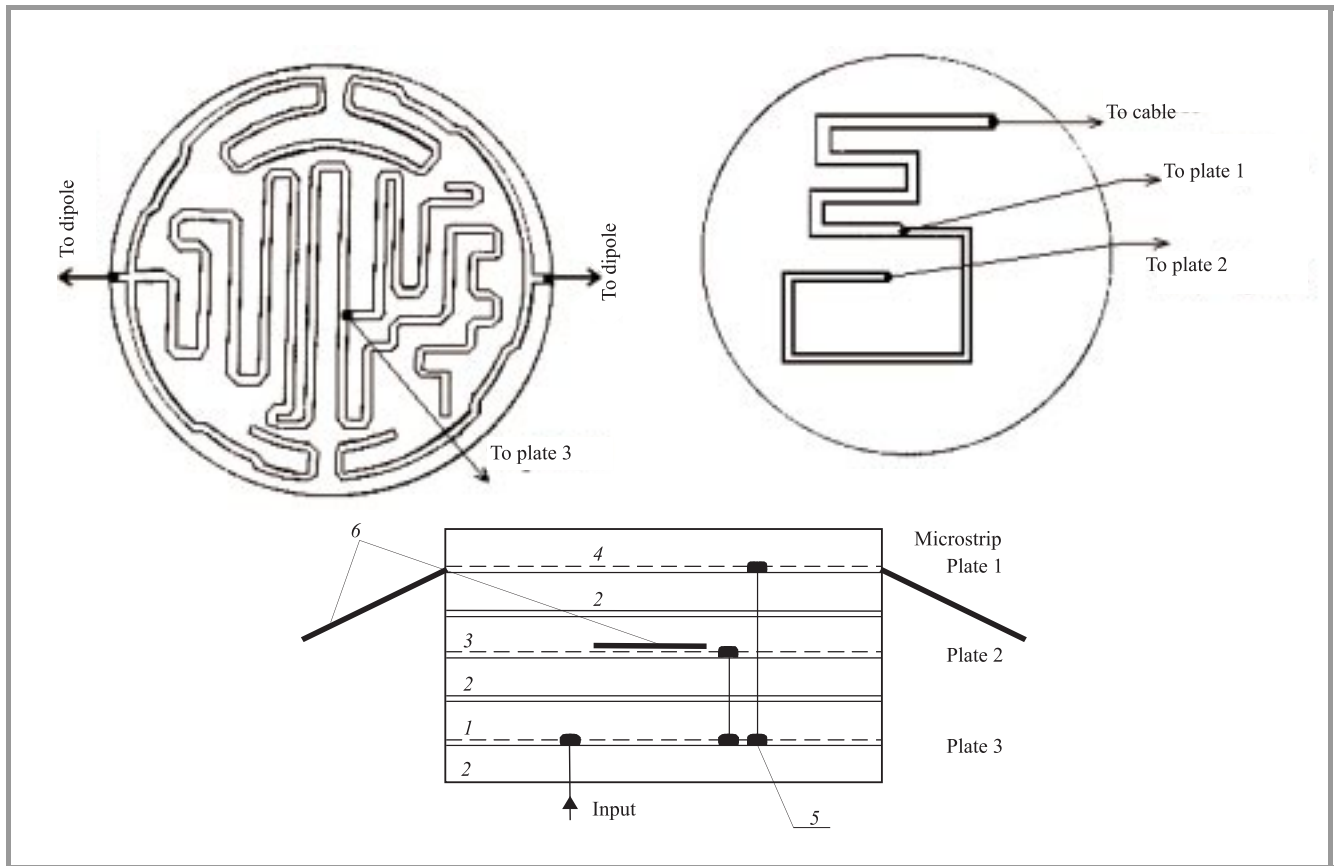
Fig. 4. Beam forming microstrip plates. Explanations: *1* – 90°-shift plate; *2* – empty layer; *3* – 180°-shift and matching plate $(1-3)$; *4* – 180°-shift and matching plate $(2-4)$; *5* – coaxial strip; *6* – dipole.

Fig. 5. Phobos mobile vehicle.

Fig. 6. Active antenna. Explanations: *1* – exciter; *2* – short-circuit vertical part; *3* – stub turner; *4* – capacity disk; *5* – dielectric shell.
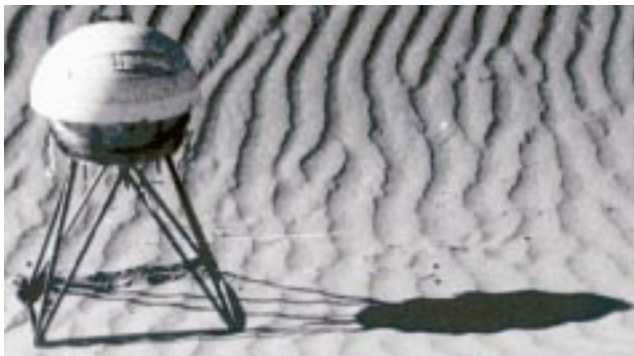
tor of an output circuit was used. Active component of input impedance was determined by the position of an exciting element relative to a short-circuit vertical part of the antenna, and reactance component was provided with selection of length of a horizontal part-stub and tuning elements – capacity disk. In a whole sphere the gain of a double-frequency telemetry system was greater than 0.4. Thus efficiency of an active antenna was determined only by thermal losses in antenna elements and shell, and at the height of vertical parts equal to $1/40\lambda$ it was high enough (about 70%). At flight tests the estimation of ground influ-
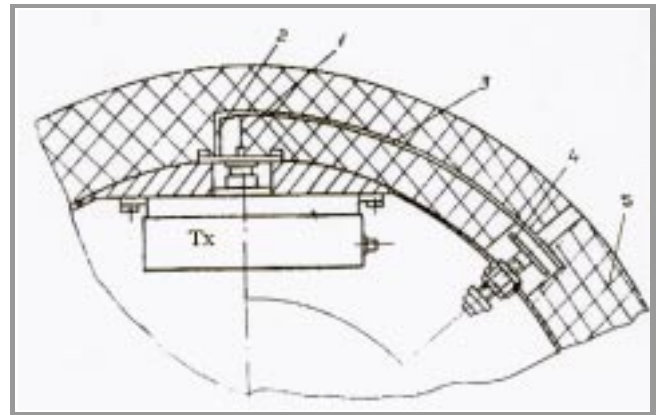
ence on the characteristics of the antenna was carried out. The tests were conducted with the completely assembled mobile vehicle covered a protective dielectric shell. It has been found that the direct contact of the mobile vehicle with soil can reduce the value of a gain by 3 dB. The thermal frequency stability of tuning was evaluated using the variation of a resonance frequency in range of temperatures

from $+50°$C to $-40°$C. For the given design the variation of an input impedance practically did not change a radiation power which was given back by the transmitter to the antenna.

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Kira K. Belostotskaya was born in Moscow, Russia, in December 1934. She received the Candidate of Technical Science (Ph.D.) degree in electrical engineering (antennas and microwave devices) from the Moscow Power Engineering Institute (MPEI) in 1971. In 1958–1966 a Research Scientist in the Special Research Bureau of MPEI (OKB MEI). In 1967–1980 a Leading Research Scientist in OKB MEI. Since 1981 a Chief of Laboratory (design of telemetry and telecommand radiolinks; energy budget of radiolinks; design of onboard antenna system; electromagnetic compatibility of onboard systems) in OKB MEI. Member of various projects, including: "Venus 15, 16" – Antenna system of SAR, "Phobos" – Antenna system of moving vehicle, "Mars 96" – Antenna system of Small station, IRS (India) – design of radiolinks, "Solar Sail" – VHF antenna. She is author of more then 100 publications, including Planetary and Space science, Telecommunications and Information Technology.
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