Astronomy

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Abstract

Full Text

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RADAR OBSERVATION OF THE PLANET MARS IN THE SOVIET UNION

Radar observations of the planet Mars were carried out in the first half of February 1963, during the period of opposition. The opposition of 1963 was unfavorable for observations, since at the time of the measurements Mars was at a distance of 100–101 million km from the Earth.

The observations of Mars were conducted at a frequency of about 700 Mc/s. The polarization of the emitted waves was circular; on reception the antenna polarization was changed to linear. The overall sensitivity of the installation was the same as in the radar observations of Mercury in 1962 ([2]). The power of the emitted signal falling on the entire visible surface of Mars was 1.2 W. Transmission was carried out in sessions during the time required for the signal to travel from the Earth to Mars and back (about 11 minutes); then reception was carried out for the same length of time.

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Fig. 2. Results of successive accumulation of the energy of the signal reflected from Mars in a 4-Hz band, February 6–10, 1963.

Figure 2: Fig. 2. Results of successive accumulation of the energy of the signal reflected from Mars in a 4-Hz band, February 6–10, 1963.

by noise.

The transmitted signal had the form of alternating rectangular pulses and pauses at two frequencies differing by 62.5 cps. The duration of the pulses and pauses at each frequency was 4.096 sec. The displacement of the carrier frequency and the keying frequency of the reflected signals, caused by the Doppler effect due to the motion of Mars and the Earth (taking into account its rotation), was compensated according to a calculated program. The received signals were recorded on magnetic tape together with an oscillation of frequency 2000 cps, serving as a scal-

time marks. Spectral analysis of the signals received on magnetic tapes was carried out in the same way as in the radar observations of Mercury and Venus in 1962 ([2,3]).

In view of the fact that the reflected signal was very weak and it was impossible to detect it in a single session, special attention was paid to checking the correct operation of all the apparatus.

The pointing of the antenna was checked with the aid of a theodolite mounted on the antenna, in the crosshairs of which Mars was visible (except on the night of February 9–10, when it was not visible because of cloudiness). Monitoring of the transmitter radiation

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was carried out with the aid of an auxiliary receiver, the signals from whose output were fed to an oscilloscope and were also listened to over a loudspeaker. Calibration of the sensitivity of the receiving installation was performed every day before the beginning of work and after its completion, by radiating the extraterrestrial discrete source Cassiopeia A. In the intervals between sessions the receiver was calibrated with the aid of a noise generator calibrated against Cassiopeia A.

The introduced value of the correction for the frequency shift due to the Doppler effect was monitored with an electronic counting frequency meter. The operation of the modulator could be checked from photographic records of the modulating signals, which were registered on a loop oscillograph together with time marks. The operation of the entire installation as a whole was checked with the aid of a simulator, from which a correspondingly attenuated transmitter signal was fed to the receiver input.

Fig. 3. Astronomical map of the planet Mars, adopted by the International Astronomical Congress in 1958 (4), with the investigated region.

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The principal measurements were carried out every night from February 6 to 10, 1963. During this time, ninety 22-minute receiving-transmitting sessions were conducted, during which all the apparatus operated normally. The signal reflected from Mars was reliably detected in 28 sessions carried out on the night of February 7-8, and in 20 sessions from February 8-9.

The results of the analysis of the spectrum of the received signal for the 48 sessions in which the reflected signal was detected are presented in Fig. 1. The analysis was performed with filters having a 4-Hz passband. The accumulation time was 8.5 hours. The spectrum in Fig. 1 is the sum of the measurement results at both frequencies radiated by the transmitter.

As is seen from Fig. 1, in the spectrum of the reflected signal there is a narrow-band component, the energy of which, accumulated in the band of the central filter, exceeds by a factor of 4 the root-mean-square value of the errorness of the measurements caused by noise. The probability that this result was caused by noise is only 0.003%.

In the calculations of the Doppler frequency shift and the delay of the reflected signals, the value of the astronomical unit was taken to be $A = 149\,599\,300$ km, which was obtained by radar observations of Venus in 1961 (1). As can be seen from Fig. 1, the frequency of the narrow-band component of the reflected signal corresponds to the calculated value (with a maximum error of $\delta f = \pm 2$ Hz, due to the bandwidth of the central filter). Thus, the radar observations of the planet Mars confirm the results of measurement of the astronomical unit obtained by radar observations of the planets Venus (1,3) and Mercury (2). The magnitude of the Doppler frequency shift caused by the motion of Mars and the Earth during the observations was $\Delta f_{\mathrm{D}} = 8 \div 12$ kHz. Therefore the error in measuring the astronomical unit by radar observations of Mars should lie within the limits

Fig. 3. Astronomical map of the planet Mars, adopted by the International Astronomical Congress in 1958 (4), with the investigated region.

$$\delta A = A\,\frac{\delta f}{\Delta f_{\mathrm{D}}} \simeq \pm 30\,000 \text{ km}. \tag{1}$$

An accurate measurement of the distance between the Earth and Mars was not carried out, owing to the insufficient signal level.

The results of successive accumulation of the energy of the reflected signals in the 4-Hz band of the central filter on the days of observation are shown in Fig. 2. The accumulation of energy is shown separately for each of the frequencies emitted by the transmitter (curves 1 and 2), and for their sum (curve 3). In the sessions conducted from February 7 to 8 and from February 8 to 9, when the reflected signal was detected, the accumulation of energy proceeded uniformly at both frequencies. In the sessions from February 6 to 7 and from February 9 to 10, when the reflected signal was not detected, the curves fluctuate about zero. The reason for the absence of a signal in these sessions has not been clarified. It is possible that this is connected with a change in the reflecting properties of the surface of Mars on those days.

For Mars, whose rotation period according to astronomical observations is 24 h 37 min, the full width of the spectrum of the reflected signals at a frequency of 700 MHz, taking into account the inclination of the axis of rotation, could reach 2200 Hz. The obtaining of a narrow-band spectrum from a planet with rapid rotation indicates the presence on the surface of Mars of sufficiently flat horizontal areas several kilometers in size or more.

The mean reflection coefficient of Mars, determined as the ratio of the energy of the reflected signals in a 4-Hz band over 48 observing sessions (February 7–9, 1963) to the energy of the signals that would have been received if Mars were a smooth, ideally conducting sphere, was found to be 7%. This reflection coefficient is close to the value obtained in the radar study of Venus, and is greater than that for the Moon.

The observed reflected signals came from that part of the Martian surface which at the given moment was closest to the Earth. As a result of the rotation of Mars, the reflecting zone moved during the day over its surface almost exactly along a parallel (see Fig. 3). The trajectory of the reflecting zone shifted from day to day by approximately 500 km in longitude and only 7 km in latitude. The region investigated was located in the northern hemisphere and had areographic (Martian) coordinates: from 14°30′ to 14° latitude, and from 310 to 360° and from 0 to 140° longitude. This region corresponds to the brighter parts of its surface (Fig. 3), conventionally called continents.

Table 1 presents the variation with longitude of the reflection coefficient of the investigated region of the surface of Mars, determined from the energy of the reflected signals in a 4-Hz band over several sessions.

Table 1

Longitude	310–320°	320–340°	340–360°	0–20°	20–40°	40–60°	60–80°	80–100°	100–120°	120–140°
Number of sessions	2	2	6	6	5	7	6	6	6	2
Reflection coefficient, %	13	7	12	7	15	5	3	3	7	3

In view of the small number of sessions, the signal-to-noise ratio in these measurements did not exceed 1.5–2.5, and the data on the reflection coefficient given in the table cannot be considered very reliable.

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CITED LITERATURE

1. V. A. Kotelnikov, V. M. Dubrovin et al., *DAN*, **145**, No. 5 (1962).
2. V. A. Kotelnikov, G. Ya. Guskov et al., *DAN*, **147**, No. 6 (1962).
3. V. A. Kotelnikov, V. M. Dubrovin et al., *DAN*, **151**, No. 3 (1963).
4. J. Ahbrook, *Sky and Telescope*, **28**, No. 1 (1958).

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