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Astronomy

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Abstract

Full Text

Astronomy

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RADAR OBSERVATION OF THE PLANET MERCURY

In June 1962, the Institute of Radio Engineering and Electronics of the Academy of Sciences of the USSR, jointly with a number of organizations, carried out radar observations of the planet Mercury. For the measurements the inferior conjunction of Mercury was chosen, when it comes closest to the Earth. The distance to Mercury during the measurements was 83–88 million km and was twice as large as during the radar observation of the planet Venus in 1961 (¹).

The study was carried out at a frequency of about 700 Mc. The transmitting antenna had circular polarization. The power-flux density during radiation was 375 MW per steradian. Because of the great distances and small dimensions (the surface area of Mercury is six times smaller than that of Venus), only about 1 W fell on the entire visible surface of Mercury. Transmission was conducted in sessions lasting about 10 min, during which the signal traversed the distance from the Earth to Mercury and back. The transmitted signal consisted of alternating telegraphic pulses at two frequencies differing by 62.5 cps. The duration of the pulses and pauses at each frequency was 1024 msec.

Reception of the reflected signals was carried out with an antenna with linear polarization. At the receiver input there were paramagnetic and parametric amplifiers. From the receiver output the reflected signals, together with noise in the frequency band from 30 to 300 cps and a 2000-cps reference oscillation, were recorded on magnetic tape. The beginning of the recording of the 2000-cps oscillations corresponded to the calculated time of arrival of the 10-minute series of reflected signals.

The shift of the carrier frequency and of the manipulation frequency of the reflected signals, caused by the Doppler effect due to the motion of Mercury and the Earth (taking into account its rotation), was compensated according to a calculated program by means of a special device that linearly varied the frequency during the session in steps of 0.2 cps. In doing this, the astronomical unit was taken to be $A = 149\,599\,300$ km (¹), and the speed of light 299,792.5 km/sec.

The distribution of energy in the spectrum of the recorded oscillations was

investigated by means of a 20-channel analyzer, similar to that used in the radar observation of Venus in 1961 (^{2,3}). The analyzer used two-circuit band-pass filters with a passband width of 16 cps (at the 3 db level), whose mean frequencies differed by 16 cps. Owing to the fourfold increase in the speed of the tape recorder during playback as compared with recording (which caused a proportional broadening of the frequency spectrum of the recorded oscillations by a factor of 4), the passband width of the analyzer channels, recalculated to the received signal, was 4 cps.

The principle of measuring the energy of the reflected signals is explained by Fig. 1. This figure shows the change in instantaneous power of the signal and noise $E'(t)$ and $E''(t)$ in two analyzer channels whose frequencies differ by 62.5 cps. During playback of the magnetic recording at the output of each—

of each channel of the analyzer, the total energy of signal and noise is determined (for notation see Fig. 1) over the even and odd half-periods of the modulation frequency, of duration $T/2 = 1024$ msec, and the difference energy is calculated

$$\Delta W_\tau = \left(\sum_{1,3,5,\dots} w'_i - \sum_{2,4,\dots} w'_i \right) - \left(\sum_{1,3,5} w''_i - \sum_{2,4} w''_i \right). \quad (1)$$

This quantity depends on the time delay τ , set during playback of the magnetic recording. Let the delay τ be chosen so that the instant $t + \tau$ corresponds exactly to the actual time of arrival of the series of reflected signals. In this case the signal falls, in one channel, into the odd intervals, while in the second channel, whose frequency is lower by 62.5 Hz, it falls into the even intervals. In the first channel the total energy over the odd intervals is equal to the energy of signal plus noise, and over the even intervals only to the noise energy; in the second channel the reverse is true. In this case the quantity ΔW_τ is maximal and is equal, on average, to the energy of the reflected signals entering both channels. The obtained values of ΔW_τ were assigned to the higher frequency.

Calibration of the sensitivity of the radar installation was performed using the radiation of the extraterrestrial discrete source Cassiopeia A. The materials of 53 sessions for the period from 10 to 15 VI 1962 were processed.

Fig. 1. Time diagram of analyzer operation: $E'(t)$, $E''(t)$ are the instantaneous power of the received signal respectively in the first and second channels (whose frequencies differ by 62.5 Hz); T is the period of signal modulation (2048 msec); w'_i , w''_i are the energy of signal and noise over intervals of duration $T/2$, respectively in the first and second channels; t_0 is the instant at which the recording of 2000 Hz oscillations begins on the magnetic tape; τ is the delay set by the operator during playback of the magnetic recording.

The combined result of measuring the spectrum of signals reflected from Mercury is presented in Fig. 2. Along the abscissa are plotted the values of the tuning frequencies of the analyzer channels, f ; along the ordinate—the sum of

Fig. 3. Probability distribution of the values of the energy reflection coefficient in the frequency band 4 Hz (a) and 12 Hz (b)

Figure 1: Fig. 3. Probability distribution of the values of the energy reflection coefficient in the frequency band 4 Hz (a) and 12 Hz (b)

Fig. 4. Accumulation of difference energy for different values of the astronomical unit

Figure 2: Fig. 4. Accumulation of difference energy for different values of the astronomical unit

the difference energies (1) over the processed sessions, recalculated as the flux density of the power S received by the antenna. The dashed line indicates the magnitude of the rms error caused by noise.

Fig. 2. Mean spectrum of signals reflected from Mercury (10-15 VI 1962).

If the astronomical unit corresponds to the value adopted by us, 149,599,300 km, then in the absence of spectral smearing the signal energy should have accumulated on all days in the channels corresponding to the nominal signal frequency of 215 Hz, which, as can be seen from Fig. 2, is what occurred.

The energy of the central band of width 4 Hz in Fig. 2 corresponds to a reflected-signal power of 0.035 W, isotropically scattered by the surface of Mercury. Since in these measurements about 1 W fell on the entire surface of Mercury, the mean reflection coefficient for this band turns out to be 3.5%. When summing the energies in the po-

in the frequency band of 12 and 20 Hz* (respectively, 3 and 5 bands in Fig. 2), the reflection coefficient of Mercury was found to be 6%. These results are close to the data known to us for the Moon. According to radar measurements (⁴, ⁵), the reflection coefficient of the Moon is 2-7.5%, and half of the energy of the reflected signals is concentrated in a frequency band about 2 Hz wide (recalculated for Mercury) (⁶).

Fig. 3. Probability distribution of the values of the energy reflection coefficient in the frequency band 4 Hz (a) and 12 Hz (b)

Since it is not possible to determine the reflection coefficient of Mercury reliably because of the small signal-to-noise ratio, the measurement results are presented in Fig. 3 in the form of probability histograms. On the abscissa axis they show the value of the reflection coefficient ρ with an interval of 1%; on the ordinate axis, the probability p that the true value of the reflection coefficient lies in the given interval. It was assumed here that the a priori distribution of the probability density of the reflection coefficient is uniform within the limits 0-100%.

Fig. 4. Accumulation of difference energy for different values of the astronom-

ical unit

The frequency of the received reflected signals and their delay depend on the magnitude of the astronomical unit A . Accumulating the difference energy (1) over the analyzer channels corresponding to different values of A , and taking the corresponding delays τ , one can obtain the value of the difference energy of the reflected signal ΔW_τ under the assumption of different values of A .

Figure 4 presents the result of such processing. Along the abscissa axis, different values of the astronomical unit are plotted at intervals of 10,000 km; along the ordinate axis, the ratio $\sum \Delta W_\tau / \sigma_{\Delta W}$, where $\sum \Delta W_\tau$ is the sum of the difference

* The period of rotation of Mercury, according to optical observations, is equal to 88 terrestrial days, which, at a sounding-signal frequency of about 700 MHz, can cause a maximum broadening of the echo-signal spectrum of ± 10 Hz relative to the mean frequency.

energies for the processed sessions, taken over the channels and delays corresponding to the given astronomical unit; $\sigma_{\Delta W}$ is the dispersion of the quantity $\sum \Delta W_\tau$, determined from the data of this figure. As can be seen from the figure, the maximum positive value of the ratio $\sum \Delta W_\tau / \sigma_{\Delta W}$ (equal to 2.3) corresponds to an astronomical unit of 149,600,000 km. Negative outliers at other values of the astronomical unit are caused by noise, since the difference energy (1) of the reflected signals, in the absence of noise, must always have a positive sign.

In view of the smallness of the obtained value of $\sum \Delta W_\tau / \sigma_{\Delta W}$, the Mercury radar experiment carried out, taken separately, cannot reliably guarantee the value of the astronomical unit determined from it. However, it provides additional confirmation of the value of the astronomical unit obtained in the radar observations of Venus in 1961 (^{1,7-9}).

Conclusions. The results of the radar observations of the planet Mercury do not contradict the results of the measurements of the astronomical unit obtained from radar observations of Venus in 1961, and give a reflection coefficient for Mercury close to the reflection coefficient of the lunar surface.

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REFERENCES

1. V. A. Kotelnikov, V. M. Dubrovin et al., DAN, **145**, No. 5 (1962).

2. V. A. Kotelnikov, L. V. Apraksin et al., Radiotekhnika i elektronika, **7**, No. 11 (1962).
3. V. A. Morozov, Z. G. Trunova, Radiotekhnika i elektronika, **7**, No. 11 (1962).
4. S. J. Fricker, R. P. Ingalls et al., J. Res. Nat. Bur. Stand., **64 D**, No. 5, 455 (1960).
5. W. K. Victor, R. Stevens, Science, **134**, No. 3471, 46 (1961).
6. *The Moon*, collected volume edited by A. V. Markov, Moscow, 1960.
7. J. H. Thomson, G. N. Taylor et al., Nature, No. 4775, 519 (1961).
8. The Staff, Millstone Radar Observatory, Nature, No. 4776, 592 (1961).
9. L. R. Malling, S. W. Golomb, J. Brit. I. R. E., **22**, No. 4, 297 (1961).

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