RADAR CONTACT WITH VENUS

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Summary: In April 1961 radar contact with Venus was established in the Soviet Union. A transmitter and receiver at about 700 Mc/s were used in conjunction with an analysing and integrating system which enabled both the range of the planet and the Doppler spread in the returned signals to be determined. From the range data a new value of the astronomical unit is found; from the Doppler spread it is deduced that the maximum rotation period of the planet is eleven days. Venus is found to re-radiate about 10% of the radio energy intercepted by the disc.

In April 1961 radar contact with Venus was made in the Soviet Union. The purpose of this experiment was to determine more precisely the Astronomical Unit (the semi-major axis of the Earth's orbit), as well as to determine the rotation period for Venus and to obtain data on the structure of its surface.

In this experiment the transmitter frequency was about 700 Mc/s. The power flux density was 250 megawatts per steradian, which gave 15 watts on the surface of Venus. The transmitted waves had circular polarization, while the receiving aerial was linearly polarized.

The transmitted signal consisted of square pulses, 128 or 64 milliseconds long with spaces of the same duration between them. Sometimes a pulse of the same duration was transmitted instead of the space, but at another frequency.

Corrections were introduced in the signal and modulation frequencies used in transmission to account for the Doppler shift caused by a change in the distance from the Earth to Venus and also by rotation of the Earth. The frequencies of the transmitter, its modulation and the frequencies of the receiver heterodyne oscillators were derived from a precision crystal oscillator having a stability greater than one part in 10^9.

Transmission was carried out during the time for the signal to travel from the Earth to Venus and back again (about 5 minutes). During about the same period of time thereafter, the equipment was switched for reception.

A simplified diagram of the transmitter is given in Fig. 1. The frequency divider oscillations control key K_2, modulating the signal; key K_1 is used to start and stop transmission, and works from the timer which has an accuracy of up to 1 ms.

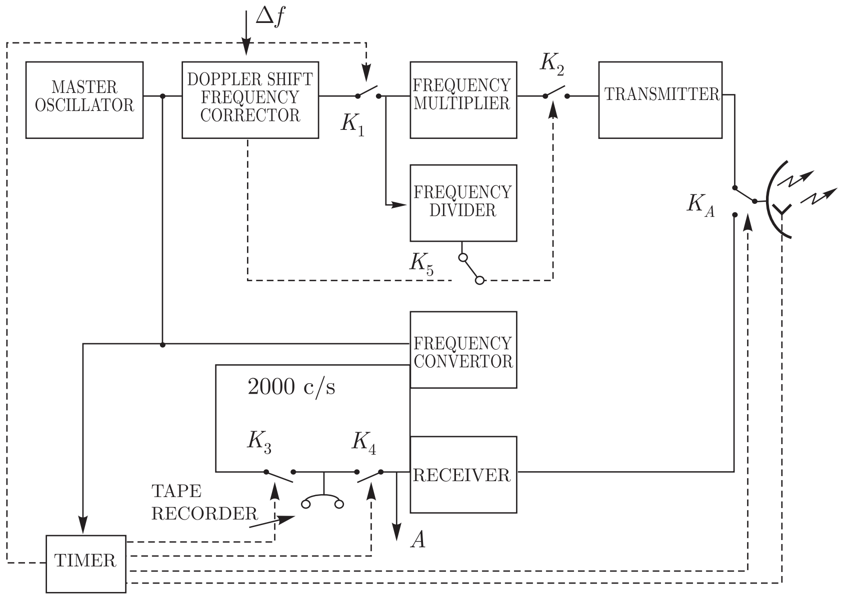

Рис. 1. Block diagram of the radar equipment

The incoming signals were received by a superheterodyne receiver having a semi-conductor parametric amplifier. A counting-down process in the receiver was so arranged that the reflected signals should produce a frequency of 743 c/s at the output of the receiver if Venus did *not* rotate. This signal together with all noise introduced was recorded on magnetic tape in the band 420 to 1020 c/s. A sine-wave of 2000 c/s was also recorded on this tape in order to provide a time scale when reproducing. Recording of this sine-wave was started exactly at the instant at which the 5-minute series of reflected signals was calculated to arrive, and was stopped at the end of the series of pulses. This served to indicate by how much the actual time of travel of a signal to Venus and back again differs from its calculated value.

After the transmission cycle has terminated key K_1 is opened, and key K_A connects the antenna to the receiver. The polarization of the antenna is changed and the receiver output is connected to the tape recorder together with the 2000 c/s time-marking oscillations. For monitoring purposes, the action of the keys was also recorded against the time marks, by means of a galvanometer oscillograph.

A frequency analyser (Fig. 2) was used for analysing the signals recorded on the tape. In it the signals from the tape recorder go to ten filters F_1–F_{10}, each having a pass band of 60 c/s. The filter outputs go to electronic relay circuits; pulses at a recurrence frequency of 1000 per second are also applied to these circuits from the divider. If the amplitude of the oscillations at the filter output exceeded a certain threshold level, the appropriate relay circuit passed the pulses to a corresponding gate switch. If it was less than this level, the pulses were blocked. The switches admitted the pulses either to pulse-counter M or N.

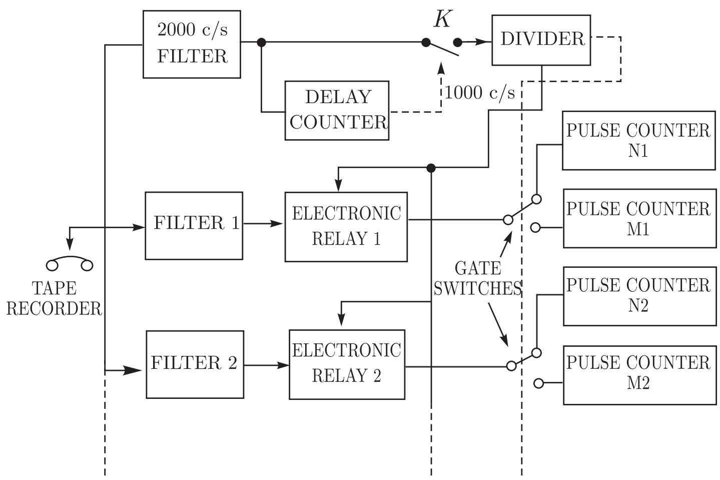

Рис. 2. Block diagram of the signal analyser

Figure 3 shows how the electronic relay circuit functions. 1 represents reflected signals drawn ideally without any noise superimposed; 2 shows amplitude of the signal plus noise; 3 pulses at the output of the circuit; and 4 represents the functioning of the switch. The pulses falling in the shaded areas go to counter N, while the rest go to counter M.

The 2000 c/s oscillations recorded were selected by a filter of that frequency as shown in the diagram and passed to the delay counter. After counting out the number of cycles corresponding to a given delay time τ, the delay counter closed switch K, through which the output of the 2000 c/s filter passed to divider. This divider, which has two outputs, then started to give out 1000 c/s pulses to relay circuits, and also to operate the gate switches at a rate equal to that of the signal modulation (about 4 c/s).

If the delay time τ was such that the switch turned on counters N during the time a signal arrived and counters M when there were none, the difference between the readings of these counters $n - m$ over a sufficiently long period will be positive; moreover, this positive difference will increase with the signal power.

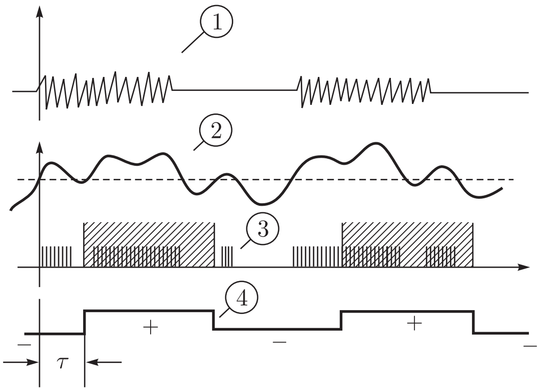

Рис. 3. Shape of signals in the analyser

By playing back this recording several times with different delay times we obtain the difference as al function of τ. One such function using the output of the 6th filter (this filter accepts signals which do not have a Doppler shift due to the rotation of Venus) is presented in Fig. 4. Here X marks the points obtained on the basis of observations on 18th April 1961 and O those on 19th April. The solid line on the drawing is the theoretical curve when no noise or signal distortions caused by reflection from different points on Venus exist. The period of a modulation cycle here amounted to 256 ms.

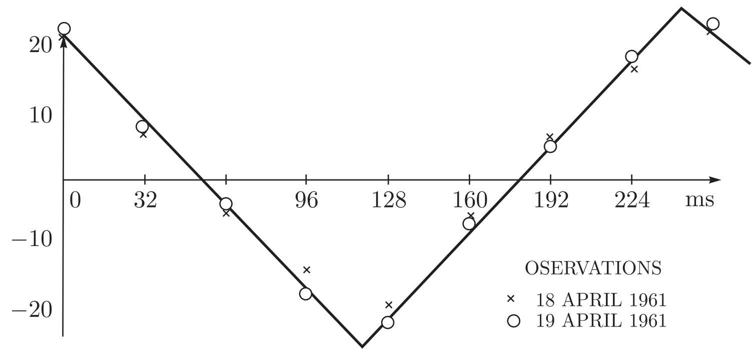

Рис. 4. Correlation function of the received signal. × — 18th April 1961 o — 19th April 1961

One can estimate the delay of the signal and, consequently, the distance to Venus and the value of the astronomical unit, from the horizontal positions of the maxima of the curve in Fig. 4. According to preliminary data the astronomical unit was found equal to $149\,457 \pm 130p$ thousand kilometers where p is an integer. The term $130p$ results from the fact that variations in the delay greater than the modulation period, that is, over 256 ms, are not detected by this method of determining distance since it cannot distinguish between integral cycles of the modulation frequency.

When Venus rotates, the signals reflected from the different points on its surface gain an additional Doppler shift in frequency.

Examples of reflected signal energy distributions in the filters for 18th, 19th and 20th of April are shown in Fig. 5. The number of the filter is marked in the X-direction, while in the Y-direction we plot the difference in the readings of the counters N and M for the given filter divided by the standard deviation of this difference due to noise. As is seen from the drawing, this quantity for one of the days amounted to 5 in filter No. 6, and to 7 when summed over three days.

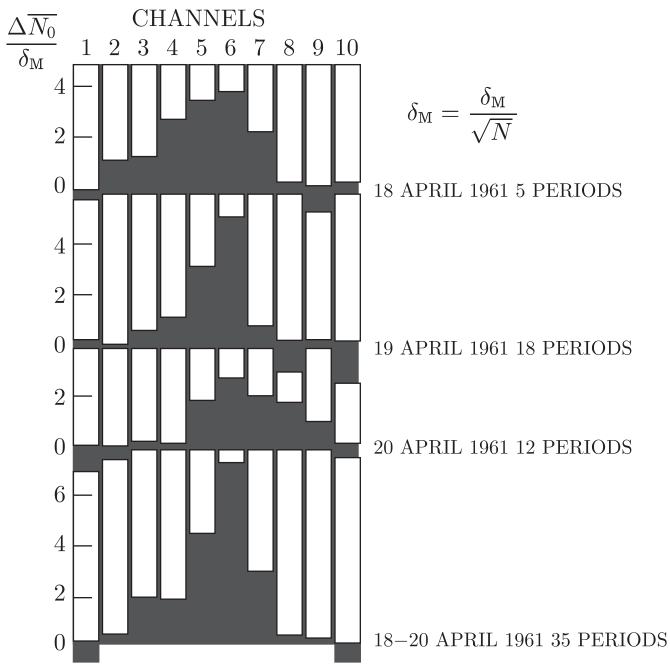

Рис. 5. Reflected signal spectrum

On the basis of Fig. 5 and similar diagrams for other days we determined the maximum frequency shift in the reflected signals caused by the rotation of Venus and from this, the speeds that caused it. These speeds turned out to be about ± 40 m/s. If we assume that the entire surface of the planet reflected and that its axis of rotation was perpendicular to the radiation direction, this speed corresponds to a period of revolution of 11 days. If the spin rotation axis were at an angle of 60 deg to the radiation direction (according to Kuiper data), this period should be about 9–10 days. If the entire surface did not participate in reflection, this period should be even less.

Changes in the reflection spectrum of Fig. 5 from day can be explained as follows: On 18th April the surface of the half of the planet going away from us (filters 2, 3, 4, 5) was rough and caused dispersion giving reflected signals, while the surface approaching us (filters 8, 9, 10) was smooth and did not reflect back signals. On 19th April this smooth surface occupied the centre of the planet facing us. This led to the strong reflections coming through the 6th filter (since the centre of the planet gives a small Doppler shift) and to the weak radar reflections from the sides of the planet, which go to the other filters. On 20th April this smooth surface moved to the edge and so disappeared. As a result, the signal energy in filters 2, 3 and 4 was small, while the centre of the planet facing us, and the edge approaching us (filters 5, 6, 7, 8, 9, 10) were occupied by a dispersive surface.

Calculations and special measurements showed that the analyser used developed a signal quite near optimum and enabled signals hundreds of times smaller than the noise (in the 60 c/s band-width) to be detected during a period lasting tens of minutes.

In order to exclude systematic errors, the modulation sign of the transmitted signal was changed every operating period, as was the sign of the difference in the readings of counters N and M.

The analyser was used in conjunction with the magnetic tape recorder when the reflected signals were arriving, and the two were therefore connected in parallel.

In order to determine the power of the signals reflected from Venus, they were compared with the power from radio star Cassiopeia A. We estimate that Venus reflected back to the Earth from its entire surface on the average about 10% of the signal energy impinging on it.

At present not all of the material has been processed completely, and this report should therefore be regarded only as a preliminary one.

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