PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

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Phil. Trans. R. Soc. Lond. A 1967 **262**, 67-69
doi: 10.1098/rsta.1967.0031

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1. Introduction

Observations of the precise frequency received from the Soviet lunar satellites Luna 9, 10 11 and 12 when in the vicinity of the Moon yield information on the orbit or landing phase. Three modes of operation of the probe are possible: (1) the transmitter operates on a constant frequency, (2) the transmitter is locked in frequency to a signal emitted from the Earth at a constant frequency, and (3) as in the previous case, but the signal transmitted from the Earth is also varied in frequency.

It is fairly simple to determine which mode is in use in a particular case, and all three have been observed from a single satellite. Case (3) is of no interest here, as a precise knowledge of the frequency emitted from the Earth is required, but data obtained in either mode (1) or mode (2) is useable. The discussion in this paper will be restricted to mode (1), as the data here is more complete, and this mode was used at the critical landing phase of Luna 9.

2. Apparatus

The 250 ft. Mark 1 radio telescope at Jodrell Bank was used to receive the transmissions at a frequency of 183·5 Mc/s. All local oscillators in the receiver were locked to a crystal frequency standard which is in turn compared with standard frequency transmissions from M.S.F. Rugby.

The receiving system has an intermediate frequency at 100 kc/s which is fed to a tracking filter which locks an oscillator in phase to the received carrier frequency. The frequency of this oscillator is recorded with a precision of 1 c/s every 2 s.

3. Observations of Luna 9

The variation of received frequency with time for approximately 1 h before Luna 9 landed on the Moon's surface on 3 February 1966 is shown in figure 1, and the landing phase is shown in more detail in figure 2. Table 1 summarizes the readings at certain key times. The frequency measured at 18 h 44 m 8 s lies on the smooth curve of motion under gravitational influences only; from 18 h 44 m 10 s to 18 h 44 m 50 s the retro-rockets were operating; thereafter the frequency remained constant, indicating that the probe was at rest on the Moon. In column 4 of table 1 the frequencies in column 2 have been converted into line of sight velocities, with the zero taken at rest on the Moon's surface. Column 5 gives the line of sight accelerations derived from these velocities. The last line of table 1 gives values extrapolated from 44 m 8 s to 44 m 30 s, when the probe would have hit the surface if the retro-rockets had not been fired. The line of sight acceleration obtained, 0·705 m/s may be compared with lunar surface gravity of 1·62 m/s, and indicates that Luna 9 landed approximately 64° from the centre of the apparent disk.

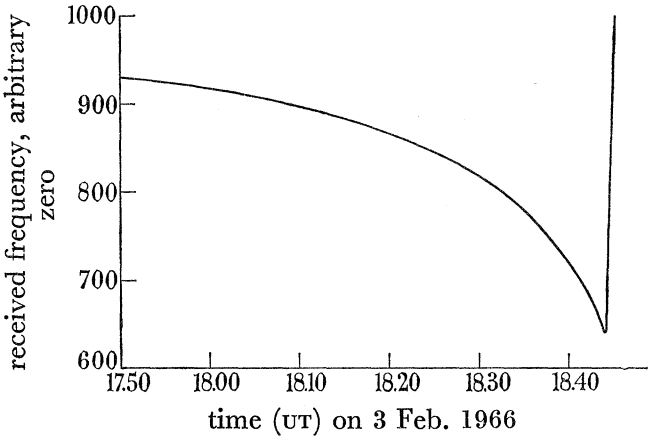

FIGURE 1. The variation in received frequency from Luna 9 up to the landing phase.

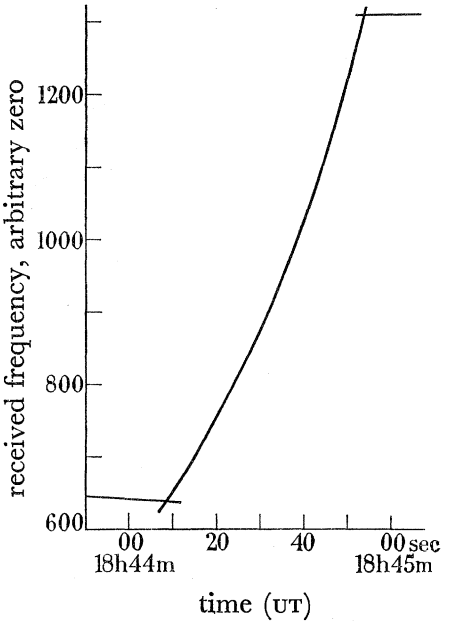

FIGURE 2. The variation in received frequency from Luna 9 during the landing phase.

TABLE 1

UT h m s	f (c/s)	$\dot{f}$ (c/s) min^{-1}	V (m/s)	$\dot{V}$ (m/s^2)
17 50 00	932	−2	614	—
18 44 08	638	−24	1108	—
18 44 10	—	+1189	—	+32·4
52	1313	+2789	0	+76
18 44 30 (extrapolated)	626	−25·8	—	−0·705

By integrating the deceleration curve from 44 m 8 s to 44 m 52 s, it appears that the rockets were fired at a height of about 68·5 km.

4. OBSERVATIONS OF LUNA 10

Figure 3 shows the variation in received frequency from Luna 10 over the injection phase on 3 April 1966 and for one orbit on each of the days April 3, 4 and 5. Transmissions of a steady carrier were rare, the transmitter was turned off for much of the time,

and at other times a rapidly sweeping frequency was transmitted, presumably as a means of measuring the distance of the probe from the Earth.

From figure 3 it can be seen that some small corrections were made to the orbit before injection at 18 h 44 m on 3 April. The change in line of sight velocity at injection was 440 m/s, which may be compared with the difference of 549 m/s between the velocity in a circular orbit of 3 h period and that in the tangential parabolic orbit. The apparent period is seen to be close to 3 h. Owing to the Moon's orbital motion round the Earth, the true period is somewhat different from this, by an amount which depends on the para-

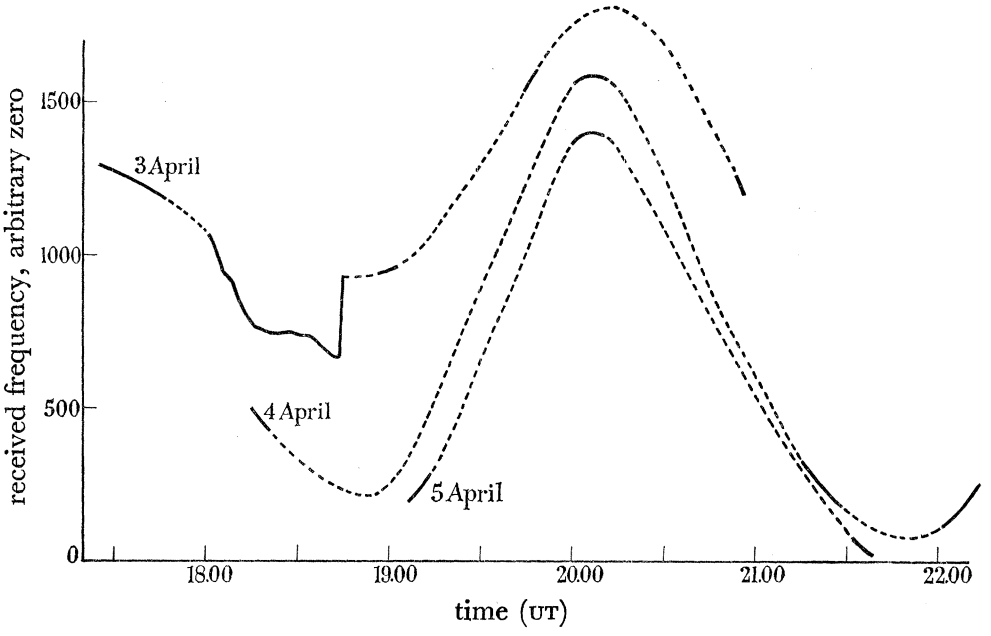

FIGURE 3. The variation in received frequency from Luna 10 on 3, 4 and 5 April 1966, including the injection into lunar orbit on 3 April at 18 44 UT.

meters of the satellite's orbit. The variation in mean frequency observed from orbit to orbit is due to the diurnal motion of the Earth and observing station. The variation from day to day is due to the eccentricity of the Moon's orbit. The amplitude and asymmetry of the curve contain information from which the eccentricity and inclination of the orbit can be deduced. Owing to the scarcity of the data in this case, however, it is not possible to make more than qualitative deductions about the orbital elements.

5. OBSERVATIONS OF LUNA 11 AND LUNA 12

Similar observations have been made on Luna 11 and Luna 12. In each case the transmissions were intermittent, and the orbital characteristics were similar to those of Luna 10. The pre-injection phase of Luna 12 showed none of the small corrections that are apparent in the case of Luna 10.