8 Recent developments show that there has been a significant surge in the number of commercial satellites being sent into low Earth orbits (LEO). LEOs are orbits situated relatively close to the Earth's surface, with altitudes of less than 2000 km, representing the height of the satellite above the Earth's surface. Some LEO satellites can orbit as close as 160 km above the Earth's surface, which, despite being considerably high, is still far above the altitudes typically reached by most commercial airplanes, which seldom exceed 14 km.

Fig. 8.1 shows the radii and periods of orbit of various LEO satellites.

satellite	**radius of orbit ,*r* / km**	**period of orbit, *T* / min**
GOCE	6630	89.6
Tiangong Space Station	6770	92.3
GRACE	6870	94.5

Fig. 8.1

Due to the fast speed of LEOs, it is not easy for ground stations to track a specific LEO satellite. The ground station can only track the LEO satellite when it has line of sight as shown in Fig. 8.2.

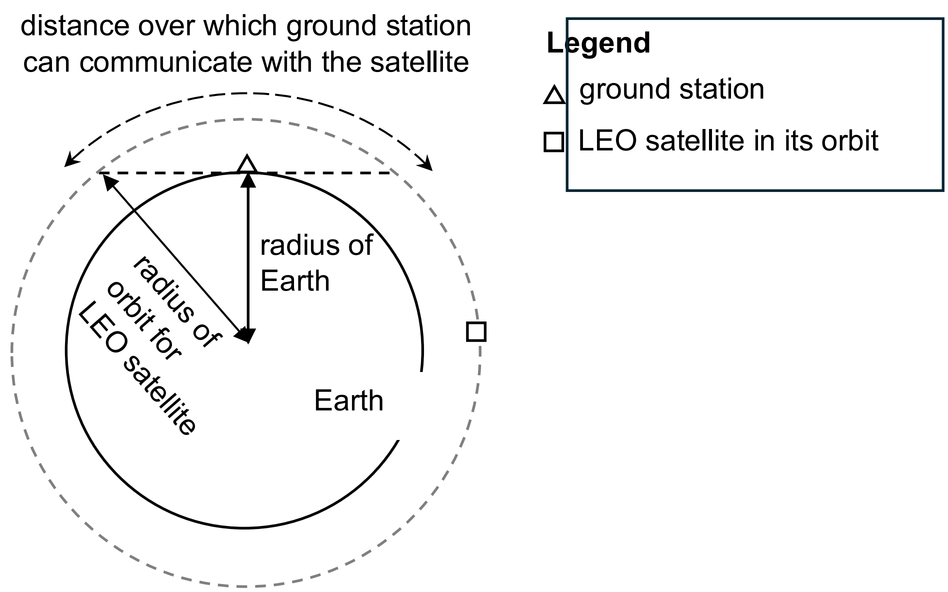

Fig. 8.2

There are challenges to operating LEO satellites. One of these challenges is atmospheric drag due to gases in the thermosphere, which leads to orbital decay, a loss of altitude over time. If the LEO satellite is not boosted back to its original altitude, the rate of orbital decay increases over time. This is partly due to the increase in the density of air with decreasing altitude.

Another challenge is space debris which can be very dangerous to LEO satellites. The Orbital Debris Program tracks over 25000 objects larger than 10 cm in LEO. It is estimated that there may also be up to 100 million smaller objects in LEO.

Satellites used for telecommunications are usually in geostationary orbits. Using suitable dishes to transmit the signals, communication over most of the Earth's surface is possible at all times by using only three satellites. Satellites used for meteorological observations and observations of the Earth's surface are usually in LEO. Polar orbits, in which the satellite passes over the North and South Poles of the Earth, are often used. One such satellite orbits at a height of about 12 000 km above the Earth's surface circling the Earth at an angular speed of 2.5×10^{-4} rad s^{-1}. The microwave signals from the satellite are transmitted using a dish and can only be received within a limited area, as shown in Fig. 8.3.

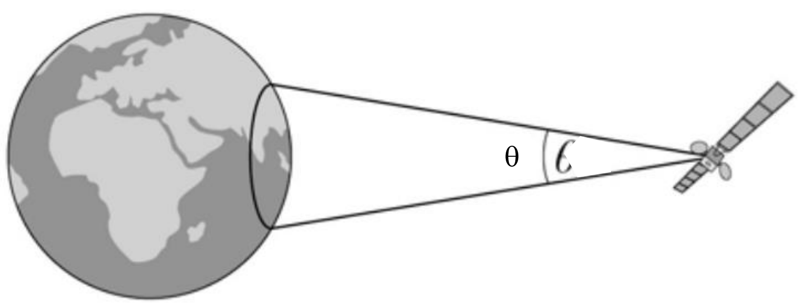

Fig. 8.3

The signal of wavelength λ is transmitted in a cone of angular width θ, in radian, given by $\theta = \dfrac{\lambda}{d}$ where d is the diameter of the dish. Th satellite transmits a signal at a frequency of 1100 MHz using a 1.7 m diameter dish. As this satellite orbits the Earth, the area over which a signal can be received moves. There is a maximum time for which a signal can be picked up by a receiving station on Earth.

(a) Show that the distance travelled by the Tiangong Space Station during which it is able to communicate with a specific ground station is 4.7×10^{6} m.
You may assume that the mass of the Earth to be 5.97×10^{24} kg.

[3]

(b) Hence or otherwise, calculate the time of contact with the ground station (the time during which the ground station can communicate with the LEO satellite) for the Tiangong Space Station.

time of contact = ... s [2]

(c) Suggest a reason other than the one given in the passage why loss of altitude causes the rate of orbital decay to increase over time.

....

....

....

.................................[2]

(d) Explain why space debris as small as 10 cm can still be dangerous for LEO satellites.

....

.................................[1]

(e) Suggest one advantage in the application of a satellite when a low polar orbit is used and one advantage when a geostationary orbit is used.

....

....

....

....................................[2]

(f) Determine the width of the area of reception on the Earth's surface when the satellite shown in Fig 8.3 is transmitting a 1100 MHz signal at a distance of 12 000 km from the Earth's surface.

width of area = ... m [3]

(g) For a satellite in a polar orbit 12000 km above the Earth's surface, determine the maximum amount of time that a stationary receiver at the South Pole can remain in contact with the satellite in each orbit.

maximum amount of time = ... s [3]

(h) The satellite in **(g)** is moved into a higher orbit. Suggest, with a reason, how this affects

(i) the signal strength received by the receiver at the South Pole and,

....

....

................[2]

(ii) contact time for the receiver at the South Pole.

....

....

................[2]

[Total: 20]

End of Paper