

## REPORT 1170

MOBILE-SATELLITE COMMUNICATION SYSTEMS USING  
HIGHLY INCLINED ELLIPTICAL ORBITS

(Question 84/8)

(1990)

1. Introduction

Mobile-satellite communication systems are based on the use of satellites in the geostationary satellite orbit operating at frequencies in band 9, using mobile terminals with either low gain omnidirectional or higher gain steerable antennas. The geostationary satellite orbit can provide virtually global coverage within latitudes of about 75°N and 75°S from three satellite locations, and is very suitable for most maritime and aeronautical mobile applications.

The elevation angle decreases not only with increasing latitude of the mobile earth station but also with increasing differences in satellite and mobile earth station longitudes (see Figure 1).

By definition of the coverage area, elevation angles at the extremes of the coverage area are very small and mobile terminals in these areas can encounter severe problems from multipath propagation effects, signal blockage and shadowing, the latter two being particular problems for land mobile-satellite service (LMSS). [Reudink, 1983]. For this service alternative satellite orbits may be desirable which would allow the mobile terminals at high latitudes, including the polar regions, to operate with higher elevation angles to the satellites.

This report considers these alternative orbits and describes in Annex I a system under study in the United Kingdom [Norbury, 1986], which proposes to use a Molnya [Chernyovski and Bartenov, 1978] type orbit. Other studies have also been carried out in the United Kingdom, (Howe, 1986).

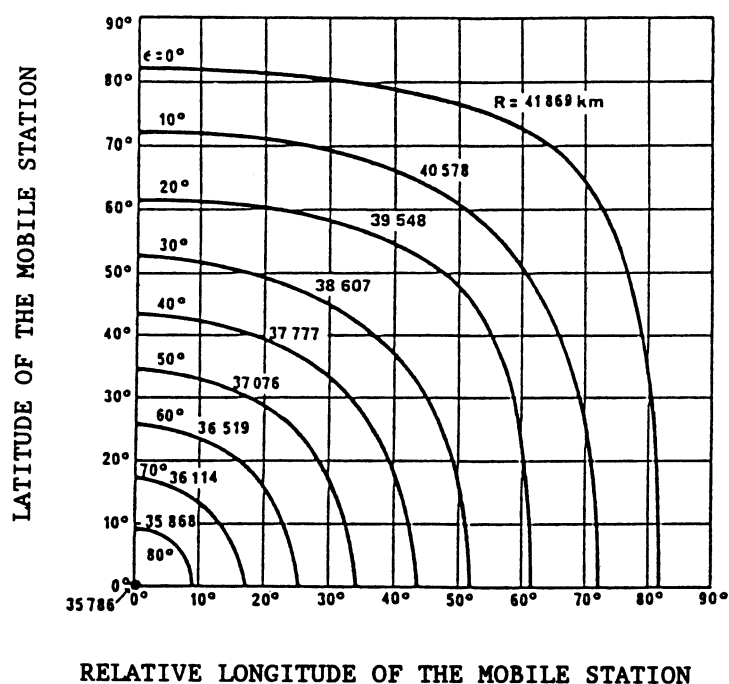


FIGURE 1

### Elevation angle and distance for geostationary satellites

$\epsilon$ : antenna elevation angle

$R$ : distance of the satellite as a function of:

- relative mobile station longitude, i.e. the difference between the station and the satellite longitudes
- mobile station latitude

## 2. Alternative satellite orbits

### 2.1 Low orbiting satellites

Several alternative satellite orbital configurations are possible which permit more economic use of satellite e.i.r.p. due in part to the removal of the need to allow for multipath fading. Several systems for polar coverage have been investigated, [Berretta, 1984].

## 2.2 Inclined elliptic orbits

The use of inclined elliptic orbits for non-geostationary satellites in preference to circular orbits is considered because unless the altitude of satellites in circular orbits is very high, access time would be limited. Furthermore, mobile terminals would require either relatively expensive tracking antennas, or broad beam (low gain) antennas. The inclined elliptical orbits that have so far received consideration are:

- the 12-hour orbits such as MOLNIYA, LOOPUS [Dondl, 1984];
- the 24-hour orbits such as TUNDRA [Collins et al., 1984], SYCOMORES [Dulk, Rouffet et al., 1988].

Other types of inclined elliptical orbits are possible.

Satellites in elliptical orbits, however, have a relatively low velocity near apogee and if this is matched to the Earth's rotational velocity the satellite will appear to be almost stationary over a particular geographical area for a substantial part of its orbital period, a phenomenon known as "apogee dwell".

If the period is synchronous or sub-synchronous, this effect will recur at the same longitude on successive days, but in general the precession of the line of apsides will slowly change the latitude at which apogee occurs. However, at a particular inclination of approximately 63° the effect can be minimized or suppressed and thus consistency of orbit can be achieved. However, all four factors of orbit; inclination, eccentricity, argument of perigee and the effects of orbital perturbations, have to be considered to satisfy a given service need.

Examples of MOLNIYA, LOOPUS, TUNDRA and SYCOMORES orbits, each of which has an inclination of about 63° are given in the following table:

TABLE 1

| Type of orbit    | Molniya<br>(3 satellites) | Loopus<br>(3 satellites) | Tundra    | Sycomores<br>(2 satellites) |
|------------------|---------------------------|--------------------------|-----------|-----------------------------|
| Orbital period   | 12 hours                  | 12 hours                 | 24 hours  | 24 hours                    |
| Apogee altitude  | 39,500 km                 | 39,100 km                | 46,300 km | 50,600 km                   |
| Perigee altitude | 1,000 km                  | 1,240 km                 | 25,300 km | 21,000 km                   |

In the United Kingdom studies have been conducted into the application of satellites in inclined elliptical orbits [Gardiner, CERS, 1986], and more recently a system based on use of the Molnya orbit as described in Annex I.

With these satellite orbits the blockage due to buildings, mountains and other obstacles can be greatly reduced because of the high elevation angle to the satellite, and in most parts of Europe for example, elevation angles well over 50 degrees can be achieved. Hence the use of low cost mobile terminals with relatively simple high gain non-tracking antennas for LMSS could be contemplated in these areas. Furthermore, multipath propagation effects are eliminated or minimized on the mobile/satellite link.

As a result improved link margins may be achieved thereby allowing a saving in satellite e.i.r.p. and also enabling the use of fairly directional antenna with gains up to 10 dB.

Although it is necessary to provide several satellites in a constellation to provide 24 hour coverage, the launch energy required to place an equivalent satellite in an inclined elliptic orbit is less than that of a geostationary satellite. For Molnya approximately half that needed for a geostationary satellite may be required. Further study of relative launch energies is needed.

Another area for investigation is the overall complexity and cost of the associated multiple-satellite constellation.

On the other hand, it is important not to overlook the potential space section economic considerations relative to geostationary satellites. For a secure system, necessary for most commercial applications, spare satellite facilities in orbit are required, which may also require provision of additional TT and C facilities. Further study is required as to how this can best be achieved.

### 2.3 Tracking requirements for base stations

Base stations, would, in most cases, have the disadvantage of requiring two antennas, one to track the outgoing satellite while the other picks up the incoming satellite. Uniquely, the Loopus configuration avoids this by arranging for the incoming and outgoing spacecraft to be simultaneously within a single high gain earth station beam at the point of handover.

### 3. The Molnya orbit

The relationship between the 12 hour Molnya orbit and the geostationary orbit is illustrated in Figure 2. This highly inclined elliptic orbit provides a near zenith satellite position, when viewed from the Earth at middle latitude, for eight of the 12 hours of its orbit. On the next orbit, it then provides a further eight hours for a region at the same latitude but separated by 180° in longitude, before returning on the third orbit to its original position relative to Earth. A 24 hour coverage for one region requires three satellites in three planes at 120° to each other. Such a constellation would also provide 24 hour coverage for the other region mentioned above.

The ground track followed by satellites in this orbit is shown in Figure 3 with an indication on the figure of the time in hours elapsed from its location at one perigee. It can be seen that the satellite spends some eight hours of each day within a few degrees of the same point in the sky.

The high elevation angles for countries at higher latitudes such as northern Europe, and for the polar regions are demonstrated in Figure 4, which shows a satellite's view of the Earth from an apogee located at 3.5°W longitude, as compared with the view from the equivalent geostationary position (Figure 5).

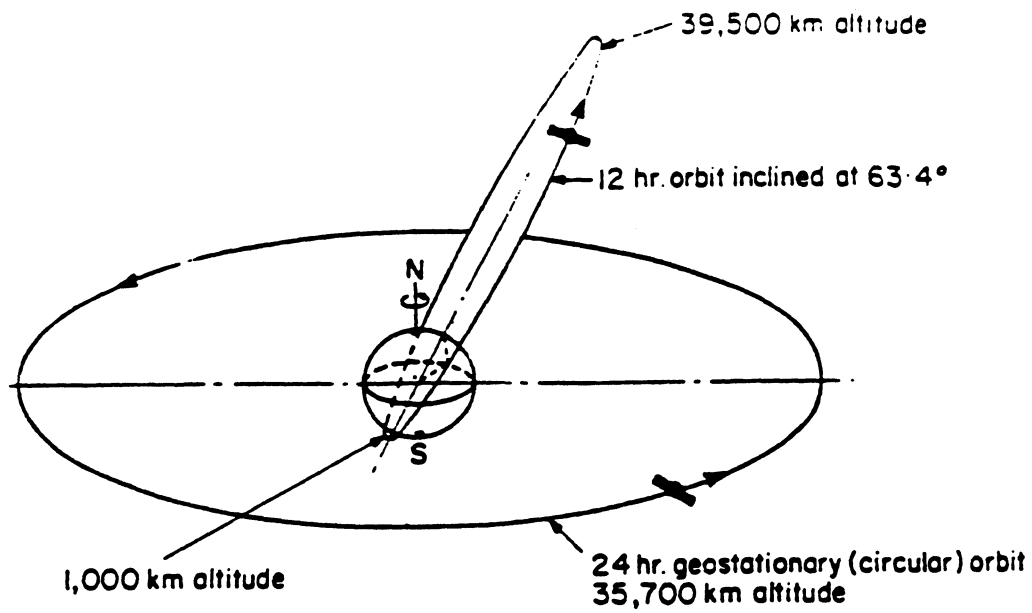


FIGURE 2

Relationship between the geostationary and Molnya orbits

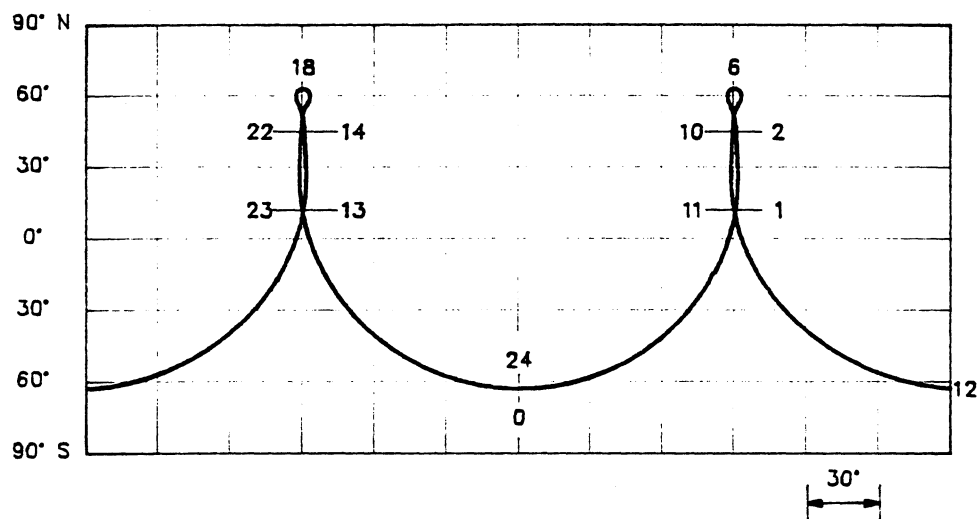


FIGURE 3

Ground track followed by satellites  
in 12-hour highly elliptical orbits