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 [Chernyvski and Bartenov, 1978] type orbit. Other studies have also been carried out in the United Kingdom, (Howe, 1986).

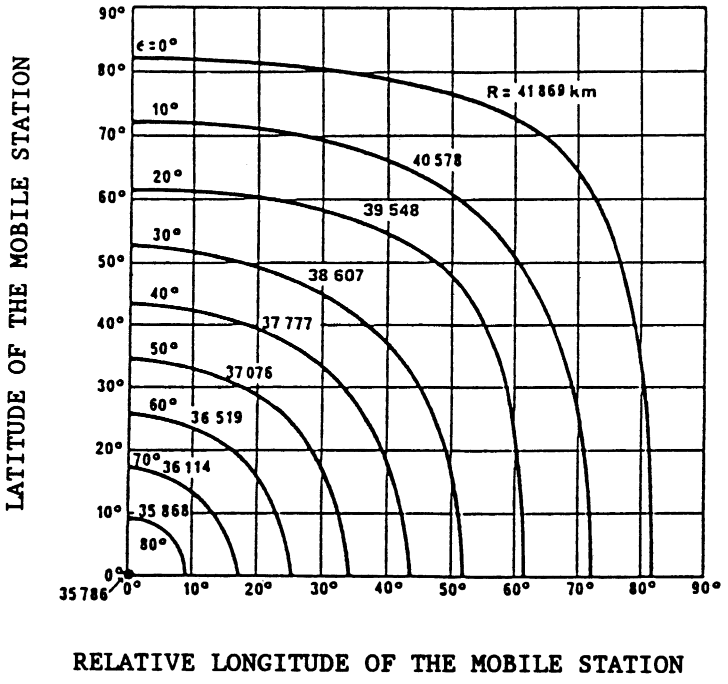

FIGURE 1

Elevation angle and distance for geostationary satellites

ε: 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 (3 satellites)	Loopus (3 satellites)	Tundra	Sycomores (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).

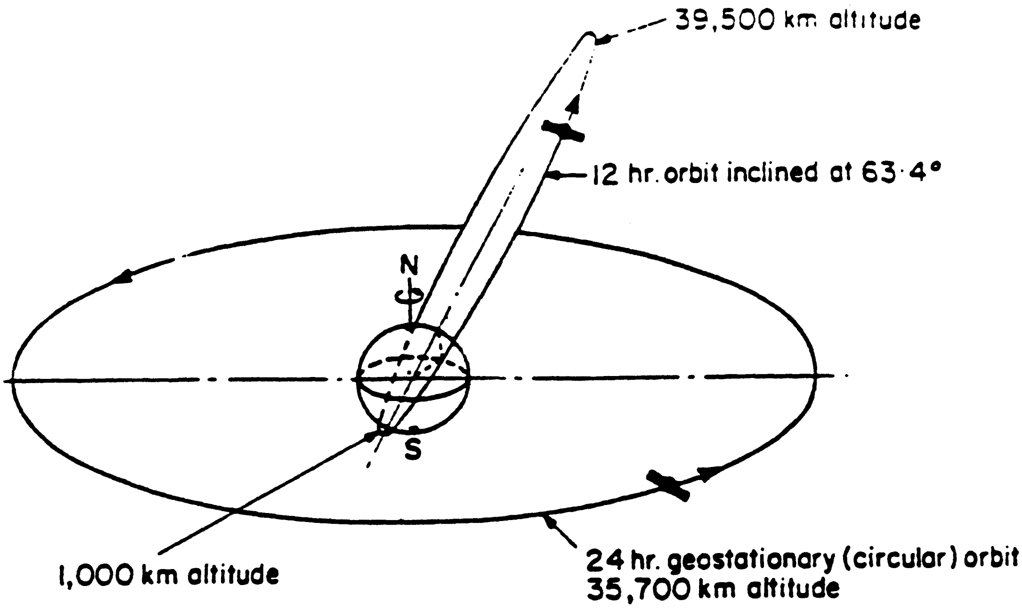

FIGURE 2

Relationship between the geostationary and Molnya orbits

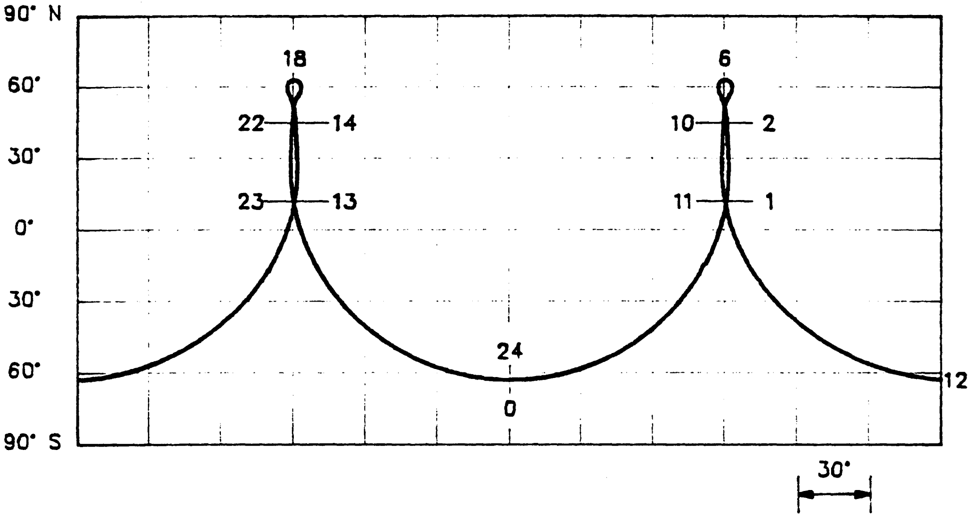

FIGURE 3

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

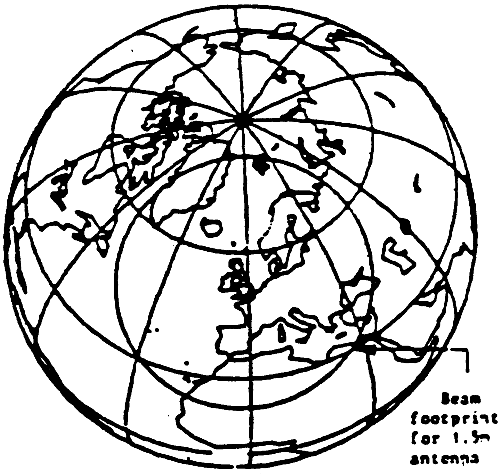

FIGURE 4

View of the earth from the apogee of a
12 hour Molnya orbit centred at 3.5°W.

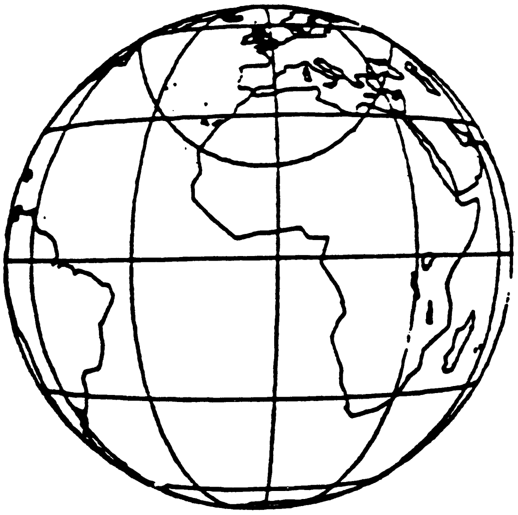

FIGURE 5

View of the earth from a geostationary position
at 3.5°W with a similar size coverage area to that of
Figure 3, centred on the UK.

4. The SYCOMORES orbit

This orbit provides a near zenith satellite position when viewed from the Earth at middle and high latitudes, comparable to geographical Europe latitudes, for 12 of the 24 hours of its period. On the next orbit, it then provides a further 12 hours for exactly the same region.

24 hour coverage a day for one region requires two satellites, in two orbits, with ascending nodes separated by 180°.

The position of the orbit plan is illustrated in Figure 6.

The ground track followed by satellites in this orbit is shown in Figure 7 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 twelve hours of each day within a few degrees of the same point in the sky.

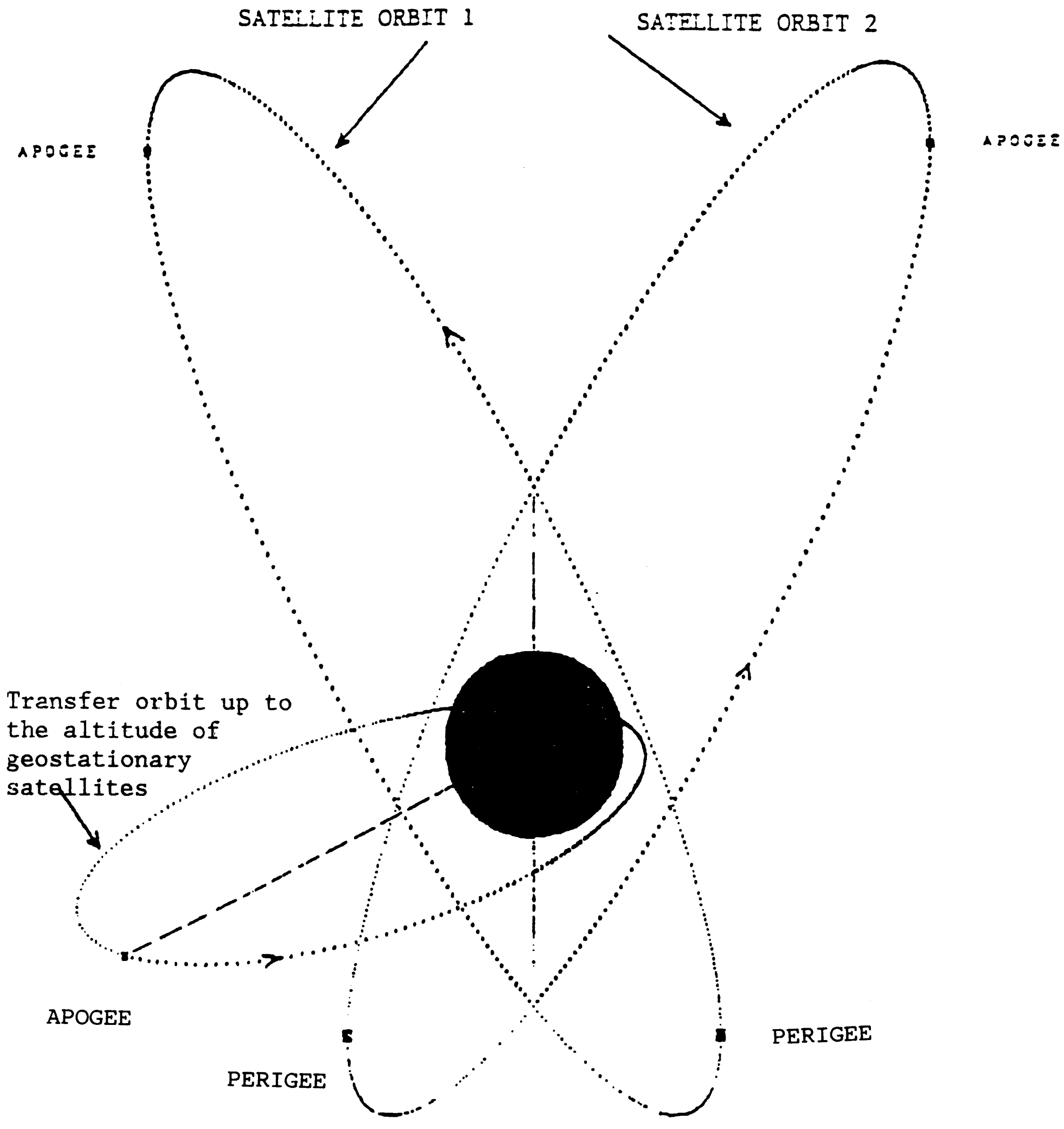

FIGURE 6

Position of SYCOMORES orbit plans

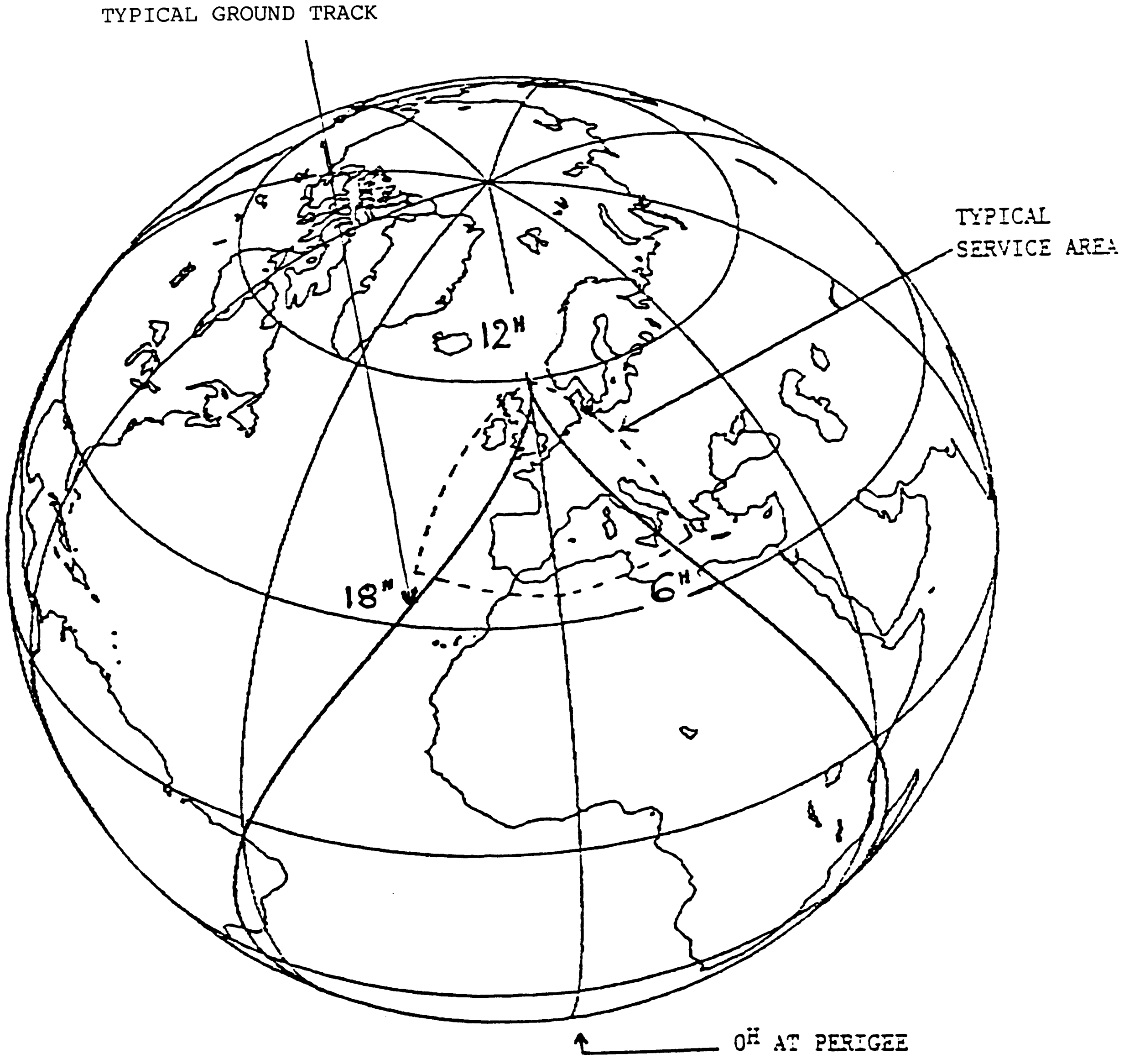

FIGURE 7

<u>SYCOMORES orbit: example of ground track and of service area</u>

5. Advantages and drawbacks of 12-hour orbits and 24-hour orbits

For transmission purposes, there is no genuinely significant difference between 12-hour and 24-hour orbits, each of which has its own advantages and drawbacks. The choice of an orbit for establishing a system for communicating with land mobile stations will inevitably be a technical and economic compromise, whatever the mission.

Other things being equal, fewer 24-hour orbit satellites are needed to ensure permanent regional coverage at middle and high latitudes than are satellites on 12-hour orbits (typical values: two satellites on 24-hour orbits, three on 12-hour orbits). This is because a satellite on a 24-hour orbit gives greater coverage at any given time and has a longer visibility time on each pass.

Doppler effects on the 24-hour orbit are much less than on the 12-hour orbit; even after compensation a part of the usable band is taken up by the Doppler effect, thus reducing the system's capacity in terms of the number of channels available in a given bandwidth.

For a given launching capacity, however, the payload mass available on 24-hour orbit is slightly less in early life than on 12-hour orbit. Disturbance due to the Earth's gravitational pull on satellites on 12-hour orbit is greater than that on 24-hour satellites. Luni-solar disturbance to satellites on 24-hour orbit is slightly greater than that on satellites on 12-hour orbit. Since atmospheric resistance occurs at altitudes of less than 1,000 km, MOLNIYA-type orbits are disturbed when passing through the perigee. The harmful effects of passing through radiation belts around the Earth are greater in the case of satellites on 12-hour orbit than on those on 24-hour orbits.

6. Frequency sharing with geostationary satellite networks

Interference between two networks using non-geostationary and geostationary satellites is likely to be very difficult to avoid if the two networks simultaneously serve the same geographic areas since mobile earth stations typically use antennas with broad beams. However, the two networks can be isolated (as suggested in Report 455-4) by deactivating the non-geostationary space and earth station in sufficient time to avoid illuminating the service area(s) of the geostationary satellite network.

Where the service areas of the two networks do not overlap, sharing may be feasible if directive space station antennas are used.

Further study is needed to determine how some parameters such as the latitudes of the covered areas, the gain of the antenna of the earth station or the multiple access techniques such as CDMA may allow frequency sharing between two networks using non-geostationary and geostationary satellites.

7. Areas for further study

The application of these highly inclined elliptic orbits for mobile communications raise a number of technical problems which warrant study. These include:

- frequency sharing considerations, particularly where the same frequency band is used for geostationary operations;
- definition of link margins for high elevation angles in urban, suburban and open country in band nine.
- Doppler shifts due to high relative velocity of the spacecraft and methods of correction;
- maintenance of communications, particulary during satellite handover.
- radiation damage due to passage of the spacecraft through the high density proton belt near the Earth;
- maintenance of earth coverage - by means of tracking antennas on the satellite or satellite manoeuvering;
- maintenance of orbit stability, in view of the effects of perturbations on the whole constellation and consequential difficulties for system planning;
- maintenance of continuous traffic operation with a multiple satellite system;
- methods of ensuring high availability;
- differences between the various 12 or 24 hour orbiting systems;
- mass implications of need for station keeping manoeuvres;
- study of launch energy requirements.

8. Conclusion

The possibilities for using highly inclined elliptic orbits to provide for particular service needs especially at high lattitudes, and to augment provision planned or existing for geostationary satellites, should be fully explored. This report provides a basis for such work to be done.

REFERENCES

BERRETTA, G. [March 1984] - Extension of mobile-satellite communications to the polar region, Space Communication and Broadcasting, Vol. 2, No. 1, pp. 33-46.

CHERNYVSKI, G.M., BARTENOV, V.A. [1978] - Satellite Communications Orbits, Moscow, Sviaz, pp. 240.

COLLINS, J. et al., [October 1984] - Technical military communications by satellite relay at high latitudes, AGARD Conf. CP 344.

DONDL, P. [1984] - Loopus opens a new dimension in satellite communications, Int. Journal, Satellite Comms. Vol. 2, pp. 241-250.

DULCK, J.F., ROUFFET et al. [October 1988], SYCOMORES, a new concept for land mobile satellite communications IEE London

DULCK, J.F. et al. [October 1989], SYCOMORES CONCEPT, 1AF, Bangalore

GARDINER, J.G. The T-SAT communications satellite payload, IEE Conference No. 262 Communication 86, pp. 109-112.

HOWE, T.D. [May 1986] - A technology satellite design study T-SAT, Aerogram (College of Aeronautics, Cranfield, United Kingdom). Vol. 4, No. 3, pp. 11-12.

NORBURY, J.R. [3-4 June 1986] - Land Mobile Systems using highly eccentric orbits, Proceedings of an ESA workshop held at ESA/ESTEC, The Netherlands, 3-4 June 1986.

REUDINK, D.O. [1983] - Estimate of path loss and radiated power for UHF mobile-satellite systems, BSTJ, Vol. 62, No. 8, pp. 2493-2512.

CCIR Volume VIII [1978] - Report 506-1 Satellite orbits for systems providing communications and radiodetermination for stations in the mobile service.

ANNEX I

United Kingdom

Study of an experimental payload design using a Molnya type orbit

1. Introduction

The purpose of the current phase of this study is to provide a payload design for "proof of concept" demonstrations of a land mobile-satellite system using a Molnya orbit. The project payload under consideration is based on the use of on-board processing techniques which could perhaps be applicable to second generation satellites in highly eccentric orbits.

2. Payload design

The essential features of the payload design are shown in Figure 8. Certain points are described in more detail below:

- The antenna is a simple front fed reflector of 1.5 m diameter. The antenna steering necessary to achieve earth pointing in a Molnya orbit is achieved through spacecraft manoeuvering.
- The transmitter power required to achieve an adequate link margin is about 10-20W depending on the data rate. This is easily achievable by present day technology at 1.5 GHz.
- The payload would include full demodulation and decoding of the received signals, using a variety of modulation schemes such as BPSK, QPSK and offset QPSK, implemented by on-board software. This software would be reprogrammable from the ground control. Decoding would be possible for a variety of coding schemes such as minimum weight decoding of Reed Solomon codes.
- An on-board microprocessor would control a buffer store to allow re-formatting of data and re-transmission on modulation and coding schemes independent of the up-link channel.
- Access schemes being studied are:
  a) TDM on the down-link to mobiles with TDMA on the return path from mobile to satellite;

  b) TDM on the down-link to mobiles with SCPC on the up-link. This scheme would require implementation of a digital transverse multiplexer in parallel to the TDMA demodulator and decoding modules. The proposed link budgets (mobile to and from satellite) for the various schemes are indicated in Tables II to V.
- The payload, by virtue of dual channels for each access system, allows full duplex operation. Both the base station to satellite and satellite to mobile channels operate in the 1.5 GHz band.
- Variations of the clock rate at 64, 256, 512 kbit/s are possible. The maximum rate could give an adequate link margin, at a reasonable error rate, provided coding is implemented (gains of 2-4 dB are anticipated).

- The motion of the satellite in the Molnya orbit causes a Doppler shift in the transmitted and received signals on the satellite. It is intended to compensate this Doppler shift on-board, by controlling the frequencies of the local oscillators through either on-board control or by correction from the ground control.
- Implementation of the RF sub-systems (with the exception of the power amplifiers) in Monolithic Microwave Integrated Circuits (MMIC) is being considered.
- Different traffic types such as short coded messages, voice, facsimile, etc., can be accommodated in the same time frame, merely by varying the length of the time slot allocated to each individual service.
- The full capacity of the system, using about 4.8 kbit/s digital voice coding, would be about 50 voice channels.

3. Mobile terminal

- The mobile antenna with a gain of about 15 dB and 3 dB beam angle of ± 15° would be achieved through a patched array antenna mounted on the vehicle roof with its axis pointing vertically.
- The RF power of the mobile transmitter is about 20W.
- The Mobile terminals would have the option of either operating in the TDM/TDMA or the TDM/SCPC modes.

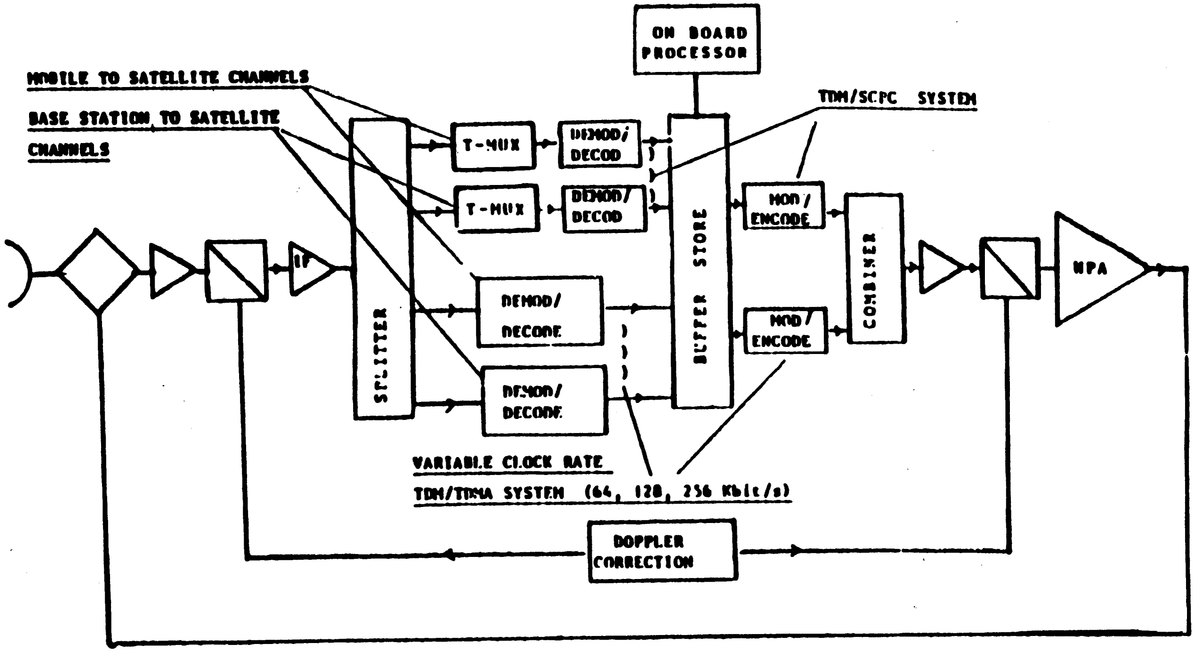

FIGURE 8

Mobile payload configuration

TABLE II: Link Budget for the Proposed TDMA/TDM Configuration

Mobile Downlink (1.555 GHz)

Satellite RF power (20W)	13.0 dBW
Diplexer, feeder loss	-1.5 dB
Satellite Antenna Gain (1.5m)	23.5 dB
Satellite EIRP	35.0 dBW
Free Space Loss (40,000 km)	-188.3 dB
Atmospheric & Rain Attenuation	-0.5 dB
Carrier Power at Mobile	-153.8 dBW
Mobile Antenna Gain	15.0 dB
Mobile Antenna Gain Ripple	-1.0 dB
Receiver & Antenna Noise Temp.	24.5 dBK
Mobile G/T	-10.5 dB/K
Boltzmann's Constant	-228.6 dBW/K/Hz
Modem Implementation Loss	-1.5 dB
Carrier-to-Noise Density (C/N_0)	62.8 dBHz
Bit Rate (256 kbit/s)	54.1 dBHz
E_b/N_0	8.7 dB

TABLE III: Link Budget for the Proposed SCPC/TDM Configuration

Mobile Downlink (1.555 GHz)

Satellite RF power (20W)	13.0 dBW
Diplexer, feeder loss	-1.5 dB
Satellite Antenna Gain (1.5m)	23.5 dB
Satellite EIRP	35.0 dBW
Free Space Loss (40,000 km)	-188.3 dB
Atmospheric & Rain Attenuation	-0.5 dB
Carrier Power at Mobile	-153.8 dBW
Mobile Antenna Gain	15.0 dB
Mobile Antenna Gain Ripple	-1.0 dB
Receiver & Antenna Noise Temp.	24.5 dBK
Mobile G/T	-10.5 dB/K
Boltzmann's Constant	-228.6 dBW/K/Hz
Modem Implementation Loss	-1.5 dB
Carrier-to-Noise Density (C/N_0)	62.8 dBHz
Bit Rate (256 kbit/s)	54.1 dBHz
E_b/N_0	8.7 dB

TABLE IV: Link Budget for the Proposed TDMA/TDM Configuration

Mobile Up-Link (1.655 GHz)

Mobile RF Power (20W)	13.0 dBW
Mobile Antenna Gain	15.0 dB
Mobile Antenna Gain Ripple	-1.0 dB
Mobile EIRP	27.0 dBW
Free Space Loss (40,000 km)	-188.9 dB
Atmospheric & Rain Attenuation	-0.5 dB
Carrier Power at Satellite	-162.4 dBW
Satellite Antenna Gain (1.5m)	23.8 dB
Receiver & Antenna Noise Temp.	27.4 dBK
Satellite G/T	3.6 dB/K
Boltzmann's Constant	-228.6 dBW/K/Hz
Modem Implementation Loss	-1.5 dB
Carrier-to-Noise Density	62.8 dBHz
Bit Rate (256 kbit/s)	54.1 dBHz
E_b/N_0	7.0 dB

TABLE V: Link Budget for the Proposed SCPC/TDM Configuration

Mobile Up-Link (1.655 GHz)

Mobile RF Power (5W)	7.0 dBW
Mobile Antenna Gain	15.0 dB
Mobile Antenna Gain Ripple	-1.0 dB
Mobile EIRP	21.0 dBW
Free Space Loss (40,000 km)	-188.9 dB
Atmospheric & Rain Attenuation	-0.5 dB
Carrier Power at Satellite	-168.4 dBW
Satellite Antenna Gain (1.5m)	23.8 dB
Receiver & Antenna Noise Temp.	27.4 dBK
Satellite G/T	3.6 dB/K
Boltzmann's Constant	-228.6 dBW/K/Hz
Modem Implementation Loss	-1.5 dB
Carrier-to-Noise Density	55.1 dBW
Bit Rate (16.4 kbit/s)	42.1 dBHz
E_b/N_0	13.0 dB