N94-22737

# ESA Personal Communications and Digital Audio Broadcasting Systems Based on non-Geostationary Satellites

**P. Lo Galbo, J. Benedicto, R. Viola**

**European Space Research and Technology Centre**
**European Space Agency**
**P.O. Box 299, 2200 AG Noordwijk, The Netherlands**
**Fax: 31-1719-84598, Telephone 31-1719-83142**

## Abstract

Personal Communications and Digital Audio Broadcasting are two new services that the European Space Agency (ESA) is investigating for future European and Global Mobile Satellite systems. ESA is active in promoting these services in their various mission options including non-geostationary and geostationary satellite systems. This paper describes a Medium Altitude Global Satellite System (MAGSS) for global personal communications at L and S-band, and a Multiregional Highly inclined Elliptical Orbit (M-HEO) system for multiregional digital audio broadcasting at L-band. Both systems are being investigated by ESA in the context of future programmes, such as Archimedes, which are intended to demonstrate the new services and to develop the technology for future non-geostationary mobile communication and broadcasting satellites.

## 1 Introduction

Following the conclusions of WARC'92 Conference, satellite personal communications will have a primary allocation in L-band (1.61-1.6265) for mobile-to-satellite links and in S-band (2.4835-2.50) for satellite-to-mobile links. Another important conclusion was the recognition of viability and market value of direct satellite radio broadcasting (DBS-R) and the assignment of a worldwide frequency allocation around 1.5 Ghz to DBS-R. As it will be detailed in the following paragraphs, one of the main technical challenges of these new services is represented by the fact that the geostationary orbit is less suited for a large penetration of personal communications and radio broadcasting services. ESA has been looking with increasingly interest to the exploitation of new orbit alternatives such as the circular Low Earth Orbit (LEO), the Intermediate Circular Orbit (ICO) and the Multiregional Highly inclined Elliptical Orbits (M-HEO). The utilization of these orbits poses challenging technological problems. The Agency's experimental programme called Archimedes has the purpose of exploring those challenges by flying one(or more) experimental satellite(s) by the year 1998 that will be representative of a future personal communication and sound broadcasting mission. This paper summarizes the definition studies that should lead to the formulation of two reference missions, personal and sound broadcasting, that will represent the basis for future technical trade-offs in the Archimedes context. In particular two systems will be presented in detail: the MAGSS-14 reference system utilizing ICO orbits around 10,000 Km of altitude for personal communications and the M-HEO(8) system utilizing 8-hours multiregional highly inclined elliptical orbit for direct radio broadcasting.

## 2 Satellite Personal Communication Systems

### 2.1 Service definition

Current or planned mobile satellite systems at Global or regional scale make use of Geostationary satellites operating at L-band.

These systems will support the traditional maritime services, and the more recently started aeronautical services. In addition, new land-mobile voice-data services will be introduced for users equipped with relatively small user terminals. These terminals can be either installed on vehicles or transported in a briefcase, or even deployed as a quasi-permanent installation in remote locations.

Contemporaneously to the development of the mobile satellite services, the terrestrial mobile systems have also experienced in the past few years a very rapid progression towards a commercial implementation of paging, messaging and telephony services using very compact lightweight (hand-held) transceivers. Progress has been possible mainly due to the technology development in the field of commercial low-power integrated digital and microwave circuits.

A clear inherent drawback of terrestrial digital cellular systems is the limited coverage, which will be restricted to the largest cities of the industrialized World and the interconnecting road and railway networks.

To offer full roaming capability is the goal of the future Universal Personal Telecommunication systems (UPTs). Such systems can only be implemented by complementing and interconnecting the Terrestrial Cellular Systems with one (Global) or several (regional) overlay Satellite Personal Communication systems, therefore extending the service also to rural and remote areas.

In the context of the above scenario, a number of Satellite Personal Communication systems have been proposed, namely Iridium, Odyssey, Globalstar, Ellipso and Constellation, and others are currently being defined, like Project 21 from INMARSAT, and Archimedes from ESA.

The main technical difficulty associated with those new satellite systems stems from the portability required to the satellite user terminal, which has eventually to be integrated within a terrestrial cellular phone. This imposes very severe restrictions to the RF transmit power and the gain of the terminal antenna, which translates into low EIRP and G/T values. Such constraints are difficult to meet with systems using satellites in the Geostationary orbit (GEO) unless very large deployable antennas and complex repeaters are installed on-board [1]. This prompted some of the system proponents to study alternative satellite constellations using Intermediate (Medium) (ICO) or Low (LEO) Earth Circular Orbits which, although leading to satellites smaller than their GEO counterparts, require a much larger number of them. Also highly inclined elliptical orbits (HEO) have been proposed (Archimedes and Ellipso) as a cost-effective solution to deploy capacity region by region.

ESA is currently studying the aspects of such satellite communication systems, based on GEO, ICO, LEO or HEO satellite constellations. The non-geo system adopted as a reference, i.e. the Medium Altitude Global Satellite System (MAGSS), will be described hereafter.

### 2.2 MAGSS system implementation

#### 2.2.1 User Terminal design

In the design of a mobile terminal for personal communications the primary requirements are to reduce its size and cost (hence complexity) to the minimum, to tailor the terminal design to the different user requirements in terms of mobility and degree of cooperation, and to offer a service compatible with those provided by the terrestrial systems. As described in Table 1, three types of satellite terminals are being envisaged: a Hand-Held (HH) terminal which can fit in a jacket pocket, a Portable (PT) terminal which can be either transported in a hand-bag or briefcase or installed in a semipermanent location, and a Vehicle-mounted (VH) terminal. A description of the technical features of those types of terminals is given in Tab. 2. Whereas the PT and VH terminals can be considered a miniaturised version of current portable and vehicle-mounted land terminal designs (operating with GEO satellites), the HH terminal represents a significant technological challenge, in particular concerning the antenna design and the miniaturisation of the RF front-end and the efficiency of HPA. Several antenna designs are currently being evaluated, all providing very low gain (0 to 3 dBi) in order to minimise the pointing requirements. The HH terminal is equipped with a low power transmitter (below 500 mW) in order to reduce the radiation exposure to the user and the size of batteries required.

#### 2.2.2 Satellite constellation

The MAGSS system employs a best single-visibility Rosette [2] constellation for a number of 14 satellites. The MAGSS constellation has been selected among others because it provides the possibility to start providing World-wide services deploying only 7 satellites, achieving a minimum angle of elevation close to 10 degrees and better than 30 degrees for more than 70% of the time.

The fully replenished constellation of 14 satellites achieves then a Global minimum angle of elevation of 28.5 degrees and better than 40 degrees for more than 90% of the time. The MAGSS constellation parameters are 10,354 Km of altitude, circular 6-hour orbits, and 56 degrees of orbit plane inclination, to maximise the coverage over the regions located between 30 and 60 degrees of latitude. A snapshot of the MAGSS constellation showing satellite coverage for a minimum angle of elevation of $28.5^o$ is shown in Fig. 1.

#### 2.2.3 Payload design and satellite capacity

In accordance with the WARC'92 frequency allocations, the MAGSS payload operates at 1.6 GHz and 2.5 GHz for the up and down mobile links respectively. The feeder links have been sized at Ka-band, although due to the complexity and cost of this option, the use of lower frequency bands (Ku and C-band) is being investigated. Fig. 2 shows a typical 37-beam spot beam coverage of the African and European regions from one of the MAGSS-14 satellites. Each spot beam has an edge-of-coverage gain of 24.5 dBi and is generated by Tx and Rx phased-array antennas. The payload transmits 300 Watts RF power at S-band , resulting into a total EIRP of 48 dBW. The total payload mass, including the Ka-band feeder-link transponder is estimated in 320 Kg, and the payload DC power consumption is 1200 Watts. The above payload would lead to a total satellite capacity of 930 duplex voice circuits ($2.4Kbit/s$) to HH-type terminals or the equivalent of 4650 to PT-type terminals, assuming a required link quality target of 39 dBHz C/No. Representative link budgets are given for illustration in Tab. 3. Such satellite capacity can be demonstrated to be compatible with the provision of World-wide personal communication services to approximately 1 million users equipped with hand-held satellite phones.

## 3 M-HEO: Multiregional Highly Inclined Orbit in the context of the Archimedes programme

Systems based on circular orbits have the advantage to provide global coverage at the expenses of a fairly large constellation of satellites. An alternative approach which reduces drastically the constellation size is based on the use of highly elliptical orbits (HEO).

HEO systems have been used with success since 1966 in the former-USSR for community TV reception and emergency communications. More than 100 satellites have been launched in elliptical , Molniya, 12 hours orbit.

HEO constellations are well suited for regional or multiregional services. A satellite in HEO lies in a plane which inclined approximately $63^o$ with respect to the equatorial plane. This gives the satellite the advantage of being viewed at very high elevation angles in northern (or southern regions). This distinctive advantage compensates for the higher slant-range in comparison with LEO or ICO systems, and makes the use of HEO satellites well suited for personal communication services and radio broadcasting in northern latitudes. In fact it allows high signal availability without penalizing the system economy by imposing large link margins. The other advantage of HEO satellites is that when low-gain user-receiver antenna are used, as in case of personal receivers, in northern latitudes higher gain can be achieved (2-3 dB's more) compared with geostationary satellites.

In a HEO constellation the satellites are not stationary and are therefore used in the orbital arc around the apogee where they present a quasi-geostationary behaviour. The number of service areas is equal to the number of the apogee points on the Earth ground track. HEO orbits with more than one coverage area are called multi-regional orbits [3]. The number of service areas is given by the least common multiple between the orbital period (expressed in hours) and 24, divided by the orbital period.

The number of satellites for a given constellation is given instead by the number of service areas multiplied by the orbital period and divided by the selected duration of the active arc.

ESA has originally studied the Tundra and Molniya orbits for coverage of Europe with high elevation angles, recently the attention has been focused on M-HEO(8) and M-HEO(16) orbit. M-HEO orbits offers the possibility to promote a wide international cooperation which implies economies of scale in the system development and in sharing of the deployment costs.

The M-HEO(8) system is particularly interesting and suited for services such as personal communications and sound broadcasting, in fact it can offer:

- high availability and continuous 24 hours service tailored to cover the three most important market areas of the world, i.e. Europe, Far East and North America.
- A minimum number of satellites for continuous coverage of these three service areas
- The apogee at 26000 km allows power savings in comparison with other HEO alternatives or geostationary satellites. The lower apogee altitude offers also a considerable advantage over the other HEOs in terms of orbit mass that can be delivered by a given launcher.

In the framework of the Archimedes project, ESA is willing to pursue of utilization of HEO constellations for multiregional personal and sound broadcasting services. In the Archimedes programme ESA intends to target the development of an experimental satellite to demonstrate the viability of later operational systems. The M-HEO constellation for personal communications intends to reach the same service objectives of the MAGSS-14 system but on regional basis. Therefore this application will not be described further. The M-HEO system for sound broadcasting will instead be discussed in detail in the next paragraph.

### 3.1 The M-HEO system for Digital Audio Broadcasting

The feasibility of DBS-R is based on the possibility of receiving the satellite signal anywhere using small table-top radio, personal walkman-type and mobile receivers. Blockage of the satellite line of sight and multipath effects would degrade DBS-R services to a non-acceptable level. This is translated into the requirements of high elevation angles and high received power flux density over wide areas. The importance of satellite elevation angles has been demonstrated in the frame of several field measurement campaigns at L and S-band. This problem is of particular relevance in all northerly regions of the earth. A geostationary orbit-based service shall include propagation margins in excess of 10 dB to serve those regions, this implies a design solution based on high-powered spacecraft with a large and complicated antenna system resulting in an high (unacceptable) cost for the telecommunication service.

In the basic configuration the M-HEO(8) system is composed by a constellation of 6 satellites in 8 hours elliptical orbits. The six-satellite M-HEO(8) system enables the users to receive the radio signals from satellites always visible with high elevation angles. The coverage area of the M-HEO(8) system includes all continental Europe where the minimum guaranteed elevation angle 100 % of the time is of more than 45 degrees. The other coverage areas are Japan, China, Asian CIS and Canada, USA, Mexico, where elevation angles better than 40 degrees 100 % of the time are guaranteed. Fig. 3 illustrates the minimum elevation angles in the three service areas.

The M-HEO(8) system in its baseline configuration provides integrated digital broadcasting services with possibility of user interaction such as:

- News and basic radiotext
- Bi-lingual News and stereo music, basic radiotext
- Multilingual News and HI-FI stereo music, full colour radiotex
- Multilingual News and CD stereo music, enhanced radiotex or television for pocket receivers
- Paging and Messaging services
- Interactive services providing users with a low bit rate response channel. The maximum bit rate is around 50 b/s.
- Navigation services integrated with meteorological data broadcasting.

In order to deliver the necessary power flux density to provide these services to small receivers, multi-beam antenna coverage of the three service areas is necessary. The M-HEO(8) coverage foresees the use of a reconfigurable antenna system providing in each service area a five beam coverage, i.e. four spot and a global beam. The four spot beams are arranged in the three service zones in order to match linguistic and geographical constraints. Each spot-beam provides 28 dBi of directivity at the 3 dB contour. The global beam is intended to provide 20 dBi gain at the 3 dB contour. The spot-beam coverage is illustrated in Fig. 4 for Europe.

The transponders are intended to provide a flexible share of resources according to the market and user population needs. The transponder can be configured to provide a given distribution of services with different quality and power level. It is fundamental that the selected modulation and multiplexing technique allows such flexible allocation of bandwidth and power resources. Approximately 1000 W of DC power are allocated for the payload.

In order to simplify the satellite design there is no frequency reuse in a given service area, but in order to minimize the overall frequency requirements of the system, frequency is re-used in different regions. The overall down-link frequency requirement is in the order of 10 Mhz for operations in the three service areas. Note that thanks to the high elevation angles frequency coordination is simplified both with respect to geostationary satellites and terrestrial radio links.

Up-link of radio programmes takes place in a ground station equipped with 5 meter tracking antennas. Each satellite is tracked independently. A single up-link location above $58^o$ can address the European, Far Eastern and North-American loops at the same time with a minimum satellite look-up angle of $5^o$ degrees. Given that the up-link antennas never cross the geostationary arc, C-band can be used without problem of coordination with respect to GEO satellites.

The sound broadcasting service is intended for a diversity of users in the three service areas. Users are equipped with terminals that can be subdivided in three main classes:

- Type 1: $G/T = -12dB/K$ table-top radios equipped with directional antennas with adjustable elevation and azimuth.
- Type 2: $G/T = -15dB/K$ mobile receivers installed in cars, recreational vehicles with medium gain antenna with onmiazimuthal pattern.
- Type 3: $G/T = -19dB/K$ personal "walkman-type" receivers with low gain antenna with onmiazimuthal pattern.

Table 4 derived from [4] provides an example of link budgets. In reference [4] an extensive investigation of the link performances of the M-HEO(8) sound broadcasting mission. Results are obtained for a mobile receiver, details on the channel modelling can be found in ref. [4]. In ref. [4] the COFDM signal has been optimized for the use on non-linear satellite channel. For the link budget of Tab. 4 a COFDM system with 280 carriers, symbol time 156.25 microsec, guard time 10 microsec and rate 1/2 convolutional coding, has been selected. In the example of Tab. 4 a maximum bit rate has been selected to 128 Kbit/s per carrier but lower data rates can be also multiplexed.

# 4 Conclusions

This paper has reviewed the user requirements and system implementation of future mobile satellite systems for personal communications and digital audio broadcasting, using the new frequency bands recently allocated by WARC'92.

The MAGSS-14 system has been described as a way to provide World-wide roaming capability to users equipped with dual terrestrial-satellite hand-held phones. The MAGSS system presented is based on 14 satellites in intermediate circular orbit, which shows to be a compromise between the satellite complexity required by equivalent Geo satellites, and the large number of satellites required by LEO constellations.

MAGSS-14 satellites have been sized to serve up to 1 Million users World-wide equipped with a hand-held terminal offering a range of voice, data, messaging and paging services, complementary to terrestrial cellular radio services.

In the context of the ESA Archimedes program, satellite systems utilizing elliptical orbits are being investigated to provide personal communications and sound broadcasting services.

Multiregional Highly Elliptical Orbits (M-HEO(8)) open-up a new market application of digital audio broadcasting with ancillary data and navigation services in the 3 key business areas of the world, i.e. Europe, North America and Far-East. Satellite radio broadcasting is attractive for users demanding international high quality radio services. Broadcasters have also shown a keen interest in satellite broadcasting and appreciate the high availability and quality that HEO systems can deliver but of course funding a full constellation goes beyond their possibilities. Manufacturers are also interested in satellite radio but are clearly waiting for concrete implementation plans for the space segment. As a result of this widespread interest it is evident that the R&D and initial build-up of an HEO constellation for satellite radio has to be provided via public initiative. ESA intends to promote this new challenging opportunity for satellite communications by flying the experimental Archimedes mission in order to substantially support this fascinating technical endeavor.

# References


[1] J. Benedicto et al., *"Geostationary Payload Concepts for Personal Satellite Communications"*, In the IMSC-93 Proceedings.

[2] J. Benedicto, J. Fortuny, P. Rastrilla, *"MAGSS-14: A Medium Altitude Global Mobile Satellite System for Personal Communication at L-band"*, ESA Journal, 92/2, February 1992

[3] G. Solari, R. Viola *"M-HEO: Multiregional HEO satellite system for optimal coverage of the northern hemisphere,"* IAF-92-0425, IAF-World Space Conference 1992, Washington, 1-4 Sept. 1992

[4] C. Elia, R. De Gaudenzi, et al. *"Analysis of Transmission Schemes for Satellite Digital Audio Broadcasting, "*, To be presented at Globecom 93.

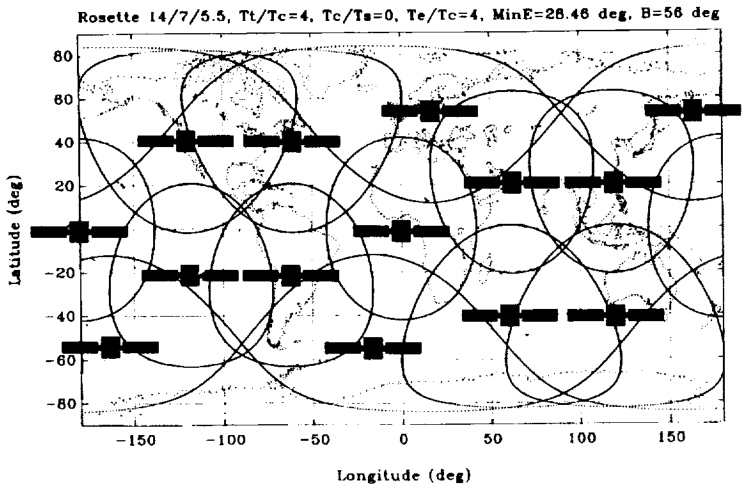


**Fig. 1** MAGSS-14 Constellation (contours at 28.5″)

|  | hand-held | portable | vehicle |
|---|---|---|---|
| size | pocket | laptop | antenna + set |
| antenna gain | 0 ~ 3dBi | +7dBi | +4dBi |
| Tx RF power | < 500mW | 1W | 2W |
| EIRP [dBW] | -3 ~ 0 | +7 | +7 |
| G/T [dB/K] | -24 ~ -21 | -17 | -20 |

**Tab. 2** User terminal characteristics

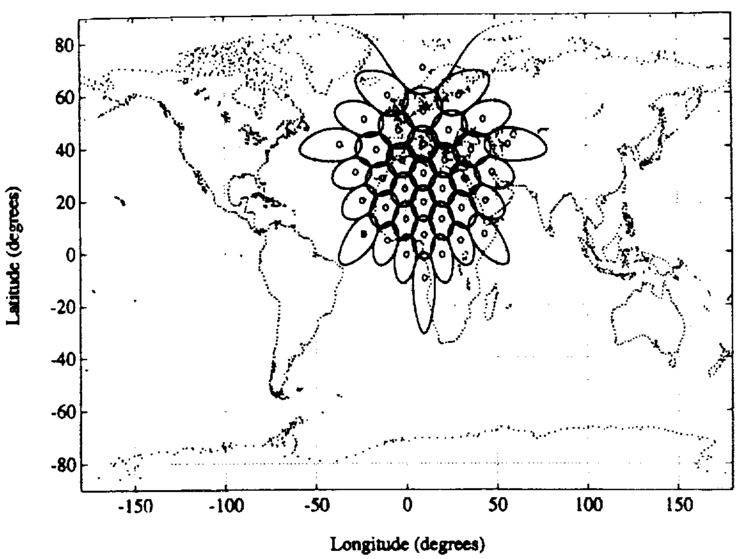


**Fig. 2** MAGSS-14 Typical Spot Beam Coverage

| MOBILE-TO-SATELLITE LINK (1.6GHz) | |
|---|---|
| elevation (deg) | 30 |
| mobile RF power (W) | 0.5 |
| mobile antenna gain (dBi) | 0 |
| mobile EIRP (dBW) | -3 |
| path loss EOC (dB) | 178.5 |
| atmospheric loss (dB) | 0.2 |
| interference loss (dB) | 1.0 |
| multipath loss (dB) | 1.0 |
| satellite antenna diameter (m) | 2.5 |
| repeater noise temperature (dBK) | 28 |
| satellite G/T (dB/K) | -4.0 |
| up-link C/No (dBHz) | 40.9 |
| overall C/No (dBHz) | 40.5 |
| required C/No (dBHz) | 39 |
| margin (dB) | 1.5 |

| SATELLITE-TO-MOBILE LINK (2.5 GHz) | |
|---|---|
| elevation (deg) | 30 |
| satellite antenna diameter (m) | 1.6 |
| satellite antenna gain (dBi) | 24.5 |
| TX power S-band (Watts) | 300 |
| Total satellite EIRP (dBW) | 47.8 |
| voice activation factor (dB) | 4 |
| number of duplex voice circuits | 930 |
| effective satellite EIRP per circuit (dBW) | 22.1 |
| path loss EOC (dB) | 182.4 |
| atmospheric loss(dB) | 0.2 |
| interference loss (dB) | 1.0 |
| multipath loss (dB) | 1.0 |
| mobile G/T (dB/K) | -25 |
| down-link C/No (dBHz) | 41.1 |
| overall C/No (dBHz) | 40.7 |
| required C/No (dBHz) | 39 |
| margin (dB) | 1.7 |

**Tab. 3** MAGSS-14 Sample Link-Budgets

| USER | MOBILITY | TERMINAL | CO-OPERATION |
|---|---|---|---|
| Traveller | open/shadow | HH dual mode | High |
| Mobile | mobile chn. | VH dual mode | Low |
| Government | mob./outdoor | HH, VH | High |
| Remote Telephony | outdoor | HH, portable PT or VH | High |
| Recreational | land/sea | HH | Low |
| Data Collection | outdoor | semi-fixed PT | High |

**Tab. 1** User categories and services

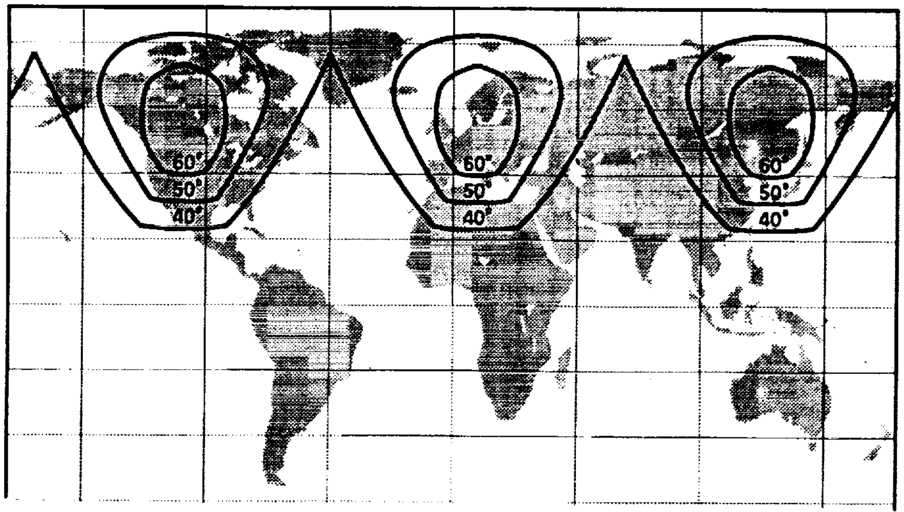


**Fig. 3 M-HEO(8) Minimum Isoelevation Contours 24/24 hours**

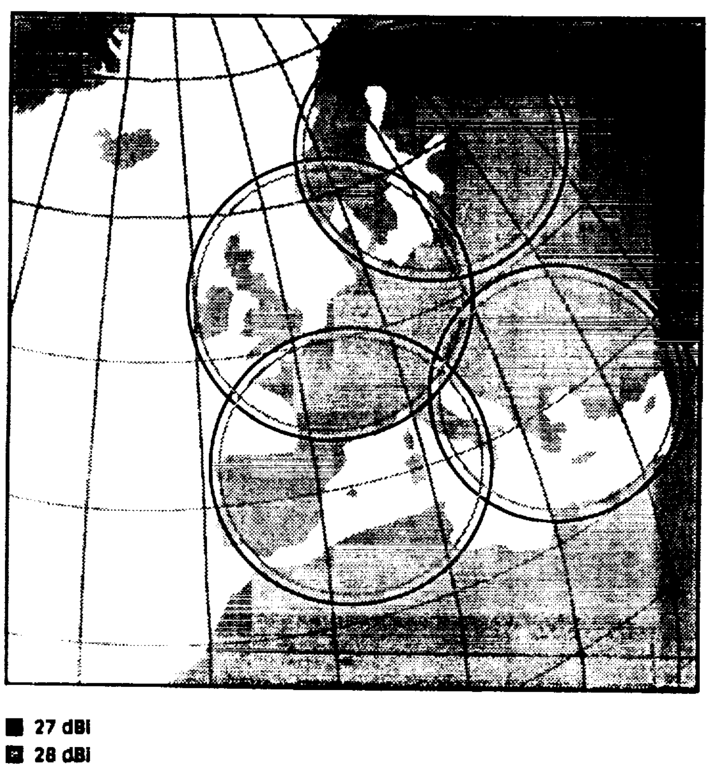


**Fig. 4 M-HEO(8) (-3 dB isogain at apogee) Contours (Europe)**

**Table 4: Link budget for a M-HEO(8) mobile users (suburban) [4]**

| Frequency | L-band | L-band |
|---|---|---|
| Receiver Type | 2 | 3 |
| Modulation scheme | COFDM | COFDM |
| Coding rate | $r = 1/2$ | $r = 1/2$ |
| Bit rate (Kb/s) | 128 | 128 |
| Average Line of Sight Attenuation (dB) | 2.5 | 2.5 |
| Carrier-to-Multipath ratio (dB) | 12 | 10 |
| Estimated service availability (%) (suburban, elevation $\geq$ 60°) | 98 | 98 |
| Required $\overline{E}_b/N_0$ (dB) (@ BER=$10^{-3}$) | 7.1 | 7.2 |
| Receiver G/T (incl. point. loss) | -16 | -21 |
| Implementation Losses (dB) | 1 | 1 |
| Number of DAB programmes | 14 | 14 |
| Nonlinear distortion losses + satellite OBO (dB) | 1.8 | 1.8 |
| Occupied (99%) bandwidth (MHz) | 1.9 | 1.9 |
| EIRP per programme (dBW) | 37.2 | 42.1 |