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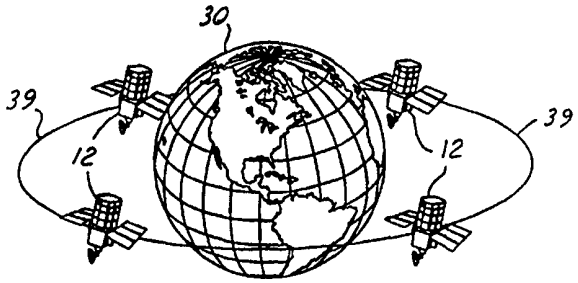
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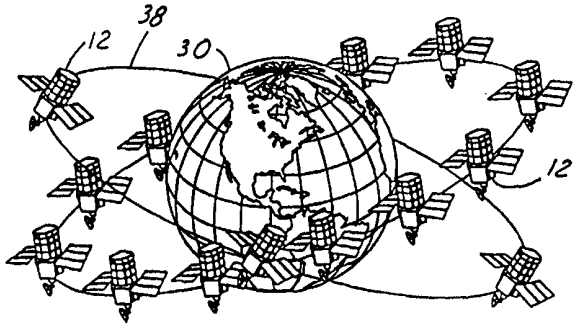
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A



D

(57) Abstract

A satellite communication system (10) has a first deployment of a plurality of satellites (12) deployed in a medium earth orbit and later deployments of a plurality of satellites (12) deployed in the medium earth orbit. The first deployment is spaced so that the second deployment may be easily deployed and interleaved into the first deployment. A ground terminal is used for communicating with the satellites in the first and second deployments.

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SATELLITE SYSTEM

Technical Field

The present invention relates to space and communications satellites, and more particularly, to a coordinated system for providing satellite communications using multiple satellites.

Background Of The Invention

Wired terrestrial systems offer communications at high data rates, but only while the user is sitting behind a computer. As soon as the user goes to a conference room, walks outside an office building, gets into a car, or drives to a park, the connection is lost. Mobility, however, can be supported in one of two ways, namely terrestrial-based wireless networks or satellite-based communications systems.

Terrestrial-based wireless networks provide voice or data communications between a mobile user and a fixed user or to other mobile users, as well as communications for modem-equipped computers and other similar devices such as mobile facsimile machines. Existing wireless networks have not been optimized for a mix of voice, data, and video, however, despite the trend towards multimedia traffic. Several wireless and wired standards, such as asynchronous transfer mode (ATM), are being designed to optimize multimedia traffic. Wireless wide area networks (WANs) typically

carry voice, whereas wireless local area networks (LANs) typically carry data. Most wireless WAN traffic operates at under 19.2 kbps. Wireless LANs that support data rates up to 10 Mbps have begun to appear, but they are limited in range to tens of meters.

To provide wireless service, satellite-based communications systems have been proposed which would provide world-wide coverage. These proposed systems typically include a constellation of satellites in one orbit only, such as geostationary earth orbit (GEO) only or non-geostationary orbits (NGSO). Communications satellites in geostationary orbit provide coverage in predetermined areas on the earth from the equator. Coverage is typically excluded from the oceans so that satellite capacity is not wasted on non-populated areas. Communications satellites in geostationary orbit, however, provide limited coverage at higher or lower latitudes than the Equator.

Communications satellites in non-geostationary orbit, such as medium earth orbit (MEO) or low earth orbit (LEO), travel relative to the Earth's rotation and typically provide high elevation angle coverage at the higher and lower latitudes, and since they are closer to earth, propagation time delays are minimized. Because of the unavailability of stationary positions it is desirable to deploy NGSO satellites.

In one known implementation of a NGSO satellite system, several disadvantages are apparent. In the known system, each satellite is deployed in its position individually. One drawback to individual launches is the high cost associated with each launch. Another drawback is that the system is not easily adaptable to increasing demand. Individual launches must be used to provide increased coverage.

Data rates up to 19.2 kbps, as available from wireless WANs, will not meet future data rate needs of consumers. For example, many computer users are upgrading their wired modems to 56.6 kbps whenever possible. Such users desire a fast response from their modems even while they are away from their desks. In addition, the nature of the information being transferred is changing from short, text-based electronic mail messages to communications with embedded video clips. Such media-rich messages consume high bandwidth and communications resources, thus requiring high data rates to allow them to be transmitted and received within a reasonable period of time.

Furthermore, a tremendous growth in Internet traffic has caused a strain on the capacity of telephony networks. Network shortcomings include network outages, insufficient access bandwidth, and insufficient internode bandwidth. Currently, providers need to make significant investments, as well as experience installation delays, to upgrade

network infrastructure, yet they cannot pass the costs on to the end users.

Corporate LANs/WANs also generate an insatiable demand for higher bandwidth. The demand for bandwidth goes up as more and more users are connected. The users, in turn, demand more services and improved network speed. Personal computers are being used to process not only text, but graphics and video as well, all on networks that are increasingly global. Widespread implementation of corporate intranets and extranets further drive the move to increased bandwidth applications. High-speed networking is also driven by the growth of video distribution, client/server technology, decentralized systems, increased processing power and developments in storage capacity.

Fixed service demand such as satellite news broadcast, distance learning, and military functions are continually increasing. It would be desirable to provide a system capable of meeting demand of such uses.

Thus, there exists a need for a satellite communications system that provides communications to mobile users as well as fixed service users. There also exists a need for a satellite communications system that provides global communications service while maximizing the useful capacity of the satellites, reducing the perceived time delay, and

maximizing the minimum elevation angle across latitudes.

Disclosure Of The Invention

The present invention provides a satellite communications system which provides global network services to fixed and mobile users. The system utilizes a first deployment of a plurality of satellites deployed in a medium earth orbit (MEO) and a few subsequent deployments of a plurality of satellites deployed in the same medium earth orbit (MEO) or other orbits. A ground terminal is provided for communicating with the first and the later deployments.

In one aspect of the invention, the satellites may be deployed in at 15000 km. One advantage of using 15000 km is that the satellites avoid interference with the Van Allen radiation belts. Another advantage is that polar orbiting satellites need not be deployed.

One advantage of the invention is that a one dimensional tracking ground antenna may be employed. A one dimensional tracking antenna is less expensive than two-dimensional antennas.

Another advantage of the invention is that the system is extremely adaptable in a business sense. That is, the system can be deployed in a first configuration. Then, as the needs of the users of the system increase, further satellites may be

deployed. The first deployment may be spaced to easily accommodate the second deployment so that the second deployment may be accomplished in a single launch.

Another advantage of the invention is that the constellation of the present invention promotes frequency reuse. That is, because the MEO satellites of the present invention are not in a direct line with GSO satellites, the frequencies of GSO satellites may be reused in the present constellation.

Yet another advantage of the present invention is that some time will lapse between the initial deployment and later deployments. Thus, the later deployments may take advantage of the newest technology, which is important in the rapidly changing satellite technology industry.

Brief Description of the Drawings

FIGURE 1 is a diagrammatic representation illustrating a satellite communications system of the present invention.

FIGURE 2 is a schematic illustration of a satellite of Figure 1 viewed from the edge of the equatorial plane.

FIGURE 3A is a schematic illustration of an initial operation configuration constellation of

communications satellites utilized in the present invention.

FIGURE 3B is a schematic illustration of a constellation of communications satellites after a second deployment.

FIGURE 3C is a schematic illustration of a constellation of communications satellites after a third deployment.

FIGURE 3D is a schematic illustration of a constellation of communications satellites after a fourth deployment into an inclined orbit.

FIGURE 4 is a schematic illustration of satellite coverage using spot beams.

FIGURE 5 is a plot of latitude with 100% coverage versus number of satellites in the constellation at an elevation of 10000 km.

FIGURE 6 is a global plot illustrating coverage and elevation angle in a constellation using 4 satellites.

FIGURE 7 is a global plot illustrating coverage and elevation angle in a constellation using 8 satellites.

FIGURE 8 is a global plot illustrating coverage and elevation angle in a constellation using 12 satellites.

FIGURE 9 is a plot of latitude with 100% coverage versus the number of satellites in the constellation at an altitude of 15000 km.

FIGURE 10 is a graph of the capacity versus time plot illustrating the advantages of the present invention.

Description Of The Preferred Embodiment(s)

Referring to Figure 1, the communication system 10 with a typical geometry for practicing the invention is diagrammatically illustrated. In general, system 10 includes a plurality of communication satellites 12 in middle earth orbit (MEO). As will be further described below, system 10 may also include satellites in an inclined medium earth orbit. The MEO satellites 12 provide quick introduction of regional services and low cost service over selected regions. The system 10 has a user segment 14 and a ground segment 16. User segment 14 generally comprises a number of fixed terrestrial sites 18 as well as a number of mobile sites. Mobile sites may include vehicles such as an airplane 20, a tractor-trailer 22, and a ship 24. Various applications within the vehicles may incorporate satellite-based communication including navigation and communication applications.

Fixed sites 18 may be used as satellite operational centers for tracking and communication control, as network operational centers for various communications such as Internet connections, or beacon stations for satellite position control. Fixed sites 18 may, for example, be coupled to a

terrestrial communications link 26. Terrestrial communications link 26 may, for example, be a connection into existing phone lines or cable/television lines.

User segment 14 and ground segment 16 each have an antenna 28. For ground segment 16, a fixed one-dimensional antenna 28 is preferred. One-dimensional tracking may be used due to the repeating path of the medium earth orbit satellites. For mobile communications, a two dimensional tracking antenna 28 is required. Antennas 28 are preferably electronically directed toward satellite 12 during movement. The system may communicate using V band or other suitable frequencies.

Various applications of a communication system formed according to the present invention include video conferencing, distance learning, corporate training, worldwide web games, internet-based interactive services, corporate communications, collaboration between suppliers and vendors, telemedicine and telehealth applications and satellite news gathering. Particular industries that may benefit from such a satellite communication system would be industries that have international exposure and provide international services such as the airline, shipping, cruise, and businesses with some international exposure. For example, parcel delivery services, airlines, and cruise lines will be able to track assets on a global basis.

Referring now to Figure 2, earth 30 has an equatorial plane 32 that divides the upper hemisphere and lower hemisphere. As shown in Figure 2, an edge view of equatorial plane 32 is shown. One satellite 12 is shown, however, the constellation preferably comprises at least four satellites in an initial operation configuration (IOC). The elevation angle 34 is shown from a point on the earth to satellite 12 with respect to equatorial plane 32. With four satellites in the IOC, semi-global coverage may be achieved. This means that most of the highly populated areas of the globe may have service from the system. As will be further discussed below, by increasing the number of satellites in the system, ubiquitous coverage of the globe may be achieved.

Satellites 12 are preferably deployed in medium earth orbit at a distance of at least 10000 km from the Earth's surface. Satellites 12 may be deployed between about 10000 km and 17000 km. In a preferred embodiment, satellites 12 are deployed at about 15000 km. By deploying the satellites at 15000 km, elevation angles are increased in the most populated latitudes of the earth.

For perspective purposes, a geostationary satellite 36 is illustrated. Geostationary satellites 36 are deployed at about 35000 km. This is over twice the distance of communication satellite 12 in medium earth orbit. The path of satellites 12 is in the line-of-sight of GSO satellites 36, except

for at a narrow region around equator 32. One advantage of the system is that frequency reuse may be accomplished between the satellites 12 of the present invention and GSO satellites 36.

Referring now to Figures 3A, communication satellites 12 are illustrated in a single plane in an initial operation configuration (IOC). Preferably, the satellites 12 are deployed in the equatorial plane. To provide semi-global coverage, four satellites are preferably deployed. Because each satellite is equipped with position-adjustment thrusters (not shown), a single launch vehicle may be used to deploy all four satellites in a single launch. This significantly reduces the IOC cost.

Once in orbit, the positions of the satellites 12 may be adjusted by east/west station keeping. That is, satellites 12 may be temporarily adjusted to a higher elevation (outward from earth), which slows the movement of the satellite. When the desired position is approaching in the lower orbit, the satellite elevation can be moved inward to the proper position in the desired orbit.

After launch, the first deployment is shifted into place using the thrusters. The first deployment of satellites 12 have orbital voids 39 therebetween.

Referring now to Figure 3B, a satellite constellation in medium earth orbit is illustrated after a second deployment. In this case, four

additional satellites were deployed simultaneously in the second deployment. The second deployment is shifted into the orbital voids 39 after they are placed into orbit. This second deployment, as will be described further below, increases the elevation angle at the most populated elevations. Satellites 12 may be positioned by east/west station keeping as described above so that the second deployment is interleaved between the first deployment.

Referring now to Figure 3C, if further satellites are deemed to be required from the second deployment, a third deployment may be employed. In this case, four satellites are launched simultaneously to obtain the third deployment. Prior to the third deployment, however, satellites 12 may be shifted in their orbiting positions so that the single third deployment may deploy each of the last four satellites 12.

Referring now to Figure 3D, if demand on the satellite constellation is increased further, more medium earth orbit satellites may be deployed on the equatorial plane. However, if spacing between the MEO satellites becomes too small, then satellites 12 may be deployed in an inclined orbit 38. The inclined orbit illustrated is also preferably filled with medium MEO satellites. The satellites 12 in the inclined medium earth orbit are also preferably launched by the single launch vehicle and are adjustable within their orbit paths. This will allow

more groups of satellites to be positioned in a single launch in the inclined orbit 38.

If the business demands on the system are such that further satellites are required, additional planes inclined at various angles with respect to the equatorial plane may also be deployed. Also, various numbers of satellites may be deployed within those inclined orbits.

Referring now to Figure 4, a preferred spot beam design is illustrated with respect to the Western Hemisphere. In this illustration, a GSO satellite sharing belt 40 is illustrated in the equatorial region. The GSO satellite sharing belt 40 is plus or minus 11 degrees of latitude. That is, the total belt north to south is 1224 km. To achieve the desired coverage, 253 beam positions are covered by the satellite 50 beams maximum will be illuminated. The beams are referred to generally by the reference numeral 42. Preferably, each satellite covers 90 degrees longitude. Thus, four satellites would provide coverage for most regions of the earth in the first phase. The beams generated are preferably 2.5 degrees in width.

Referring now to Figure 5, a plot of latitudes with 100 percent coverage versus the number of satellites in a constellation at an elevation of 10000 km is illustrated with respect to various elevation angles. As is shown at point 44, at about 39 degrees latitude, 100 percent of the area is

covered by at least an elevation angle of 0 degrees. At about 55 degrees latitude, 100 percent coverage is attained if the elevation angle requirement is ten degrees using eight satellites as illustrated at point 45. Coverage of 100 percent is achieved at a 10 degree elevation angle at about 57° latitude with greater than twelve satellites in the equatorial plane as illustrated at point 46.

Referring now to Figure 6, a map of the world is illustrated with various elevation angles of coverage. The coverage for four satellites 50 at an altitude of 10000 km on the equatorial plane is illustrated. The uppermost 52 and lowermost 54 regions of the map have no coverage. The next band lower 56 in latitudes has zero to ten degrees elevation angle coverage. The next band 58 in latitude has 10 to 20 degrees coverage in latitude, and the center portion 60 of the map has over the 20 degrees elevation angle.

Referring now to Figure 7, a similar map to that of Figure 6 is illustrated. In this illustration, eight satellites 70 deployed at 10000 km in altitude on the equatorial plane are shown. The same reference numerals as in Figure 6 are used to identify the various regions of coverage.

Referring now to Figure 8, the coverage for 12 satellites 80 at an altitude of 10000 km on the equatorial plane is shown. As can be seen, most land regions of the earth are covered in areas having

between 0 and 10 degrees of elevation angle. The same reference numerals as in Figure 6 are used to identify the various regions of coverage.

Referring now to Figure 9, a graph similar to that of Figure 5 is shown with satellites having a 15000 km altitude. The advantage of using a 15000 km altitude rather than a 10000 km is evident. At point 89, similar elevation angles as that shown in Figure 5 are present at 50 degrees latitude. For example, at latitudes near 60 degrees, elevation angles up to ten degrees may be achieved using eight satellites as illustrated at point 90. At point 91, about 63° latitude, 100 percent coverage may be achieved with twelve satellites. Increasing the satellite distance to 15000 km increases all of the elevation angles.

In operation, a first plurality of satellites is launched into a medium earth orbit in a first configuration. When traffic on the satellites approaches capacity for communications, the second plurality of satellites is deployed in medium earth orbit. The second plurality of satellites is preferably launched in a single launch. The first set of satellites and the second plurality of satellites are then interleaved in the same orbital path. Preferably, the satellites are in orbit 15000 km above the earth. This allows higher elevation angles to higher latitudes of the earth.

If further satellites are required because of increasing communications on the satellite,

further deployment to satellites may be launched in a similar manner. When the spacing approaches capacity for the medium earth orbit orbit, inclined medium earth orbits may be employed. Several planes of medium earth orbit satellites may be used to substantially increase the capacity of the system. Preferably, each of the deployments preferably is deployed in groups from a single launch.

Satellite technology is rapidly changing. The second deployment is launched some time after the first deployment. This allows the second deployment and subsequent deployments the opportunity to use more current technology. Also, because groups of satellites are deployed together, the launch schedule is more flexible than launching individual satellites into their exact positions.

Referring now to Figure 10, several advantages of the system as described with respect to the present invention are illustrated. As can be seen, actual demand may not align with projected demand for the system. In this manner, if actual demand is lower, a second or subsequent launch may be delayed until demand increases. Likewise, if demand increases more rapidly than expected, the launch schedule can be moved forward. The advantage of the lower cost of the initial system makes the system more practical than other systems where a full system is initially deployed at a high cost.

While particular embodiments of the invention have been shown and described, numerous variations and alternate embodiments will occur to those skilled in the art. Accordingly, it is intended that the invention be limited only in terms of the appended claims.

What Is Claimed Is:

1. A communications system 10 comprising:

a first deployment of a plurality of satellites 12 deployed in a medium earth orbit;

a second deployment of a plurality of satellites deployed in a medium earth orbit interleaved with said first deployment; and

a ground terminal 16 for communicating with said first and second deployment.

2. A communications system as recited in claim 1 wherein said ground terminal 16 scans in a single dimension.

3. A communications system as recited in claim 1 wherein said ground terminal 16 scans in two dimensions.

4. A communications system as recited in claim 1 wherein said plurality of satellites 12 are deployed in a medium earth orbit.

5. A communications system as recited in claim 1 wherein said medium earth orbit is substantially about 15000 km above the earth.

6. A satellite constellation comprising:

a first deployment of a plurality of position-adjustable satellites 12 deployed in a medium earth orbit;

the first deployment of satellites 12 having a first configuration corresponding to an initial operation configuration having orbital voids; and

a second deployment of a plurality of position-adjustable satellites 12 deployed in the medium earth orbit in said orbital voids.

7. A satellite constellation as recited in claim 6 wherein said medium earth orbit is substantially about 15000 km above the earth.

8. A satellite constellation as recited in claim 6 wherein said satellites 12 use the same frequencies as geostationary satellites.

9. A satellite constellation as recited in claim 6 wherein said first plurality of satellites 12 and said second plurality of satellites 12 are deployed on an equatorial plane.

10. A satellite constellation as recited in claim 6 further comprising a third deployment of satellites 12 deployed on an orbit inclined with respect to the equatorial plane.

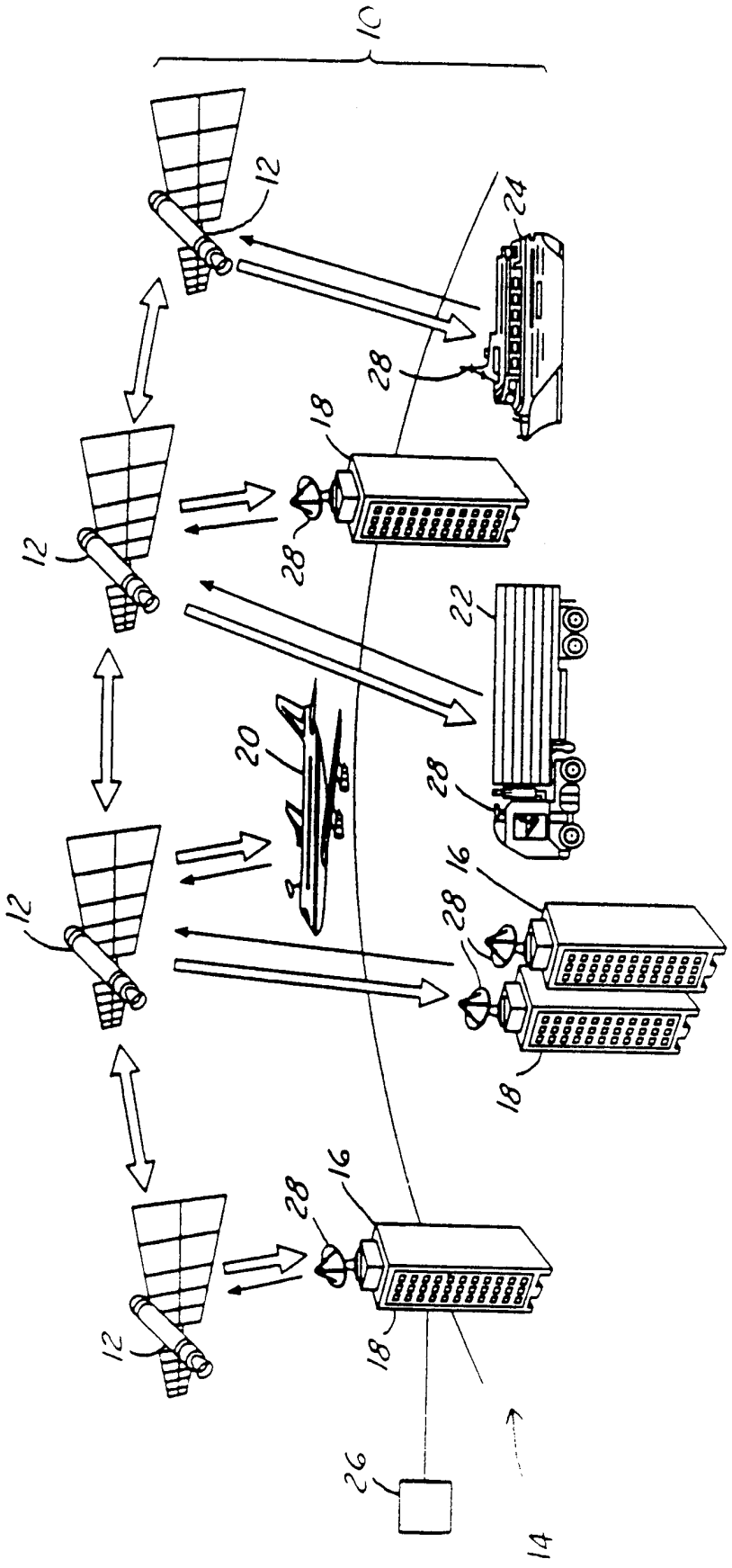


FIG. 1

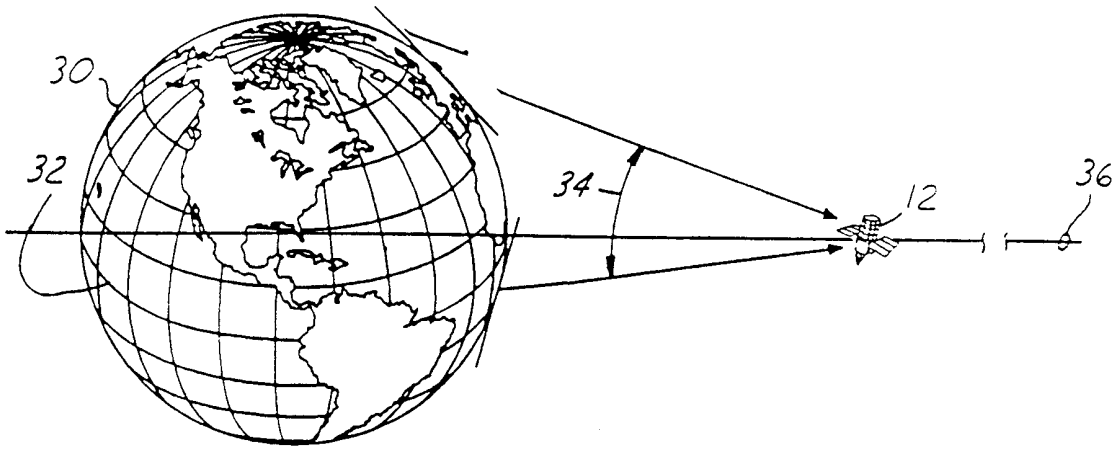


FIG.2

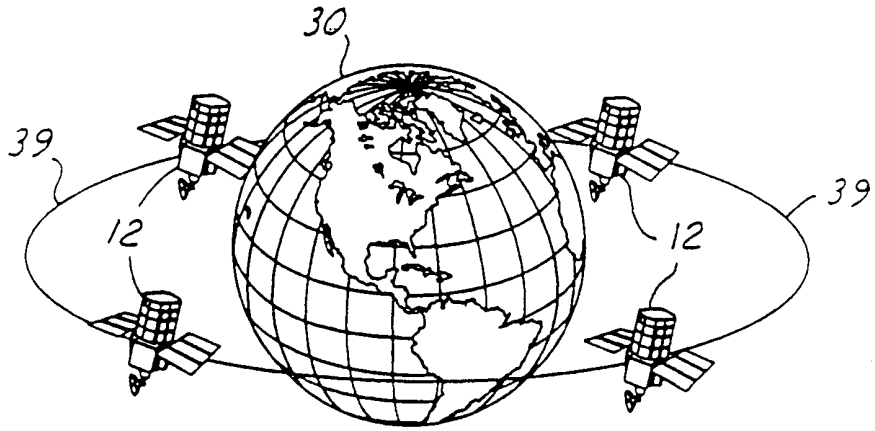


FIG.3A

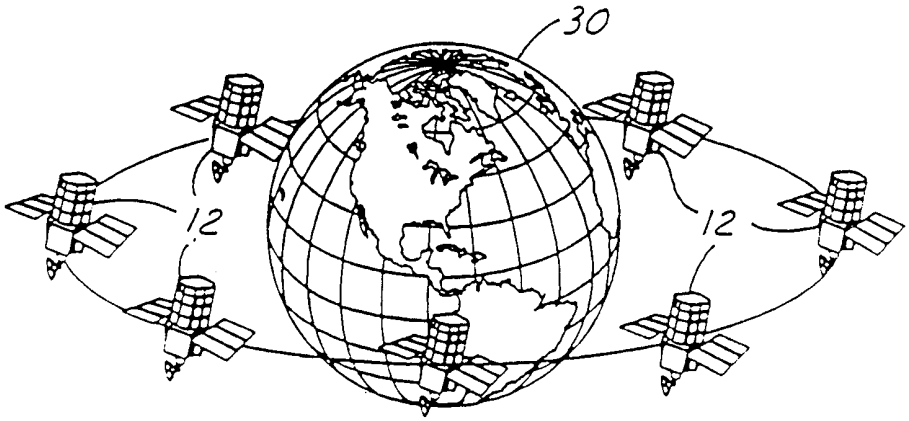


FIG.3B

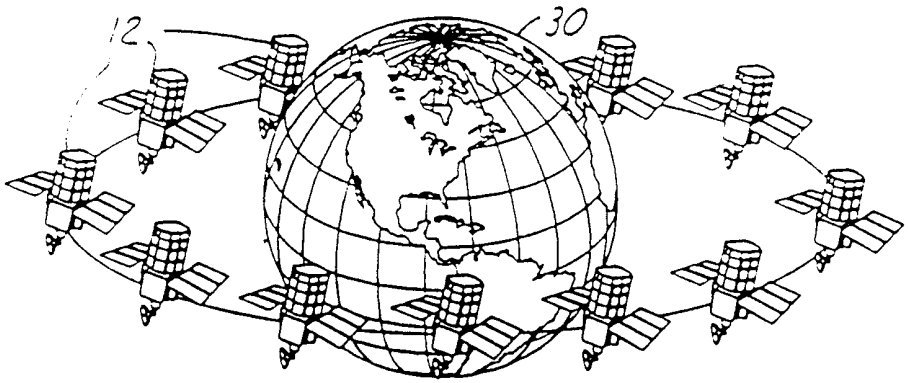


FIG.3C

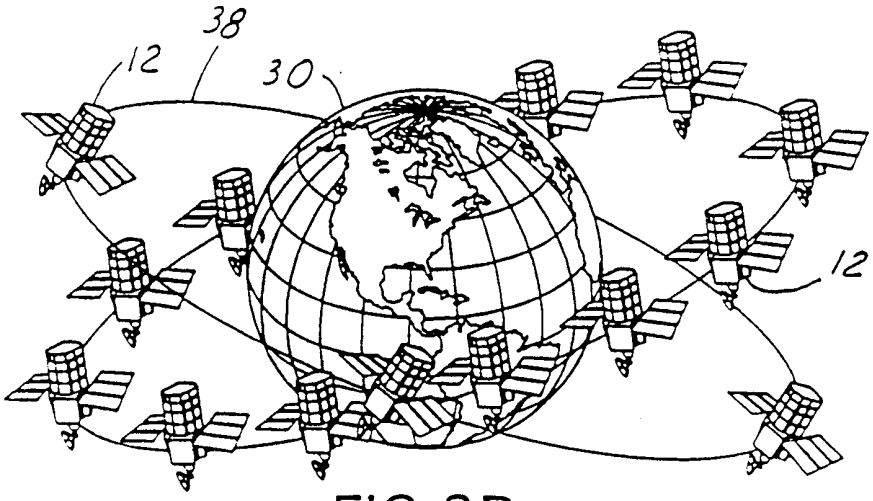


FIG.3D

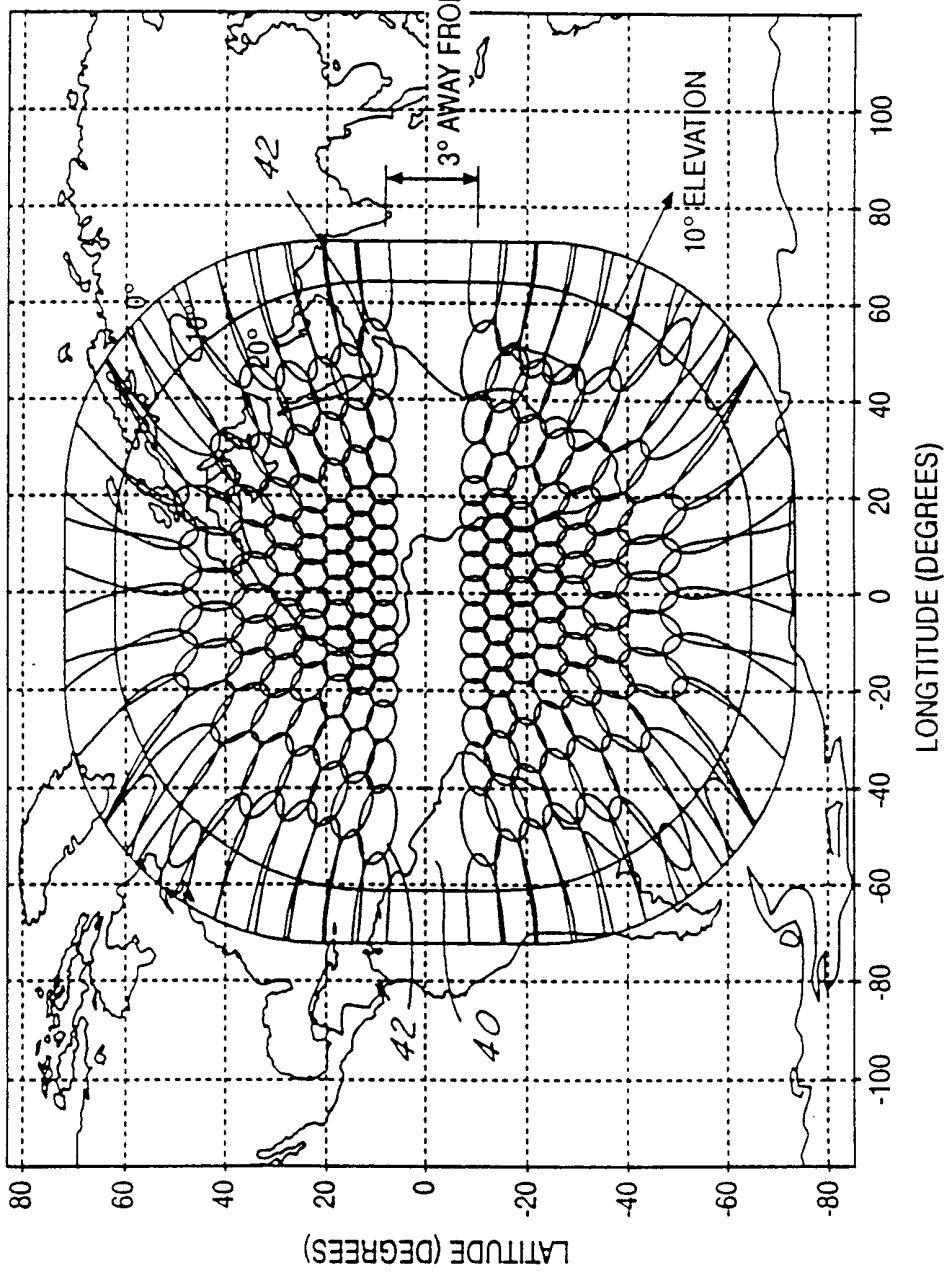
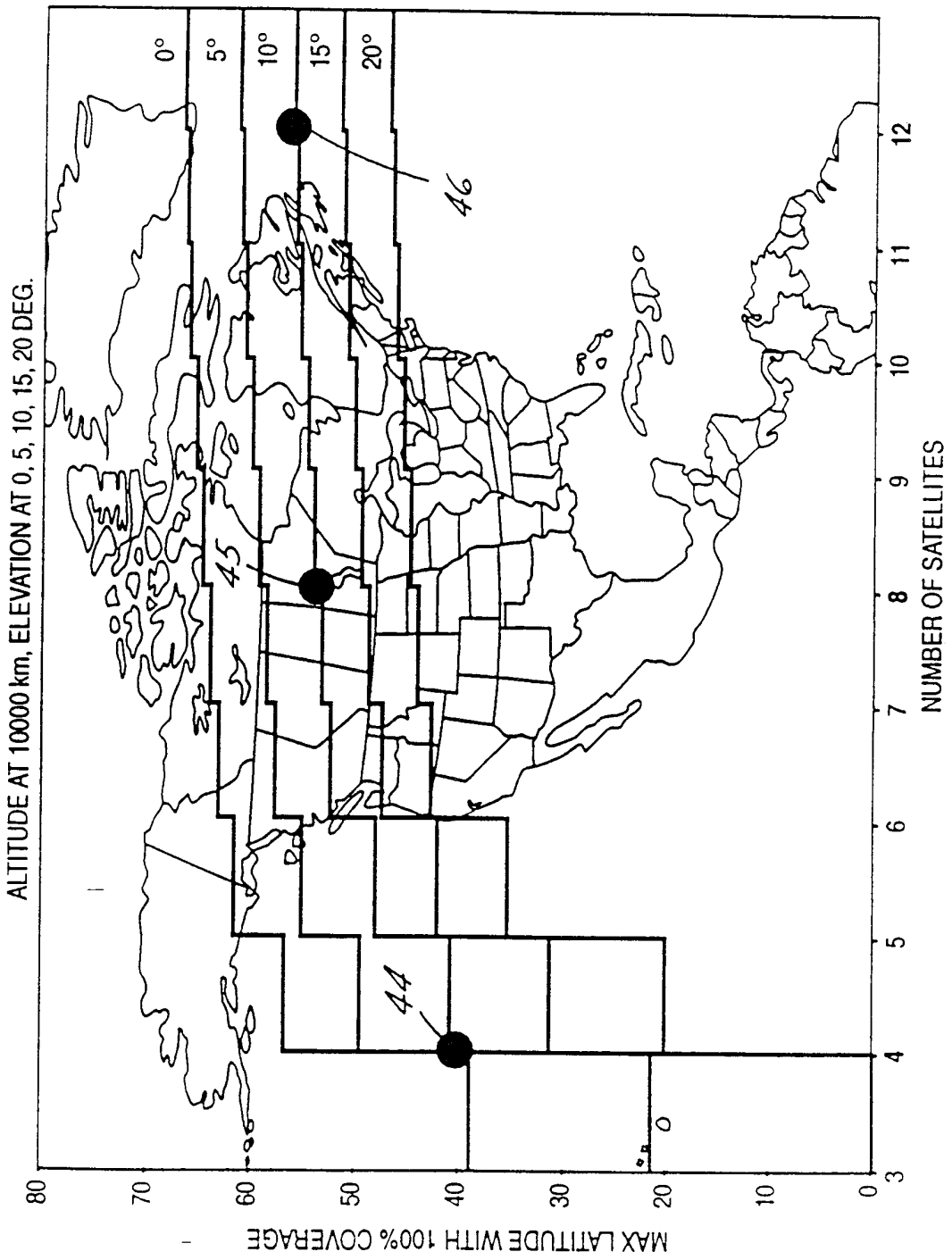

3° AWAY FROM GSO
10° ELEVATION
42
40
20°
LONGTITUDE (DEGREES)
LATITUDE (DEGREES)
100
80
60
40
20
0
-20
-40
-60
-80
-100
80
60
40
20
0
-20
-40
-60
-80

FIG. 4

FIG. 5


ALTITUDE AT 10000 km, ELEVATION AT 0, 5, 10, 15, 20 DEG.
0°
5°
10°
15°
20°
46
45
44
MAX LATITUDE WITH 100% COVERAGE
80
70
60
50
40
30
20
10
0
NUMBER OF SATELLITES
3
4
5
6
7
8
9
10
11
12



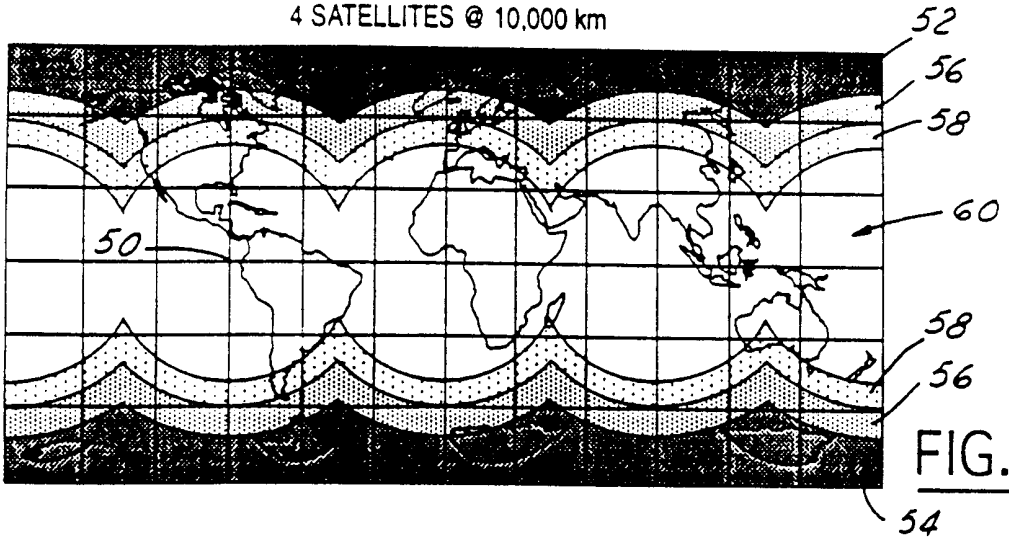


FIG.6

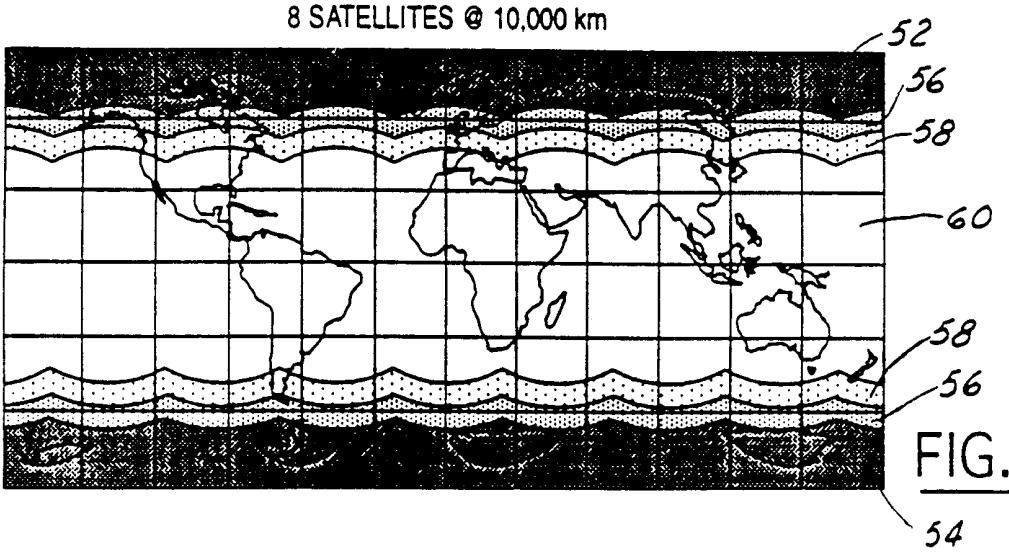


FIG.7

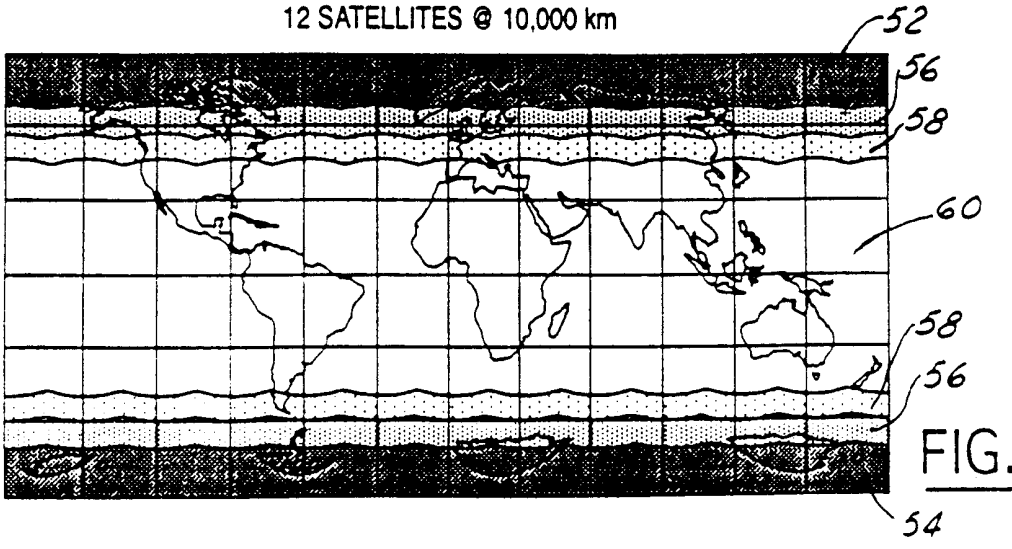
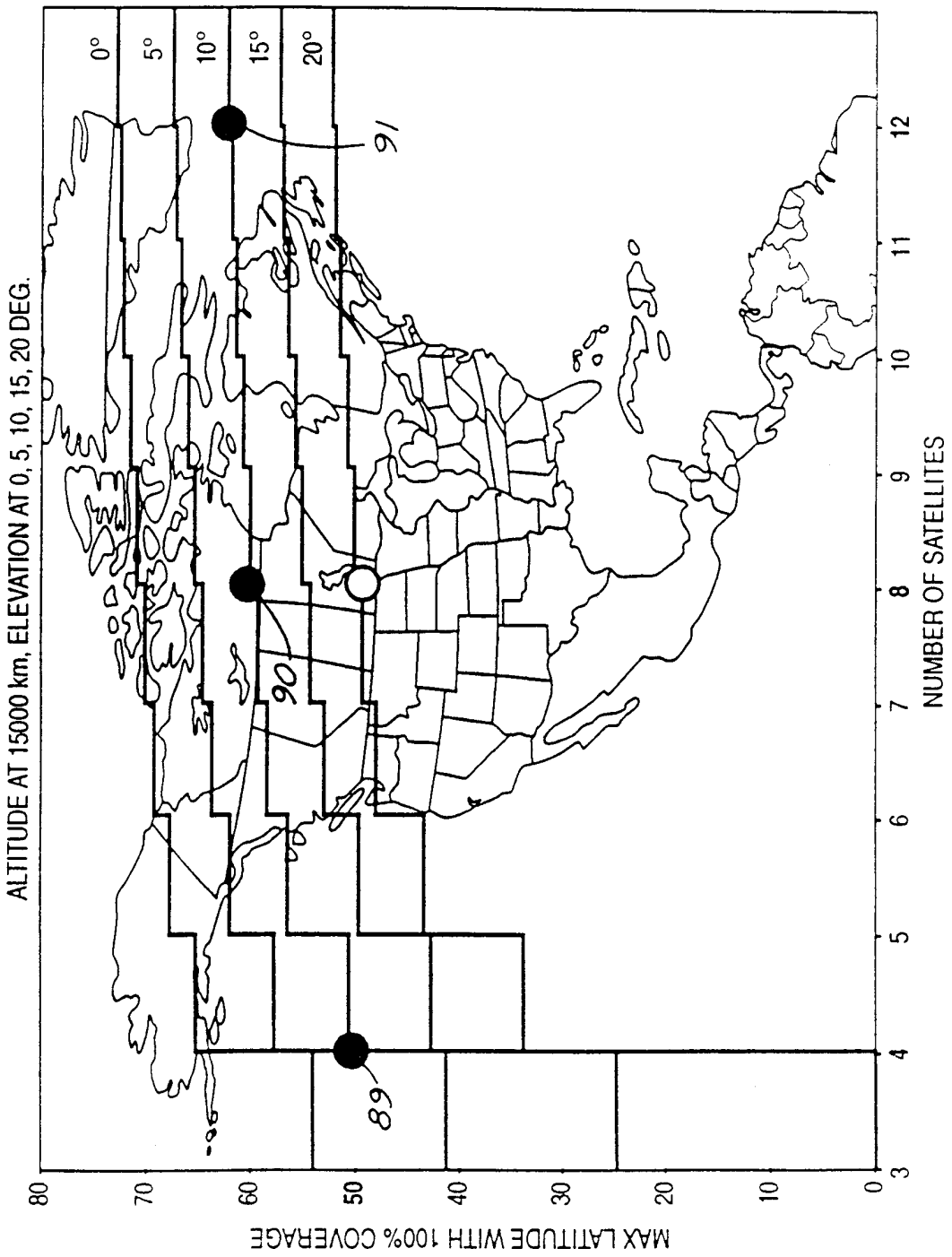


FIG.8

FIG.9


ALTITUDE AT 15000 km, ELEVATION AT 0, 5, 10, 15, 20 DEG.
0°
5°
10°
15°
20°
91
90
89
MAX LATITUDE WITH 100% COVERAGE
80
70
60
50
40
30
20
10
0
NUMBER OF SATELLITES
3
4
5
6
7
8
9
10
11
12

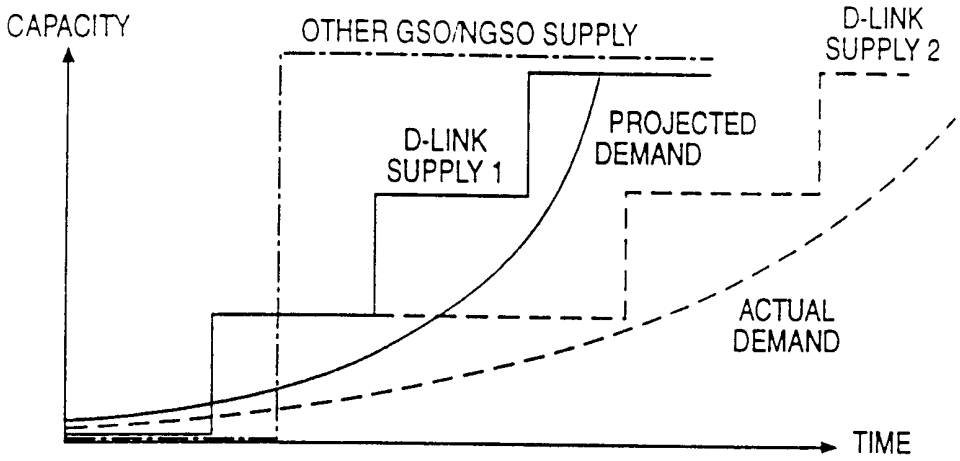

CAPACITY
OTHER GSO/NGSO SUPPLY
D-LINK SUPPLY 2
D-LINK SUPPLY 1
PROJECTED DEMAND
ACTUAL DEMAND
TIME

FIG.10

INTERNATIONAL SEARCH REPORT

Inter nal Application No
PCT/US 99/26147

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B7/185

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04B B64G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	ANONYMOUS: "ORBITAL PLANS HIGH-CAPACITY "SPACE CABLE" GLOBAL SATELLITE NETWORK" PRESS RELEASE, 'Online! 25 September 1997 (1997-09-25), XP002132567 Dulles, VA, US Retrieved from the Internet: <URL:http://www.orbital.com/OSC/Press_Releases/pr92.html> 'retrieved on 2000-03-07!	1-4
Y	the whole document	5-10
X	US 5 765 098 A (BELLA LUIGI) 9 June 1998 (1998-06-09) column 10, line 11; claims 18-22	1-4
Y	US 5 551 624 A (CRESS PETER H ET AL) 3 September 1996 (1996-09-03) column 1, line 64 - line 67	5-7

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[X] Further documents are listed in the continuation of box C. [X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 March 2000	24/03/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Felsen, J

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INTERNATIONAL SEARCH REPORT

Inte onal Application No
PCT/US 99/26147

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	EP 0 792 799 A (ORBITAL SCIENCES CORP) 3 September 1997 (1997-09-03) column 12, line 10 - line 36	6,9
Y	THIEL A K: "MEDIUM ALTITUDE PHASED ORBIT SATELLITE SYSTEMS" CONFERENCE PROCEEDINGS WINTER CONVENTION ON MILITARY ELECTRONICS, 1 January 1965 (1965-01-01), pages 17-24, XP000564901 page 21, right-hand column -page 22, left-hand column	6
Y	LOGSDON: "Mobile Communication Satellites" 1995 , MCGRAW-HILL INC. , NEW YORK, US XP002132568 page 156 -page 157 page 208 -page 209 page 223	5,7,8,10

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INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte onal Application No
PCT/US 99/26147

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