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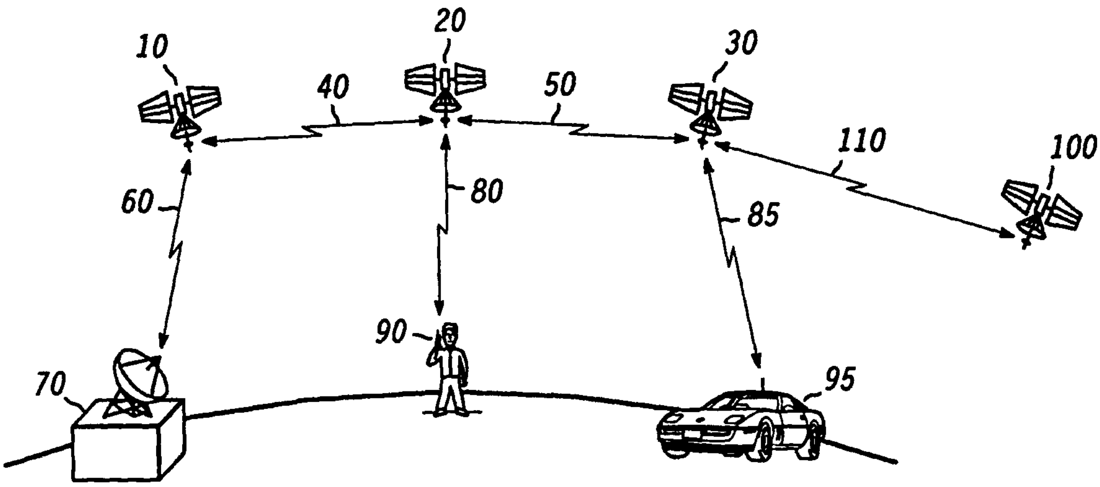
(54) Title: SATELLITE RELAY METHOD AND APPARATUS



(57) Abstract: Satellite telemetry, tracking, and control (TT & C) for a user satellite (100) is accomplished using satellites (10, 20, 30) in a satellite communications system as relays. A user satellite includes a modified space subscriber unit (302, FIG. 3) that includes a commercially available, mass-produced subscriber unit (304) modified for use in a space environment. A ground control facility includes a controller (202, FIG. 2) and a ground control facility subscriber unit (218) that includes a commercially available, mass-produced subscriber unit (216). The subscriber units in the user satellite (100) and the ground control facility (70) communicate using the satellite communications system. The relatively inexpensive subscriber units provide TT & C for the user satellite at reduced cost.

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SATELLITE RELAY METHOD AND APPARATUS

Field of the Invention

The present invention relates generally to satellite systems and, in particular, to satellite telemetry, tracking, and control systems.

Background of the Invention

In typical satellite telemetry, tracking, and control (TT&C) systems, a line-of-sight (LOS) communications link is set up between a satellite ground control facility and the satellite. Once the link is set up, TT&C information can be exchanged between the satellite and the ground control facility. Control information can be sent to the satellite, and the satellite can send telemetry (health and status) information to the ground control facility. Typically, when the satellite is a low earth orbit (LEO) satellite, a number of ground control facilities are placed strategically around the globe, because the satellite may not pass over the same point on the earth during each orbit.

Satellite TT&C can be very expensive. One reason is that construction, operation, and maintenance of multiple ground control facilities can be very expensive. Also, satellites controlled by ground control facilities in this manner typically have very expensive transponders that are designed to generate enough power to transmit back to the earth even when the satellite is at low elevation angles. Transponders are also usually manufactured in very low volume. These factors and others contribute to the cost of satellite TT&C.

Many modern satellites are smaller and cheaper than their older counterparts. These smaller and cheaper satellites typically have small payloads and are sometimes referred to as "micro-satellites" or "nano-satellites." One benefit of micro-satellites is reduced cost. As the cost of micro-satellites decreases, the cost of satellite TT&C as a percentage of total satellite cost increases.

It would be desirable to reduce the cost of satellite TT&C. Accordingly, a significant need exists for a method and apparatus for providing satellite TT&C at reduced cost.

Brief Description of the Drawings

The invention is pointed out with particularity in the appended claims. However, a more complete understanding of the present invention may be derived by referring to the detailed description and claims when considered in connection with the figures, wherein like reference numbers refer to similar items throughout the figures, and wherein:

FIG. 1 shows a simplified block diagram of a satellite communications system in accordance with a preferred embodiment of the present invention;

FIG. 2 shows a block diagram of a satellite ground control facility in accordance with a preferred embodiment of the present invention;

FIG. 3 shows a block diagram of a user satellite in accordance with a preferred embodiment of the present invention;

FIG. 4 is a flowchart of a method for transmitting telemetry information in accordance with a preferred embodiment of the present invention; and

FIG. 5 is a flowchart of a method for transmitting control information in accordance with a preferred embodiment of the present invention.

Detailed Description of the Drawings

In the following detailed description, reference is made to the accompanying drawings that show, by way of illustration, specific embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present invention.

As used herein, the term “user satellite” refers to a relatively small, low-budget satellite, such as what is referred to in the aerospace industry as a “micro-satellite” or a “nano-satellite”. However, the present invention is not limited to user satellites and has general applicability to TT&C with any type of satellite.

As used herein, the term “subscriber unit” refers to a communications device capable of communication with the satellite communications system.

The method and apparatus of the present invention provide a mechanism for using a satellite communications system as a relay for TT&C of one or more “user satellites.” By using a satellite communications system as a relay, control of user satellites can be achieved without a direct line of sight from a ground control facility to the user satellite being controlled. Further, the ground control facility controlling the user satellite can be mobile. A subscriber unit or modified subscriber unit is coupled to the user satellite, and a subscriber unit or modified subscriber unit is also coupled to the ground control facility. The user satellite can initiate calls to, and receive calls from, the ground control facility. The subscriber unit coupled to the user satellite is relatively inexpensive in comparison to a satellite transponder, and this significantly reduces the cost of user satellite TT&C.

Turning now to the drawings in which like reference characters indicate corresponding elements throughout the several views, attention is first directed to

FIG. 1. FIG. 1 shows a simplified block diagram of a satellite communications system in accordance with a preferred embodiment of the present invention. Included within the satellite communications system are satellites 10, 20, and 30, subscriber unit 90, and subscriber unit 95. Satellites 10, 20, and 30 can be any type of satellite, including geosynchronous (GEO), medium earth orbit (MEO), or low earth orbit (LEO). In some embodiments, multiple satellites are included in the satellite communications system, and in other embodiments, a single satellite is in the satellite communications system. In a preferred embodiment, satellites 10, 20, and 30 are part of a constellation of LEO communications satellites. However, the present invention is not limited to use with satellites of any particular orbit, size, or type.

In a preferred embodiment, the satellite communications system is a commercial system. Commercial systems typically employ low cost subscriber units that are manufactured in relatively high volume. Subscriber units 90 and 95 are preferably commercially available, relatively inexpensive subscriber units that are mass-produced. Subscriber unit 90 is a handheld unit, and subscriber unit 95 is a vehicle-mounted unit.

Satellites 10, 20, and 30 communicate on inter-satellite links 40 and 50. Inter-satellite links 40 and 50 are used to route calls from a satellite receiving the call to a satellite that will send the call to a subscriber unit. For example, in a call placed by subscriber unit 90 to subscriber unit 95, satellite 20 receives the call on link 80, communicates with satellite 30 on inter-satellite link 50, and sends the call to subscriber unit 95 on link 85. As satellites in the communications system move relative to the earth's surface, satellites can hand-off calls to each other. Calls are handed-off from satellite to satellite such that a subscriber unit involved in a call communicates with a satellite within its field of view.

Also shown in FIG. 1 are user satellite 100 and ground control facility 70. In a preferred embodiment, user satellite 100 is not part of the satellite communications system that includes satellites 10, 20, and 30. Instead, user satellite 100 incorporates a subscriber unit similar to subscriber unit 90 or subscriber unit 95, and it utilizes the communications services of the satellite communications system. Ground control facility 70 is a facility for providing TT&C for user satellite 100. Ground control facility 70 also incorporates a subscriber unit similar to subscriber unit 90 or subscriber unit 95. As a result, the satellite communications system acts as a relay for performing TT&C for user satellite 100.

In another embodiment, user satellite 100 can be part of the same satellite communications system that includes satellites 10, 20, and 30.

User satellite 100 can be in an earth orbit that is higher or lower than the orbits of satellites in the satellite communications system. In a preferred embodiment, user satellite 100 is in a lower orbit, in part because this allows user satellite 100 to communicate with satellites 10, 20, and 30 as if it were a subscriber unit on or near the surface of the earth. In this embodiment, satellites 10, 20, and 30 can communicate with user satellite 100 using the same type of antennas that are used for communication by subscriber units on or near the earth, such as subscriber units 90 and 95. In other embodiments, user satellite 100 is in an orbit higher than that of the satellites in the satellite communications system. In these embodiments, satellites in the communications system, such as satellites 10, 20, and 30, have antennas that point in appropriate directions that allow communication with user satellite 100.

The method and apparatus of the present invention are advantageous in part because the subscriber unit included in user satellite 100 can replace a much more expensive transponder. A further advantage arises because the satellite communications system serves as a relay mechanism that routes control information from ground control facility 70 to user satellite 100. This results in the ability to have "virtual line-of-sight" between ground control facility 70 and user satellite 100 even though user satellite 100 may be on the opposite side of the earth. Yet another advantage is that the ground control facility for the user satellite can be located virtually anywhere and can be extremely portable. The method and apparatus of the present invention allow the ground control facility to include a small list of inexpensive components, such as a laptop computer, and a standard or modified subscriber unit for use in the satellite communications system. This is in contrast to typical ground control facilities for satellite TT&C which are expensive to build and maintain.

In some embodiments, links 40, 50, 60, 80, 85, and 110 utilize time division multiple access (TDMA) signals. In these embodiments, signals on links 40, 50, 60, 80, 85, and 110 are divided into time slots, within which multiple subscriber units can be assigned resources. In other embodiments, links 40, 50, 60, 80, 85, and 110 utilize code division multiple access (CDMA) signals. In these embodiments, multiple subscriber units are assigned resources based on orthogonal pseudo-random codes. In other embodiments, links 40, 50, 60, 80, 85, and 110 utilize frequency division multiple access (FDMA) signals. In these embodiments, multiple subscriber units utilize different frequency channels. In yet other embodiments, links 40, 50, 60, 80, 85, and 110 utilize a combination of TDMA, CDMA, and FDMA signals. The invention is not limited to a particular type of multiple access scheme. Any suitable multiple access scheme can be utilized.

FIG. 2 shows a block diagram of a satellite ground control facility in accordance with a preferred embodiment of the present invention. Ground control facility 70 is a ground control facility capable of placing and receiving calls in a satellite communications. Ground control facility 70 includes controller 202 and ground control facility subscriber unit 218.

Controller 202 can be any piece of equipment capable of communicating with a user satellite through ground control facility subscriber unit 218. In a preferred embodiment, controller 202 is a portable computer. When controller 202 is a portable computer such as a laptop computer, ground control facility 70 can be extremely mobile. Commands to a user satellite such as user satellite 100 (FIG. 1) originate in controller 202 and are sent to ground control facility subscriber unit 218 on node 204.

Ground control facility subscriber unit 218 includes commercial subscriber unit 216 and ground control facility interface 212. In a preferred embodiment, commercial subscriber unit 216 is an unmodified commercially available subscriber unit such as subscriber unit 90 (FIG. 1). In other embodiments, commercial subscriber unit 216 is a subscriber unit modified to operate within ground control facility subscriber unit 218. Commercial subscriber unit 216 communicates with satellites in a satellite communications system over a communications link 222 using antenna 220. Ground control facility interface 212 is coupled between commercial subscriber unit 216 and controller 202 at nodes 214 and 204 respectively. Ground control facility interface 212 includes commercial data interface 206 and forward error correction (FEC) coder/decoder (codec) 210. FEC codec 210 provides error correction in support of quality of service (QOS). In some embodiments, FEC codec 210 is omitted, and in other embodiments, FEC codec is implemented within controller 202.

In the embodiment of FIG. 2, ground control facility 70 includes controller 202 and ground control facility subscriber unit 218. In this and other similar embodiments, commercial subscriber unit 216 is integrated with other components to create a "modified" subscriber unit that couples controller 202 to the satellite communications system. The "modified" subscriber unit of FIG. 2 is ground control facility subscriber unit 218.

In some embodiments, the operations performed by ground control facility interface 212 are included within controller 202. In these embodiments, commercial subscriber unit 216 can be coupled directly to controller 202 using a standard data interface present on commercial subscriber unit 216. An example of a standard data interface is an RS-232 serial interface. In these embodiments, ground control facility 70 can include controller 202 and commercial subscriber unit 216 without ground control facility interface 212. In a preferred embodiment, commercial subscriber unit 216 is a handheld subscriber unit and controller 202 is a laptop computer.

Ground control facility 70 is advantageous in part because the ground control facility can be very mobile, thereby allowing someone to control user satellites from almost anywhere. For example, the method and apparatus of the present invention provide a mechanism that would allow someone such as a college professor to control his experiment on-board a user satellite from his office, his home, the middle of the desert, or anywhere he wished to locate his laptop/subscriber unit configuration so long as he had line-of-sight to a satellite in the satellite communications system.

FIG. 3 shows a block diagram of a user satellite in accordance with a preferred embodiment of the present invention. User satellite 100 includes payload 340, geolocation unit 350, modified space subscriber unit 302, antenna 306, and TT&C bus 330. Payload 340 can be any satellite payload on a user satellite. Payload 340 communicates with modified space subscriber unit using TT&C bus 330. TT&C bus 330 also provides communications to other modules (not shown) included within user satellite 100.

Modified space subscriber unit 302 includes subscriber unit 304, high velocity compensation module 312, forward error (FEC) coder/decoder (codec) 316, and spacecraft data interface 320. In a preferred embodiment, subscriber unit 304 is a commercially available subscriber unit such as subscriber unit 90 (FIG. 1), that has been modified to a form having environmental properties suitable for use in space, in accordance with techniques well known in the art. In this embodiment, subscriber unit 304 communicates with the satellite communications system using a protocol substantially similar to ground-based subscriber units such as subscriber unit 90. This is advantageous in part because the satellite communications system can communicate with subscriber unit 304 without using a different protocol.

In operation, modified space subscriber unit 302 communicates with satellites such as satellites 10, 20, and 30 (FIG. 1) in the satellite communications system. Relative velocities between user satellite 100 and satellites in the satellite communications system can be large, resulting in considerable Doppler frequency shifts of received signals. For example, the Doppler frequency shift experienced by subscriber unit 304 is generally much larger than the Doppler frequency shift experienced by either of subscriber units 90 or 95 (FIG. 1). High velocity compensation module 312 accounts for Doppler frequency shift, time shift, and derivatives thereof. High velocity compensation module 312 is preferably predictive in nature, such that it pre-corrects for frequency and timing uncertainties as well as time variations in frequency and timing. For example, high velocity compensation module 312 can shift the frequency of a signal prior to transmission by subscriber unit 304, and it can shift the frequency of a received signal that has undergone a Doppler frequency shift.

FEC codec 316 performs the inverse operation of FEC codec 210 (FIG. 2). FEC codecs are well known in the art and are not further described here. Spacecraft data interface 320 couples the remainder of modified space subscriber unit 302 to

TT&C bus 330. Spacecraft data interface 320 receives telemetry information from TT&C bus 330 for transmission using subscriber unit 304. Spacecraft data interface 320 also drives TT&C bus 330 with control information received by subscriber unit 304.

User satellite 100 also includes geolocation unit 350. Geolocation of user satellite 100 can be useful for such purposes as billing and in aiding the satellite communications system by broadcasting information to user satellites to help them with functions such as beam acquisition. In some embodiments, user satellite 100 provides its location information derived from geolocation unit 350 to the satellite communications system. In other embodiments, user satellite 100 does not provide its location to the satellite communications system.

In some embodiments, geolocation unit 350 is integrated into modified space subscriber unit 302. In other embodiments, geolocation unit 350 is another satellite module coupled to TT&C bus 330.

Satellite 100 is advantageous in part because modified space subscriber unit 302 provides a low cost TT&C alternative to expensive transponders. Subscriber unit 304 is an inexpensive unit based on a commercial subscriber unit capable of communicating with a satellite communications system. The satellite communications system acts as a TT&C relay for user satellite 100. As a result, user satellite 100 can communicate with a ground control facility such as ground control facility 70 (FIG. 2) with a "virtual" line of sight.

FIG. 4 is a flowchart of a method for transmitting telemetry information in accordance with a preferred embodiment of the present invention. Method 400 begins in block 410 when a subscriber unit coupled to a ground control facility is designated as a call recipient. In block 420, a call is initiated through a satellite communications system using a modified space subscriber unit such as modified space subscriber unit 302 (FIG. 3). The user satellite, e.g. user satellite 100 (FIG. 1) initiating the call can be a satellite that is not part of the satellite communications system. The modified space subscriber unit is preferably coupled to the user satellite that is performing method 400. Telemetry information is transmitted on the call in block 430.

Method 400 describes an embodiment wherein the call is initiated by the user satellite, and telemetry is transmitted on the call. In other embodiments, the user satellite receives a call, and it transmits the telemetry. The user satellite performing method 400 can either originate or receive the call upon which telemetry data is transmitted without departing from the scope of the present invention. In the embodiment of method 400 shown in FIG. 4, telemetry data is transmitted from a user satellite to a ground control facility. In other embodiments, other types of information are transmitted.

FIG. 5 is a flowchart of a method for transmitting control information in accordance with a preferred embodiment of the present invention. Method 500 begins when a modified space subscriber unit in a user satellite is designated as a call recipient in block 510. In block 520, a call is initiated through a satellite communications system that does not necessarily include the user satellite. In block 530, control information is sent to the user satellite.

Method 500 describes an embodiment wherein the call is initiated by a ground control facility and control information is transmitted on the call. In other embodiments, the ground control facility receives a call, and it transmits the control information. The ground control facility performing method 500 can either originate or receive the call upon which control information is transmitted without departing from the scope of the present invention. In the embodiment of method 500 shown in FIG. 5, control information is transmitted from a ground control facility to a user satellite. In other embodiments, other types of information are transmitted.

In summary, the method and apparatus of the present invention provide a mechanism for low cost TT&C of user satellites such as micro-satellites and nano-satellites. While we have shown and described specific embodiments of the present invention, further modifications and improvements will occur to those skilled in the art. For example, while the method and apparatus of the present invention have been described with reference to satellite TT&C, the method and apparatus of the present invention also apply to other applications for space-borne subscriber units. For example, in some embodiments of the present invention, modified space subscriber units are used for dissemination to the ground of data resulting from the main mission of the satellite. We desire it to be understood, therefore, that this invention is not limited to the particular forms shown, and we intend in the appended claims to cover all modifications that do not depart from the spirit and scope of this invention.

CLAIMS

What is claimed is:

1. A method of transmitting information from a satellite to a ground control facility comprising:

initiating a call to the ground control facility using a modified subscriber unit coupled to the satellite; and

transmitting the information during the call via the modified subscriber unit.

2. The method of claim 1 wherein initiating a call comprises initiating a call through a satellite communications system that does not include the satellite.

3. The method of claim 2 wherein the satellite communications system includes the satellite.

4. The method of claim 1 wherein the information comprises information from a group consisting essentially of telemetry information, tracking information, and control information.

5. The method of claim 2 wherein the satellite communications system comprises at least one low earth orbit satellite.

6. A modified subscriber unit comprising:

a subscriber unit configured to communicate through a satellite communications system; and

a spacecraft data interface configured to couple the subscriber unit to a satellite.

7. The modified subscriber unit of claim 6 wherein the spacecraft data interface is configured to be coupled to a telemetry, tracking, and control data bus within the satellite.

8. The modified subscriber unit of claim 6 wherein the subscriber unit is configured to initiate calls through the satellite communications system utilizing a protocol substantially similar to protocols used by ground-based subscriber units.

9. The modified subscriber unit of claim 6 wherein the subscriber unit further comprises a high velocity compensation module.

10. The modified subscriber unit of claim 6 wherein the subscriber unit further comprises a geolocation unit.

11. A communications system comprising:

a first subscriber unit having a spacecraft data interface, the spacecraft data interface being configured to couple the first subscriber unit to a satellite; and

a second subscriber unit having a ground control facility interface, the ground control facility interface being configured to couple the second subscriber unit to a ground control facility, wherein the first subscriber unit and the second subscriber unit are configured to communicate through a satellite communications system.

12. The communications system of claim 11 further comprising at least one low earth orbit satellite configured to communicate with both the first subscriber unit and the second subscriber unit.

13. The communications system of claim 11 wherein the first subscriber unit is a commercially available subscriber unit adapted to operate in space.

14. The communications system of claim 11 wherein the second subscriber unit comprises a commercially available subscriber unit.

15. The communications system of claim 11 wherein the ground control facility comprises a portable computer.

16. The communications system of claim 11 wherein the coupling of the second subscriber unit to the ground control facility includes means for locating the ground control facility at any position on Earth.

17. The communications system of claim 11 wherein there is further included means for providing line of sight communication between the ground control facility and the satellite at any position on Earth of the ground control facility.

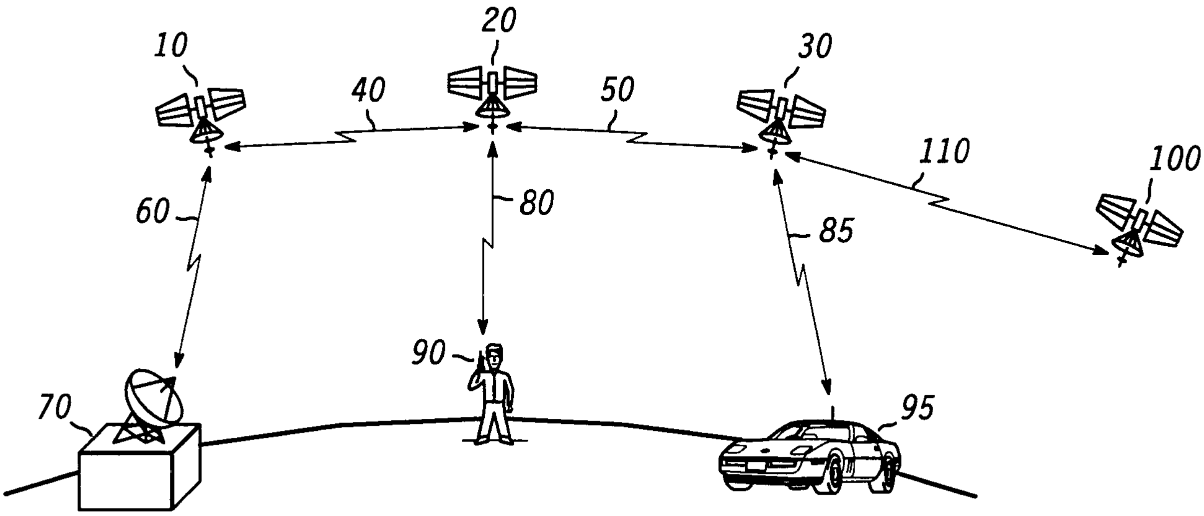
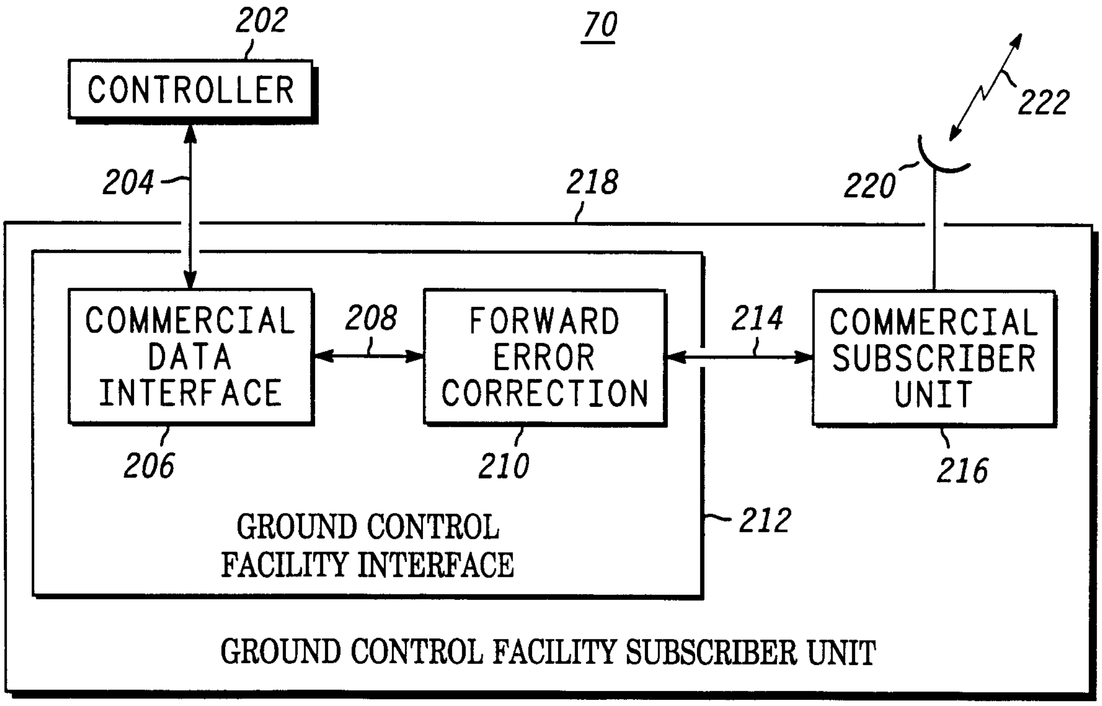

10
20
30
40
50
110
100
60
80
85
90
70
95

FIG. 1

FIG. 2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218
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FORWARD ERROR CORRECTION
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210
216
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GROUND CONTROL FACILITY INTERFACE
GROUND CONTROL FACILITY SUBSCRIBER UNIT

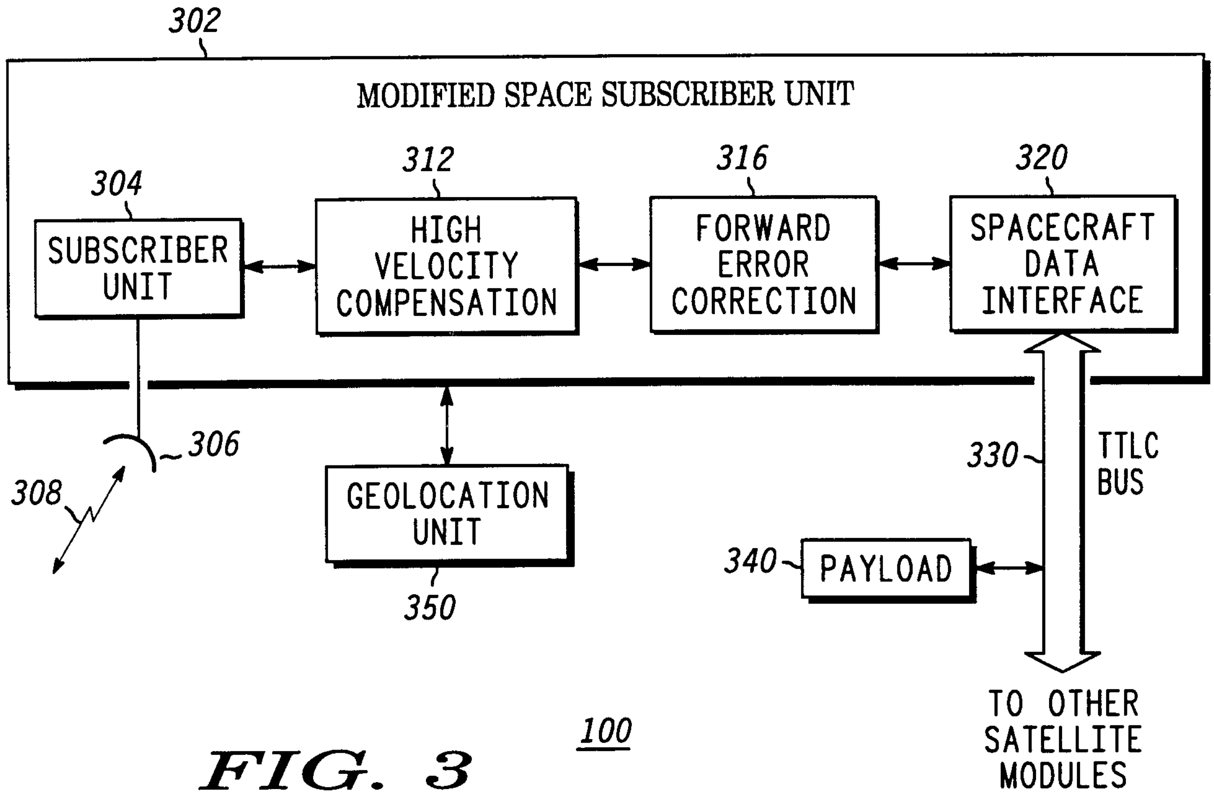
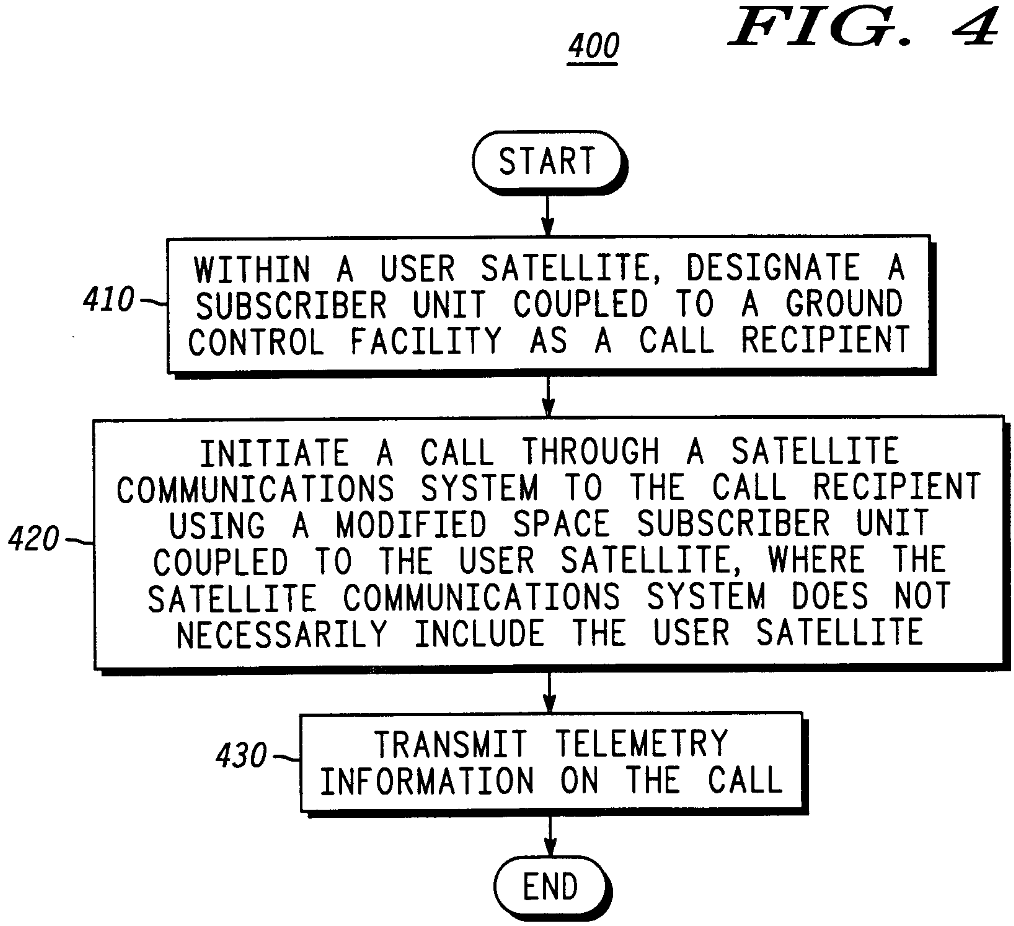

302
MODIFIED SPACE SUBSCRIBER UNIT
304
SUBSCRIBER UNIT
312
HIGH VELOCITY COMPENSATION
316
FORWARD ERROR CORRECTION
320
SPACECRAFT DATA INTERFACE
306
308
GEOLOCATION UNIT
350
330
TTLC BUS
340
PAYLOAD
TO OTHER SATELLITE MODULES
100

FIG. 3

FIG. 4


400
START
410
WITHIN A USER SATELLITE, DESIGNATE A SUBSCRIBER UNIT COUPLED TO A GROUND CONTROL FACILITY AS A CALL RECIPIENT
420
INITIATE A CALL THROUGH A SATELLITE COMMUNICATIONS SYSTEM TO THE CALL RECIPIENT USING A MODIFIED SPACE SUBSCRIBER UNIT COUPLED TO THE USER SATELLITE, WHERE THE SATELLITE COMMUNICATIONS SYSTEM DOES NOT NECESSARILY INCLUDE THE USER SATELLITE
430
TRANSMIT TELEMETRY INFORMATION ON THE CALL
END

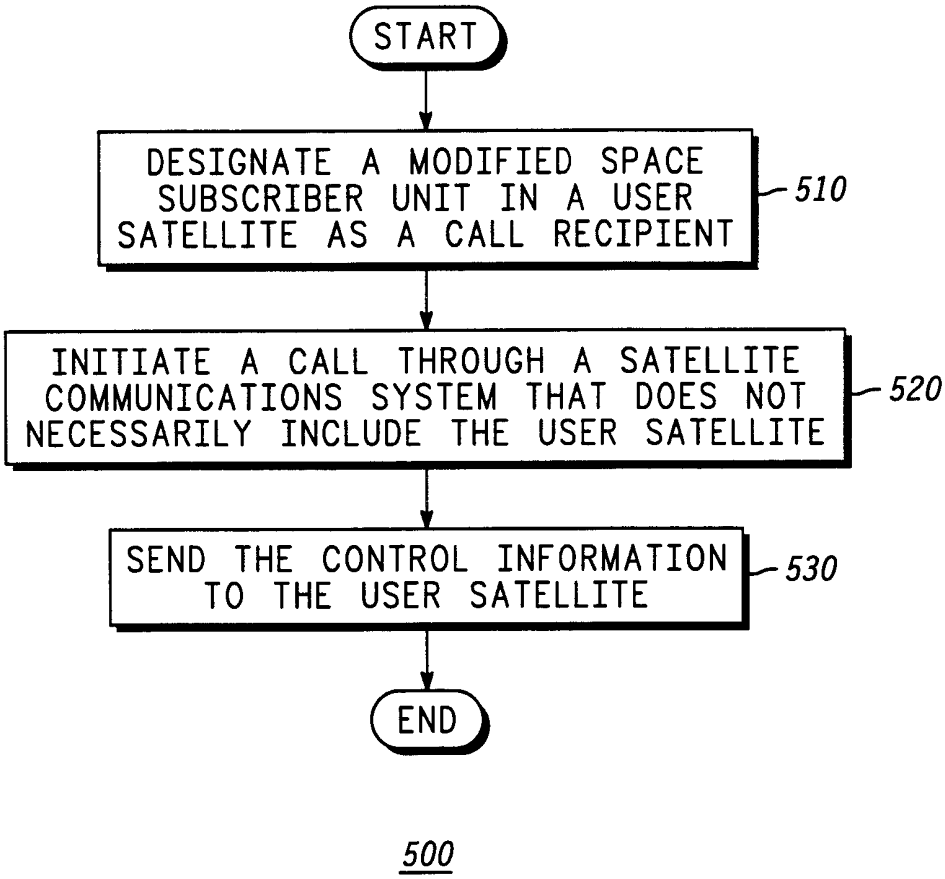

START
DESIGNATE A MODIFIED SPACE SUBSCRIBER UNIT IN A USER SATELLITE AS A CALL RECIPIENT
510
INITIATE A CALL THROUGH A SATELLITE COMMUNICATIONS SYSTEM THAT DOES NOT NECESSARILY INCLUDE THE USER SATELLITE
520
SEND THE CONTROL INFORMATION TO THE USER SATELLITE
530
END
500

FIG. 5