

DUAL SATELLITE NAVIGATION METHOD AND SYSTEM

BACKGROUND OF THE INVENTION

5 Technical Field

This invention relates to object position determination using satellites. More specifically, this invention relates to a novel and improved method and system for mobile vehicle position determination using signal propagation time delays through a plurality of
10 communication paths to calculate the vehicle position.

Background Art

A need is recognized by many in the mobile vehicle environment for vehicle location information. One industry in particular in which
15 such information is particularly desirable is the commercial trucking industry. In the commercial trucking industry an efficient and accurate method of vehicle position determination is in demand. With ready access to vehicle location information, the trucking company home base obtains several advantages. The trucking company can keep the customer
20 apprised of location, route and estimated time arrival of payloads. The trucking company can also use vehicle location information together with empirical data on the effectiveness of routing, thereby determining the most economically efficient routing paths and procedures.

Heretofore, vehicle location information has been communicated
25 to the trucking company home base by the truck drivers themselves, via telephones, as they reach destinations and stopovers. These location reports are intermittent at best, because they only occur when the truck driver has reached the destination or stopover and can take the time to phone the trucking company home base. These location reports are also
30 quite costly to the trucking company because in effect they cause substantial down time of the freight carrying vehicle. This down time is due to the fact that to make a location report, the tractor driver must remove his vehicle from route, find a telephone which he can use to phone the home base, and take the time to make the location report. This
35 method of location report also leaves room for substantial inaccuracies. For example, truck drivers may report incorrect location information



communication system.

It is another object of the present invention to provide a novel and improved method of object position determination whose accuracy does not require independent and highly precise time keeping equipment
5 located either in the satellites of the system or the object whose position is being determined.

It is a further object of the present invention to introduce a new approach for determining time intervals (hence distance) without maintenance of an absolute time base at the vehicle, contrary to methods
10 as prescribed in U.S. Patent No. 4,161,730.

It is still further object of the present invention to introduce the use of standard transponder satellite payloads for the purposes of vehicle position determinations. These communication transponders, which used in the majority of communications satellites, are adequate for
15 relaying the signals used for position determination of the vehicle. Special time and frequency standards within the satellite are not required. It is only necessary to know their characteristics.

It is a further object of the present invention to provide a novel and improved method of vehicle location which does not require vehicle
20 down time.

It is yet another object of the present invention to provide a novel and improved method of vehicle location determination which allows the trucking company home base to determine vehicle location at will rather than relying on intermittent reports from a truck driver.
25

SUMMARY OF THE INVENTION

The present invention is a method of object position determination which relies upon the theory of trilateration. Trilateration prescribes that
30 if the position of three objects are known relative to each other, and the distance from each of these three objects to a fourth object is known, then the three dimensional position of the fourth object can be determined within the coordinate frame which described the location of the first three objects.



More specifically, a fixed ground station continuously transmits two radio signals, each with an identical periodic carrier modulation, via each of the satellites to the object being located. The object is typically a mobile unit or vehicle having a communications terminal. The fixed ground station signals, as transmitted to the object, are referred to herein as forward signals. The object continuously receives these periodic forward signals and measures the percent of periodic phase offset between the two carrier waveforms. The difference in phase between these two carrier waveforms is due to one of the signals traveling a longer path length via one satellite than the other. The object transmits a return signal, after some arbitrary delay in which the amount the delay is not important nor required to be known, containing the percent offset information. The return signal is transmitted upon the same path as the forward signal from the first satellite, back to the fixed ground station.

In monitoring the received carrier periodic signal through the first satellite, the object performs functions that slave the clock standard of the object to the reception of the periodic signal. Thus the object clock standard is offset in time from the fixed ground station transmitted signal on account of the signal propagation delay. The object is then allowed to transmit the observed percent offset between the two forward signals, starting at some specific period in the future. The fixed ground station then receives the return signal back through the first satellite whenever it comes back, but realizes the receipt of a message starting with that specific period identification number, or frame, has arrived later than the current period being sent out on the forward carriers. The amount of this late arrival is interpreted as the instantaneous round trip delay of signals traveling a path from the fixed ground station to the object and back, through the first satellite.

The forward signal propagation delay changes as the object changes position. However, since the object clock standard is slaved to the received forward signal, the object clock standard changes as does the propagation delay. Therefore, position determination functions to be performed by the object at some arbitrary time in the future are not hampered even though the object has moved since the request was sent to the object. The object merely needs to make a timely measurement of the



Typically it is the trucking company home base that initiates a vehicle position determination. However, the mobile communications terminal itself may initiate a position determination. One such case is when a trailer is detached from the tractor. This trailer detachment location may then be communicated to the trucking company home base. Given such an embodiment, at will determination of the location of a vehicle can be accurately and instantly determined without requiring down time of the freight hauling vehicle.

The present invention provides for earth vehicle position determination from values derived from signal propagation delays. Values corresponding to a round trip propagation of a signal communicated through a transponder of a first satellite and a propagation delay difference of one way signals communicated through the first satellite transponder and transponder of a second satellite are generated and used in computing vehicle position.

The round trip delay is computed implicitly by comparison of the current time of the fixed station transmission clock with the time of the fixed station reception clock upon receipt of the relevant return path transmissions from the vehicle. The vehicle local time clock is slaved directly to the reception of a forward link transmission from the fixed station and thus includes an inherent propagation delay with respect to the current time at the fixed station transmission clock. The vehicle return transmissions are transmitted according to normal communication methods of TDMA assignments on the return channels. At the fixed station the return clock is allowed to dynamically adjust in real time to demodulate with highest probability any return link transmission from many vehicle communication transmissions.

With respect to the propagation delay difference between the one way communicated signals there is no absolute time markings of any kind required nor reported to determine the time differentiation between the arriving signals. The time differential is computed as a function of phase offset in periodic modulation of the received signals.

It is a further aspect of the invention that the location of different vehicles in different user groups may be determined. Various arrangements of primary and secondary satellite transponders can be



DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The method of object position determination of the present invention is best illustrated in the context of the location of a land based mobile unit typically a vehicle in the commercial trucking industry. The components required for mobile unit location are depicted in Figure 1. A hub or fixed ground station 10 in Figure 1 includes a communications terminal 10a which is capable of satellite communications. Terminal 10a typically includes a transceiver, an interface to the customer home base and a processor each (not shown).

Fixed station 10 also includes primary antenna 10b and secondary antenna 10c. Primary antenna 10b is in line of sight with primary satellite S1 and is capable of tracking satellite S1. Transmissions on primary antenna 10b typically contain digital information modulated on a signal carrier. The signal carrier is characterized as an RF signal with sawtooth periodic frequency modulation. Secondary antenna 10c is in line of sight with secondary satellite S2 and is capable of tracking satellite S2. Transmissions on secondary antenna 10c typically consist of the signal carrier lacking the digital information modulation although the sawtooth periodic modulation remains.

Primary satellite S1 is an earth orbiting satellite carrying a standard transponder payload and is positioned in geosynchronous orbit above the earth in line of sight of both fixed station 10 and the object to be located, object 12. The secondary satellite S2 is also an earth orbiting satellite carrying a standard transponder payload and is positioned in geosynchronous orbit above the earth in line of sight of fixed station 10 and object 12. It is preferred that satellites S1 and S2 have an angular separation in the range of 8°- 24° although angles as low as 3° and as high as 70° are possible.

In this case the object is a mobile unit. Mobile unit 12 is a typical commercial trucking vehicle having a mobile communications terminal 14 mounted in the tractor or cab of the vehicle. Mobile communications terminal 14 includes antenna 16 and is capable of tracking satellites S1 and S2. Mobile communications terminal 14 is



on satellite position may be obtained through a reverse process of trilaterating the satellites from a plurality of fixed observing sites whose cartesian x-y-z coordinates are known. The process of determining satellite position is described later herein with reference to Figures 3 and 4.

5 Determination of the distance between the satellites and the vehicle whose position is to be determined is accomplished by translating radio signal propagation times into distance through which that signal has traversed. As shown in Figure 2, forward signals are transmitted from station 10, at antennas 10b and 10c, via primary satellite S1 and secondary
10 satellite S2 respectively to mobile unit 12. The signal transmitted from antenna 10b via satellite S1 to mobile unit 12 is identified as the forward link signal 20 with the uplink and downlink portions thereof being respectively identified by the reference numerals 20a and 20b. The signal transmitted from antenna 10c via satellite S2 to mobile unit 12 is
15 identified as the forward link signal 22 with the uplink and downlink portions thereof being respectively identified by the reference numerals 22a and 22b. The signal carrier waveforms of forward link signals 20 and 22 are identical and synchronized when generated for transmission. A forward link clock is used in generating the periodic
20 sawtooth frequency modulation carrier of the forward link signals. When forward link signal 22 is used only for ranging purposes, the satellite transponder through which this signal is relayed may be operated at a significantly lower power. For example, the transponder power level may be only 10% of a 10 KW transponder to support an unmodulated carrier
25 and still provide an adequate ranging signal.

At mobile unit 12, mobile communications terminal 14 receives upon antenna 16 forward link signals 20 and 22. The periodic modulation for both these signals is shown in Figure 5. Mobile communications terminal 14 measures the percent phase offset, with respect to the forward
30 link signal period, in the sawtooth periodic modulation of the carrier signals arriving from the two forward link signals 20 and 22. Phase offset can be measured using either independent match filtering on both signals and comparing time differentials between them, or mixing the two signals together and deriving the time differential from the phase of the resulting
35 signal.



demodulate its information. This clock offset of the return link clock relative to the forward link clock, the forward link clock used in generating the sawtooth periodic modulation shown in Figure 5, is marked as the instantaneous RTD (round trip delay). This RTD
5 corresponds to the instantaneous round trip time (or distance) for a signal transmitted from fixed station 10 via primary satellite S1 mobile unit 12, and instantly retransmitted from mobile unit 12 via primary satellite S1 to fixed station 10, where:

10
$$\text{RTD} = \text{Hub Forward Clock} - \text{Hub Receive Clock.} \quad (5)$$

The reference clock of mobile unit 12 is slaved to the received forward link periodic carrier waveform. Since the forward link signal undergoes a propagation delay between transmission and reception, the
15 reference clock of mobile unit 12 is delayed with respect to the transmitted forward link periodic carrier by this propagation delay.

In the communications between fixed station 10 and mobile unit 12, the periodic carrier waveform transmitted by fixed station 10 contains information. Mobile unit 12 thus synchronizes its timing to the received
20 signal to demodulate this information from the carrier.

Information communicated between fixed station 10 and mobile unit 12 are transmitted in time frames in a Time Division Multiple Access (TDMA) format as is known in the art. Such a communication system is disclosed in U.S. Patent Application Serial No. 07/145,176 filed
25 January 19, 1988, entitled "ALTERNATING SEQUENTIAL HALF DUPLEX COMMUNICATION SYSTEM", now U.S. Patent No. 4,979,170, issued December 18, 1990, and assigned to the Assignee of the present invention. Thus fixed station 10 may command mobile unit 12 to immediately initiate position determination steps or at some future time. Whenever
30 mobile unit 12 reference clock is in synchronization with the received forward link periodic carrier waveform, valid position determination steps can be executed.

Figure 6 illustrates in graphical form the relative reference clock offsets at fixed station 10 and mobile unit 12. Fixed station 10 transmits
35 data in frames with the transmit reference clock timing frames illustrated



demodulate frame data.

Fixed station 10 receives in frame 103, according to the receive reference clock timing, mobile unit 12 transmitted DT data. Several bits of information are collected as frames are demodulated and tracked by the fixed station receiving equipment. Within several frames from the beginning of frame 103 of the fixed station receive reference clock timing, a decision is made that tracking is settled and a determination of RTD is made and recorded at the fixed station 10. In the example illustrated in Figure 6, tracking is settled at during frame 105 of the fixed station receive reference clock timing. A determination of propagation delay is then made by comparing the receive reference clock with the current transmit reference clock. In this example, the transmit reference clock is ending frame 107 and beginning frame 108 when the RTD is interpreted against the receive clock in the middle of frame 105. This 2 1/2 frame offset is readily computed into a RTD since each frame is a known quantity of time.

Dividing round trip propagation time value RTD in half yields a value FL1 which corresponds to the propagation time of forward link signal 20, i.e.

$$FL1 = RTD/2. \quad (6)$$

Adding the value DT which corresponds to the time difference of forward link signal 20 and 22 at mobile unit 12, to the value FL1 corresponding to the propagation time of forward link signal 20 yields a value FL2 which corresponds to a derived propagation time of forward link signal 22, i.e.

$$FL2 = FL1 + DT. \quad (7)$$

The values FL1 and FL2, corresponding to the propagation times of forward link signals 20 and 22, are then multiplied by the value corresponding to the propagation velocity of an electromagnetic signal in free space. This multiplication process yields the propagation distance of forward link signals 20 and 22 respectively. FL1 and FL2 are then used to determine single leg distances between satellites S1 and S2 toward the



from fixed observing sites using the same RTD and DT values described previously.

To employ trilateration in the manner presented herein, the cartesian x-y-z coordinate system is most conveniently referenced relative to the center of the earth. The positions of primary and secondary satellites are determined in much the same manner as the position of the mobile unit. In essence, the distance from these satellites to at least three geometrically diverse but known positions are measured to yield the positions of the satellites. Located at the three geometrically diverse sites are fixed communication terminals whose positions are known accurately in the earth-fixed coordinate frame. The distance from each of these sites to each of the satellites is measured by the same means of RTD and DT combinations with the additional requirement that one of the fixed communications terminals collocated with Hub station 10 so that the common link distance between station 10 and each satellite can be removed from the forward link distance to each of the other fixed observation sites.

It is noted that the velocity of the satellite must also be estimated so that satellite position may be extrapolated accurately to any arbitrary time point, especially future time points. Without accurate extrapolation, the performance of the mobile unit navigation function suffers. The "best" way, in a minimum variance estimate sense, to perform extrapolations of position from the information contained in the tracking data is to estimate position and velocity simultaneously in a sequential filtering scheme, such as a Kalman filter. Such Kalman filtering techniques are well known in the art.

The Kalman filtering approach has the advantage that tracking data need not occur simultaneously in time and that it can be processed one-at-a-time. When each new observation is available, it can be folded into a new position/velocity estimate which reflects the best current estimate of the satellite from all the data and it is not necessary to wait for three such reports. The filter then has a minimum of 6 states, three position states and three velocity states. By adding three acceleration states to the filter the tracking behavior improves substantially for motion that is in fact, due to an orbit. The filter also tracks nonorbital motions, which



antenna 10b (uplink portion 40a) via primary satellite S1 to fixed mobile unit 30 located at the fixed observing site immediately adjacent fixed station 10 (downlink portion 40b). Forward link signal 40 is also transmitted by antenna 10b via satellite S1 to fixed mobile unit 32, uplink portion 40a and downlink portion 40c.

Upon reception of this forward link signal 40 at fixed mobile unit 30, fixed mobile unit 30 transmits a return link signal 42, comprised of uplink portion 42a and downlink portion 42b, via primary satellite S1 to fixed station 10. At fixed station 10 the RTD due to the signal path combination of 40 and 42 is measured. The resulting RTD value is divided by four to yield the propagation time of a radio signal traversing a path from fixed station 10 to primary satellite S1. Furthermore the round trip propagation time value RTD divided in half results in the value which is indicative of FLS1, the elapsed time for a signal traveling one way between fixed station 10 and fixed mobile unit 30 via satellite S1. Multiplying the one-way trip propagation time value (RTD/4) by the velocity of propagation of a radio signal in free space, the constant c, yields a distance value D1. The distance value D1 is the distance between fixed station 10 and satellite S1 and can be expressed as follows:

$$D1 = (RTD/4) \cdot c = (FLS1/2) \cdot c. \quad (11)$$

Figure 4 further illustrates the signals used in measuring the distance between fixed station 10 and secondary satellite S2. Transmitted at antenna 10c, simultaneously and coordinated with the forward link signal 40 transmitted by fixed station antenna 10b, is a forward link signal 44. Forward link signal 44 is comprised of uplink portion 44a and downlink portions 44b and 44c. Forward link signal 44 is transmitted from antenna 10c (uplink portion 44a) via secondary satellite S2 to fixed mobile unit 30 (downlink portion 44b) collocated with fixed station 10 and remote fixed mobile unit 32 (downlink portion 44c).

Fixed mobile unit 30 measures the percent offset of the sawtooth modulation of forward link signals 40 and 44. Fixed mobile unit 30 then transmits a return link signal 42, comprised of uplink and downlink portions 42a and 42b respectively, via primary satellite S1 to fixed



This extrapolated D1 value is obtained by tracking the time-rate-of-change of D1 in addition to measuring current values of D1 in order to extrapolate future times. Dividing the time value RTD1A in half yields the propagation time value FLS1A of a radio signal traveling from fixed station 10 via primary satellite S1, to fixed mobile unit 32, i.e.

$$FLS1A = RTD1A/2. \quad (14)$$

Thus the time value FLS1 corresponds to the propagation time of signal 40a and 40b.

Multiplying the propagation time value FLS1 by the velocity of propagation of a radio signal through free space, c, yields the distance traveled of signals 40a and 40c. Subtracting from this path length the previously measured distance value D1 yields the distance LS1A which is the distance between satellite S1 and fixed mobile unit 32 where:

$$LS1A = ((RTD1A/2) \cdot c) - D1 = (FLS1A \cdot c) - D1. \quad (15)$$

The distance from secondary satellite S2 to fixed mobile unit 32 is similarly computed. The propagation time FLS2A of a signal traveling from fixed station 10 via secondary satellite S2 is equal to the propagation time value FLS1 plus the time difference value DT, i.e.

$$FLS2 = FLS1 + DT. \quad (16)$$

The propagation time value FLS2A times the velocity of propagation of a radio signal in free space, c, results in the distance traveled of signals 44a and 44c. Subtracting from this path length the previously measured distance value D2 yields the distance LS2A which is the distance between satellite S2 and fixed mobile unit 32. This distance determination process may be expressed as follows:

$$LS2A = (FLS2 \cdot c) - D2. \quad (17)$$

It should be noted that D2 may also be an extrapolated value, in similar fashion to the extrapolation used in computing the D1 value for the primary satellite.



signals, for example signals 20 and 22 of Figure 2, reach the mobile unit, be it in motion or fixed, their waveforms no longer overlap because they have traversed paths of different lengths.

The signal carrier waveform of the signals 20 and 22 as shown in Figure 5 are as received at a mobile unit. The signal carriers are swept linearly up and down in frequency from a nominal base or center frequency in a chirping manner. The base frequency of signals 20 and 22 may be the same if polarization is used to identify each signal. Alternatively the base frequency for signals 20 and 22 would be different. The base frequency from which the carrier is chirped is about 14 GHz with frequency chirping over a typical 2 MHz bandwidth. These signals emulate video signals for which conventional satellite transponders are configured to operate. Emulation of the video signal reduces interference to terminals which are not tuned to receive such signals. Each linear up/down frequency sweep or frequency chirp period in the preferred embodiment is approximately 30 milliseconds. The use of a triangle chirp waveform on the forward link signal is particularly suited to permit measuring of phase offsets at the object of the forward link signals when relayed through two or more satellites.

In the preferred embodiment of the present invention the difference in time of arrival of timing signals 20 and 22 can be no greater than 8 milliseconds. Using the chirped carrier, a mobile unit making the DT measurement can thus unambiguously measure the difference in arrival times by measuring the offset of one of the waveforms with respect to the other.

Figure 7 illustrates one embodiment in communications between fixed station 10 via satellites S1 and S2 to two different groups of users respectively represented by mobile units 32 and 36. Signals transmitted between fixed station 10 and mobile units 32 and 36 via satellites S1 and S2 containing message data modulated upon a carrier signal are illustrated as solid lines. The dashed lines illustrate communication forward link signals for one group of users which are borrowed as ranging signals for the other group of users, and thus serve as replicas of the forward link periodic modulation. The ranging signals are used only for the chirping periodic pattern with the digital information on these signals, intended for



uplink portions 70a and 70b via transponder S1a of satellite S1 to mobile unit 32 of the first user group. A return link communication signal comprised of uplink portion 72a and downlink portion 72b is transmitted from mobile unit 32 to antenna 10b of fixed station 10 via transponder S1b of satellite S1. The ranging signal, which is the forward link communication signal between fixed station 10 and truck 36 comprised of uplink and downlink portions 76a and 76b, is transmitted upon antenna 10c. This ranging signal, comprised of uplink portion 76a and downlink portion 76b, is relayed to mobile unit 32 via transponder S2a of satellite S2. As discussed above, the ranging signal and the previously discussed techniques are utilized in determining the position of the mobile unit 32.

Fixed station 10 also communicates with the second user group as represented by mobile unit 36. In this environment a forward link communication signal comprised of uplink portion 76a and downlink portion 76b is transmitted from antenna 10c via transponder S2a of satellite S2 to mobile unit 36. A return link communication signal comprised of uplink portion 78a and downlink portion 78b is transmitted from mobile unit 36 via transponder S1b of satellite S1 to antenna 10b of fixed station 10. The ranging signal, which is the forward link communication signal for mobile unit 32, comprised of uplink and downlink portions 70a and 70b, is transmitted from fixed station 10. This ranging signal is comprised of uplink portion 70a and downlink portion 70b' and is transmitted from antenna 10b via transponder S1a of satellite S1 to mobile unit 36. This ranging signal and the previously discussed techniques are utilized in determining the position of mobile unit 36.

Although not illustrated it is further envisioned that communication and ranging between two user groups can be accomplished using only one transponder on each of two satellites. Each satellite would serve as a primary satellite for communications for a respective user group. Each satellite would also serve as a secondary satellite for ranging purposes for the other user group. In this case, for both satellites, a single transponder would handle both forward and return link communications for one user group in addition to the ranging signal



CLAIMS

1. A method for determining the position of an object in a reference coordinate system using a fixed station and plurality of earth orbit satellites wherein the positions of said fixed station and said satellites are known in said reference coordinate system with respect to a reference point and the distances from said fixed station to said satellites are also known, said method comprising the steps of:
- transmitting from said fixed station a forward periodic signal synchronized to a fixed station transmission clock via first and second satellites to an object whose position is to be determined;
 - receiving at said object said forward periodic signal;
 - synchronizing at said object an object clock to said received forward periodic signal transmitted via said first satellite;
 - measuring at said object a first relative time difference in said forward periodic signal as transmitted via said first and said second satellites and received at said object;
 - transmitting from said object to said fixed station via said first satellite a return signal synchronized with said object clock and modulated with information indicative of said first relative time difference;
 - receiving at said fixed station said return signal;
 - synchronizing at said fixed station a fixed station reception clock to said received return signal;
 - measuring at said fixed station a second relative time difference between said fixed station transmission and reception clocks;
 - calculating at said fixed station, from said first and second relative time differences, respective distances from said first and second satellites to said object; and
 - computing the position of said object in said reference coordinate system.

2. The method of Claim 1 wherein said step of transmitting said forward signal comprises the steps of:
- generating a first forward periodic signal having a signal carrier swept linearly in frequency in a cyclical fashion over a first predetermined



satellite;

- 8 determining from said return signal said first relative time
difference by demodulating said information modulated on said return
10 signal indicative of said first relative time difference;
determining from said round trip time value and said first relative
12 time difference, forward propagation times for said forward signal as
transmitted via said first and second satellites to said object;
14 determining distances that said forward signal traversed by
multiplying a value corresponding to each forward propagation time by a
16 known value corresponding to a velocity of propagation of said forward
signal; and
18 subtracting from values each corresponding to said distances said
forward signal traversed, a respective value corresponding to said known
20 distance from said fixed station to each respective satellite.

2 6. The method of Claim 4 wherein said step of calculating
respective distances from said first and second satellites to said object
comprises the steps of:

- 4 determining from said second relative time difference a round trip
time value corresponding to a round trip signal propagation delay of a
6 signal traveling from said fixed station to said object and back via said first
satellite;
8 determining from said return signal said first relative time
difference by demodulating said information modulated on said return
10 signal indicative of said first relative time difference;
determining from said round trip time value and said first relative
12 time difference, forward propagation times for said forward signal as
transmitted via said first and second satellites to said object;
14 determining distances that said forward signal traversed by
multiplying a value corresponding to each forward propagation time by a
16 known value corresponding to a velocity of propagation of said forward
signal; and
18 subtracting from values each corresponding to said distances said
forward signal traversed, a respective value corresponding to said known
20 distance from said fixed station to each respective satellite.



* C L N S *

This Sheet Has Been Replaced



14 provide a third distance value corresponding to a distance traveled by said
forward signal between said fixed station and said object via said second
satellite;

16 subtracting from said third distance value a second known distance
value corresponding to said known distance between said fixed station and
18 said first satellite to provide a fourth distance value corresponding to said
distance between said second satellite and said object.

9. The method of Claim 4 further comprising the steps of spread
2 spectrum modulating said return signal for transmission.

10. The method of Claim 2 wherein said step of transmitting said
2 return signal comprises the steps of:

generating said return signal, said return signal encoded with
4 information indicative of said first relative time difference between said
forward signal as received at said object via said first and second satellites
6 as measured just prior to transmission of said return signal; and

radiating said return signal from an object antenna to said fixed
8 station via said first satellite.

11. The method of Claim 10 further comprising the steps of:
2 modulating information, intended for said object of a first user
group, upon said first forward signal for communication to said object;
4 and

modulating other information intended for said fixed station upon
6 said object return signal for communication to said fixed station.

12. The method of Claim 11 further comprising the steps of:
2 modulating information, intended for another object of a second
user group, upon said second forward signal for communication to said
4 another object;

transmitting another return signal from said another object, said
6 another return signal containing information indicative of a measured
time difference at said another object in reception of said first and second
8 forward signals; and



6 components in cartesian x-y-z coordinates, known satellite components in
cartesian x-y-z coordinates, a known approximate distance from the center
8 of the earth to said object and measured respective distances from said first
and second satellites to said object.

17. A method of object position determination using a plurality
2 of earth orbiting satellites and a fixed station whose positions are known
in an Earth Centered-Earth-Fixed (ECEF) coordinate frame and an earth
4 shape model in which the distance from the center of the earth to any
location on the surface of the earth is known within said ECEF coordinate
6 frame, comprising the steps of:

simultaneously transmitting from a fixed station first and second
8 forward periodic signals, synchronized to a fixed station forward
transmission clock, via first and second satellites respectively to an object
10 whose position is to be determined;

receiving said first and second forward signals at said object, said
12 first forward signal bearing information indicative of a future time frame
which said object will begin transmitting a return signal according to an
14 object clock synchronized to said first forward signal as received at said
object;

16 measuring at said object a percent phase offset of a total modulation
period between similar portions of received carrier modulation of said
18 first and said second forward signals, said percent offset corresponding to a
first relative time difference in said first and second forward signals as
20 received at said object;

transmitting from said object via said first satellite to said fixed
22 station said return signal encoded with information indicative of said first
relative time difference;

24 measuring at said fixed station a round trip delay where said round
trip delay is a second relative time difference between said fixed station
26 forward transmission clock and a fixed station return reception clock
synchronized with said return signal as received at said fixed station;

28 calculating a first distance from said first satellite to said object
according to said round trip delay;

30 calculating a second distance from said second satellite to said object



22. A system for determining the position of an object in an
2 Earth-Centered-Earth-Fixed (ECEF) reference coordinate system using a
fixed station located at a known position and a plurality of earth orbit
4 satellites whose positions are also known along with the distances
between the fixed station and the satellites, comprising:
6 first communications means located at said fixed station for,
generating a periodic signal synchronized to a first communications
8 means transmission clock and transmitting said periodic signal to said
object via at least two of said satellites;
10 second communications means located at said object for, receiving
said periodic signal, synchronizing a second communications means clock
12 to said received periodic signal transmitted via a first satellite of said at
least two of said satellites and received by said second communications
14 means, measuring a first relative time difference between said periodic
signal as transmitted via said first satellite and a second satellite of said at
16 least two of said satellites and receive by said second communications
means, generating a return signal indicative of said time difference, and
18 transmitting said return signal via said first satellite to said first
communications means; and
20 wherein said first communications means further is for, receiving
said return signal, synchronizing a first communications means reception
22 clock to said received return signal, measuring a second relative time
difference between said first communications means transmission and
24 reception clocks, determining from said first and second relative time
differences and said Known distances between said first and second
26 satellites respective distances between said first and second satellites and
said object, and for determining from said known positions of said first
28 and second satellites, said distances between said first and second satellites
to said object and a known distance from said object to a reference point
30 within said reference coordinate system, said object position.

23. The system of Claim 22 wherein said first and second
2 communications means are capable of two-way communications with
respect to one another via said plurality of satellites.



This Sheet Has Been Replaced

