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GPS/REFSAT Definition Study Report

For

Low-Cost Terminals

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ABSTRACT

The NAVSTAR Global Positioning System (GPS) is a satellite navigation system currently under development by the Department of Defense. It will consist of 18 satellites in circular, 12-hour orbits at an altitude of 11,000 NM, inclined 63° to the equator. GPS satellites will broadcast pseudo-random noise codes and ephemerides on two L-band signals to users worldwide, including military and civil users.

This report describes a concept that utilizes a relay transponder, located either on a satellite in geostationary orbit or on a local tower to relay acquisition-aiding data, ephemerides, etc. from a ground-based remote control station to a GPS civil user terminal located on a ship or land-transportation vehicle. Termed REFSAT (Reference Satellite), this concept reduces significantly the circuit complexity and cost of user terminals. A low-cost, REFSAT user terminal might range in price from $1,000 to $2,000 per terminal, in lots of 3,000.

This report defines the various systems needed to implement the REFSAT concept for low-cost, GPS civil terminals. The GPS/REFSAT system compatible with the NAVSTAR GPS system consists of a space segment (geostationary relay satellite), a ground terminal segment (civil user terminals), and the remote control station (the central facility which performs operations common to all users for relay via the space segment). Each segment is described in detail.

A GPS/REFSAT system utilizing a local tower for the relay transponder is also described.

The results of a study of civil user requirements is presented.

Detailed specifications for the GPS/REFSAT system and its individual segments are presented in the appendix.

1. NAVSTAR GPS System & GPS/REFSAT System

The GPS/REFSAT System* augments the planned NAVSTAR Global Positioning (GPS) System, allowing a significant reduction in the cost and complexity of civil user terminals.

A number of operations common to all civil users within a particular geographic area may be performed at a central remote control station. Information containing the result of these operations is broadcast along with a precision frequency reference to all civil users through the REFSAT/GPS geostationary space segment.

The following sections develop the definition of the GPS/REFSAT system, detailing its method of operation and relation to the NAVSTAR GPS system.

1.1 NAVSTAR GPS System

The NAVSTAR Global Positioning System (GPS) offers accurate three-dimensional position (and velocity if desired) information to users anywhere in the world. A user position fix consists of the following steps:

- Measuring the transit time of RF signals from three GPS satellites of a total constellation of 18 satellites and computing the resultant distances. (Transit time is determined using the speed of light).
- Computing the current position of three GPS satellites using the ephemeris data transmitted with each satellite signal,
- Solving the resultant "triangulation" equations to determine the position of the user terminal.

If user terminals maintained precision clocks synchronized with GPS system time, a position fix could be accomplished in this simple manner. The user terminal would then be at the intersection of three spheres whose centers were located at the respective satellites.

In practice, the requirement for user terminals to contain a precision clock is eliminated by making range measurements to four satellites. In this case, the navigation equations contain four unknowns: the user position in three dimensions and the error, or fixed bias, in the user's imprecise clock.

The navigation signal transmitted from each NAVSTAR GPS satellite consists of two RF frequencies, L1 and L2. As shown in Table 1-1, the L1 signal at 1575.42 MHz is modulated with both the P and C/A pseudo-random noise (PRN) codes in phase quadrature. The L2 signal at 1227.6 MHz is modulated with the P-code. Both signals are also continuously modulated with the navigation message data-bit stream at 50 bps.

* J. W. Sennott, A. K. Choudhury, R.E. Taylor, "The REFSAT Approach to Low-Cost GPS Terminals", NASA Goddard Space Flight Center, TM 79655, April 1979.

Table 1-1. NAVSTAR GPS Signal Characteristics.

L1 RF Frequency	= 1575.42 MHz
Contains:	PRN P-Code PRN C/A Code 50 BPS Data Stream
L2 RF Frequency	= 1227.60 MHz
Contains	PRN P-Code 50 BPS Data Stream
Long (P) Code	
Frequency	= 10.23 MHz
Epoch	= 267 Days
(Reset each 7 days)	
Short (C/A) Code	
Frequency	= 1.023 MHz
Epoch	= 1 millisecond

The data stream includes satellite ephemeris information, to allow a user to compute the satellite position coordinates needed for solution of the navigation equation. The PRN codes serve two functions:

1) Satellite identification. The code patterns are unique to each satellite and are matched with like codes in the user receiver and,

2) The measurement of navigation signal transit time, by measuring the phase shift required to match the codes.

The user terminals discussed in this document utilize the L1 signal at 1575.42 MHz and the short C/A code which repeats every millisecond. More sophisticated users may make use of both L1 and L2 signals to measure ionospheric propagation delays or to utilize the longer P-code for extreme accuracy.

The baseline constellation of 18 NAVSTAR satellites will be placed in 12-hour orbits providing at least five satellites at 5 degrees or more above the local horizon to a worldwide user.

Figure 1-1 shows ground tracks of the four Phase 1 NAVSTAR satellites operational as of 1 January 1980 (orbit positions 1, 3, 5, and 6). A given satellite ground track repeats each 12 hours. Also shown is the 20 degree visibility contour about Washington, DC. A satellite whose ground track is north of the visibility contour will appear 20 degrees or more above the horizon.

1.2 The GPS/REFSAT System

The GPS/REFSAT System illustrated on Figure 1-2 offers a significant reduction in both the cost and complexity of user ground terminals. A remote control station performs many of the tasks required of a conventional GPS user terminal. Data from the remote control station is then broadcast over a wide geographical area via a geostationary reference satellite (REFSAT) in the form of an L-band "aiding signal". GPS/REFSAT user terminals in the service area of the remote control station use the L-band REFSAT signal to aid GPS satellite signal acquisition and to simplify computation of the user's position.

Before discussing the GPS/REFSAT system in detail, two observations from Figures 1-1 and 1-1A/1-1B are pertinent. An examination of Phase 1 GPS ground tracks north of the 20° visibility contour shows that the geometry of the GPS satellites relative to a user terminal:

(1) Changes rapidly with time. A particular group of 4 satellites remains visible to a user terminal, above the 20° elevation angle, for 2 to 3 hours. However, the horizontal dilution-of-precision (HDOP) for the same four satellites is 5 or less for only 2 hours.

(2) Changes slowly with user geographical location. At a given instant in time, users anywhere in the continental United States could utilize the same 4-satellite constellation.

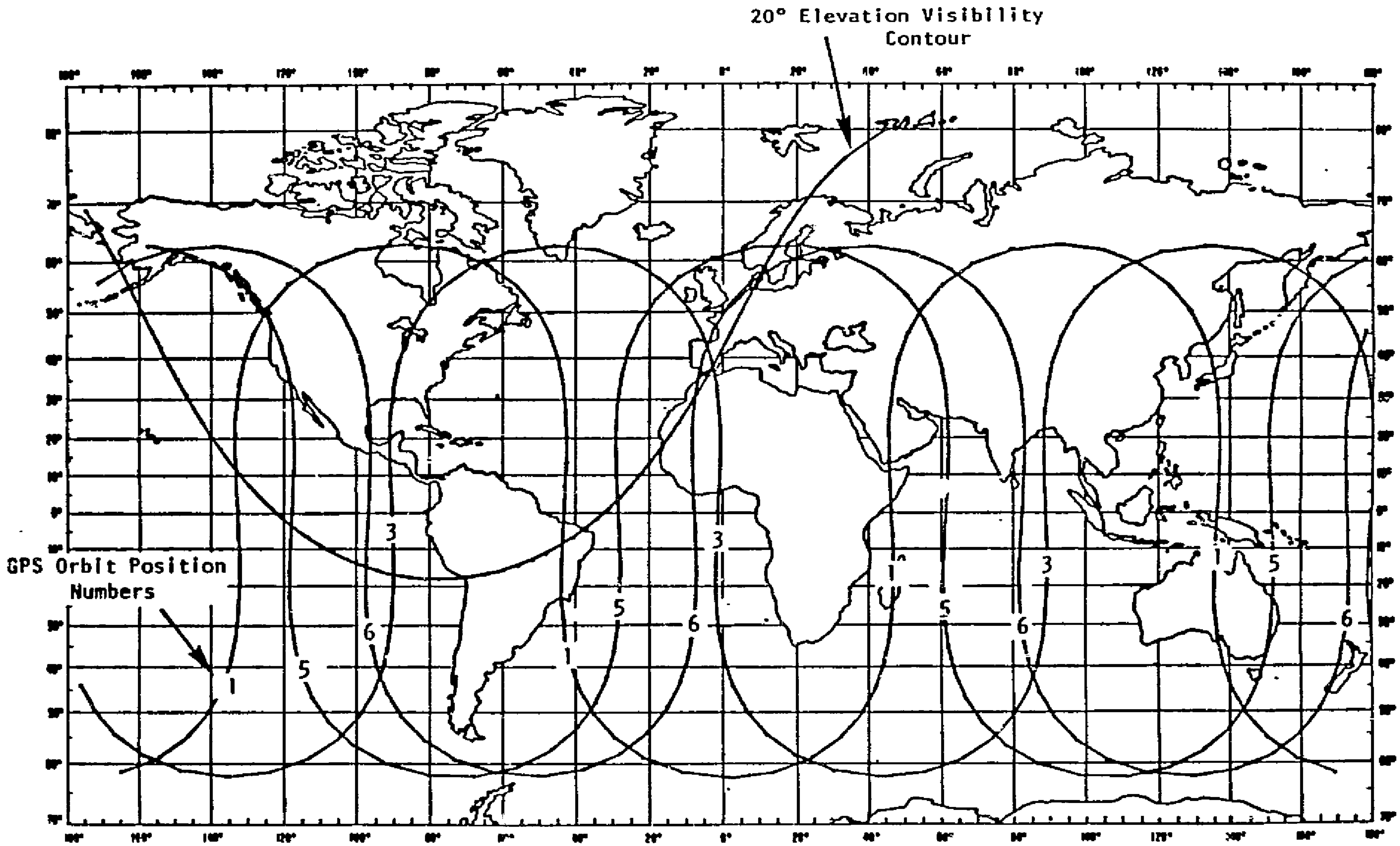


Figure 1-1. GPS Satellite Ground Tracks (20 degree elevation visibility contour shown around Washington, D.C.)

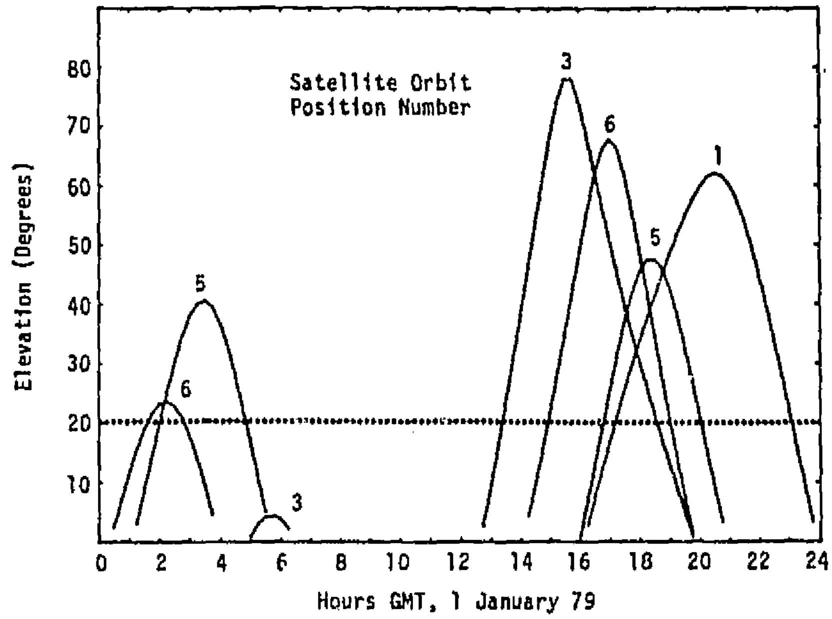


Figure 1-1A. GPS Satellite Elevation Angles at Wash., D.C.

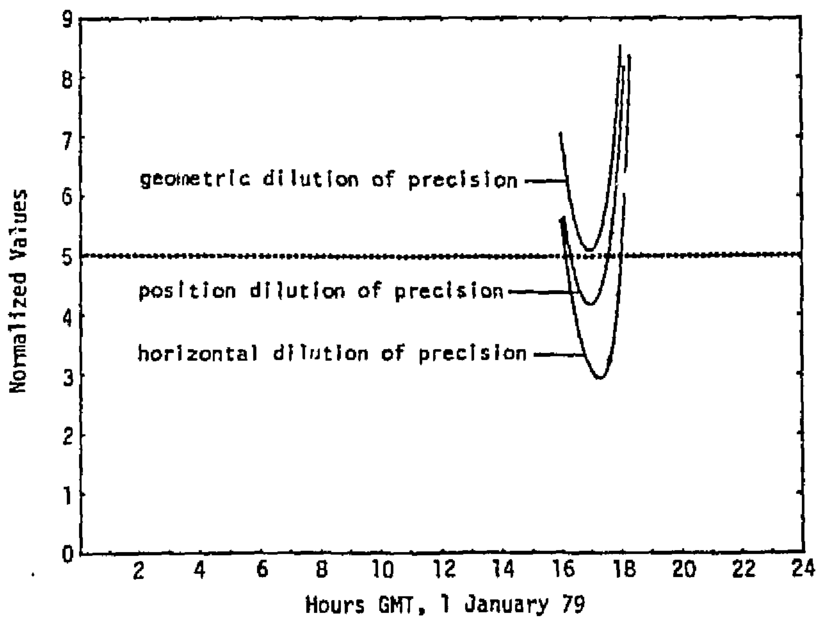


Figure 1-1B. Dilution-of-Precision (DOP) Values at Wash., D.C.

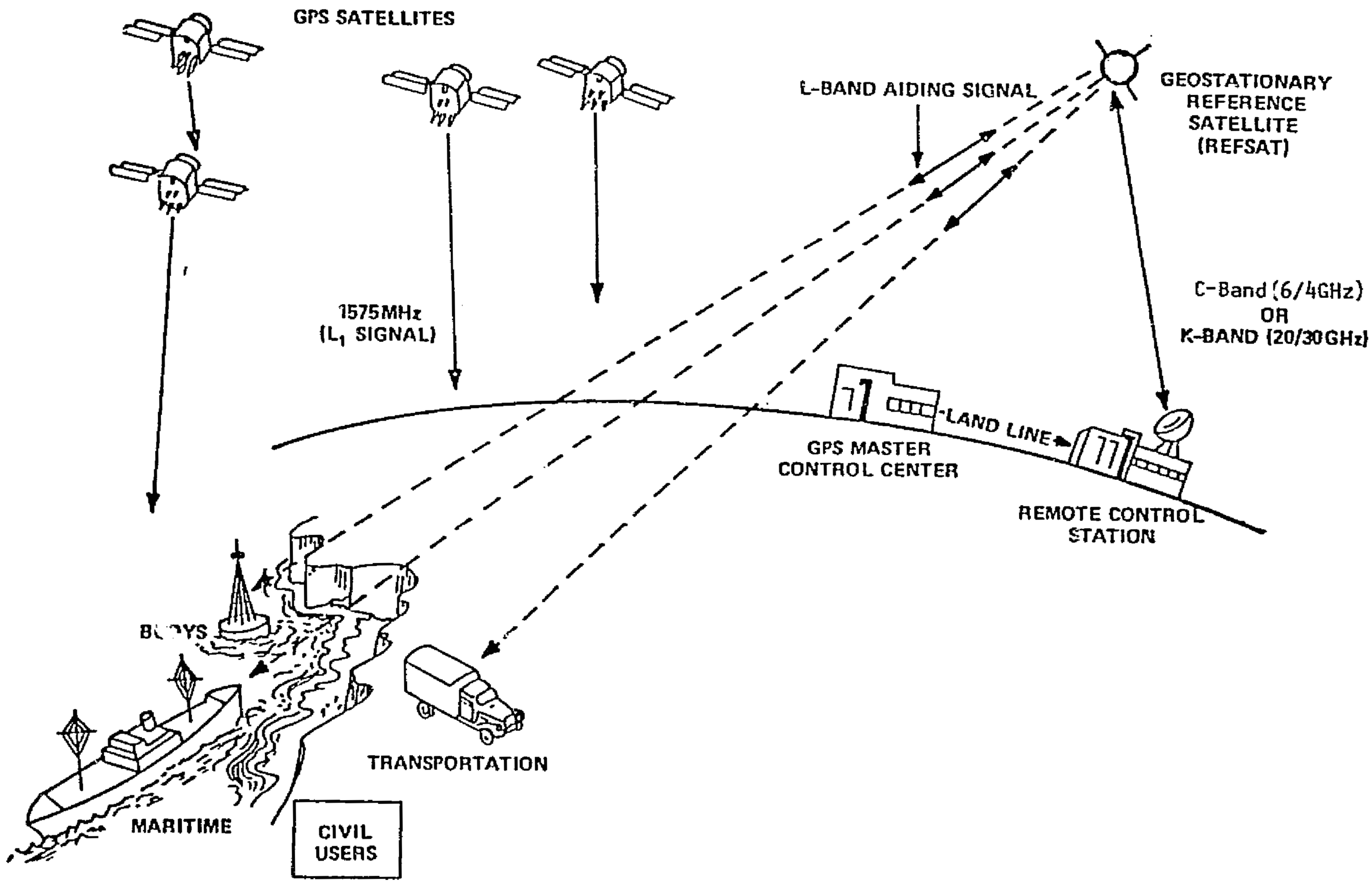


Figure 1-2. The GPS/REFSAT System

The first step required to perform a GPS navigation fix is that of selecting from the visible GPS satellites those four that provide the minimum horizontal dilution-of-precision (HDOP). This initial step shown on Figure 1-3 is important since the magnitude of the user position errors in the computed GPS navigation fix depend not only upon the user's ranging errors, but on the relative geometry of the four selected satellites.

1.2.1 Initial GPS Satellite Selection

In general, all user terminals within a large geographical area would select the same four GPS satellites in order to achieve minimum HDOP at a particular time. This selection requires the maintenance of current GPS satellite almanac data in memory and the solution of an "HDOP" algorithm. The REFSAT system performs this task at a central location and then broadcasts the results to all users, relieving individual user terminals of this software and storage function.

1.2.2 Doppler and Delay Acquisition

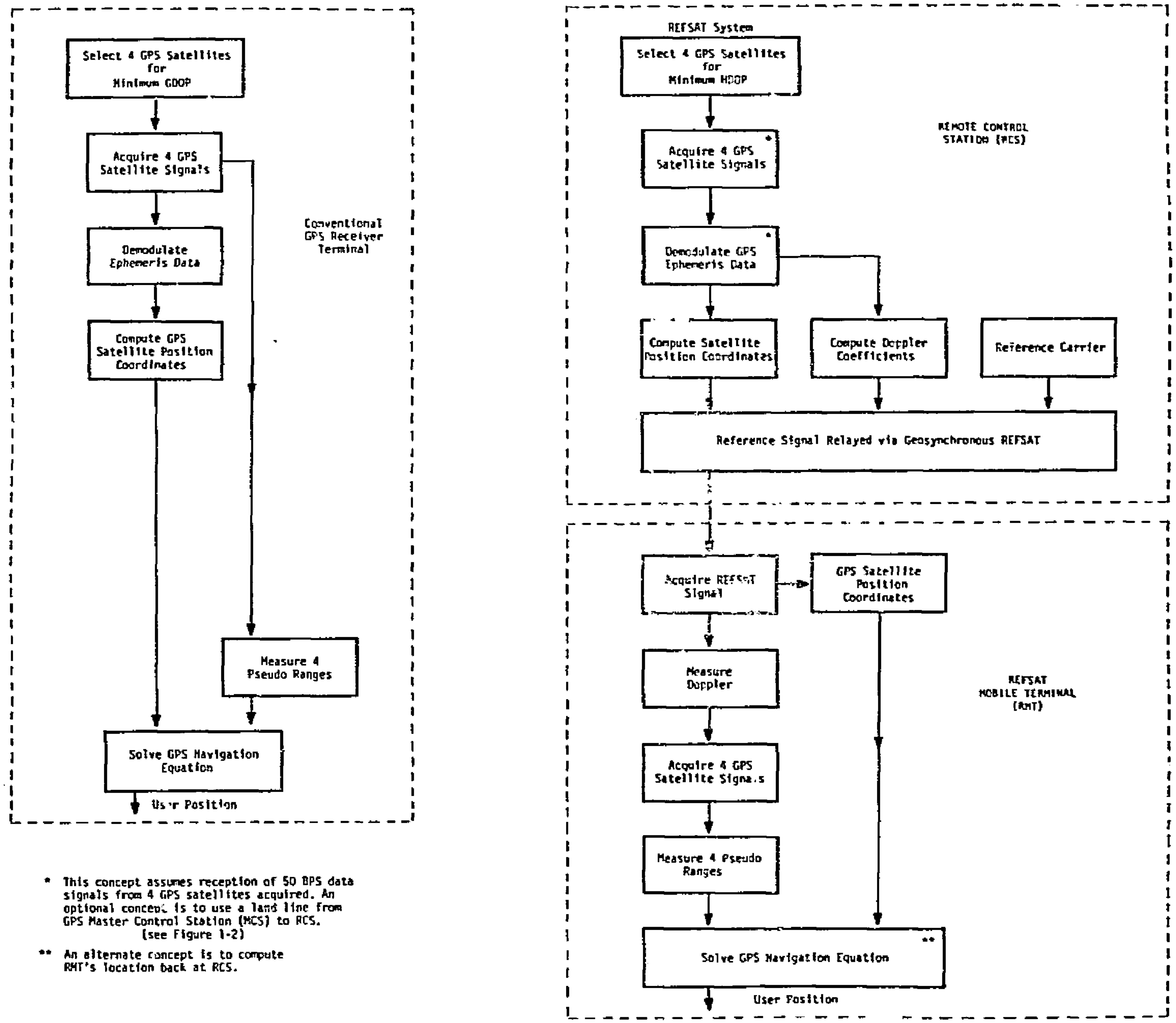
For signal acquisition (4 GPS satellites), a conventional user terminal may perform a frequency and code delay search or make use of stored GPS almanac data to compute expected doppler shifts for the four satellite signals. A precision frequency reference is required at the user terminal to reduce doppler acquisition time.

In the REFSAT System, a major portion of this function is performed by the remote control station. As shown on Figure 1-3, the REFSAT provides a precision frequency reference to all users (the REFSAT Carrier Frequency Signal). In addition, the data message carried on the REFSAT signal provides "doppler coefficient" information allowing a simple computation of doppler offsets at the user terminal.

1.2.3 Position Fixing

Both conventional GPS and GPS/REFSAT user terminals make "pseudo-range" measurements to the 4 selected GPS satellites. Solution of the navigation equation requires a knowledge of the position coordinates of the 4 selected GPS satellites. These coordinates must be computed from GPS ephemeris data contained in the GPS satellite signals. Demodulation of this data requires GPS carrier phase tracking in the conventional GPS terminal.

As shown on Figure 1-3, this function is performed by each conventional GPS user terminal. In contrast, the REFSAT system performs this function at a central location. Current position coordinates for the four selected GPS satellites are then broadcast to all GPS/REFSAT users as part of the REFSAT signal. The user may utilize this information directly to solve the navigation equation or simply transmit measured pseudo-range values via a "report back" link for position computation at a central location.



* This concept assumes reception of 50 BPS data signals from 4 GPS satellites acquired. An optional concept is to use a land line from GPS Master Control Station (MCS) to RCS. (see Figure 1-2)

** An alternate concept is to compute RMT's location back at RCS.

Figure 1-3. The REFSAT Concept.

Figure 1-3 and Table 1-2 illustrate the manner in which the above steps are accomplished in conventional GPS and the proposed GPS/REFSAT systems. Figure 1-4 contrasts the receiver functions required of each system.

1.2.4 Format of the REFSAT Data Message

Figure 1-5 shows a proposed format for the REFSAT data message broadcast with the REFSAT signal for GPS satellites A, B, C and D. In addition to the precision REFSAT carrier which provides each GPS/REFSAT user terminal with a precise frequency reference, the REFSAT signal contains a 128 bit-per-second FSK signal.

Each REFSAT data frame is transmitted "on time" relative to GPS system time. Each of the 4 subframes contains:

(1) synchronization (3 bytes, 24-bits)

(2) current X, Y, and Z earth-centered coordinates for a selected GPS satellite (9 bytes).

(3) current doppler coefficient data for computation of doppler gradient (3 bytes).

(4) code select to identify the selected GPS satellite (1 byte).

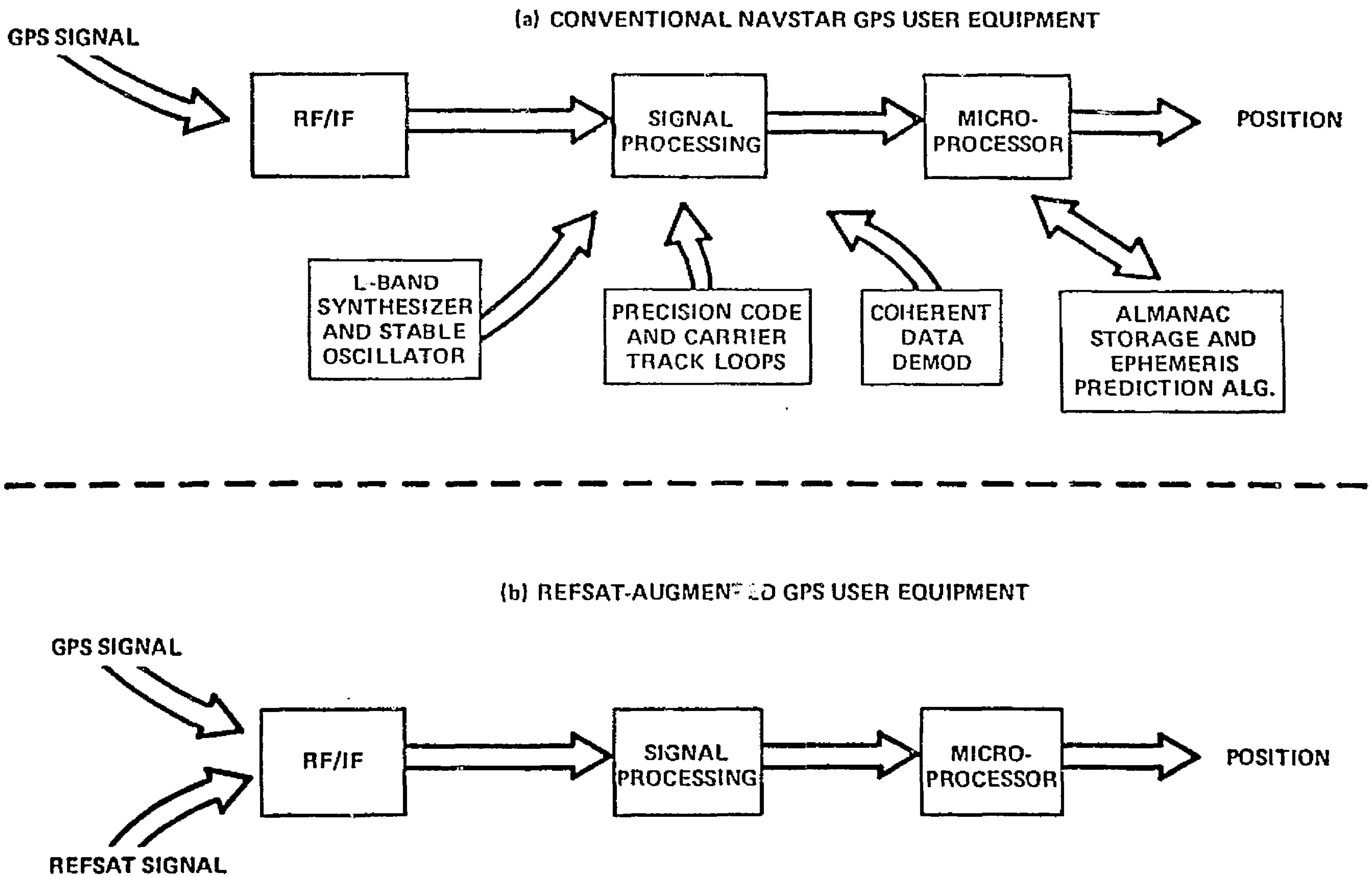
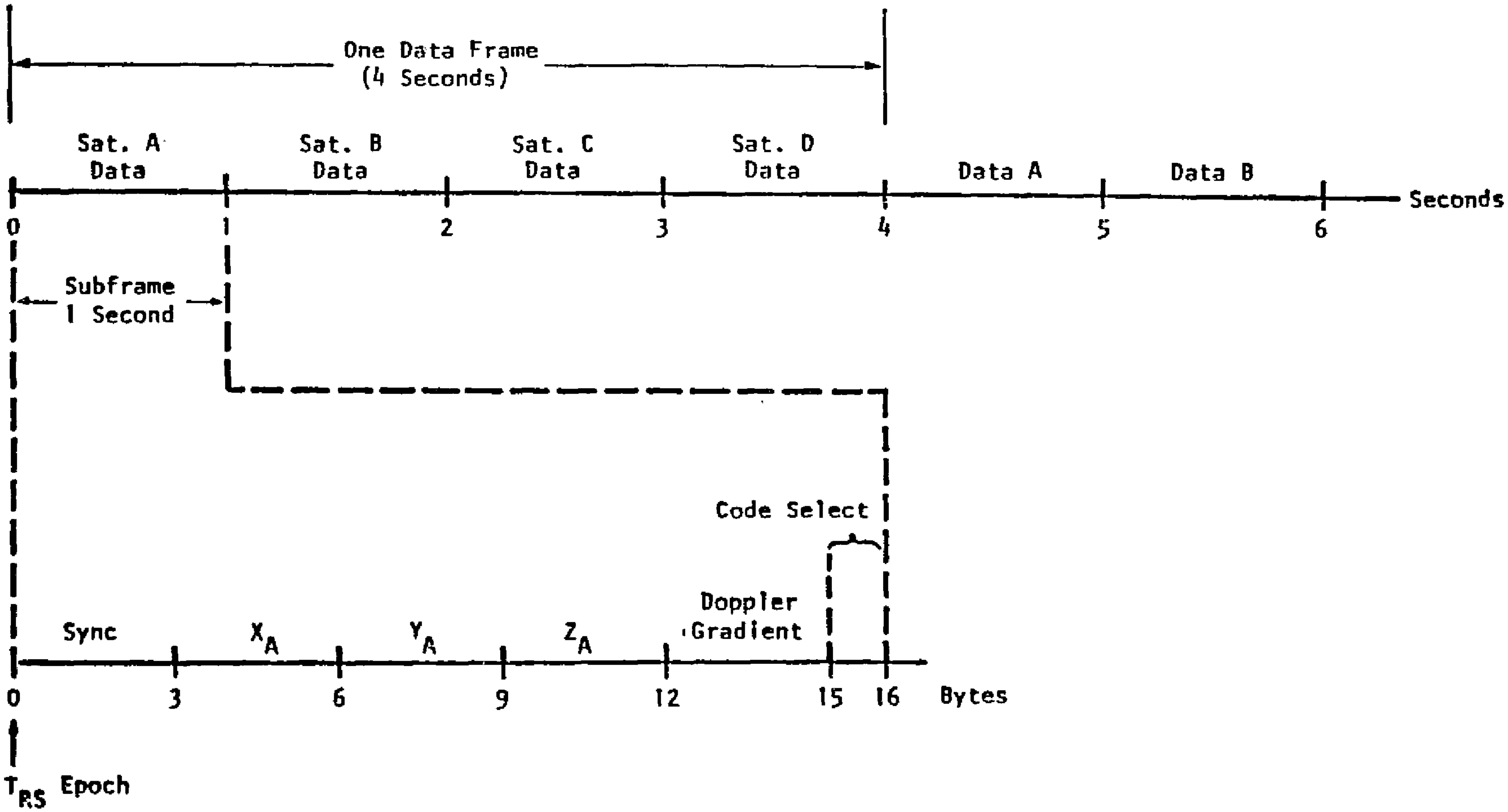


Figure 1-4. REFSAT VS. Conventional Receiver.

Table 1-2. GPS Receiver Functions Comparison.

		Conventional GPS Terminal		
Major Function	**Sub-Function**	**Hardware**	**Software**	**REFSAT Simplification**
Signal Acquisition	1. Initial Satellite Selection		GPS Almanac Compute satellites in view	Eliminate this software/ storage function
	2. Doppler Acquisition	1 part 10^8 synthesizer (in oven)	Compute range rate for selected satellites	VCXO to 1 part in 10^6
	3. Delay Acquisition	PSK spread spectrum programable synthesizer (in-phase & quadrature)	Filter error signals Advance/retard commands	Reduce code generator precision
Signal Tracking	4. Fine Delay Track	Delay-lock loop	Filter error signals Advance/retard commands	No punctual code, employ interpolation
	5. Fine Doppler Acquisition	AFC loop	Filter error signals VCXO freq. step commands	Not essential for all users
	6. Carrier Phase Track	Costas loop	Filter error signals VCXO phase step commands	Eliminate entirely
Position Fixing	7. Telemetry Acquisition	PSK demodulate using above phase reference		Simple non-coherent FSK
	8. Ephemeris Update		Real-time predictor	Eliminate entirely
	9. Position Computation		Pseudo range to lat.-long. conversion	



NOTE: 1 Byte = 8 Bits

Figure 1-5. REFSAT Data Format.

2. REFSAT Space Segment

This section examines the requirements of the REFSAT space segment in order to form the performance specifications listed in Appendix 1. The geostationary reference satellite shown on Figure 1-2 must provide:

(1) A space-to-earth downlink broadcast of the REFSAT reference carrier, and the REFSAT data message (128 bps), relayed over an earth-to-space uplink.

(2) A user terminal-to-space uplink for those users requiring a report-back capability to the REFSAT remote control station via space-to-earth downlink.

2.1 Required Frequency Assignments

Before firm frequency assignments can be made, it will be necessary to study the possible mutual interference effects between REFSAT and those users presently allocated in the frequency bands that may be considered. The following discussion serves the purpose of demonstrating feasibility and pointing out major requirements. The precise frequencies that are discussed are not necessarily those that would be employed in an operational system.

REFSAT Space-to-Earth Reference Signal

The frequency band for the REFSAT space-to-earth reference signal should be chosen to minimize the size, weight, complexity, and cost of individual user terminals over those already required to receive GPS satellite signals at 1575.420 MHz (a maximum doppler shift of ± 4 kHz may be expected).

In order to best meet the above considerations, the REFSAT signal frequency should be within a few percent of the GPS satellite signal frequency so that a common antenna and RF front-end may be used. For the purposes of this definition study, REFSAT downlink reference carrier frequencies at 1555 MHz and 1560 MHz will be assumed to cover the continental United States (CONUS) and Alaska, respectively.

User Rep rt-Back, Earth-to-Space Frequency

Should a report-back function be required of a particular user, a transmitter and suitable antenna must be added to a basic user terminal. The antenna should have sufficient beamwidth to avoid the need for antenna pointing. Although a number of frequency bands would be suitable, this definition study assumes that the same user antenna would be used for both transmission and reception, placing the desired earth-to-space transmit frequency near 1600 MHz.

2.2 Spacecraft Antenna Footprint Coverage Requirement

Using the REFSAT System, the choice of a particular 4-satellite GPS constellation (for minimum HDOP) is made at the remote control station. As a result, all GPS/REFSAT user terminals in a particular REFSAT coverage area use the same 4-satellite GPS constellation. The maximum dimensions of the REFSAT antenna footprint are therefore limited.

Although additional study is required to define the maximum feasible REFSAT coverage area, preliminary investigation indicates that geographical regions as large as the continental United States (CONUS) are practical. Separate beams covering CONUS and Alaska will be assumed for this document. (See specifications in Appendix 1).

2.3 RF Link Budget Computations

RF link budget computations are given on Table 9.1 of the Appendix.

A nominal REFSAT effective isotropic radiated power (EIRP) of about 40 decibels above one-watt (dBW) and a user terminal report-back EIRP of about 10 dBW would be required.

2.4 Spacecraft Antenna System

The REFSAT system places no special design constraints upon the spacecraft antenna system. A CONUS-coverage antenna array structure is assumed for both transmission and reception.

2.5 Transponder System

The REFSAT reference signal imposes very modest requirements on the spacecraft transponder in terms of bandwidth (a few tens of kHz) and output power (12 dBW). There are, however, stringent limits upon the frequency accuracy and stability of the REFSAT carrier as received at a user terminal.

In order to avoid the need to perform a frequency search to acquire the selected GPS satellite signals, it is desirable that the REFSAT carrier be maintained within 50 Hz of its nominal value (3 parts in 10^8) as a precision frequency reference to aid GPS signal acquisition at the user terminal.

The carrier frequency of the REFSAT transponder, as seen by a user terminal, must remain constant to within 50 Hz by employing a very precise master oscillator in the spacecraft. Doppler shift due to REFSAT satellite motion must also be held to limits not exceeding 50 Hz.

The transponder used for user report-back signals may take a number of forms depending upon whether FDMA or TDMA techniques are employed. Considering the brevity and low data rate (e.g. 128 bps) of the report-back message that would be required of any given user, a single TDMA channel of 10 kHz bandwidth should be adequate for CONUS coverage. A detailed list of specifications is given in the Appendix.

3. Alternate Methods For Implementing a GPS/REFSAT System

This section describes two alternate methods for implementing a GPS/REFSAT system:

(1) Use of a VHF link (rather than L-band) for the REFSAT reference signal,

(2) Use of a local tower (rather than a geostationary satellite) to broadcast the REFSAT signal over a limited geographical area.

3.1 Use of a VHF Link for the REFSAT Signal

The REFSAT concept previously illustrated on Figure 1-2 assumed a REFSAT signal frequency (1555 MHz) below the GPS downlink frequency (1575.42 MHz), in order to minimize GPS/REFSAT Civil User Terminal complexity.

The narrowband (10 kHz) REFSAT signal may, of course, be broadcast at any desired frequency provided that the user terminal is equipped with an antenna and receiver channel to translate the received REFSAT signal to the terminal IF frequency (21.4 MHz).

A block diagram for a GPS/REFSAT civil user terminal accommodating a VHF REFSAT broadcast signal is shown on Figure 3-1. Except for the separate VHF and L-band antenna and RF front-end components, the terminal block diagram functions are identical to those described for an L-band REFSAT system described in Section 4 of this document.

Since the REFSAT signal is used as the user terminal precision frequency reference, the first LO signals (to M1 and M6 on Figure 3-1) must be sufficiently stable in frequency to maintain the precise 50-Hz, frequency difference required between the GPS and REFSAT channels. The recovered reference carrier from the REFSAT signal is corrected for GPS satellite doppler (in M4) and used with the locally-generated PRN codes (M5) as the local reference for correlation with received GPS satellite signals.

Demodulated data from the REFSAT signal provides the terminal with:

(1) Identification of the 4 GPS satellites which currently provide minimum horizontal dilution-of-precision, (HDOP),

(2) Doppler coefficient data (allows computation of doppler shifts for acquisition),

(3) Position coordinates for the 4 selected GPS satellites.

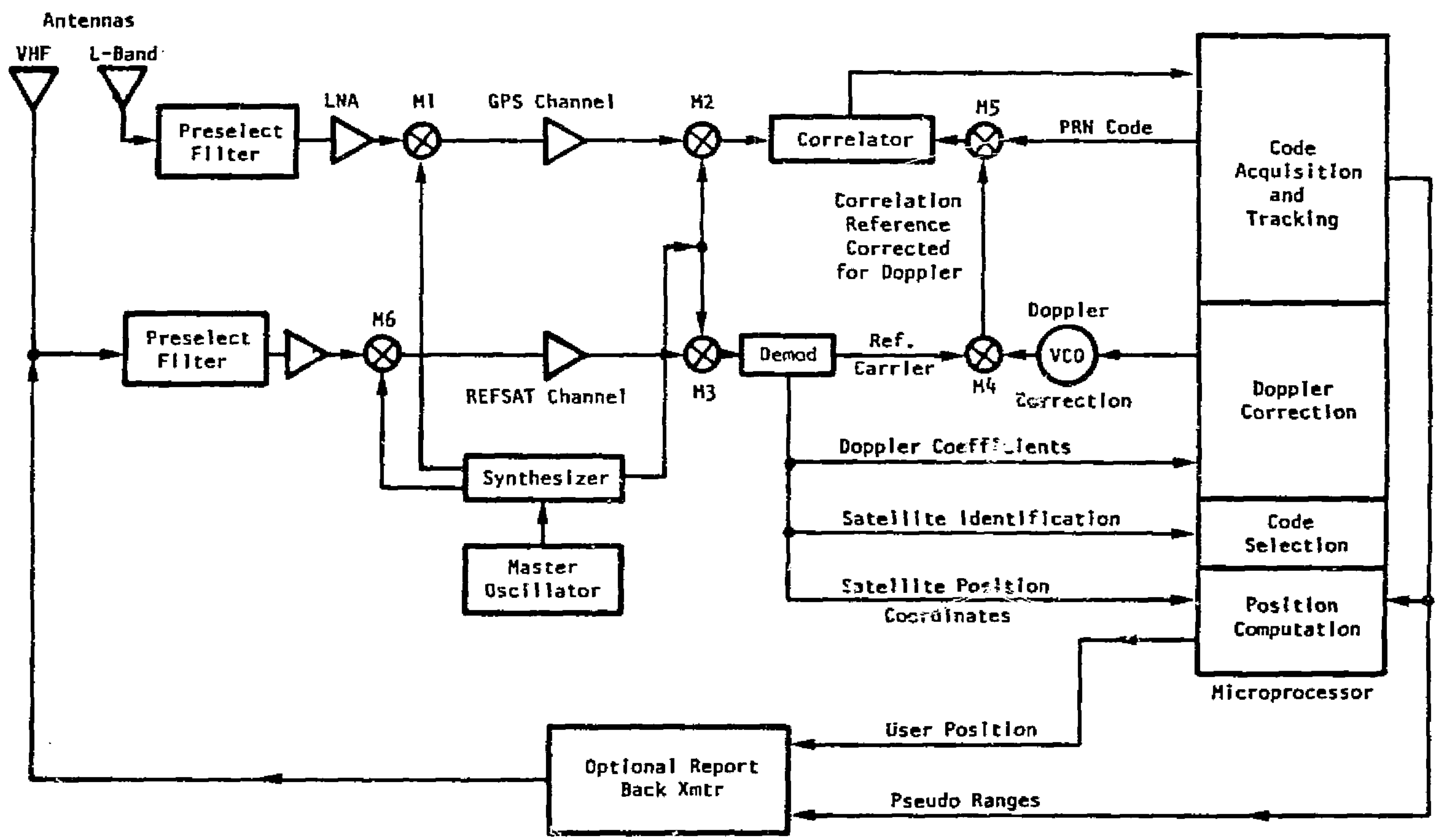


Figure 3-1. GPS/REFSAT Terminal (VHF REFSAT Signal Link).

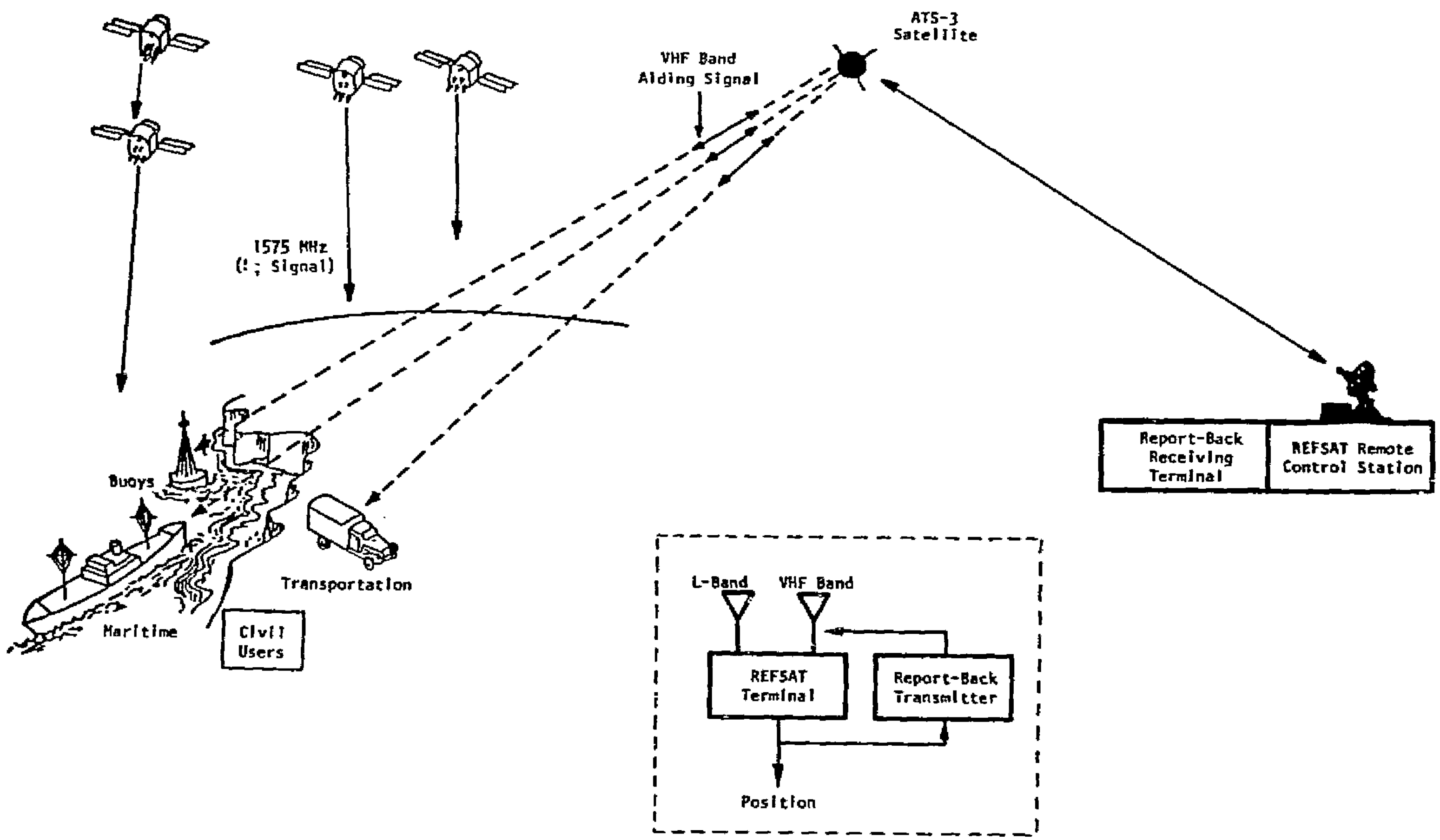


Figure 3-2. GPS/REFSAT System Utilizing the ATS-3 Satellite.

An alternative implementation of a GPS/REFSAT system is shown in Figure 3-2 using the geostationary ATS-3 spacecraft as the REFSAT transponder.

The REFSAT transponder broadcasts the REFSAT signal over the geographical coverage area. Individual GPS/REFSAT user terminals may then make use of the REFSAT signal to acquire the four GPS satellite signals which currently provide the minimum value of horizontal-dilution-of-precision, and measure pseudo-range values.

Once the user terminal has measured pseudo-range values to the 4 selected GPS satellites, several options are available:

(1) The user may make use of the GPS satellite position coordinate data contained in the REFSAT signal to compute the position of the user terminal, and,

(a) Make use of position information for navigation, or other purposes or,

(b) Report-back computed position via a user report-back transmitter and the REFSAT transponder to a Report-back Receiving Terminal or,

(2) The user may simply report-back measured pseudo-range, timing, and user ID data. Computation of user position may then be accomplished at the Report-back Receiving Terminal, relieving the user terminal of this task.

3.2 Use of a Local Tower for REFSAT Signal Broadcast

There are many applications where a specialized group of users occupy a limited geographical area that may be economically served by placing the REFSAT transponder on a local tower rather than on a geostationary satellite.

Figure 3-3 illustrates the application of the REFSAT concept to maritime navigation and control in a congested waterway. A REFSAT transponder placed on an 800 ft. high tower, for example, would provide coverage over at least 40 mile radius. Precision tracking and control would then be available for all vessels equipped with a user terminal such as that shown previously on Figure 3-1.

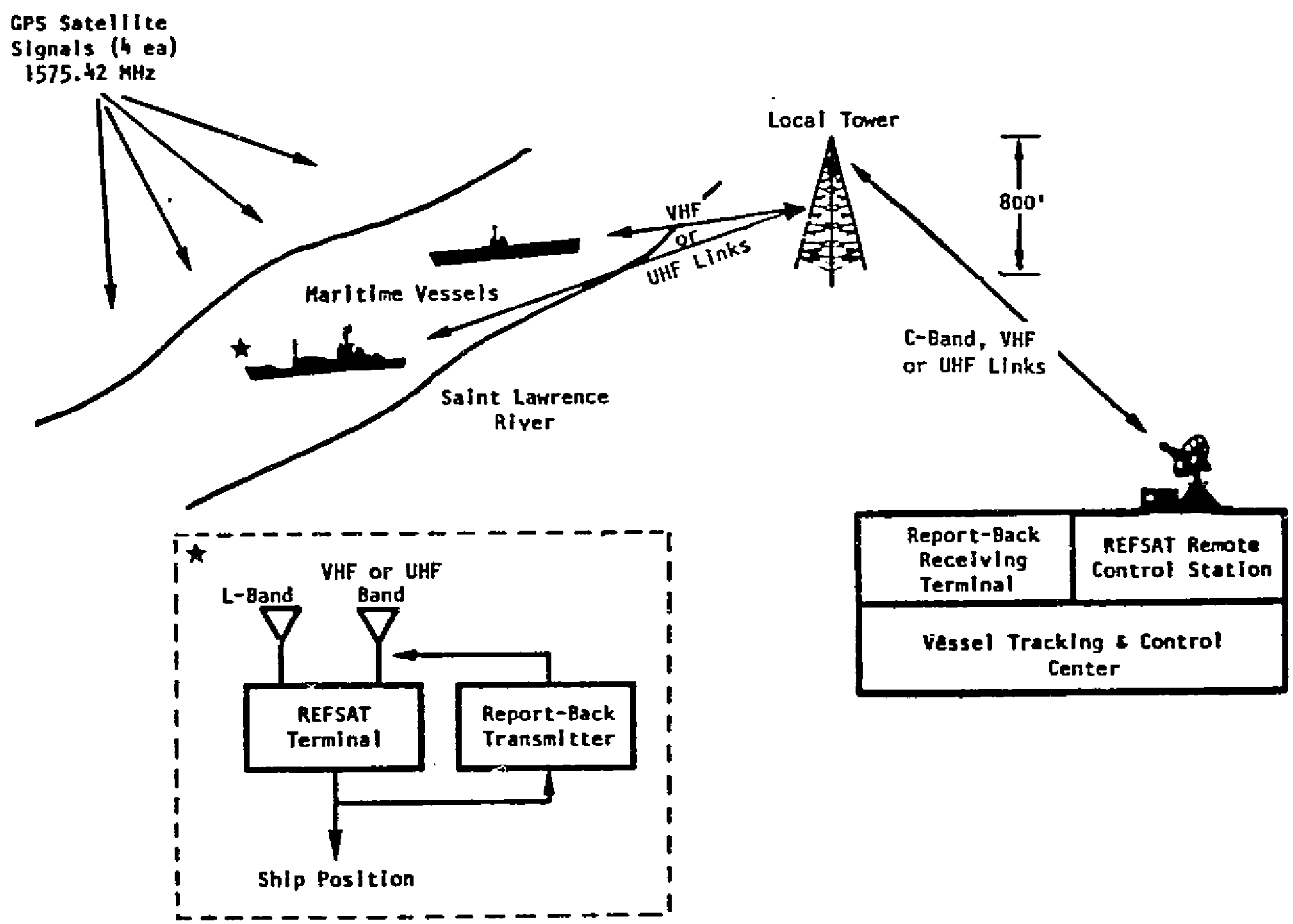


Figure 3-3. GPS/REFSAT System Using a Local Tower.

4. GPS/REFSAT User Terminal Segment

This section describes the requirements of the GPS/REFSAT user terminal segment of the REFSAT system. A list of specification is given in Section 8 in the Appendix.

4.1 2-Channel Receiver Requirements

Under the REFSAT concept described in Section 1, the user terminal receiver must process both GPS satellite signals (1575.420 MHz ± a maximum 4 kHz doppler shift) and the REFSAT reference signal. For the most economical receiver design, the REFSAT carrier should be within a few percent of the GPS signal frequency to allow a common user antenna and RF front end to be used.

In order to satisfy the majority of projected user requirements (see Section 6), a maximum time-to-first-fix of about 100 seconds should be allowed (REFSAT signal acquisition + acquisition of 4 selected GPS satellite signals + output of user position or pseudo-range values). A maximum position update time of 10 seconds following initial acquisition will meet the needs of most potential users.

A survey of potential user requirements indicates that a horizontal position accuracy of about 100 meters would meet all but the most stringent user needs. The C/A code (1.023 Mbps) is capable of meeting this accuracy requirement.

4.2 Data Transmitter

Since a significant portion of the potential civil user market identified in Section 6 consists of "location" or "surveillance" type users, a data transmitter for "report-back" of user position may be required as an option. The report-back message may consist of user position coordinates computed at the user terminal or measured pseudo-range values to allow later computation of user position at a central location.

Specifications for the report-back message are given in Section 8.5 in the Appendix.

The choice of the particular frequency band to be employed for the user report-back link requires further study (see Section 2), but should be near the GPS signal frequency to allow use of a single antenna for user terminal transmission and reception. A transmitter power level in the order of 10 watts would be needed (see Appendix for link budget computations).

4.3 Simplified Block Diagram, GPS/REFSAT User Terminal

Figure 4-1 illustrates a simplified GPS/REFSAT user terminal block diagram capable of meeting the requirements discussed above. The GPS satellite and REFSAT reference signals are sufficiently close in frequency to share a common RF front-end and first mixer (M1). Separate intermediate-frequency channels are then employed. Should a second frequency conversion be desirable, the local oscillator frequencies applied to the two channels must be identical or derived from the same source in order to maintain the precise frequency difference between the REFSAT reference carrier and the GPS satellite carrier frequencies (note M2 and M3).

Following the REFSAT channel on the block diagram, the REFSAT carrier is recovered for later use in the correlator. The REFSAT data message is demodulated and applied to the micro-processor.

The micro-processor makes use of the satellite identification portion of the REFSAT data message to select the 4 PRN codes corresponding to the 4 GPS satellites currently visible with minimum horizontal dilution-of-precision (HDOP).

The micro-processor makes use of the doppler coefficient portion of the REFSAT data message along with estimated user position (within 150 km) to compute doppler correction. The doppler correction, when compared to the recovered REFSAT reference carrier, insures a corrected correlation reference that is within 50 to 100 Hz of the GPS channel signal. GPS signal acquisition may then be rapidly accomplished without the need to perform a frequency search and without employing a precision oscillator within the user terminal. A long-term frequency stability of 1 part 10^6 is adequate instead of 1 part 10^8.

The doppler-correction signal from the micro-processor is applied to a low-frequency voltage-controlled oscillator (VCO). The resulting doppler correction is added to the recovered REFSAT carrier (mixer M4). The corrected correlation reference is then modulated with the appropriate PRN code (mixer M5) and applied to the correlator. The micro-processor monitors the correlator output while performing a code delay search until GPS signal acquisition has been achieved.

After signal acquisition (4 GPS satellites), the micro-processor adjusts both the doppler correction and PRN code delay (sequentially for 4 GPS satellites) to minimize correlation errors. The relative code phases when computed using the speed of light, constitute the required pseudo-range measured values.

Various options are available for the user terminal design:

(1) Pseudo-range values may be transmitted via the report-back transmitter, eliminating the need for the position computation function in the micro-processor or,

(2) Computed user position latitude/longitude coordinates may be transmitted via the report-back transmitter or,

(3) User position coordinates may be displayed or otherwise used directly by the user terminal when a report-back transmitter is not required.

Detailed specifications are given in Section 6.0 in the Appendix.

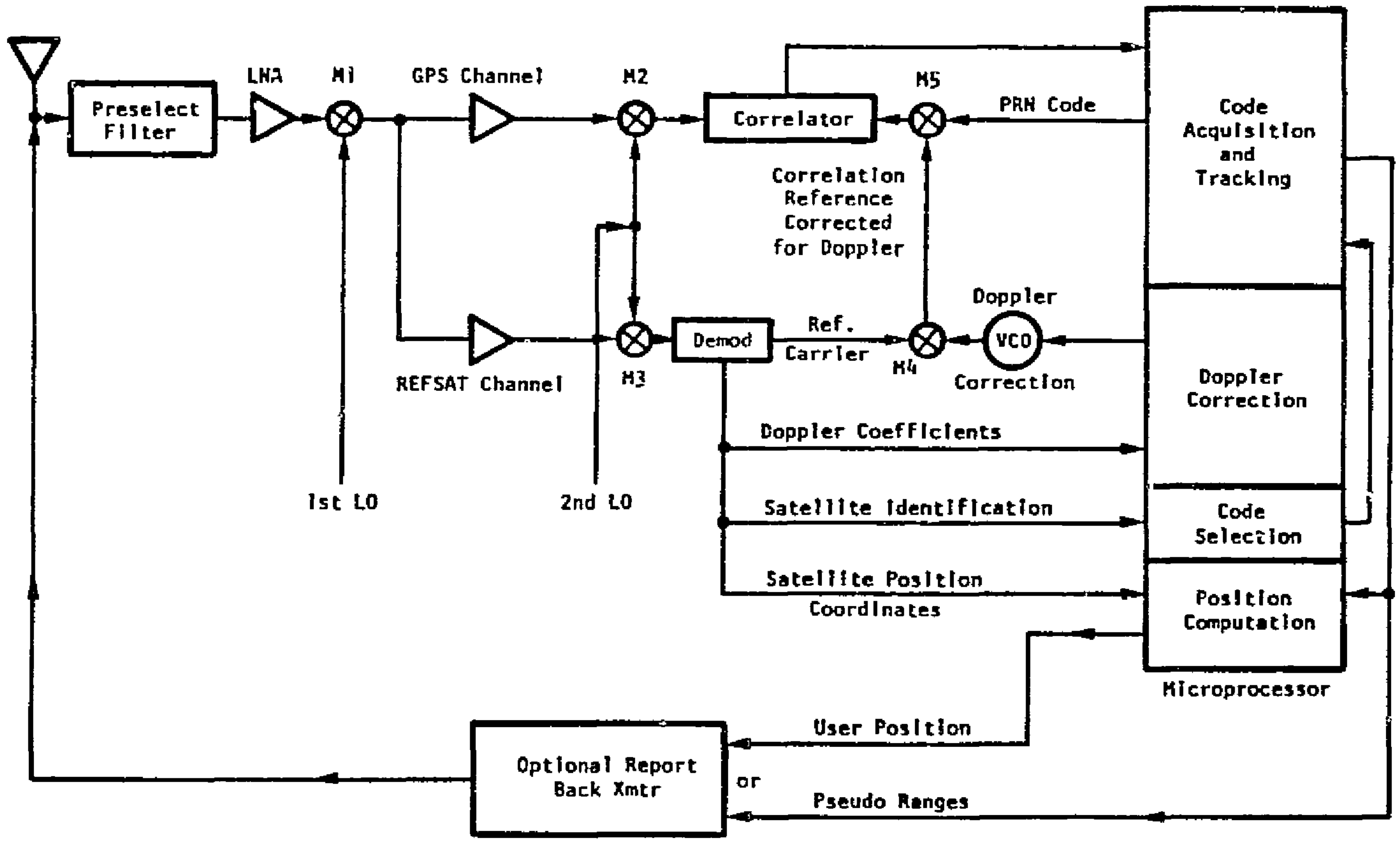


Figure 4-1. Simplified Block Diagram, GPS/REFSAT Mobile Terminal.

5. GPS/REFSAT Remote Control Station

The GPS/REFSAT remote control station (RCS) as part of the REFSAT system is illustrated in Figure 1-2. The remote control station performs three primary functions:

(1) Generation and transmission of the REFSAT reference carrier and REFSAT data message for relay broadcast by a geostationary reference satellite,

(2) Generation and transmission of a polling message to control those user terminals having a report-back capability and

(3) Reception and processing of report-back messages.

Figure 5-1 illustrates these functions.

5.1 Generation of the REFSAT Data Message

The REFSAT data message provides information to all users to aid in rapid acquisition of the 4 GPS satellites visible with minimum horizontal dilution-of-precision (HDOP). In order to accomplish this function, the remote control station must have access to the weekly navigation message upload data for the entire constellation of GPS satellites.

The remote control station selects those 4 GPS satellites which are visible and provide the minimum HDOP over the REFSAT user area. The selection should be updated at 15-minute intervals.

In addition, the remote control station computes doppler coefficients for the four selected GPS satellites to allow computation of GPS signal doppler shifts by the individual user terminals. This portion of the REFSAT data message should be updated at 2-minute intervals.

For navigation, and other users wishing to report their positions, the remote control station computes position coordinates for the four selected GPS satellites for inclusion in the REFSAT data message. A 4-second update interval is available and provided in the REFSAT data message (See Figure 5-1).

5.2 REFSAT Reference Carrier and Message Timing

The REFSAT reference carrier provides each user terminal with a precision frequency reference, allowing rapid GPS satellite signal acquisition without the necessity to perform a frequency search. The reference carrier must be maintained within about 50 Hz of its nominal value as received at a user terminal.

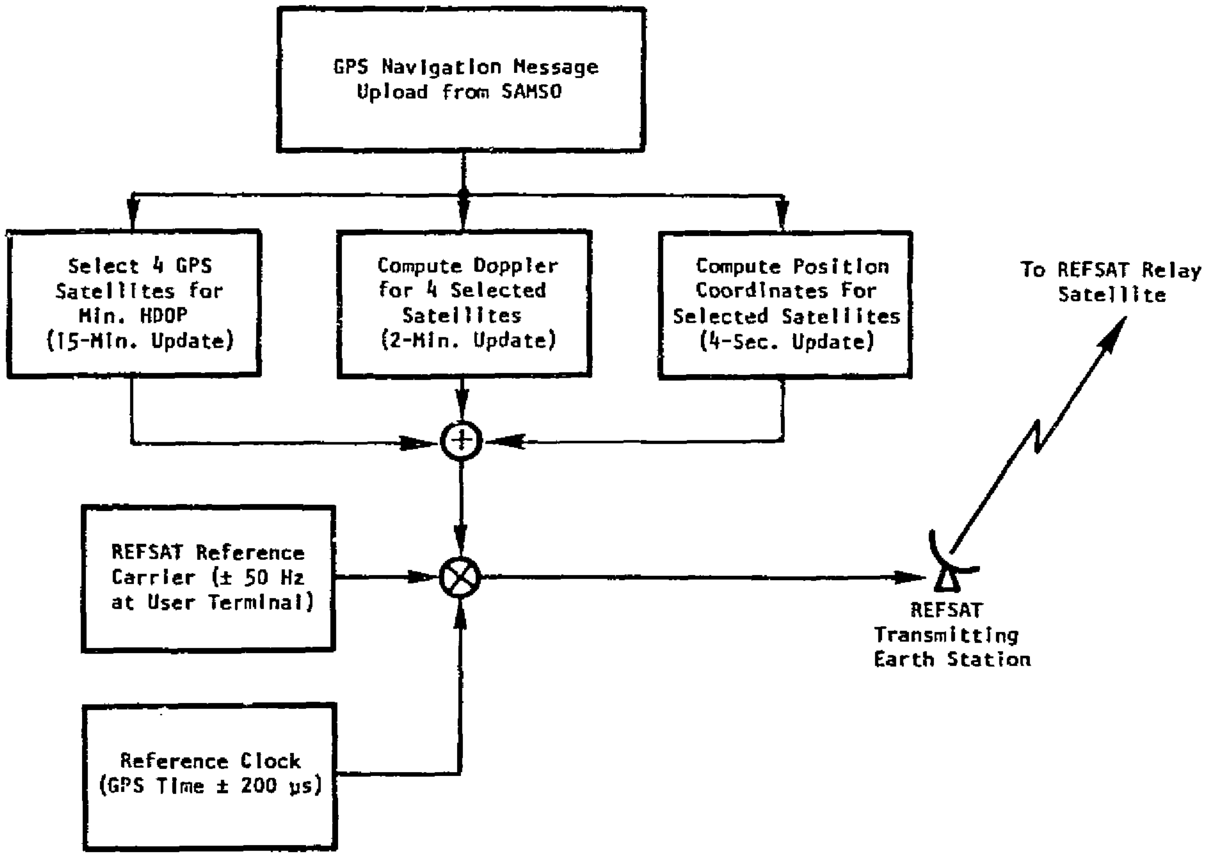


Figure 5-1. Simplified Functional Block Diagram, REFSAT Remote Control Station.

In order to allow user terminals to properly associate measured pseudo-range values with the corresponding GPS satellite position coordinates, it is necessary that the REFSAT data message be synchronized with GPS system time to an accuracy of about 200 microseconds.

6. Civil-User Requirements

An examination of civil-user requirements is important in the GPS/REFSAT definition phase to identify market potentials which in turn determine:

- Geographical areas to be covered
- Position accuracy requirements
- Acceptable unit costs for mobile terminals
- Position update rate requirements

The major findings of a user requirements study performed for NASA are summarized on Table 6-1*. "Estimated User Volume" (number of users) and "Estimated Dollar Volume" were computed from the study data, weighting each by the tabulated "Estimated Probability of Use".

Two distinct user functions are identified:

(1) Maritime Navigation Function: Permits a user to determine its own position at intervals to compute present position, present heading, and distance tr. eled. User terminal makes direct use of measured position data.

(2) Location Report-back Function: Allows current position of a remote user to be determined. The remote user terminal transmits measured position data to some central location, making no direct use of the data itself.

* "Definition Study of Land/Sea Civil User Navigational Location Monitoring Systems For NAVSTAR GPS", Task 1, User Requirements, September 1978, Prepared by Magnavox for NASA/GSFC Contract NAS5-23425.

USER		AREA	HORIZONTAL ACCURACY (METERS)	UPDATE INTERVAL (MINUTES)	ESTIMATED # OF USERS	ACCEPTABLE TERMINAL COST (K$)	ESTIMATED PROBABILITY OF USE	ESTIMATED USER VOLUME	ESTIMATED DOLLAR VOLUME (K$)
A IA	USCG VESSELS-LAW ENFORCEMENT	SU	100.0	0.1	1,000	10.0	0.80	800	8,000
A IB	USCG SAR-PEOPLE	SW	1,000.0	0.1	10,000	10.0	0.80	8,000	80,000
A II	US MERCHANT FLEET	SW	500.0	1.0	2,000	10.0	0.50	1,000	10,000
AIII1	US TOWING VESSELS	SW	500.0	1.0	5,000	10.0	0.10	500	5,000
AIII2	US VESSELS & BARGES	SW	7,000.0	1.0	30,000	10.0	0.10	3,000	30,000
A IV	US PASSENGER SHIPS	SW	500.0	1.0	7,000	50.0	0.50	3,500	175,000
A V	US RECREATIONAL BOATS	SU	200.0	1.0	9,000,000	2.0	0.01	90,000	180,000
A VI	US DOM. FISHING VESSELS	SW	500.0	1.0	20,000	2.0	0.02	400	800
B IA	US DOM. FISHING VESSELS	SW	200.0	720.0	20,000	5.0	0.10	2,000	10,000
B IB	FOREIGN FISHING VESSELS	SW	2,000.0	720.0	1,000	5.0	0.50	500	2,500
B IC	OIL TANKERS (FOREIGN REGISTRY)	SW	2,000.0	15.0	3,700	5.0	0.70	2,590	12,950
B ID1	US TOWING VESSELS	SW	1,000.0	15.0	5,000	2.0	0.20	1,000	2,000
B ID2	US BARGES	SW	1,000.0	15.0	30,000	2.0	0.20	6,000	12,000
B IE	GENERAL CARGO VESSELS	SW	1,000.0	15.0	8,300	5.0	0.20	1,660	8,300
B IIA1	US TRUCKS-REGULAR	LU	2,000.0	240.0	1,000	2.0	0.05	50	100
B IIA2	US TRUCKS-SPECIAL	LU	2,000.0	30.0	300	2.0	0.05	15	30
B IIB	RR CARS-SENSITIVE CARGO	LU	1,000.0	15.0	1,000	2.0	0.10	100	200
BIIIA	METEOR. BUOYS	SW	200.0	30.0	1,000	5.0	1.00	1,000	5,000
BIIIB1	METRO BALLOONS	BW	1,000.0	15.0	1,000	2.0	0.70	700	1,400
BIIIB2	BALLOONS-RADIOSONDE	BU	*	0.1	73,000	0.1	0.50	36,500	3,650
BIIIC	OTHER DATA COLL. PLATFORMS	LU	1,000.0	720.0	1,000	2.0	0.70	700	1,400
B IVA1	POLICE CARS	LU	15.0	0.5	2,000	2.0	0.20	400	800
B IVA2	EMERG. VEHICLES	LU	150.0	0.5	10,000	2.0	0.30	3,000	6,000
B IVA3	PUBLIC TRANSPORT	LU	150.0	0.5	3,000	2.0	0.10	300	600
B IVA4	UTILITY VEHICLES	LU	150.0	1.0	3,000	2.0	0.10	300	600
B IVA5	PARK POLICE	LU	50.0	1.0	2,000	2.0	0.20	400	800
B IVC1	FORESTERY SERVICE	LU	150.0	1.0	700	5.0	0.70	490	2,450
B IVC2	STATE POLICE CARS	LU	1,000.0	1.0	10,000	2.0	0.30	3,000	6,000
B V	GEOLOGY	LW	30.0	60.0	500	5.0	0.30	150	750
B VI	GEODESY	LW	0.1	720.0	100	20.0	0.50	50	1,000
BVII	COMMERCIAL TRUCKING (UNSCHEDULED)	LU	1,500.0	60.0	200,000	1.4	0.80	160,000	224,000

NOTES: * 1 METER/SEC. VELOCITY MEASUREMENT REQUIRED.
ESTIMATED DOLLAR VALUE = (ESTIMATED # OF TERMINALS)*(ESTIMATED PROB. OF USE)*ACCEPTABLE COST PER TERMINAL)
ESTIMATED USER VOLUME = (ESTIMATED # OF TERMINALS)*(ESTIMATED PROB. OF USE)
USER CODES A = MARITIME NAVIGATION FUNCTION B = LOCATION REPORT-BACK FUNCTION
AREA CODES SU = SEA, US ONLY LU = LAND, US ONLY SW = SEA, WORLD-WIDE USE LW = LAND, WORLD-WIDE USE
BU = LAND & SEA, US ONLY BW = LAND & SEA, WORLD-WIDE USE

Table 6-1. Survey of User Requirements.

Appendix

Performance Specification

For

REFSAT/NAVSTAR Civil User System

July 1980

National Aeronautics and Space Administration

Goddard Space Flight Center

Greenbelt, Maryland 20771

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LIST OF FIGURES

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Performance Specification
for
REFSAT/NAVSTAR Civil User System

1.0 Scope

This specification defines the performance requirements for a REFSAT/NAVSTAR GPS Civil User System including a geostationary reference satellite (REFSAT), a Remote Control Station (RCS) and REFSAT Mobile Terminals (RMT).

2.0 Applicable Documents

a) "Definition Study of Land/Sea Civil User Navigation Location Monitoring Systems for NAVSTAR/GPS" prepared by Magnavox Government and Industrial Electronics Company, September 1978.

b) "The REFSAT Approach to Low-Cost GPS Terminals" NASA/GSFC Technical Memorandum No. TM 79655 October 1978.

c) "System Segment Specification for the User System Segment of the NAVSTAR Global Positioning System" SS-US-101B 30 Sep 74, USAF Space and Missile System Organization.

d) "Space Vehicle Navigation Subsystem and NTS PRN Navigation Assembly/ User System Segment and Monitor Station", Rockwell International Corp. Interface Control Document No. MH08-00002-400, 13 Apr 77.

e) "REFSAT Low-Cost GPS Terminal Hardware Design Report", prepared by Systematics General Corporation, National Scientific Laboratories, for NASA/Goddard Space Flight Center, Greenbelt, Maryland, May 1980.

3.0 Background

NAVSTAR is a major, space-based navigation system being implemented to satisfy the military requirements of the Department of Defense. The characteristics and capabilities of NAVSTAR are such that it can provide for a wide variety of civil user needs for navigation and position location.

The Department of Defense (DOD) currently plans to make the navigation signals from the NAVSTAR System available to civil users. Inherent in the NAVSTAR design is the ability to provide a spectrum of location accuracies (from 10 to 100 meters) depending on the complexity of the user receiving terminals.

DOD is currently considering a reduction in the C/A code accuracy, when NAVSTAR GPS becomes operational in 1986 or 1987, to provide a CEP (circular probable error) of 200 meters (50% of the time) with an upper accuracy limit of 500 meters. This would still meet many civil user needs (see Table 6-1).

Military receiver terminals, due to their sophistication, are quite costly. To provide a navigation system with moderate performance to a broad base of civil users, it is proposed to use the military NAVSTAR system with lower cost, less sophisticated receivers and still obtain navigation performance comparable to Loran C but better than Omega. This is to be accomplished by providing navigation-aiding signals from a reference satellite (REFSAT) in geostationary orbit for CONUS, Alaska, and maritime reception. This obviates the necessity for the ground receivers to contain a precision oscillator and to perform certain computations and thus permits a less complex, lower cost mobile terminal design.

This document provides the system definition and performance requirements for the REFSAT/NAVSTAR System as well as subsystem requirements for the Remote Control Station, REFSAT Satellite, and Mobile Terminal.

4.0 System Definition

The REFSAT/NAVSTAR System is a radionavigation aid designed for civil and maritime users. REFSAT provides a simplified method for determination of horizontal geographical coordinates (X-Y position) by augmenting the signal structure of an existing military radio navigation system, NAVSTAR/GPS.

Figure 4-1 depicts the major elements of the REFSAT/NAVSTAR System.

NAVSTAR System Elements

- NAVSTAR Satellites: A constellation of radionavigation satellites (18 for Phase III), part of the military global positioning system (GPS).

- Master Control Station: The central control facility which uploads navigation-aiding data and timing information to the individual NAVSTAR satellites.

- Monitor Station: Monitors the individual NAVSTAR satellites and provides updated ephemeris and other data to the Master Control Station.

REFSAT System Elements

- Remote Control Station: The earth transmitting station originates the navigation-aiding REFSAT signal. Ephemeris and other data is accepted from the NAVSTAR Master Control Station. The Remote Control Station selects those four NAVSTAR satellites which currently provide maximum position fix accuracy to mobile terminals within the REFSAT coverage area and computes navigation-aiding data for broadcast via the REFSAT satellite.

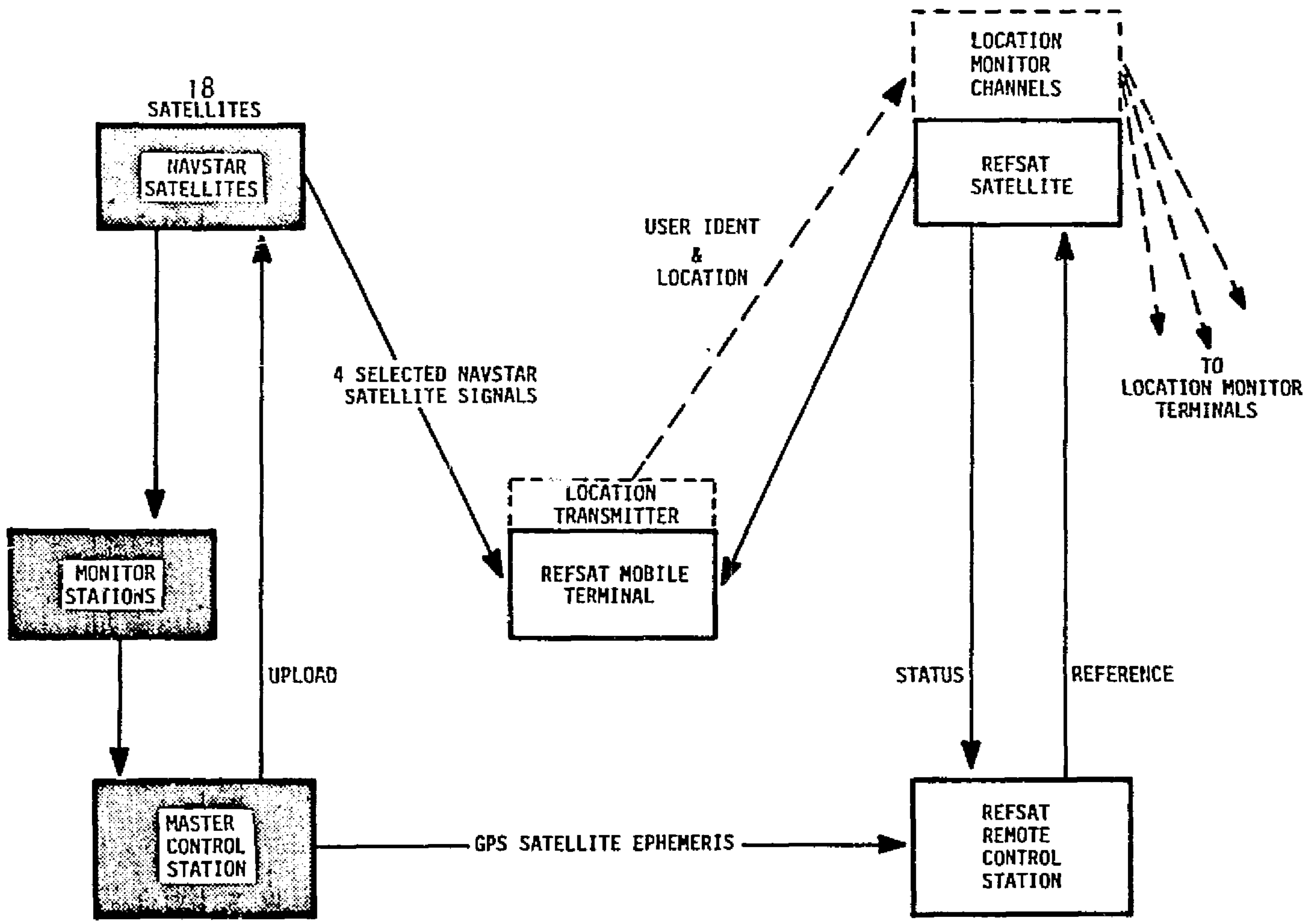


Figure 4-1. REFSAT/NAVSTAR System Elements.

- REFSAT Satellite: A geostationary relay satellite that accepts uplink signals from the Remote Control Station and broadcasts those signals over broad geographical areas. The REFSAT satellite may include a location monitor transponder for selected users to "report-back" their geographical position.

- REFSAT Mobile Terminal: Individual user which makes use of the navigation-aiding signal broadcast from the REFSAT to select, acquire, and process four NAVSTAR satellite signals to determine the position of the user terminal. Certain user terminals may include a "report back" function, wherein the user's position is transmitted to a central location monitor station via the REFSAT satellite.

- Location Monitor Station: Receiving earth stations accepting user "report-back" signals relayed by location monitor transponder contained in the REFSAT satellite.

4.1 Principle of Operation

User terminal position coordinates, using the NAVSTAR/GPS are determined by 4-dimensional (3 position coordinates and time) "triangulation". Pseudo-ranges to 4 selected NAVSTAR satellites are measured at the user terminal. This data is then combined with known (computed from ephemeris data) NAVSTAR satellite locations.

The navigation-aiding signal broadcast by the REFSAT consists of:

- A precision reference carrier,
- Identification of the four NAVSTAR satellites which currently provide the most favorable "triangulation" geometry,

- Doppler coefficient data, allowing a user terminal to compute the doppler shift of each selected NAVSTAR satellite signal. This information, in conjunction with the precision reference carrier, allows the user terminal to begin NAVSTAR signal acquisition "on frequency",
- Position coordinates for the four selected NAVSTAR satellites, relieving the user terminal of the task of demodulating the NAVSTAR data message and computation of satellite position from ephemeris data contained in that message.

A user terminal, with the aid of the REFSAT signal, may then rapidly acquire the four selected NAVSTAR satellite signals by performing a code delay search, matching the timing of locally generated pseudo-random-noise (PRN) codes with the appropriate NAVSTAR signals. Pseudo-ranges to the selected satellites are then determined from the relative timing of local PRN codes.

5.0 System Performance Requirements

The performance specifications for the REFSAT/NAVSTAR System are shown in Table 5-1. The navigation signals processed by the REFSAT Mobile Terminal received from REFSAT and NAVSTAR satellites shall have the characteristics shown in Table 5-2. Under the specifications of Tables 5-1 and 5-2, the REFSAT/NAVSTAR system shall comply with the following performance requirements:

5.1 Time-to-First-Fix (TTFF)

TTFF is defined as the amount of time required to produce a single navigation fix from the start of the acquisition mode. With a probability of success of 0.95, each REFSAT Mobile Terminal shall achieve a first fix within 100 seconds.

5.2 Time-to-Subsequent-Fix (TTSF)

TTSF is the time necessary to reacquire the navigation signals and execute a navigation solution. With a probability of 0.95, TTSF shall be less than 10 seconds.

5.3 Position Accuracy

The 1σ horizontal position error shall not exceed 100 meters.

The Department of Defense (DOD) is currently considering a reduction in the C/A code accuracy, when NAVSTAR GPS becomes operational in 1986 or 1987, to provide a CEP (circular probable error) of 200 meters with an upper limit of 500 meters. In any event, the C/A code accuracy is sufficient to meet the majority of civil user applications.

TABLE 5-1

RMT PERFORMANCE SPECIFICATIONS

C/N_o at RMT receiver input (REFSAT link)	43 dB-Hz, minimum
C/N_o at RMT receiver input (GPS links)	38 dB-Hz, minimum
User Velocity	35 m/sec, maximum
Interference to Signal Ratio (GPS links)	25 dB, maximum
User Position Estimate Uncertainty for Acquisition	150 km, maximum

TABLE 5-2

SATELLITE RF SIGNAL CHARACTERISTICS

	NAVSTAR	REFSAT
Center Frequency (Nom)	1575.42 MHz	1555 (Alaska) 1560 MHz (CONUS)
Bandwidth	20 MHz	10 kHz, each signal
Modulation	QPSK	FSK (-10 dB reference carrier)
PRN C/A Code	1023 bit Gold Code	
C/A Code Rate	1023 kbps	
Carrier Frequency Stability	$\leq$ 1 part in 10^8	$\leq$ 2 parts in 10^8
In-Band Spurious Emissions	< -40 dB below unmodulated carrier level	< -40 dB below unmodulated carrier level

6.0 Remote Control Station Characteristics

The function of the REFSAT Remote Control Station (RCS) is to:

- accept NAVSTAR satellite ephemeris, almanac, and other data from the GPS Master Control Station,
- select the four NAVSTAR satellites which currently provide the most favorable "triangulation" geometry for users in the REFSAT coverage area,
- compute doppler coefficient data for each selected NAVSTAR satellite,
- compute current position coordinates for each of the selected NAVSTAR satellites,
- transmit this data along with a precision reference carrier signal to the REFSAT satellite for broadcast over the REFSAT service area (C-Band uplink).

6.1 Transmitted Data

The message data transmitted to REFSAT by the RCS shall include:

a) identification for the four selected NAVSTAR satellites

b) NAVSTAR satellite doppler shift coefficients

c) NAVSTAR satellite position coordinates

d) timing and synchronization as required.

6.2 EIRP

The effective isotropic radiated power (EIRP) of the remote control station shall be 39 dBW, minimum.

6.3 RF Signal Characteristics

6.3.1 Uplink Frequencies

Dual uplink frequencies in C band (6 GHz nominal), separated by 5 MHz, shall be transmitted by the RCS (separate signals for Alaska and CONUS coverage).

6.3.2 RF Signal Bandwidth

Each uplink RF signal shall have an RF bandwidth of 10 kHz, minimum.

6.3.3 Frequency Stability

The RCS shall maintain reference frequency stable within 2 parts in 10^8 relative to the NAVSTAR satellite signals, for zero doppler.

6.3.4 Spurious Emissions

In-band spurious emissions shall be less than -40 dB referred to the unmodulated carrier level.

6.3.5 Signal Structure

Each uplink signal shall consist of a reference carrier and associated FSK modulated (128 bps digital data stream) signal. The power contained in the FSK signal shall be approximately -10 dB relative to the reference carrier.

The format of the RCS uplink data signal is shown on Figure 6-1. One data frame consists of 4 subframes each of 1 second duration for each of the four selected NAVSTAR satellites. Each subframe shall contain sync and timing data, NAVSTAR satellite position coordinates (X, Y, Z earth-centered), doppler

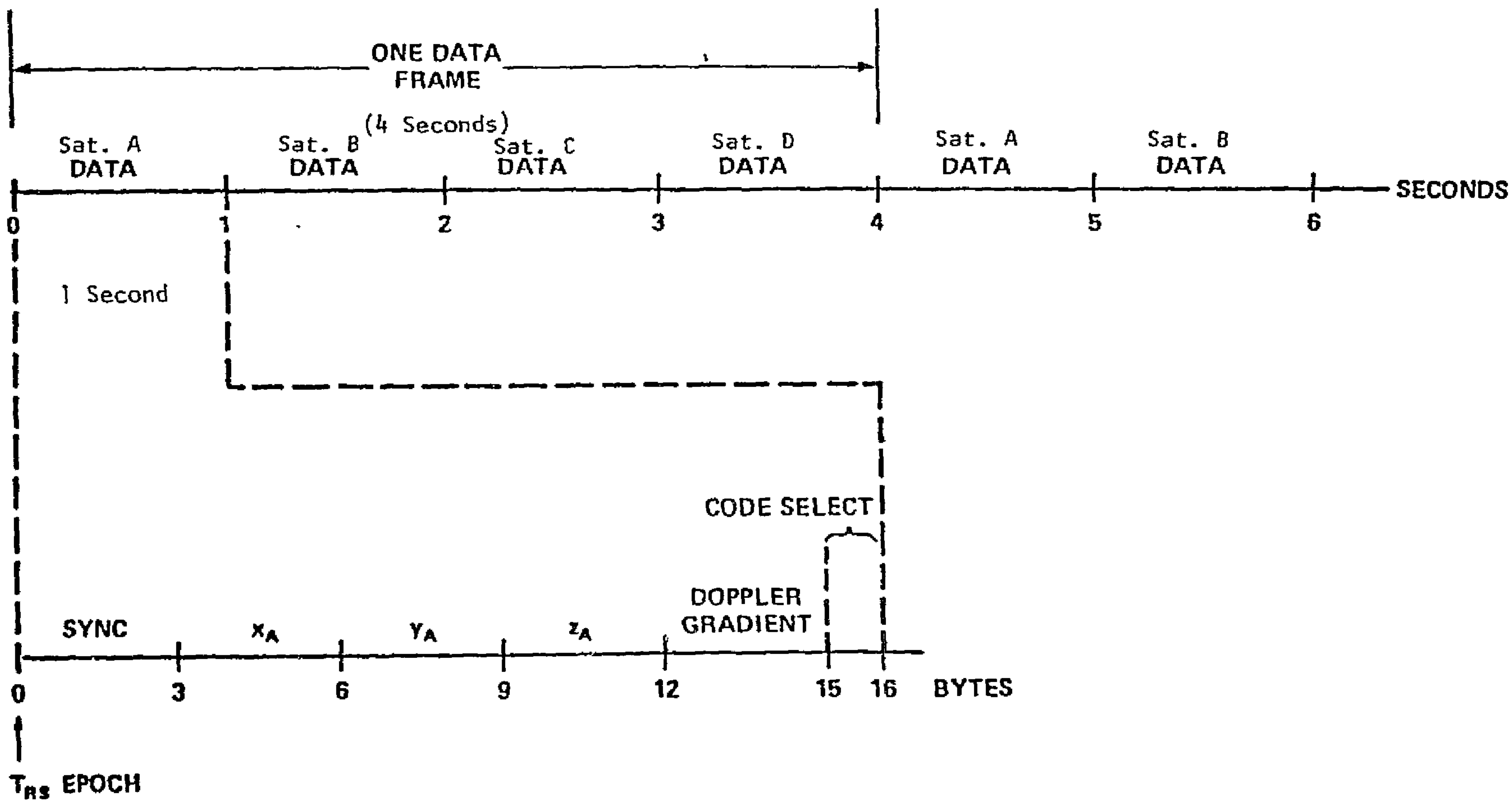


Figure 6-1. RCS Signal Format.

gradient data, and NAVSTAR satellite code identification. Doppler gradient data shall allow initial estimates of the doppler shift associated with each GPS satellite signal to an accuracy of $\pm$ 100 Hz prior to acquisition.

Timing of the data signal as broadcast from the REFSAT shall be maintained synchronous with GPS system time within $\pm$ 200 microseconds.

System modulation shall be non-return-to-zero frequency-shift keyed at 128 bps. Doppler gradient data shall be updated at intervals not to exceed 2 minutes. Satellite position coordinates whall be updated each major frame.

7.0 REFSAT Satellite Characteristics

7.1 Typical Operational Requirements

7.1.1 Orbit

REFSAT shall be placed in geostationary orbit at a particular West Longitude location for optimum CONUS and Alaska coverage.

7.1.2 Typical Geostationary Location

REFSAT shall be centered over the equator at 130 degrees West Longitude within $\pm$ 0.5 degrees.

7.1.3 Drift Correction

Orbital position location shall be maintained by control thrusters.

7.1.4 Attitude Control

Three axis attitude control shall be maintained to an accuracy of $\pm$ 0.1 degrees per axis.

7.1.5 Primary Power

Sun tracking extensible solar arrays shall provide primary spacecraft power. These arrays shall be designed to fit folded within a Delta launch vehicle shroud. Initial overdesign shall be 25% to compensate for deterioration over the satellite lifetime. The estimated area of solar cells is 10 square meters.

7.1.6 Power Storage

Power storage shall be accomplished by dual nickel cadmium batteries. These batteries shall be rechargeable singly through the solar arrays.

7.1.7 Solar Eclipse

During solar eclipses (88 days per year, 65 minutes maximum duration) REFSAT shall be capable of operating only on battery power.

7.1.8 Temperature Control

Electronics bay temperature shall be maintained to 20°C $\pm$ 15°C.

7.1.9 Reliability

REFSAT shall be designed to meet a 5-year mission requirement with a probability of not less than 0.995.

7.2 Transponder

The REFSAT transponder shall receive uplink C band signals from the RCS containing user navigation coding information. Two channels shall be provided by the transponder, one for the signal intended for users located in the contiguous 48 states (CONUS), and the other for the signal intended for users located in Alaska. The transponder shall down convert these signals to L-band, provide amplification and transmit the converted signals on the CONUS and Alaska antenna beams, respectively.

7.2.1 Input Frequencies

The frequencies of the CONUS and Alaska signals received by REFSAT from RCS shall be nominally at 6 GHz and separated by 5 MHz.

7.2.2 Output Frequencies

Transmitted frequencies shall be nominally 1555 and 1560 MHz, each with a bandwidth of 10 kHz, minimum.

7.2.3 Spurious Emissions

Spurious emissions shall be at least 40 dB below the unmodulated carrier level.

7.2.4 Frequency Conversion

The transponder shall convert the dual C band constant amplitude signals to dual L band signals with a local oscillator stability of 2 parts in 10^8 relative to the NAVSTAR satellite signal carrier frequency. During frequency conversion, baseband data shall be preserved.

7.2.5 Carrier Phase Noise

The phase noise spectral density of an unmodulated carrier relayed by REFSAT shall be such that a phase locked loop of 10 Hz one-sided noise bandwidth shall be able to track the carrier to an accuracy of 0.1 radians RMS.

7.2.6 Power Input to Antenna

The transmitter power input to the antenna shall be 10 Watts average for each of the two channels. No power backoff shall be utilized.

7.2.7 RF Power Stability

RF power shall be stable within $\pm$ 0.5 dB per year.

7.2.8 Noise Temperature

Transponder receiver system noise temperature shall be 1000 K, or less.

7.2.9 Phase Linearity Over Operating Bandwidth

Departure from linear phase versus frequency shall be less than $\pm$ 0.32 radian over the operating bandwidth.

7.2.10 Redundant Design

Redundant transponders shall be utilized in REFSAT. In case of malfunction, transponders shall be switchable by ground command.

7.3 Antenna Characteristics

The REFSAT satellite antennas shall consist of an uplink receive antenna and downlink area coverage transmit antennas. If the REFSAT Mobile Terminal's "report-back" transmitter is utilized, the downlink and uplink satellite antennas shall also act as receive and transmit antennas, respectively, for the REFSAT Mobile Terminal location monitor signals.

7.3.1 Uplink REFSAT Antenna

The RCS uplink receive antenna shall have the following characteristics:

Operating Frequency	C band
Form	TBD
Gain	23 dBi, minimum
Beam pattern	Elliptical
Polarization	Right hand circularly polarized
Boresight point	TBD

7.3.2 Downlink Area Coverage REFSAT Satellite Antennas

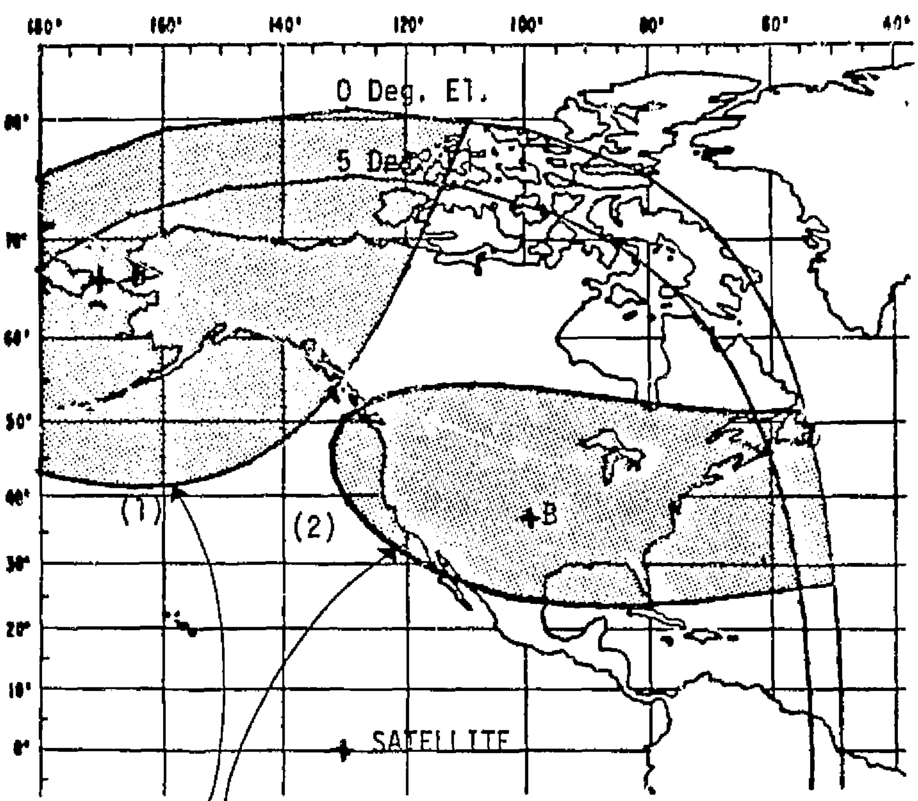
The downlink area coverage transmitting antennas shall have the following characteristics:

Operating Frequency	L band
Form	Planar array
Gain	31.0 dBi, minimum for CONUS and Alaska beams.
Polarization	Right hand circularly polarized
Beam patterns	Elliptical

The beam sizes and orientations, boresight points, and footprints are shown in Figure 7-1.

7.4 Location Monitor REFSAT Transponder

The REFSAT location monitor transponder in the satellite which relays location information to the Location Monitor Stations shall have the following characteristics.



	REFSAT	0 Deg.; W 130 Deg. Long.	
(1)	BORESIGHT	65 Deg. Lat.; W 170 Deg. Long. Major Axis Rotated 20 Deg. CCW from East	
	ANTENNA	7 Deg. Major Axis 3 Deg. Minor Axis	3 dB points
(2)	BORESIGHT	37 Deg. Lat.; W 98 Deg. Long. Major Axis Rotated 17 Deg. CW from East	
	ANTENNA	9 Deg. Major Axis 3 Deg. Minor Axis	3 dB points

Figure 7-1. REFSAT Antenna Characteristics

7.4.1 Power Output

The power output of the location monitor power amplifier shall be 10 watts (dBW), minimum.

7.4.2 Limiter

Power output shall be hard limited such that system noise alone will provide full power output.

7.4.3 Input and Output Frequencies

Input and output frequencies shall be in the L and C bands, respectively.

7.4.4 Bandwidth

The Location Monitor channel bandwidth shall be 10 kHz, minimum.

7.4.5 Antenna

The Location Monitor transponder shall utilize the REFSAT CONUS and Alaska L band antennas for reception and the C band antenna for transmission.

7.5 Physical Characteristics

7.5.1 Transponder

The REFSAT transponder shall have the following characteristics:

Size	less than 0.018 m^3 volume
Weight	not more than 16 kg
Design operating temperature	20°C ± 15°C

7.5.2 Downlink Antenna

The downlink antenna shall have the following characteristics:

Size	Unfolded	not to exceed 2.4m L x 2.4m W x 0.15m D
	Folded	to fit within the Delta launch vehicle shroud. Dimension not to exceed 2.4m L x 1.2m W
Weight	not to exceed 6 kg	

7.5.3 Solar Arrays

Dual solar tracking arrays shall provide the primary spacecraft power (except during solar eclipse.) The arrays shall be integrated to fit within the Delta launch vehicle shroud. Estimated sail area is $10m^2$.

8.0 REFSAT Mobile Terminal Characteristics

8.1 General

This section defines specifications for the design of a low-cost receiver terminal for civil users of the GPS system. A number of the tasks involved in performing a navigation "fix" are common to all users at a given instant, while others are unique (location dependent) to each user. Central to the design is the concept of performing common tasks at a central location and relaying the results in the form of acquisition aiding and reference signals via a geostationary reference satellite (REFSAT) to each user terminal. By this method, the REFSAT system reduces the cost and complexity of civil user receivers.

Reference information relayed by the REFSAT includes GPS satellite selection for optimum "triangulation" geometry, a priori doppler information and precomputed GPS satellite position coordinate data. The REFSAT Mobile Terminal (RMT) shall be designed to receive these multiple navigation signals and data and, by solution of the appropriate navigation equations, permit users to determine their latitude and longitude (X,Y) positions within the REFSAT service coverage area on the earth.

An optional add-on package to the RMT receiver shall consist of a Location Monitor Transmitter (LMT) to transmit user location to a terrestrial receiver via REFSAT.

8.2 User Area Coverage

The baseline system operating areas for the civil user terminals are the contiguous U.S. states (CONUS) and Alaska, including the 200-nautical mile territorial limits. Typical antenna footprint patterns are shown in Figure 7-1. Users in Alaska and CONUS will operate on different frequencies (e.g. 1555 and 1560 MHz) to receive navigation signals optimized for their area.

8.3 Performance Requirements

The REFSAT Mobile Terminal receivers shall be capable of the following performance while operating under the conditions given in Tables 5-1 and 5-2.

8.3.1 Time-to-First Fix

TTFF is defined as the amount of time required to produce a single navigation fix from the start of the acquisition mode. With a probability of success of 0.95, each Mobile Terminal shall achieve a first fix within 100 seconds.

8.3.2 Time-to-Subsequent-Fix

TTSF is the time necessary to reaquire the navigation signals and execute a navigation solution. With a probability of 0.95, TTSF shall be less than 10 seconds.

8.3.3 Horizontal Position Accuracy

The 1σ error in calculated X-Y user horizontal position shall not exceed 100 meters. (See Section 5.3).

8.3.4 Data Recovery Performance

The REFSAT Mobile Terminal receivers shall recover the data from the REFSAT signal with a Bit Error Rate (BER) not greater than 1×10^{-6}.

8.4 Design Parameters

Parameters used in the design of a user REFSAT Mobile Terminal receiver are given in the following paragraphs.

8.4.1 Received Power Levels

Received power levels for the C/A code (L_1) signal, at elevation angles above five degrees, shall be -160 dBW, minimum, from any NAVSTAR GPS satellite and -147 dBW, minimum, from REFSAT at the output terminals of a 0 dBi gain, right hand circularly polarized antenna.

8.4.2 Noise Temperature

The REFSAT Mobile Terminal system noise temperature (including antenna) shall be 500 K or less.

8.4.3 RF Signal Structure

Received RF navigation signal characteristics from NAVSTAR and REFSAT satellites are listed in Table 5-2. RF signal characteristics have been defined in Section 6.3. The RMT does not need to demodulate the GPS navigation data contained in the NAVSTAR signals.

8.4.4 REFSAT Mobile Terminal Receiver Antenna

The REFSAT Mobile Terminal receiver antenna shall have the following characteristics:

Frequency coverage	-	L band
Pattern	-	Hemispherical
Gain	-	3 dB at zenith, 0 dBi at 5° elevation angle
Polarization	-	Right Hand Circular

8.5 REFSAT Mobile Terminal Transmitter (MTT)

The MTT transmitter shall transmit digital data position coordinates including an identification code to the REFSAT transponder for relay to a ground monitor station.

8.5.1 Power Output

The MTT transmitter power output shall be at least 10 Watts (10 dBW), average.

8.5.2 Transmit Antenna

The MTT shall utilize the REFSAT Mobile Terminal receiver antenna. The tranmit antenna gain shall exceed 0 dBi for a 5° elevation angle or greater.

8.5.3 Transmission Frequency

Carrier signal frequency shall be 1600 MHz, nominal.

8.5.4 Baseband Characteristics

The baseband modulation signal shall be a binary, non-return-to-zero waveform.

8.5.4.1 Modulation

Modulation shall be coherent binary phase-shift keyed at a rate not exceeding 0.5 kilobits per second (kbps). This is equivalent to an RF bandwidth of 2.0 kHz.

8.5.4.2 Bandwidth

Digital data shall be transmitted in a bandwidth of 10 kHz.

8.5.4.3 Data Content

Transmitted data shall include user identification (ID) and latitude and longitude position coordinates, plus preamble.

8.5.4.4 Data Access

The transmission of position data to location monitors via REFSAT shall be by time-division multiple access with preassigned transmission time slots. The time slots shall be referenced to system time as corrected by user position. During the preassigned user time slot, the transmitter shall send a 25 millisecond (ms) burst of information at 4 kbps. Each message shall consist of a preample to generate carrier reference and establish synchronization, a user identification word, and latitude and longitude position.

Estimated number of bits is as follows:

Preamble	-	50 bits
Station ID.	-	17 bits
Latitude	-	15 bits
Longitude	-	15 bits
Total		97 bits

8.5.5 Electromagnetic Compatibility

Out-of-band field strength shall be less than 23 dB uv/m/kHz when measured at a distance of 10 meters from the transmitter/receiver.

8.6 Functional and Physical Characteristics

User REFSAT Mobile Terminals shall simultaneously receive the navigation signals transmitted by the NAVSTAR satellites and the REFSAT transponder, providing the user with a two-dimensional horizontal position-fix capability.

8.6.1 Equipment Operation

User receivers shall perform the following functions:

a) a. Acquire the navigation-aiding signal generated by REFSAT,

b. Demodulate the REFSAT data message including:

1) NAVSTAR satellite identification
2) doppler coefficient data
3) NAVSTAR satellite position coordinates

c. Utilizing b 2) above in conjunction with the precision REFSAT carrier, compensate tuning of the receiver's GPS channel for doppler shift associated with each of the 4 selected NAVSTAR signals. NAVSTAR signal acquisition may then be accomplished without a frequency search.

d. Utilizing b 1) above, generate the 4 PRN codes needed to acquire the selected NAVSTAR signals.

e. Perform the required code delay search to acquire the 4 selected NAVSTAR signals.

f. Track the 4 selected NAVSTAR signals (in frequency and code delay) to allow measurement of pseudo-ranges.

g. Use measured pseudo-range values, and NAVSTAR position coordinates (from b 3)), to compute the position of the user terminal.

h. Display the user position (optional).

8.6.2 Required Skills

No special training or skills shall be required to operate the user REFSAT Mobile Terminals. The microprocessor shall operate from preprogrammed memories.

8.6.3 Physical Specifications

The following are design goals for the REFSAT Mobile Terminal receivers:

a. Weight 2.5 kg, maximum (excluding antenna)

b. Volume 5000 cm^3, maximum (exclusive antenna)

c. Power required 40 Watts, maximum

8.6.4 Environmental Performance

The user REFSAT Mobile Terminals (receiver and transmitter) shall operate over the following ambient environment conditions:

a. Temperature range - -20°C to +55°C

b. Humidity - 10% to 100% R.H.

c. Precipitation - to 16 mm/hr.

d. Vibration - 15 g's random

e. Shock - 300 g's maximum

f. Operating altitude - Sea level to 5000 meters

g. Icing on Antenna - up to 20 mm thickness

h. Wind - up to 100 knots, with icing, on antenna.

8.6.5 Reliability

The Mean-Time-Between-Failure (MTBF) for the user REFSAT Mobile Terminal shall not be less than 10,000 hours.

9.0 REFSAT/NAVSTAR Link Budgets

Link budget summaries for links in the NAVSTAR/REFSAT system are shown in Table 9-1. The links include the RCS to REFSAT uplink at 6 GHz, the REFSAT to RMT downlinks at 1555 and 1560 MHz, the GPS to RMT downlink at 1575 MHz, the RMT to REFSAT uplink at 1600 MHz, and the REFSAT to Location Monitor Station downlink at 4 GHz. The link calculations reflect the design values assumed in this specification for a worst-case RMT location.

Table 9.1

LINK BUDGETS IN THE REFSAT/NAVSTAR SYSTEM

	REFSAT Reference Signal				
	RCS/REFSAT 6 GHz up link	REFSAT/RMT 1555 and 1560 MHz down link	GPS/RMT 1575 MHz down link	RMT/REFSAT 1600 MHz up link	REFSAT/RCS 4 GHz down link
P_T, dBW	39.6 (EIRP)	12.6	13.1	10	7.1
G_T, dBW		31.0	12.0	0	26
L_{FS}, dB	-200.1	-188.4	-184.6	-188.4	-200.1
L_{ATM}, dB	-2.0	-1.0	-1.0	-1.0	-2.0
G_R, dBi	26	0	1.0	31.0	30.0
Polarization Loss, dB	-1.0	-1.0	-1.0	-3.0	-1.0
P_R, dBW	-137.5	-146.8	-160.5	-151.4	-140.0
T_{noise}, °K	1000	1000	1000	800	1000
Boltzmann's Constant	-228.6	-228.6	-228.6	-228.6	-228.6
Data-to-reference carrier ratio	-10	-10			
C/N_o, dB-Hz	51.1	41.8	38.1	48.2	58.6
Symbol Rate data, bps	128	128	N/A	4000	4000
Symbol Rate code, Mbps			1.023	N/A	N/A
E_b/N_o, dB data	30.0	20.7	N/A	12.2	22.6
E_b/N_o, dB code			-22.0	N/A	N/A