Telesat Canada

CONCEPT OF PROVIDING

POSITION DETERMINATION SERVICE VIA MSAT

Prepared for:
Communications Research Centre
Department of Communications

Submitted by:
T E L E S A T   C A N A D A

CONCEPT OF PROVIDING

POSITION DETERMINATION SERVICE VIA MSAT

Prepared for:
Communications Research Centre
Department of Communications

Submitted by:
T E L E S A T   C A N A D A

		Date
Prepared by:	Ignace R. Mnungi Sr. Service Development Engineer	Jan 26, 1987
Approved by:	[signature] Supervisor, Business Development Projects	Jan 26, 1987
	[signature] Manager, Business & Network Planning Development	Jan 26, 1987
Released by:	M. Zuliani Director, Satellite Services Planning & Development	Jan. 26 1987

MSAT ENGINEERING SUPPORT CONTRACT
DSS CONTRACT FILE OISM. 36001-2-2568
TASK NO. 26

EXECUTIVE SUMMARY

The provision of Location Determination Service via MSAT is viewed from two perspectives. The first perspective is whereby existing position determination systems such as Loran-C and the Navstar Global Positioning System (GPS) are used to derive position data. The MSAT satellite would then provide the necessary communications link to relay the position data to a central location. This is now called Dependent Radio Determination Satellite Service (DRDSS). The second perspective is whereby a Radio Determination Satellite Service (RDSS) package is "piggybacked" on MSAT satellites to do the actual position determination.

It is recommended that the first course based on DRDSS be pursued, with MSAT utilizing the Loran-C system as an interim measure until GPS is fully operational. The second option does not appear to be economically viable since the current MSAT satellite is severely power and bandwidth limited.

In the United States, the Federal Communications Commission (FCC) has allocated spectrum for RDSS and granted licenses to three operators: Geostar Corporation, McCaw Space Technologies Inc., and MCCA American Radiodetermination Corp. The U.S. operators envisage a dedicated system involving the deployment of two or more geostationary satellites. The current Canadian market for RDSS is insufficient to justify such a dedicated RDSS system in Canada. This market need can be met by using the MSAT system as proposed in the DRDSS concept. However, as the mobile satellite market grows, it may not be possible to support RDSS in the mobile satellite service spectrum.

This means that future RDSS growth would have to be accommodated in frequency bands allocated for these purposes. This spectrum may be used for position determination as an alternative to Loran-C or GPS, as well as for links to a central location. Therefore, the necessary spectrum allocations should be made to support future Canadian RDSS. In this regard, we recommend that the Department of Communications negotiate a spectrum sharing arrangement between Canada and the United States within the bands proposed by the FCC.

This report constitutes a preliminary concept evaluation of position determination via MSAT. We recommend, as the next step, that a detailed technical and economic study of the DRDSS concept be undertaken.

CONCEPT OF PROVIDING POSITION DETERMINATION SERVICE VIA MSAT

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

Position determination has many applications, such as:

- Geophysical Survey and Exploration
- Land Survey
- Aircraft and Marine Navigation
- Automobile Navigation
- Hazardous Cargo Control
- Wide Area Vehicle Management

In order to distinguish between the various applications of position determination, it is necessary to give a few definitions:

Radiodeterminattion: The determination of position, or the obtaining of information relating to position by means of the propagation properties of radio waves. [Code of U.S.A. Federal Regulations, Title 47, Part 2, Section 2.1]

Radionavigation: Radiodetermination used for the purpose of navigation including obstruction warning.

Radiolocation: Radiodetermination used for purposes other than those of radionavigation.

Radiodetermination Satellite Service (RDSS): A radio communication service for the purpose of radiodetermination involving the use of one or more space stations.
[Code of U.S.A. Federal Regulations, Title 47, Part 25, Section 25.201]

Most of the radiodetermination systems described in the literature use radio waves from a source external to the vehicle. These include Transit, Loran-C, the Navstar Global Positioning System (GPS) and Radiodetermination Satellite Service (RDSS). Chapter 2 provides a brief overview of Loran-C, Transit, GPS and RDSS, with respect to system concept, accuracy and limitations.

In Chapter 3, system concepts are proposed for those position determination systems that could be implemented via MSAT. "Dependent RDSS" (DRDSS) concept is described.

A preliminary market forecast for RDSS users is derived in Chapter 4.

Conclusions and recommendations are given in Chapter 5.

Appendix A gives the principle of operation of GPS NAVSTAR. A summary of the comparison of automatic vehicle location systems and a list of GPS equipment suppliers are given in Appendix B.

2.0 POSITION DETERMINATION SYSTEMS

2.1 LORAN-C

Loran-C is a triangulation principle based on pairs of ground transmitters that send radio pulses indicating the time that the pulses originated. Loran-C uses low-frequency pulses (100 kHz). A "master" station emits a pulse that is relayed by a distant "slave" station. Thus, both the original and relayed pulse are received by the vehicle (See Figure 1), enabling it to calculate the time it took a signal to travel from each beacon to the vehicle. The loran receiver then computes its distance from the master and slave, yielding a hyperbolic path along which the vehicle is located. A broadcast from a second master/slave combination gives a second hyperbolic plot; the intersection of the two represents the vehicle's location. Because Loran-C was originally set up by the U.S. Coast Guard for off-shore use, positioning becomes less accurate with increasing distance - and diminished signal strength on land. Loran-C is accurate to 100 - 200 metres in good signal areas. Motorola and II-Morrow manufacture Loran-C receivers. Receivers can be bought for $800.

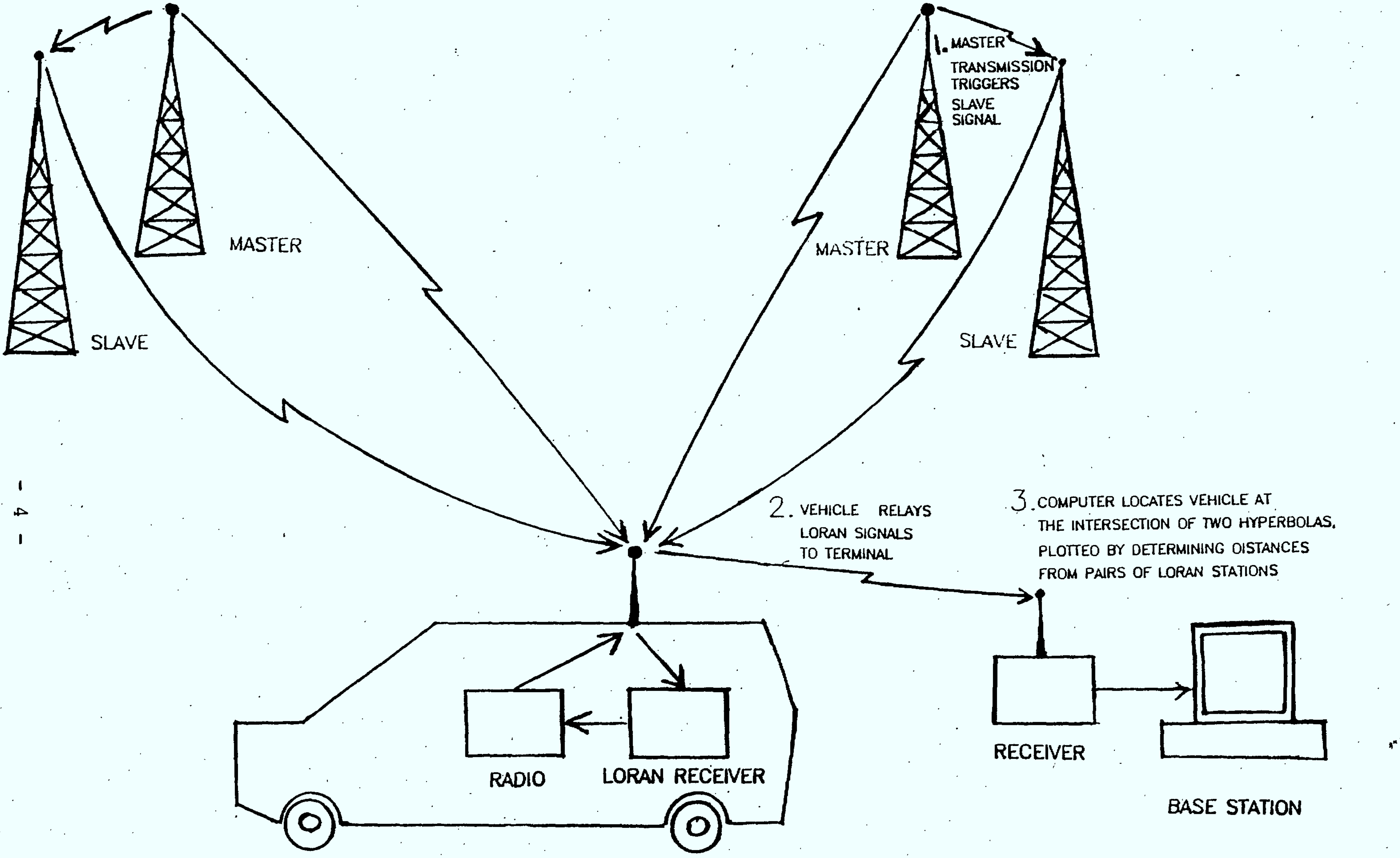

FIGURE 1. LORAN-C VEHICLE LOCATION SYSTEM

2.2 LOW ORBIT SATELLITE SYSTEMS

Low orbit satellite position determination systems currently in use are: 1) the U.S. Navy's Transit Navigation Satellite System and 2) the U.S. Department of Defence's Global Positioning System (GPS).

2.2.1 TRANSIT SYSTEM

The U.S. Navy's Transit Navigator Satellite System is a 24-hour, world-wide satellite navigation system already in operation. It uses five satellites to broadcast navigation signals. About 40,000 transit navigators are in use in ships. Perhaps 500 are in use on land mobiles [1].

Transit receivers get position fixes by measuring the doppler frequency shift of the sequential positions of a single satellite as it passes over a receiver. The process of getting a position fix takes 10 to 16 minutes, so vehicle motion reduces position fix accuracy.

Transit is the only position location device available today that will effectively provide coverage over the entire North American continent (or world). Transit navigators cost about $3,000 each. Magnavox is a leading transit navigator manufacturer.

2.2.2 GLOBAL POSITIONING SYSTEM (GPS)

The GPS entails the continuous broadcast of navigation signals by 18 (or 24) satellites (when fully operational) in low-earth orbits, as shown in Figure 2. GPS mobile receivers compute their positions based on ranging algorithms applied to signals received from GPS satellites. The principle of operation of NAVSTAR GPS is given in Appendix A and in reference [3].

Enough satellites (7) are now operating to make intermittent (7 hours per day) fixes. With the completion of the GPS/Navstar satellite constellation planned for the early 1990's time frame, a precise positional navigation capability will be available.

The GPS navigation processor can determine three-dimensional position, velocity, and user clock errors, if at least four satellites are within the view of a user and with good geometric separation.

Each Navstar satellite transmits signals on two L-Band RF frequencies; [L1 = 1575.42 MHz and L2 = 1227.60 MHz]. The signals are modulated with two codes: P, which provide for precision measurement of time and C/A (coarse acquisition) code which provides for easy lock-on to the desired signal. The transmitted message contains ephemeris parameters that enable the user to calculate the position of each satellite at the time of transmission of the signal.

Figure 3 gives a GPS Navigation System concept. Commercial operators will have access to the C/A code signals which will be capable of providing navigational accuracy of +/- 80 metres in three dimensions (longitude, latitude and altitude), and time accuracy to 350 nanoseconds. GPS receivers can be purchased off-the-shelf now, but cost $10,000 or more. GPS manufacturers appear to agree that the price will drop to about $500 by the 1990's. GPS receivers are manufactured by Magnavox, Rockwell-Collins and Motorola.

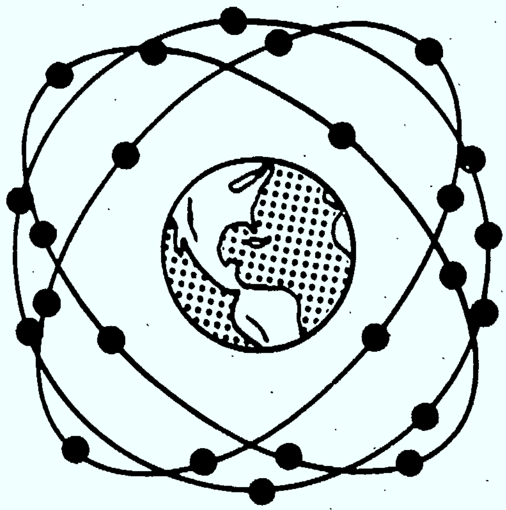

FIGURE 2. GPS SATELLITE CONSTELLATION (8 SATELLITES IN EACH OF 3 ORBIT PLANES)

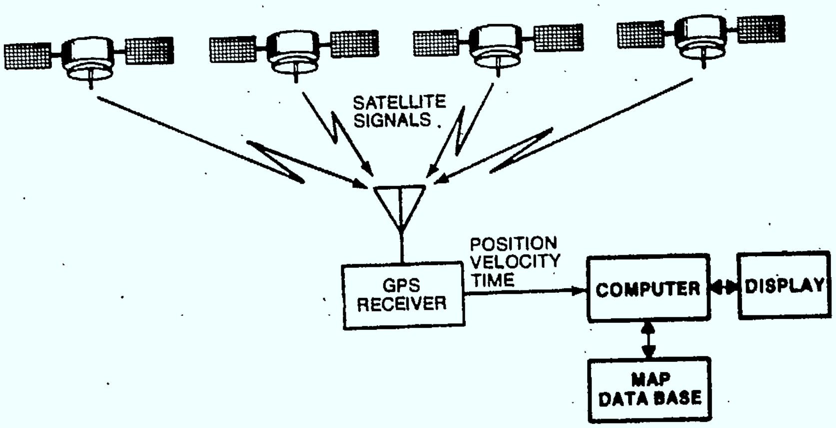

FIGURE 3. GPS NAVIGATION SYSTEM BLOCK DIAGRAM.

2.3 RADIO DETERMINATION SATELLITE SERVICE (RDSS)

One of the techniques proposed for Radiodetermination Satellite Service (RDSS) to determine vehicle location is known as "tone-code responding". RDSS mobile radios would determine their position by sending a coded signal to two satellites in geosynchronous orbit, which would, in turn, each retransmit the signal to a central earth station. This station would compare the times required for the signal to reach the earth station through the different satellites and use this information to generate preliminary position estimate and, using the station's map data base, correct the result for altitude [4].

RDSS has not been demonstrated, so actual operational accuracy is hard to predict. To a degree, accuracy will depend on the placement of the satellites used to carry RDSS packages.

2.3.1 RDSS SPECTRUM AND LICENSEES

The Federal Communications Commission (FCC) has allocated spectrum for RDSS as follows:

- 1610 MHz to 1626.5 MHz for RDSS user uplinks (mobile to satellite),
- 2483.5 MHz to 2500 MHz for user downlinks (satellite to mobile), and
- For RDSS system computational functions, 5117 MHz to 5183 MHz (satellite to ground station), and 6525 - 6541.5 MHz (ground station to satellite).

The FCC has also named 3 RDSS applicants as licensees; Geostar Corporation, McCaw Space Technologies, and MCCA American Radio Determination [5]. All the licensees have proposed systems modeled on Geostar's spread spectrum technology using a dedicated space segment.

2.3.2 GEOSTAR'S SYSTEM

Figure 4 shows Geostar's RDSS position location and message exchange sequence and Figure 5 shows Geostar's fully-operational system concept [4]. This service will not be available until 1993 at the earliest. Geostar Corporation, in the interim, is planning to launch its "Link One" Service. This service will provide one way (mobile-to-satellite and satellite-to-ground station) communications services, with no RDSS capability. Positions will be determined by Loran-C receivers, and sent to dispatchers over this "Link One " service. Link one will use one satellite to relay raw position information and digitally coded messages input by the driver from a vehicle to Geostar's Princeton, N.J. ground station, where a computer will correlate the position information with the map data base. The resultant position data will then be transmitted to the vehicle's dispatch center via land-line facilities. A payload is scheduled for launch with the GTE GSTAR-3 spacecraft in July/August 1987. Link one transmitters are reported to be priced at about U.S. $2,900. Sony and M/A-COM are building Link One transmitters.

RDSS has undergone a number of radical changes from the time it was first proposed in 1983 as a time-division multiple- access system with many dedicated satellites to the present, where it has become a spread spectrum scheme using payloads piggybacked on commercial satellites devoted to other purposes.

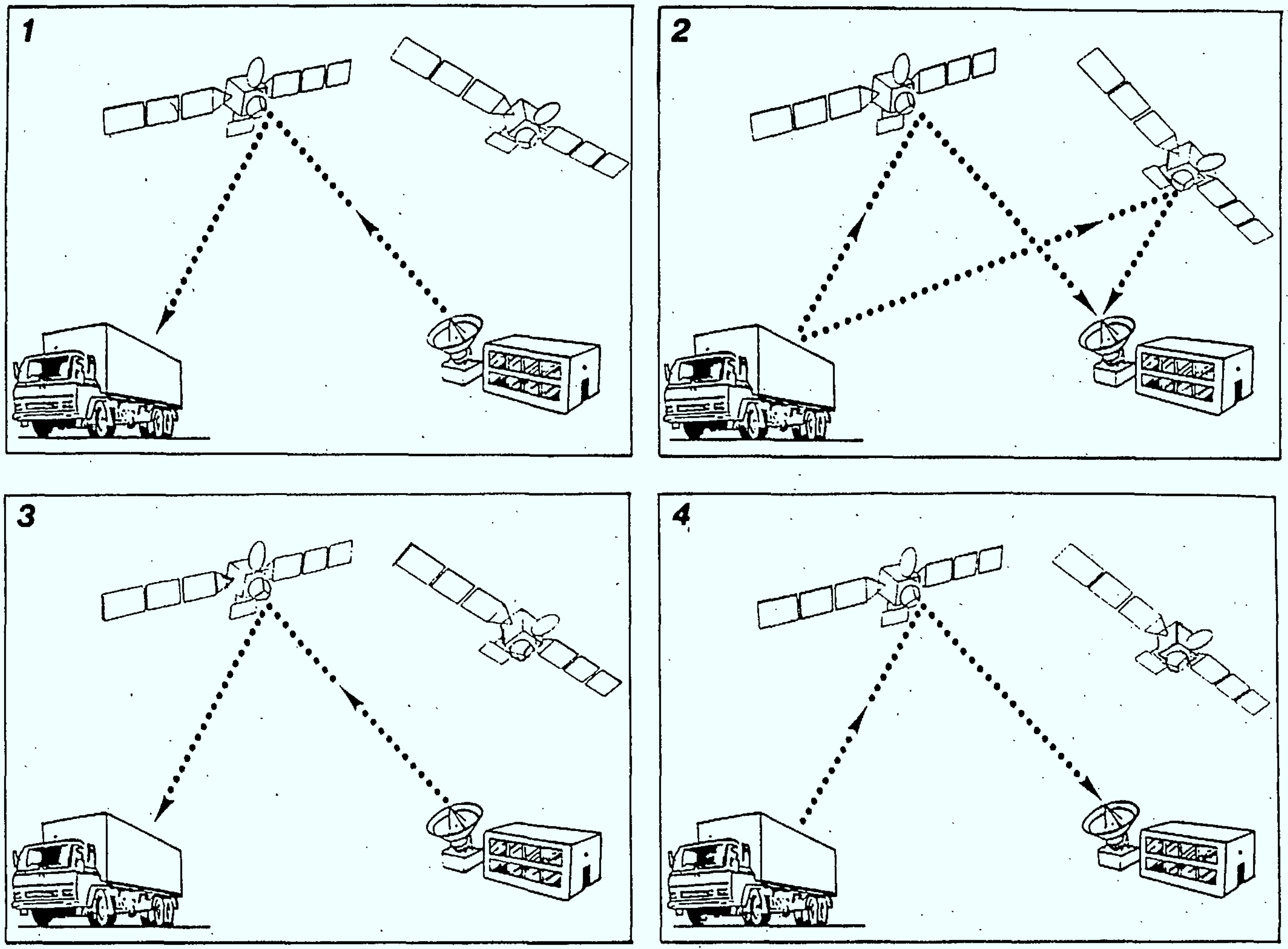

FIGURE 4. GEOSTAR'S SYSTEM:POSITION LOCATION SEQUENCE.

Figure 4 shows how a typical position location and message exchange operation will be performed with Geostar's RDSS. The sequence is as follows:

1. The Geostar central station sends a signal to user terminal-equipped mobile unit (in this case a truck).

2. The truck's unit "answers" the call via two geostationary satellites, and its position is determined at the central station.

3. The position information is relayed back to the truck, along with a message from headquarters.

4. The truck's unit acknowledges the transmission with a message.

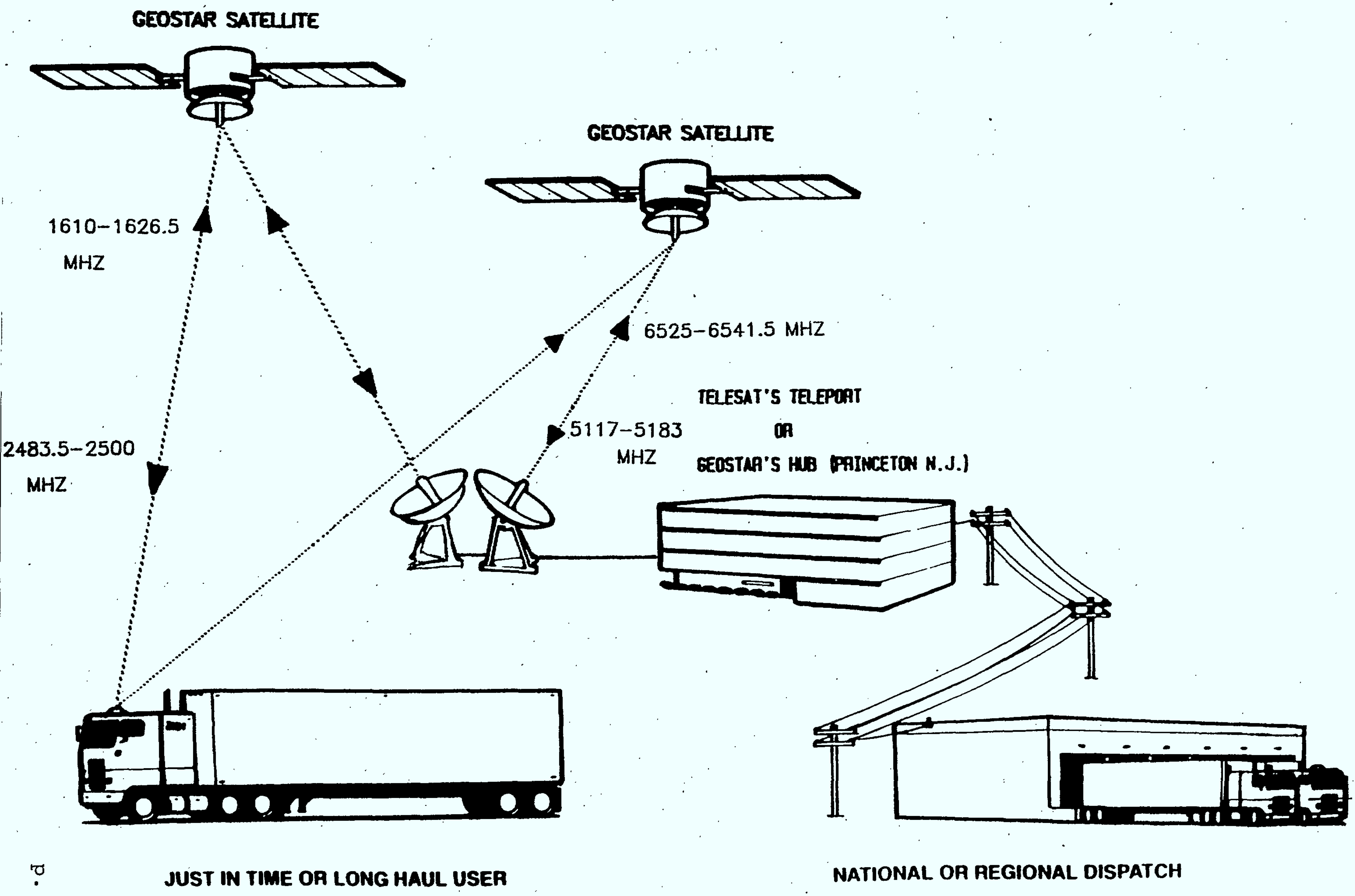

FIGURE 5. FULLY-OPERATIONAL GEOSTAR SYSTEM CONCEPT

3.0 POSITION DETERMINATION SERVICE CONCEPT EVALUATION

There are two alternatives available to provide position determination service via MSAT:

1) In the first option, Loran-C and the GPS position determination systems are used to derive position. The MSAT satellite provides the necessary communications link to relay the position information to a central location. This option can be called "Dependent RDSS" (DRDSS) since the MSAT satellite does not do the actual position determination. MSAT "depends" on Loran-C or GPS for this purpose.

2) The second option involves piggyback RDSS payloads carried on MSAT satellite and another on a scheduled commercial geostationary satellite. (At least two satellites are needed for position determination.) This concept is similar to the fully-operational Geostar system (see Figure 5).

3.1 DEPENDENT RDSS (RDSS) CONCEPT

3.1.1 LORAN-C ON MSAT

The proposed service concept on MSAT would be similar to Geostar's proposed Link One service. MSAT would, however, provide a two-way communication capability. Figure 6 shows this concept for a dispatch type of service application. The position of the mobile would be derived separately using an on-board Loran-C receiver. The Loran-C receiver would be integrated with the MSAT terminal in a manner as indicated in Figure 7.

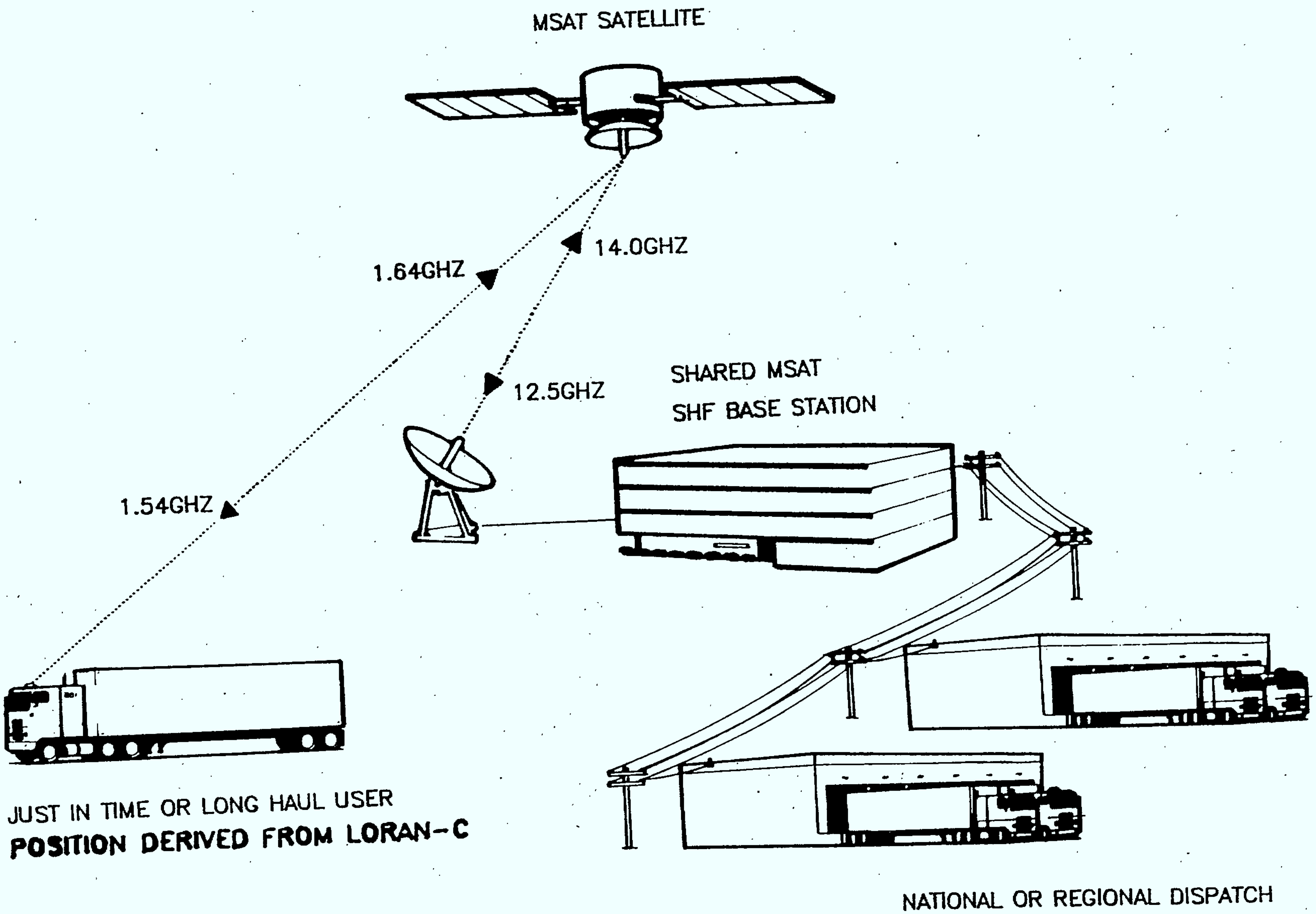

FIGURE 6. LORAN-C ON MSAT

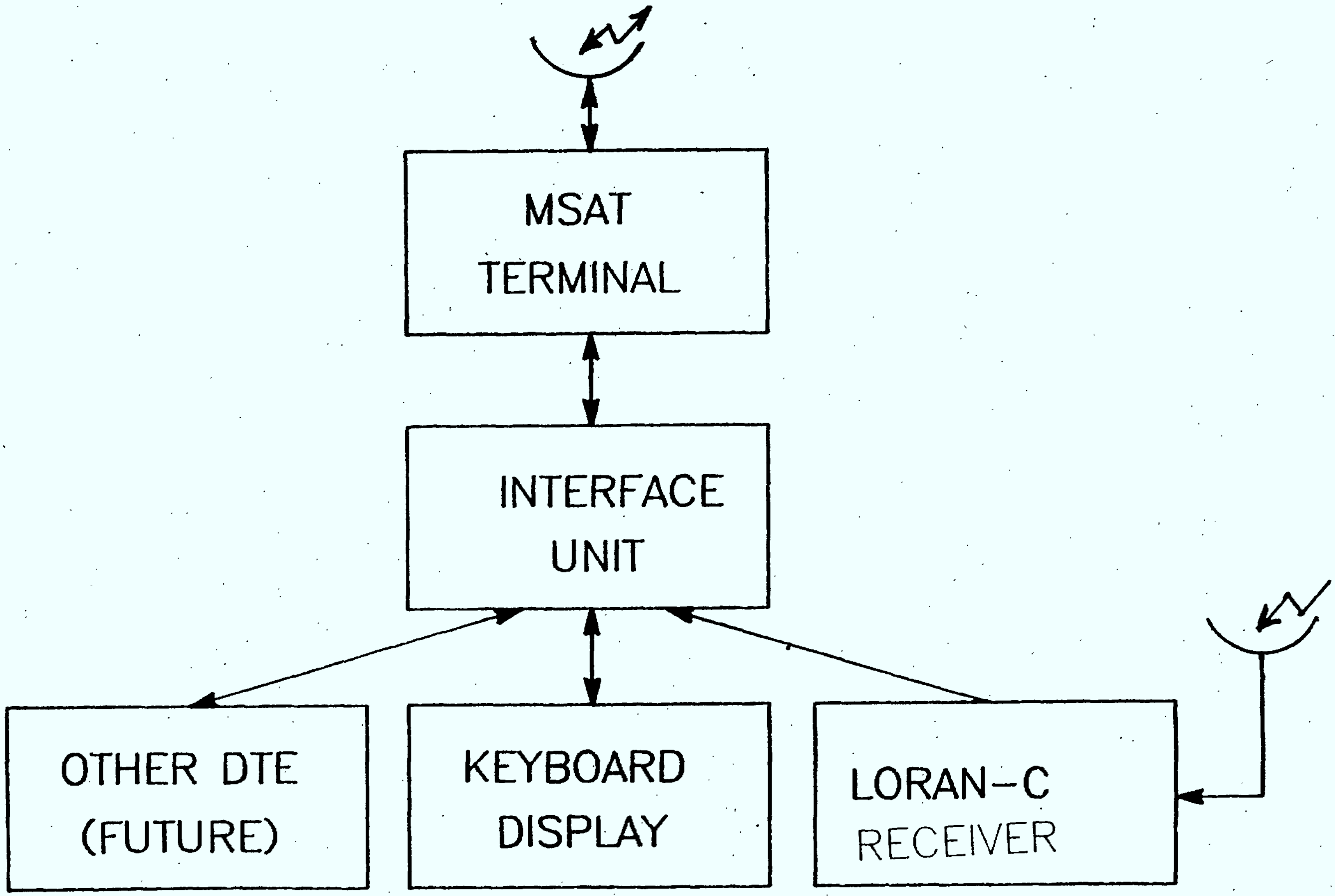

FIGURE 7.INTEGRATED MSAT/LORAN-C TERMINAL FUNCTIONAL REQUIREMENTS

There are two key issues affecting the use of Loran-C.

Firstly, the integrated MSAT/Loran-C terminal would be expensive. Two antennas would be required; one for the MSAT terminal and another for the Loran-C receiver. With the MSAT terminal at about $4,500 and Loran-C receiver at $800, the total cost would be about $5,300.

Secondly, Loran-C coverage of Canada (see Figure 8) is inadequate. This affects the accuracy of the position location. Field trials (using a Loran-C receiver) made by M/A-COM staff over the continental U.S. (Conus) came up with the following results of positioning accuracy of Loran-C chains [6].

- 100 to 200 metres accuracy in good signal conditions was obtained in the eastern and western part of Conus (the rough estimate for Canada, Atlantic provinces, Trans-Canada highway from east up to Kenora in Western Ontario and areas west of the Rocky Mountains)

- 400 metres accuracy was obtained in central part of Conus (south-eastern part of Manitoba, northern Ontario, central Quebec and part of the Yukon)

- 800 metres accuracy (if any signal is present at all) was obtained in Montana and New Mexico (Alberta, Saskatchewan and the rest of Canada)

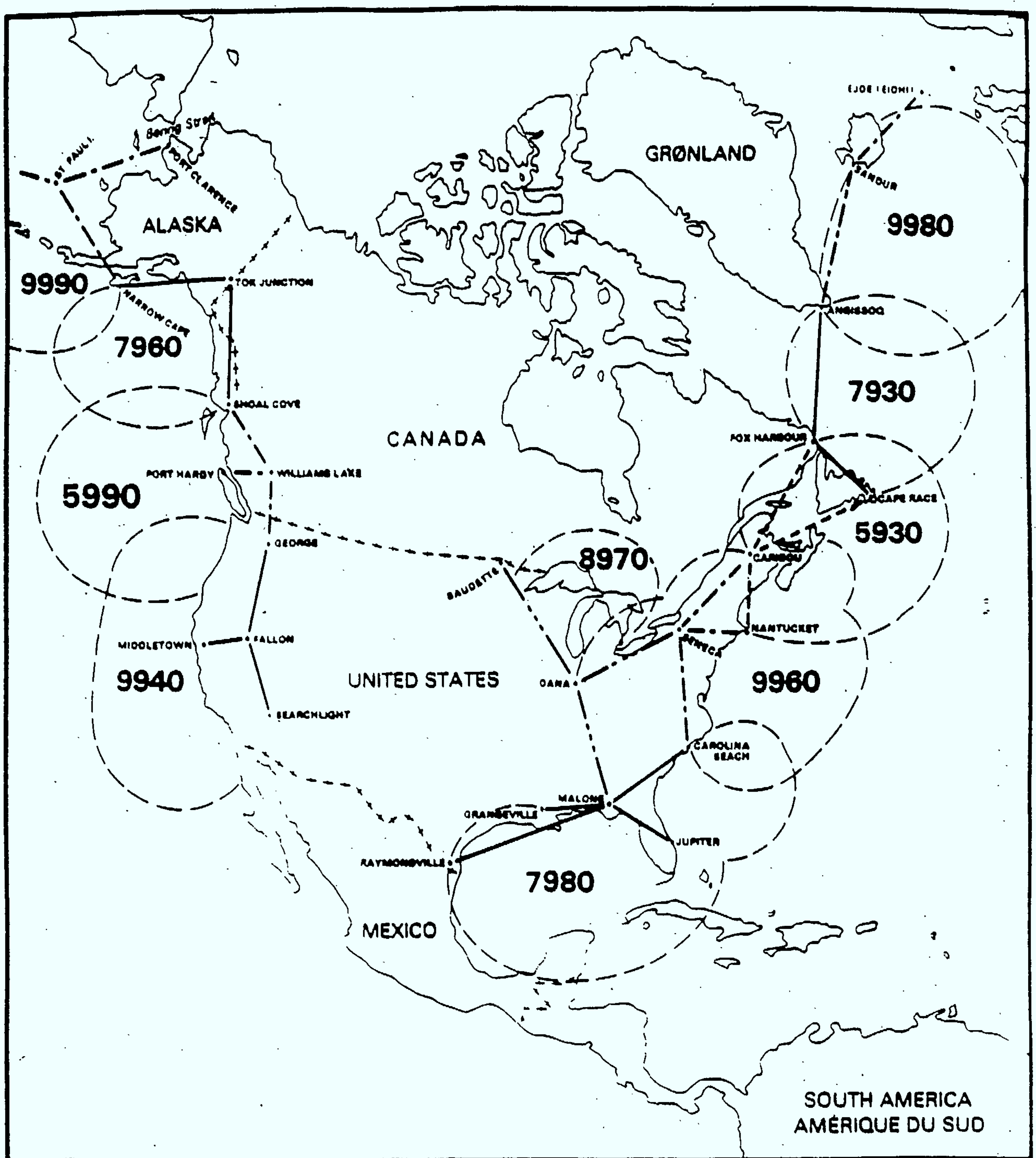

FIGURE 8.

NORTH AMERICAN COVERAGE OF LORAN - C CHAINS

To improve the Canadian coverage of Loran-C, an additional chain of transmitters would have to be installed. However, Transport Canada simulations indicate that this would be prohibitively costly (in the order of hundreds of millions of dollars), and has recommended to the government not to expand the Loran-C system in Canada.

Consequently, it appears that MSAT Position Determination service using Loran-C would appeal to the following 3 user groups:

i) Those users whose operations are mainly in the coastal regions.

ii) Those users who do not require high accuracy of position location and,

iii) Those users who would use it on an interim basis until the GPS system is available.

3.1.2 GPS ON MSAT

Figure 9 shows the service concept of GPS on MSAT for a dispatch type application. MSAT would provide a two-way communication capability. The on-board GPS receiver would determine the position of the vehicle by using GPS NAVSTAR L1 signals. The positional data would then be transmitted to the base station via MSAT. The functional requirements of the proposed GPS/MSAT integrated terminal are illustrated in Figure 10.

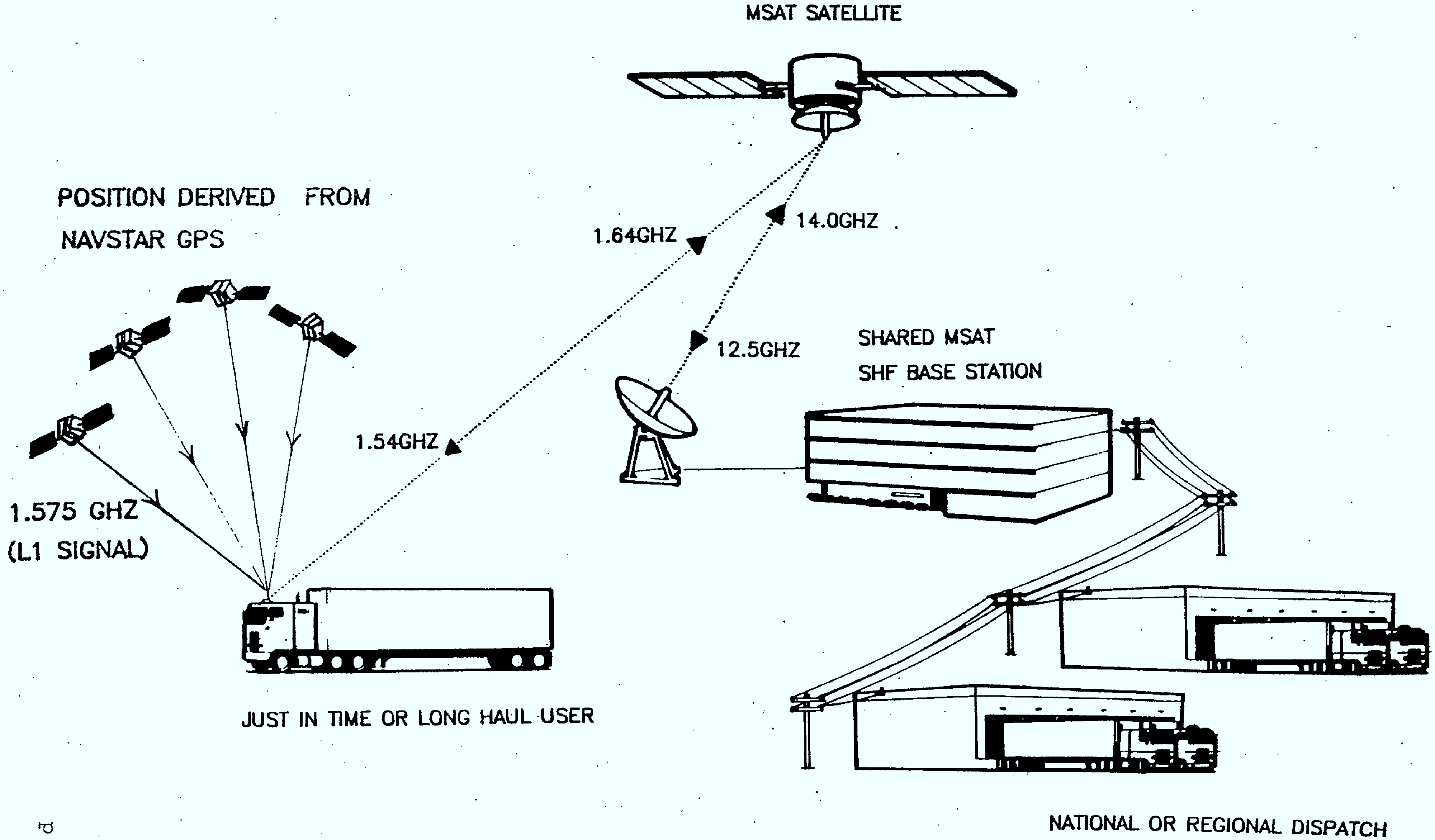

FIGURE 9. GPS ON MSAT

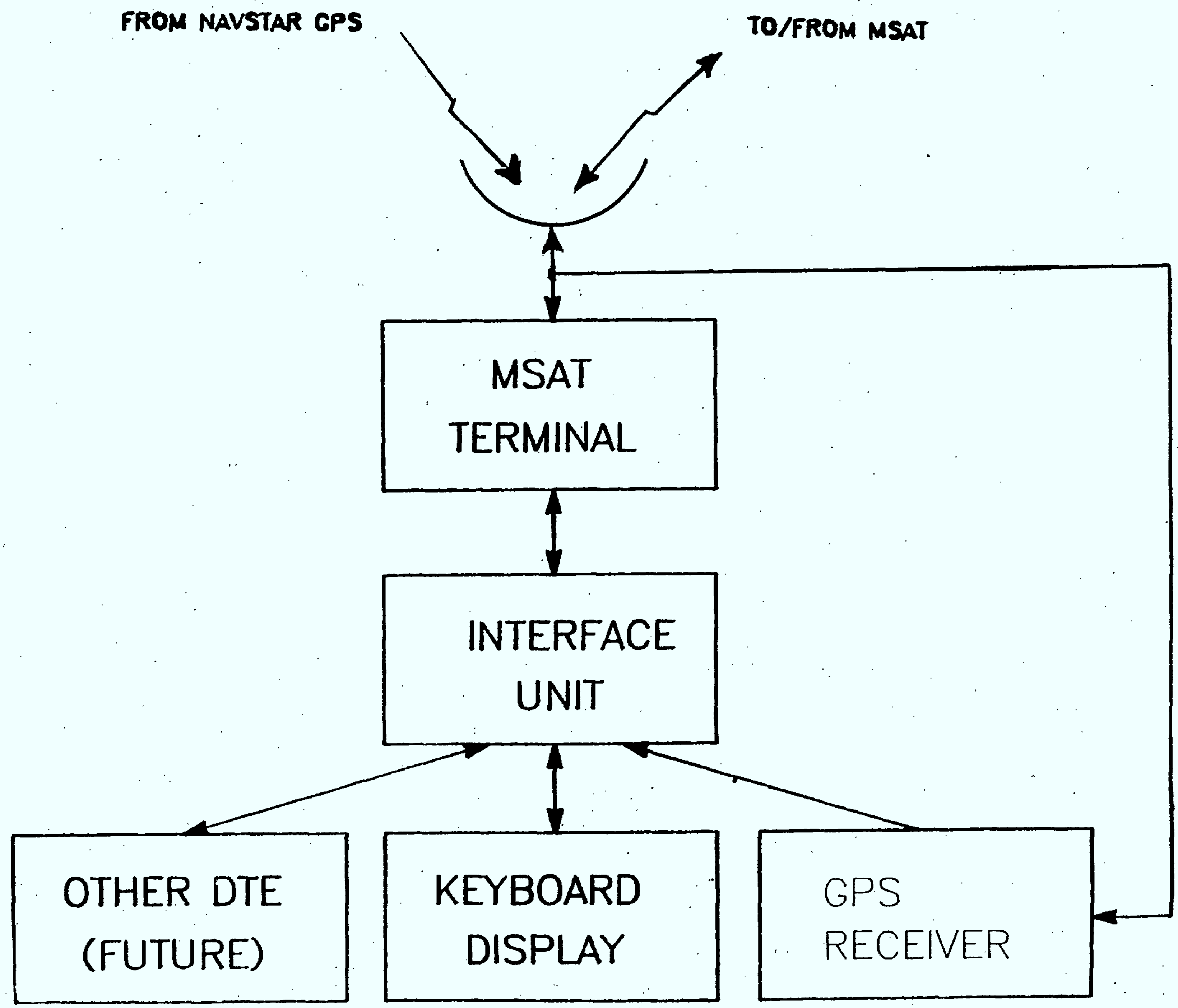

FIGURE 10. INTEGRATED MSAT/GPS TERMINAL FUNCTIONAL REQUIREMENTS

GPS with only the L1 (1575.4 MHz) and C/A code is capable of giving navigation and position fixes better than other navigation systems. The C/A code is the only one available to commercial civilian users. The P code is restricted to military and certain authorized civilian users. The inherent accuracy of the C/A code is close to 30 metres instantaneously, but it has been deliberately degraded to 100 metres.

There is a great range of complexity in GPS user equipment. The simplest sets receive only the L1 carrier, C/A code as shown on Figure 11 [7]. Because the GPS receiver and MSAT terminal share the same L-Band frequency (GPS receiver L1 signal 1575.42 MHz, MSAT terminal receive 1544-1559 MHz) an integrated GPS/MSAT terminal can share the same antenna and front end as illustrated in Figure 10.

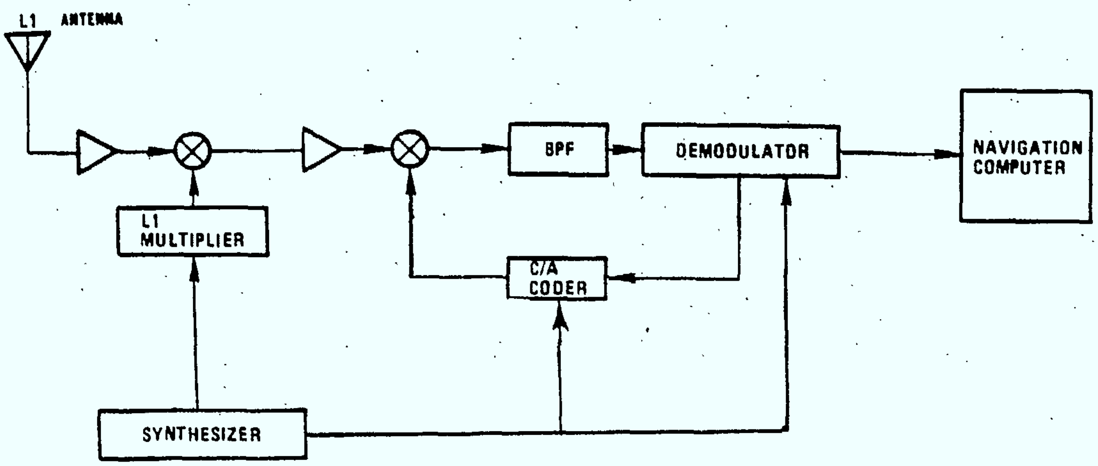

FIGURE 11.BASIC SINGLE-FREQUENCY SINGLE CHANNEL C/A CODE GPS RECEIVER [7].

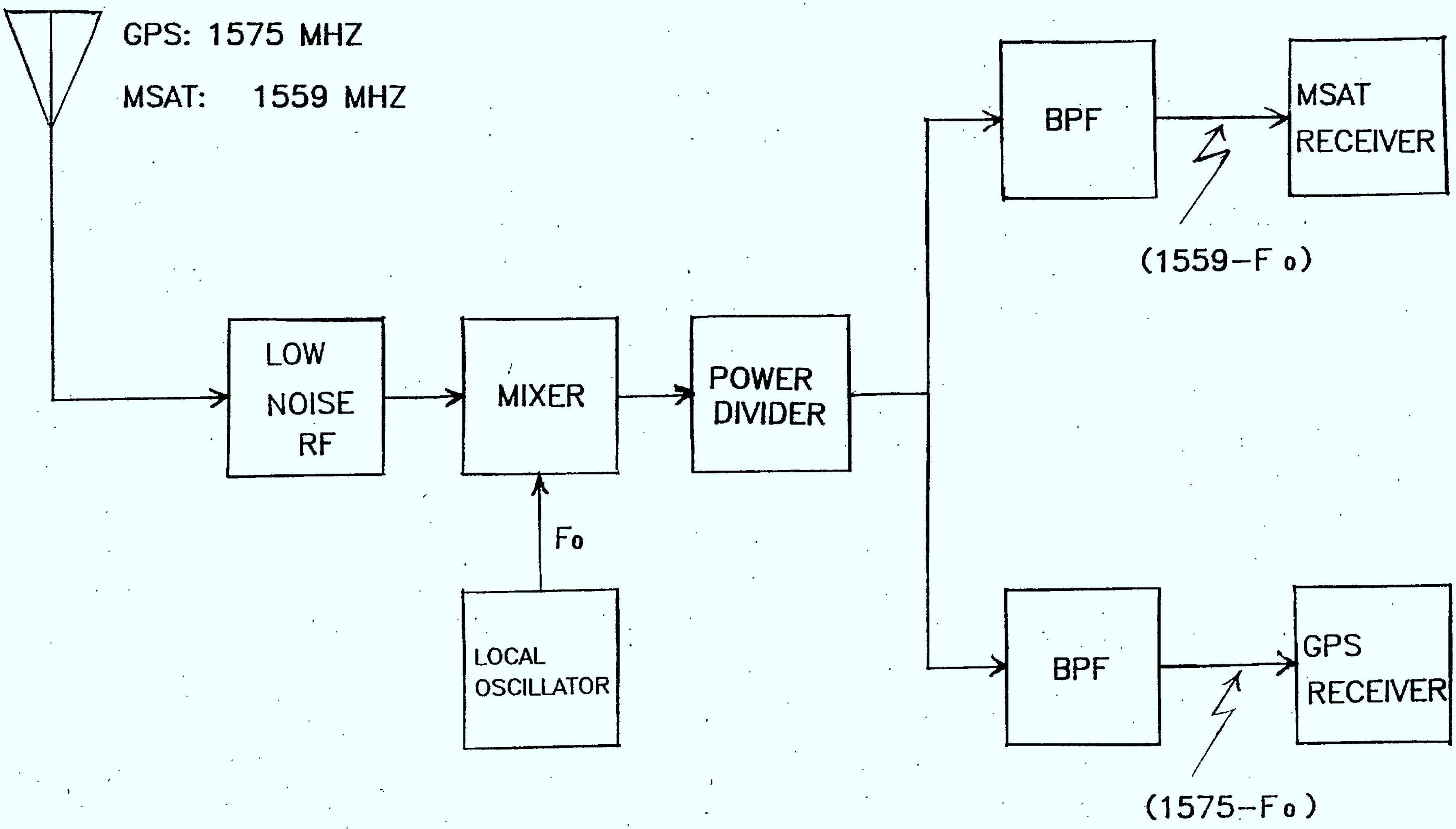

FIGURE 12. GPS/MSAT RECEIVER CONCEPT

The proposed GPS/MSAT integrated terminal would be very expensive. Currently available GPS receivers cost typically about U.S. $20,000. With the completion of the GPS/NAVSTAR satellite constellation planned by the United States for the 1988-1989 timeframe, a precise positional capability will be available in the early 1990's. A constellation of 18 satellites plus three spares is planned. As MSAT is planned for the 1991-1992 timeframe, there is sufficient lead time to develop an integrated GPS/MSAT terminal. However, this requires participation of credible terminal manufacturers. These manufacturers have to be convinced that there will be a market to achieve economies of scale. Indeed this augurs well for MSAT since manufacturers appear to agree that the price of a GPS receiver will drop to about U.S. $500 by 1990. [8]

3.2 RDSS ON MSAT CONCEPT

The provision of RDSS on MSAT is premised on the assumption that RDSS and Mobile Satellite Service (MSS) will be provided on the same satellite. This might be difficult without adverse consequences for efficiency and MSS capacity. It should be noted that Omninet Corporation proposed such a system in its submission to the FCC for a license. The FCC turned down Omninet's application on the reasons cited above. In granting RDSS licenses to Geostar, McCaw, and MCCA, the FCC took the following position on RDSS:

[Gen. Docket No. 84-690]

1. Spread spectrum multiple access technique is the chosen technology.
2. RDSS to be provided on a primary basis.
3. Any associated non-voice service to be provided on an auxiliary basis only.
4. RDSS should not be regulated on a common carrier basis.
5. Financial Standards similar to the private international satellite industry to be adopted for RDSS.
6. Service provider to schedule construction and launch within specified milestones.
7. Service provider to apply for blanket license for transceiver units.

The FCC has subsequently allocated spectrum for RDSS (1610 - 1626.5 MHz for user uplinks, 2483.5 - 2500 MHz for user downlinks and 5117 - 5130 MHz for computational functions). What is the impact of the above on the concept of providing RDSS on MSAT?

The provision of position location information requires two satellites to generate the signals to be used in performing position calculations. [See Geostar's fully operational system concept on Figure 5.] Under the co-operative system for MSAT, this means that RDSS packages would be "piggybacked" on both the Canadian and U.S. satellites. Figure 13 is a block diagram illustrating how an add-on package could be "piggybacked" on an MSAT satellite to provide RDSS. The current MSAT satellite is, however, severely power and bandwidth limited. An RDSS piggyback payload would adversely affect system capacity.

Since RDSS licensees have been named in the United States, it would not be in the best interest of a U.S. MSS operator to piggyback an RDSS payload (under a co-operative system) to serve the Canadian market. This means that Telesat would have to bear the full cost for the RDSS payload on a scheduled geostationary satellite.

Based on the above arguments, it would appear that the concept of providing RDSS on MSAT is neither technically sound nor economically viable.

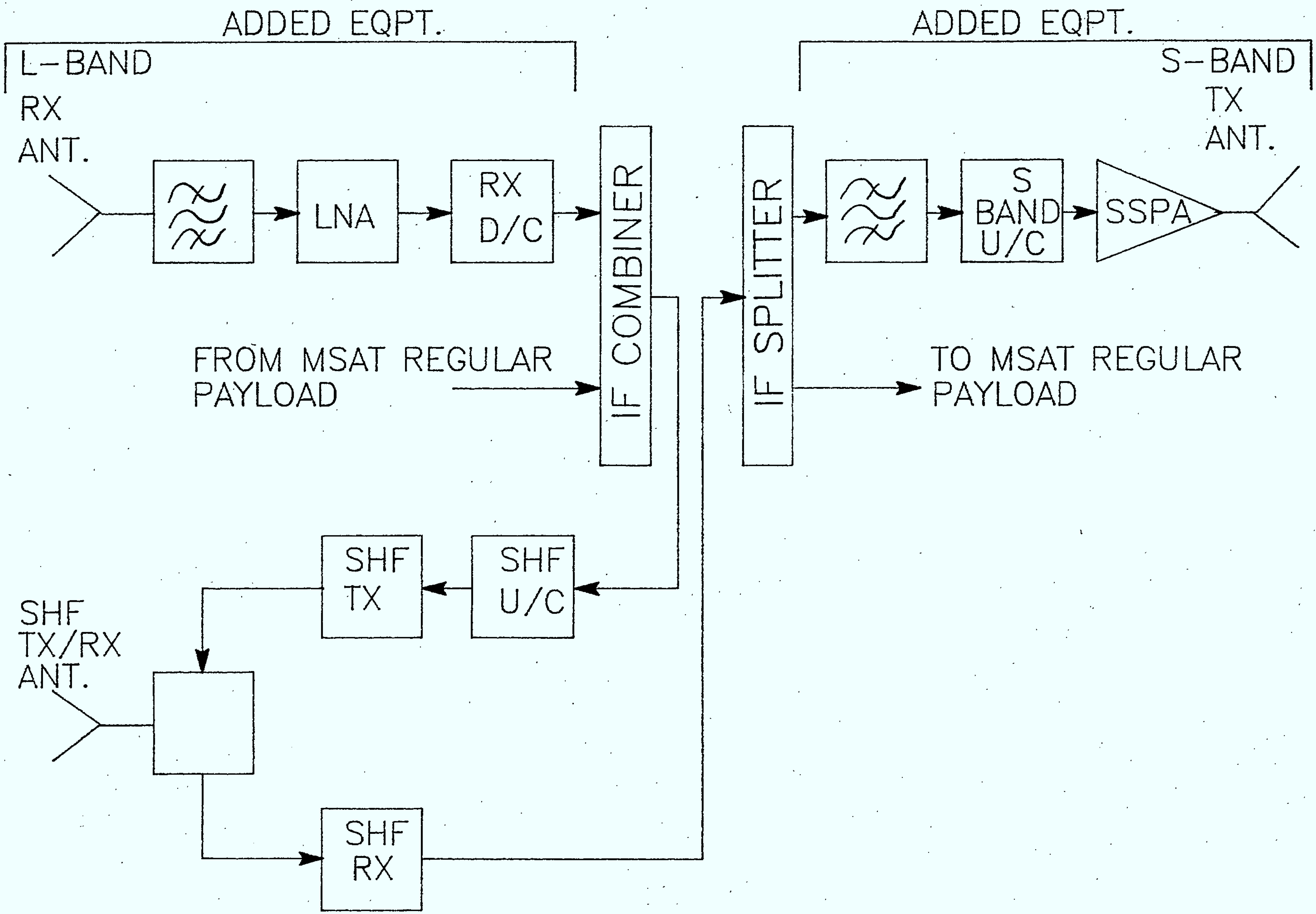

FIGURE 13. BLOCK DIAGRAM OF RDSS "PIGGYBACKED" ON MSAT PAYLOAD

4.0 RDSS MARKET FORECAST

Telesat Canada is endeavouring to include position determination as part of the corporation's Interim Mobile Satellite Service (IMSS) plans. IMSS is designed to serve several user groups who have expressed requirements for two-way mobile communications and position location. A technical trial of the interim service is scheduled for the latter part of 1987. The market forecast for the IMSS can be used as a proxy for the Canadian market forecast for RDSS. A preliminary user forecast for IMSS has been estimated using secondary data [6]. This forecast is shown in Table I.

Table I [6]

Total Projected IMSS Mobile Users From 1987 to 1992

YEAR	Total IMSS Mobile Users
1987	1,050
1988	4,000
1989	8,010
1990	17,700
1991	27,400
1992	38,150

The above forecast (a proxy for RDSS market) indicates that the current Canadian market for RDSS is insufficient to justify a dedicated RDSS system involving the deployment of two or more geostationary satellites as proposed by U.S. RDSS operators.

5.0 CONCLUSION

Telesat Canada has investigated the concepts of establishing a commercial RDSS in Canada. The results indicate that there is a demand for this service. However, the current Canadian market for RDSS is insufficient to justify a dedicated RDSS system involving the deployment of two or more geostationary satellites. Telesat has had discussions with representatives of the transportation industry. These discussions have led us to believe that RDSS is a logical adjunct to mobile satellite services and that it should be treated as part of the mobile satellite services portfolio. We therefore recommend the proposed "Dependent RDSS" (DRDSS) concept. Initially position location will be provided by the Loran-C system and later by GPS when this system becomes fully operational.The MSAT satellite would provide the necessary communications link to relay position information to a central location.

As the mobile satellite market grows, it may not be possible to support DRDSS in the mobile satellite services spectrum. This means that future RDSS growth would have to be accommodated in frequency bands allocated for these purposes. This spectrum may be used for position determination as an alternative to Loran-C or GPS, as well as for links to a central location. Therefore, spectrum allocation for RDSS should be made to support future Canadian RDSS. In this regard, we recommend that the Department of Communications negotiate a spectrum sharing arrangement between Canada and the United States within the bands proposed by the Federal Communications Commission.

APPENDIX A. PRINCIPLE OF OPERATION OF NAVSTAR GPS.

PRINCIPLE OF OPERATION OF NAVSTAR GPS

The NAVSTAR/Global positioning system (GPS) will provide accurate, within 10-30 m, three-dimensional position and velocity information as well as precise time to users anywhere in the world. The technical data of GPS are summarized in Table 1. A brief explanation follows.

GPS will use 18 (or 24) satellites in 55° inclined orbits in such a way that user will see at least 4 satellites at the same instant of time. Operation of the system requires precise synchronization of space vehicle (SV) clocks with "GPS system time". For this purpose cesium clocks with overall accuracy better than few parts x 10^{-14}, located at Master control station (MCS), are used. SV is equipped with a clock 10.23 MHz $\pm 10^{-12}$ stability. Four monitoring stations, including MCS, are estimating precise ephemerides of each satellite to improve the overall performance of the system. Each SV is transmitting signals on two, L_1 and L_2, RF frequencies to permit corrections to be made for ionospheric delays in signal propagation time by the user terminal. The signals are modulated with two codes: P, which provide for precision measurement of time, and C/A, which provides for easy lock-on to the desired signal. The transmitted message contains ephemeris parameters that enable the user to calculate the position of each satellite at the time of transmission of the signal. The receiver is processing signals and messages and calculates its own location.

The basic equations using four satellites are:

$$\sqrt{(x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2} + T = R_1$$

$$\sqrt{(x-x_2)^2 + (y-y_2)^2 + (z-z_2)^2} + T = R_2$$

$$\sqrt{(x-x_3)^2 + (y-y_3)^2 + (z-z_3)^2} + T = R_3$$

$$\sqrt{(x-x_4)^2 + (y-y_4)^2 + (z-z_4)^2} + T = R_4$$

Where x, y, z, and T are user position and clock bias (unknowns); x_i, y_i, z_i are the ith satellite position; z=1, ..., 4 (known); and R_i is the pseudorange measurements to the ith satellite.

The accuracy with which one can measure position and time is related to the accuracy in radial range measurement by factor known as geometric dilution of precision (GDOP). The value of GDOP itself is a composite measure that reflects the influence of satellite geometry on the combined accuracy of the estimate of user time and user position, i.e.

$$GDOP = \sqrt{(TDOP)^2 + (PDOP)^2} = \sqrt{(TDOP)^2 + (HDOP)^2 + (VDOP)^2}$$

The Position dilution of precision (PDOP) is minimal, the best, if the one satellite is at the user's zenith and the other three are separated by 120° and are as low on the horizon as possible.

The range error budget is summarized in Table 2. With GDOP as given in Table 3, the expected location precision is about 10 m (with P-code) and about 100 m (with C/A) code. The suggested annual charge of $3700 for P-code access (where permitted) and $370 for unclassified civil access C/A-code may apply.

Texas Instruments came with the first commercially available equipment, i.e., High dynamic user equipment (HDUE), Missile-born receiver set (MBRS) and Manpack/vehicular user equipment (MVUE). The data are given in Table 4.

<u>TABLE 1</u>

SYSTEM	18 (24) satellites in 12h, 55° inclined, 20,183 km high orbits
	GPS Time standard: cesium clocks few parts x 10^{-14} stability located at Master control station (MCS)
	Space vehicle clock 10.23 MHz $\pm 10^{-12}$
	Precise satellites ephemerides tracking and prediction from four monitor stations
	L_1 RF frequency 154 x 10.23 = 1575.42 MHz
	L_2 RF frequency 120 x 10.23 = 1227.60 MHz
	Spread spectrum P-code: reset 7 days, frequency 10.23 MHz C/A code: epoch 1 ms, frequency 1.023 MHz data 50 b/s
SPACE SEGMENT	$EIRP_p \sim 21.5$ dBW RH circular polarized antenna $EIRP_{C/A} \sim 24.5$ dBW *EIRP calculated from permissible RX levels L_1 = 1575.42 MHz L_2 = 1227.00 MHz
RECEIVER	Frequency / P-code / C/A-code level L_1 / -163 dBW / -160 dBW L_2 / -166 dBW / -166 dBW Number of receiver channels 1 - 5 Memory size 40 - 80 k Bits/word 16 Price (1000 units) 15-25 k$ (Texas-In.)

TABLE 2 - RANGE ERROR BUDGET

UNCORRECTED ERROR SOURCE	User Equivalent Range Error Metres	Feet
SV Clock Errors Ephemeris Errors	1.5	5.0*
Atmospheric Delays	2.4 - 5.2	8.0 - 17.0
Group Delay (SV Equipment)	1.0	3.3
Multipath	1.2 - 2.7	4.0 - 9.0
Receiver Noise and Resolution Vehicle Dynamics	1.5	5.0
RSS	3.6 - 6.3	11.8 - 20.7

* Two hours after update.

TABLE 3 - ANTICIPATED WORLDWIDE USER ERROR DISTRIBUTION

	HORIZONTAL				VERTICAL				TIME		
	HDOP	User Error Param	User Error (Metres)	User Error (Feet)	VDOP	User Error Param	User Error (Metres)	User Error (Feet)	TDOP	User Error Param	User Error (Nanosec)
50th Percentile	1.39	1.15	4.1 - 7.2	14 - 24	1.99	1.39	5.0 - 8.8	16 - 29	1.05	0.73	8 - 15
RMS	1.44	1.45	5.2 - 9.1	17 - 30	2.16	2.21	8.0 - 13.9	26 - 46	1.21	1.22	14 - 25
90th Percentile	1.71	2.19	7.9 - 13.8	26 - 45	2.80	3.57	12.9 - 22.5	42 - 74	1.76	1.96	23 - 40

Based on Range Error Budget 11.8 - 20.7 Feet
24 - Satellite Baseline Constellation
5 - Degree Satellite Elevation Mask Angle

TABLE 4 - PHASE I GPS SYSTEMS - HARDWARE COMPARISONS

PARAMETER	HDUE	MBRS	MVUE
No. of LRU's	4	1	1
No. of Receiver Channels	5	4	1
Size (feet)	3.5	1.6	0.75
Weight (pounds)	200	77	25
Power (watts)	529	208	45
Design-to-Cost Goal (1,000 units)	25K	NA	15K
Receiver Modules/Channel	6	7	6
Total Common Modules	65	50	12
Total Unique Units	13	13	6
Memory Size (maximum capacity)	68K	82K	48K
Memory Size Required	62.3K	62K	40K
Bits/Word	16	16	16

HDUE: High Dynamic User Equipment
MBRS: Missile - Born Receiver Set
MVUE: Manpack/Vehicular User Equipment

APPENDIX B. AUTOMATIC VEHICLE LOCATION SYSTEMS AND GPS EQUIPMENT SUPPLIERS.

B.1 AUTOMATIC VEHICLE LOCATION SYSTEMS COMPARISON

Table B.1 gives the cost of receivers/transmitters (in U.S.$) for the various automatic vehicle location systems. Two systems, SIGNPOSTS and ETAK have been included for comparison purposes, although they were not described in Chapter 2.

B.2 GPS EQUIPMENT SUPPLIERS

Table B.2 lists U.S. companies that manufacture and supply GPS commercial and military user equipment. Features and applications of the equipment also are listed. The following symbols are used in the table: C/A-Code, coarse acquisition code; CEP, circular error probability; diff, differential mode measurement; inst, instantaneous measurement; P-code, precision code; SEP, spherical error probability (3D); and U, uncoded mode.

TABLE B.1

AUTOMATIC VEHICLE LOCATION (AVL) SYSTEMS

AVL SYSTEM	TERMINAL COST/MANUFACTURER	ACCURACY/LIMITATIONS
SIGNPOSTS (electronic transmitters in fleet deployment area)		• Several hundred metres • Follow fixed route • Replace batteries every 5 years • Vandalism and theft
TRANSIT (U.S. Navy) 5 satellites	• 40,000 transit navigators in use in ships • 500 in use on land mobiles • Cost $3,000 • Magnovox	• Fix takes 10 to 16 minutes • Motion vehicle reduces fix accuracy
LORAN-C	• Cost $800 • II-Morrow • Motorola	• 100 to 200 metres • Lacks coverage of much of central U.S.
ETAK (Solid State compass, tape drive)	• Cost $2,000 to $2,500	• 20 metres
GPS	• Cost currently $20,000 or more • $500 by 1990 • Magnovox • Rockwell-Collins • Motorola	• 10 metres (millitary) • 30 to 75 metres (commercial)
RDSS	• Geostar link 1 (1987?) • Cost $2,900 • Sony • MA-COM	

TABLE B.2

GPS EQUIPMENT SUPPLIERS

Company	Equipment Type	Codes	Channels	Pos. Accuracy	Price	Comments
Allen Osborne Associates, Westlake Village, CA Frank J. Lynch (805) 495-8420	Model GPS-TTR-5 precise timing, fixed navigation and positioning	C/A	1	Absolute; 5m relative sub-meter	$14,950 complete with computer and software	Different ID tracking capability will increase accuracy to 20 cm with two receivers.
EDO Western Division Salt Lake City, Utah Carma Ingram (801) 486-7481	Commercial navigation and surveying	C/A	1	±20 m 10 m diff 30 m inst. CEP	$25,000	4 c/S sampling speed, weight: 22 lb.
Interstate Electronics Anaheim, CA Bob Geddes (714) 758-0500	Astrolab-2 for GPS training and development systems, on land, sea and air, and a variety of military systems	C/A P-code within 1 year	1	±20 m CEP	$49,950	Interstate is mainly a defense contractor, but will produce GPS systems for the commercial market. Two receivers required for differential measurement.
ISTAC Inc. Pasadena, CA Peter and Judy MacDoran (818) 793-6130	Commercial 3-D seismic and geological surveying, marine navigation, anti-submarine warfare	U Uses both C/A and P-Code modulation	2 $L_1 = 1575.42$ MHz or $L_2 = 1227.8$ MHz or both	200 m inst. 1 m in 1005 10 cm in 15 min up to sub-cm in 100 min SEP	$57,000	Unique uncoded reception yields surprisingly high accuracies. Two receivers are required for highly accurate cm positioning in the differential mode.
King Radio Olathe, KS Doug Henkel (913) 782-0400, Ext. 2521	Multi-sensor navigation system KNS-660. It is especially designed for commercial and general aviation use.	C/A	1	100 m	$46,000 including computer and data base	This is a Bendix/King joint venture.
Litton Aeroproducts Moorpark, CA Ralph Bonswor (805) 378-2318	LTN-700 Commercial aviation receiver, also for authorized non-DoD users	C/A and PC (for authorized users). Uses L_1 frequency.	1 For CA code	40 m CEP (C/A) 16 m SEP P-users	$55,000	
Magnavox/Wild Heerbrugg Torrance, CA Maureen Anderson (213) 618-1200	Transit MX-1100 navigators in use by 36 navies, upgraded to GPS	C/A P L_1, L_2	2	1 cm in differential mode SEP	$39,000 for GPS	Upgrade of T-set to five-channel operation $50,000 Transit system upgrade to use GPS Navstar signal $20,000/$25,000

TABLE B.2 CONTINUED

GPS EQUIPMENT SUPPLIERS

Company	Equipment Type	Codes	Channels	Pos. Accuracy	Price	Comments
Motorola (with Sperry Aerospace and Marine Systems) Tempe, AZ Phil Boyle (602) 897-4278	Air/sea/land navigation; all-weather capability	C/A	4	<30 m SEP	$18,000	Sampling rate: 1/S 1 channel—longitude 1 channel—latitude 1 channel—amplitude 1 channel—time resolution error correction First prototype released March 1986
Rockwell/Collins Cedar Rapids, Iowa Robert M. Woods (319) 395-1000	Military	P	5	15 m (3D) SEP	N/A	Five-channel for high performance aircraft. One-channel for ma-pack, using C/A and P-codes.
	Commercial NAVCORE-1	C/A	1	25 m (3D) SEP	$17,500	
Texas Instruments Dallas, TX George Consolver (214) 462-5273	TI4100 NAVSTAR NAVIGATOR Commercial navigation and point positioning.	C/A and P (L_1 and L_2)	1 Multiplexing up to four satellites	13 m inst. point positioning 14 m inst. navigation 2-5 m, 3D differential navigation and positioning within minutes.	$139,000	Price includes antenna, receiver, signal processor, PROM memory, control and display unit and cabling. Up to 510K bytes of data storage and dual cassette throughput $17,800.

REFERENCES

(1) Noreen, G.E., "Vehicle Location Technology - Evaluating Your Options", Personal Communications Technology, July/August 1986.

(2) Zygmont, J., "Keeping Tabs on Cars and Trucks", High Technology, September 1986.

(3) Stiglitz, M.R., "The Global Positioning System", Microwave Journal, April 1986.

(4) "Signposts in Space: Geostar positioning system begins operations", Space Markets, Spring 1986.

(5) FCC Gen. Docket No. 84-689 RM-4426, Gen. Docket No. 84-690, April 28, 1986.

(6) Telesat Internal Memos and Studies:

Kucar, A., "On Loran-C Coverage in Canada", July 31, 1986.
Kucar, A., "Geostar Update, Loran-C and GPS", June 27, 1986.
Kucar, A., "Geostar via GTE's GSTAR2", May 16, 1986.
Sloboda, C., "Demand Forecasts of Mobile Data Service - One-Way Mobile-to-Base."
Auger, M., "A Preliminary User Forecast for an Interim Mobile Satellite Service 1987-1992".

(7) Eastwood, R.A., "Early Applications of Civil GPS", PLANS '84 IEEE Position and Navigation Symposium, November 27 - 30, 1984, San Diego, CA, by Magnavox Advanced Products and Systems Company.

(8) Stansell, T.A., "Civil GPS from Future Perspective", Proceeding of the IEEE, Vol. 71, No. 10, October 1983.