#2 - D. S. Rosene

FEASIBILITY STUDY
OF A
SCOUT-LAUNCHED COMMUNICATION SATELLITE
PROVIDING
SEARCH AND RESCUE AND DATA COLLECTION
SERVICES

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FEASIBILITY STUDY OF A SCOUT-LAUNCHED COMMUNICATION SATELLITE PROVIDING SEARCH AND RESCUE AND DATA COLLECTION SERVICES

Performed for

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FIGURES

TABLES

1. INTRODUCTION

There have been several experimental, satellite data collection systems (DCS) launched by the U.S. (NIMBUS/IRLS, ERTS/DCS, NIMBUS/TWERLE) and one by France (EOLE). The success of these experiments, especially the ERTS/DCS in which Canadian users have played a substantial role, has led to consideration of operational systems. To this end, the TIROS-N polar orbit weather satellites will be equipped with a DCS developed by CNES in France and will start service in 1977. The SMS/GOES series of geosynchronous orbit weather satellites, now in service, also carry a DCS. However, these systems have a limited capacity and it is therefore appropriate to examine alternate systems for satisfying future Canadian data collection requirements.

In this study, performed under Contract OPL5-0078 for the Department of Communications, the objective was to examine the feasibility of a communications satellite providing Search and Rescue and Data Collection services in the context of a low altitude, polar orbit mission. The statement of work (Appendix A) emphasizes consideration of a random access data collection system from fixed and moving platforms with an ability to determine platform location. The Search and Rescue Satellite (SARSAT) system design as described in Reference (2) was used as a baseline. It is briefly summarized in Chapter 2 of this report.

2. SEARCH AND RESCUE SATELLITE BASELINE DESIGN

2.1 System Concept

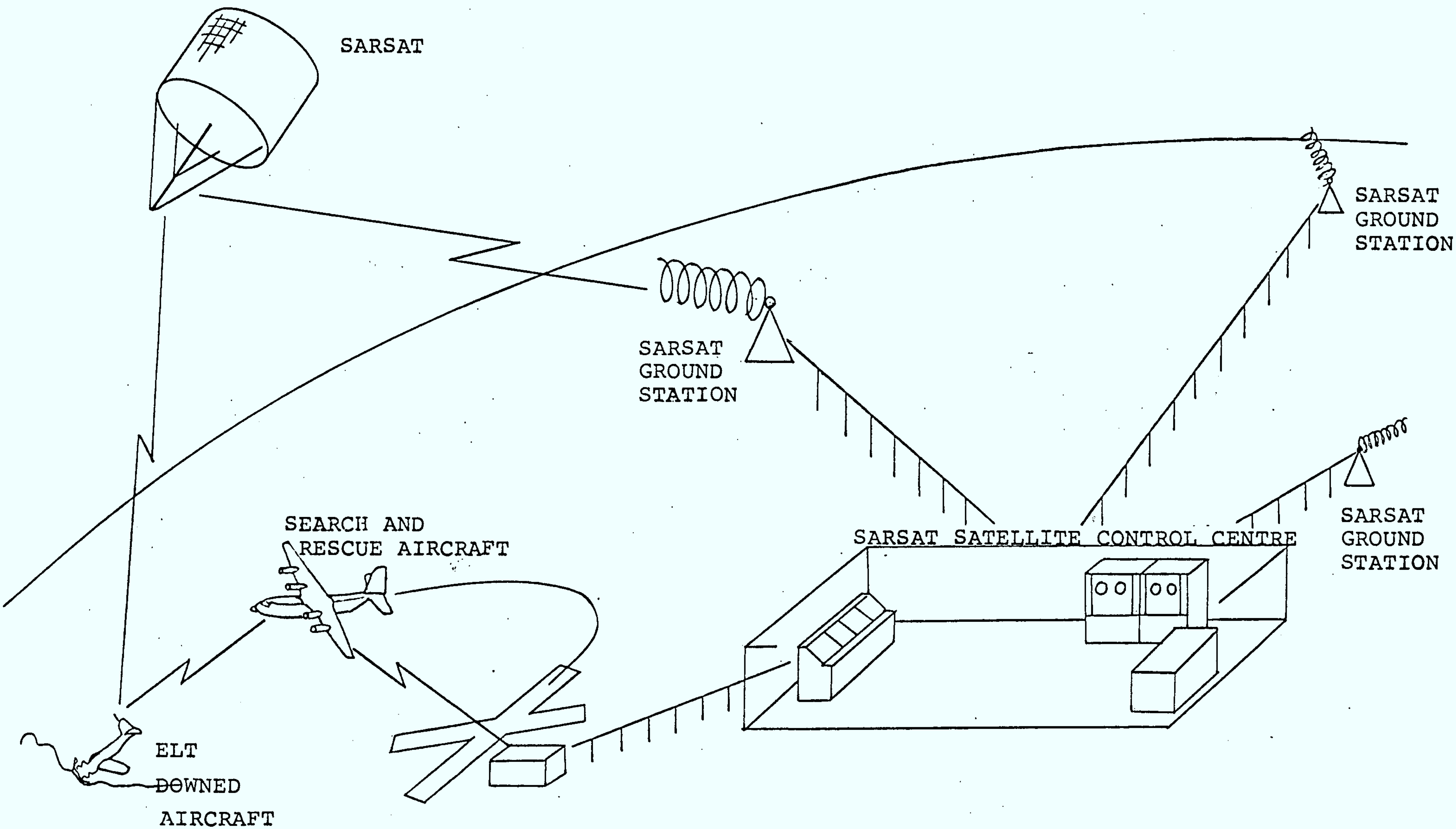
Studies (1,2) have been made concerning the feasibility of a small, polar orbit satellite for the detection and location of emergency locator transmitters (ELT's) which, by legislation, are now required to be carried by all aircraft in Canada. The results of these studies indicate that a search and rescue satellite concept is feasible and plans for implementing such a system are currently under study by government officials.

The system concept involves a satellite, travelling in a roughly circular orbit at an altitude of 1000-1500 km, which contains a communications transponder designed to accept ELT signals at both 121.5 MHz and 243 MHz. The transponder retransmits an ELT signal to a ground station at a suitable frequency in the UHF band. The ground station detects the ELT signal and measures its doppler shift during the 10-15 minute period of satellite visibility. The location of the ELT is then determined by computer processing of the doppler data. Figure 2-1 illustrates the system concept.

2.2 System Description

A previous study (2) examined several Scout-launched spacecraft configurations to implement a search and rescue satellite. Two configurations, as illustrated in Figures 2-2 and 2-3, were recommended. The first one uses spin stabilization and a low gain (1-2 db) spacecraft antenna. Magnetic torquing coils are used to align the satellite spin axis parallel to the earth's spin axis. The second configuration uses a gravity gradient stabilization boom and a slightly higher antenna gain (2-3 db).

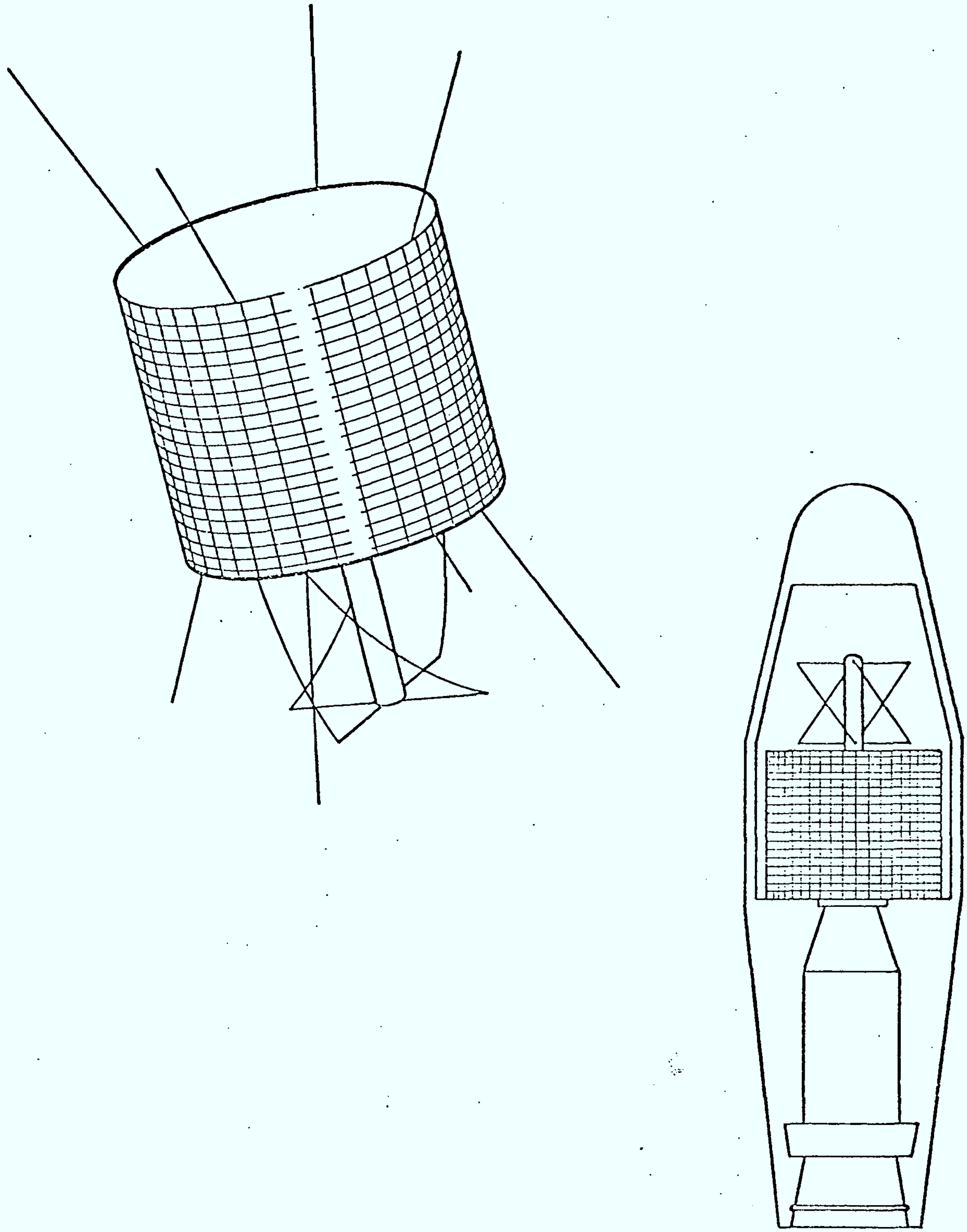
In Tables 2-1 to 2-4, the preliminary weight and power budgets for these two spacecraft configurations are presented. The spin stabilized spacecraft configuration has 22 lbs. and 19 watts (EOL) of excess margin whereas the gravity gradient stabilized configuration has 34 lbs. and 3 watts (EOL) available. The relatively large amount of excess power available in the spin stabilized configuration is due to the higher efficiency of a cylindrical solar array as compared to the omni-directional paddle array of the other configuration. However, the available payload weight of the spin stabilized configuration is relatively less because it requires the heavier 42 inch diameter nose fairing as compared to the 34 inch diameter nose fairing used with the gravity gradient stabilized configuration. The figures given above for excess weight and power are in addition to a 25% design margin on weight and a 35% design margin on power.



SARSAT SYSTEM CONCEPT

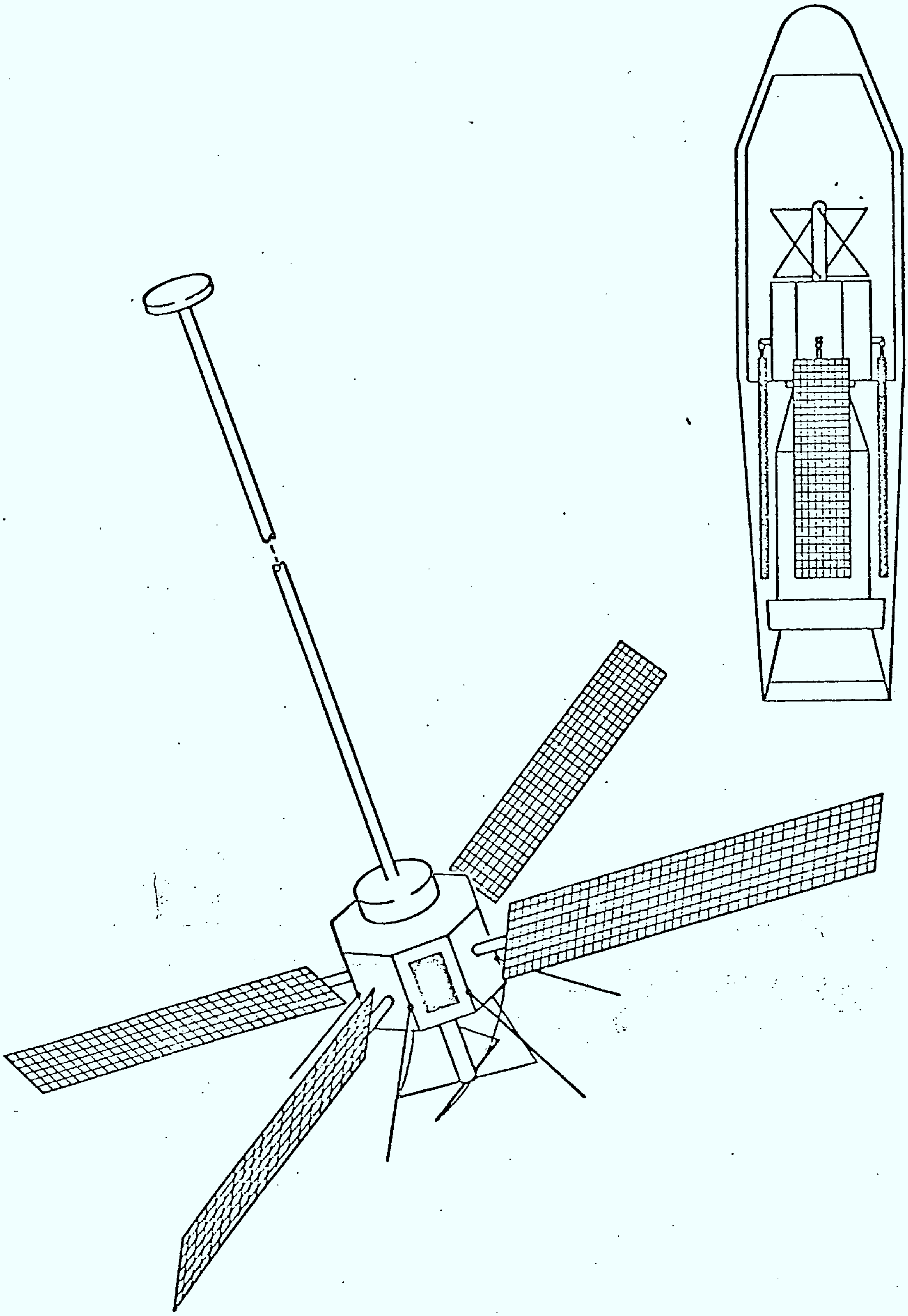
Figure 2-1

(From Ref.8)



SPIN STABILIZED SAR SATELLITE AXIS PARALLEL TO EARTH AXIS

Figure 2-2 (From Ref.2)



GRAVITY GRADIENT STABILIZED SAR SATELLITE

Figure 2-3 (From Ref.2)

The search and rescue (SAR) transponder receives signals at 121.5 and 243 MHz and retransmits them at a UHF frequency with an RF power output of approximately one watt. Two ground stations receive the SAR transponder signals and provide coverage over the entire Canadian SAR zone. One station is located near Summerside, PEI and the other near Yellowknife, NWT. The stations use a helical antenna and a program track steering system. The measured doppler shift of the received SAR signals is digitized and sent to a central control facility for processing to determine ELT location. The ground stations are also used for gathering tracking data from the satellite to accurately determine the orbit parameters which are needed in order to solve for the ELT location. The tracking data may consist of doppler measurements of the satellite's telemetry beacon or ranging measurements through the satellite's T&C subsystems.

The system described above is able to provide complete coverage of the Canadian search and rescue zone every 12 hours using a single satellite at an 1100 km altitude. The coverage swath for each orbital pass is defined by a minimum ELT antenna elevation angle of 35 degrees. Since the tracks of a polar orbit converge in northern Canada, more frequent coverage is obtained since any point is visible to the satellite on two or more consecutive passes.

The accuracy of ELT location was studied (2) using a modified orbit determination computer program. The accuracy obtained from a single pass under worst case conditions was approximately 50 km. This result was achieved with an ELT oscillator drift rate of 10 Hz/min, an oscillator bias of 6 kHz, and doppler noise of ±40 Hz (all values are 3σ). Better accuracy is obtainable using data from two or more orbit passes.

ITEM		WEIGHT-LBS
1. Structure		35 ± 10
2. Thermal		10 ± 2.5
3. Solar Array		18 ± 2
4. Power Conditioning (redundant)		5 ± 0.5
5. Batteries (redundant)		18 ± 2
6. TM & Command (redundant		16 ± 3
TM1 + Encoder	5 ± 1	
TM2 + Encoder	5 ± 1	
Rx1 + Decoder	3 ± 0.5	
Rx2 + Decoder	3 ± 0.5	
7. SAR Transponder (redundant)		14 ± 3
TX1	4 ± 1	
TX2	4 ± 1	
Rx1	3 ± 0.5	
Rx2	3 ± 0.5	
8. Antenna (including coax, diplexers, etc.)		10 ± 4
SAR Rx Antenna	5 ± 2	
SAR Tx, TM & CMD Antenna	5 ± 2	
9. Wire Harness		5 ± 2
10. Torquing Coils		2 ± 1
TOTAL		133 ± 30
Design Margin 25%		33
Max S/C Weight		166
Addition Payload Capacity (1000 Km orbit with Scout assuming 42 inch nose fairing)		22
Gross Payload		188

SPINNING SPACECRAFT WEIGHT BUDGET

Table 2-1

(From Ref.2)

ITEM		WEIGHT-LBS
1. Structure		30 ± 10
2. Gravity Boom and Damper		10 ± 2
3. Thermal		10 ± 2
4. Solar Array (including deployment mechanism)		15 ± 2
5. Power Conditioning (redundant)		5 ± 0.5
6. Batteries (redundant)		18 ± 2
7. TM & Command (redundant)		16 ± 3
TM1 + Encoder	5 ± 1	
TM2 + Encoder	5 ± 1	
Rx1 + Decoder	3 ± 0.5	
Rx2 + Decoder	3 ± 0.5	
8. SAR Transponder (redundant)		14 ± 3
Tx1	4 ± 1	
Tx2	4 ± 1	
Rx1	3 ± 0.5	
Rx2	3 ± 0.5	
9. Antenna (including coax, diplexers, etc.)		10 ± 4
SAR Rx Antenna	5 ± 2	
SAR Tx, TM & CMD Antenna	5 ± 2	
10. Wire Harness		5 ± 2
11. Torquing Coils		2 ± 1
TOTAL		135 ± 31.5
Design Margin 25%		34
Max S/C Weight		169
Additional Payload Capacity (1000 Km orbit with Scout assuming 34 inch nose fairing)		34
Gross Payload		203

GRAVITY GRADIENT SPACECRAFT - WEIGHT BUDGET

Table 2-2

(From Ref.2)

ITEM	POWER-WATTS
1. Household Power	
TM1 and Encoder	5 ± 2
CMD Rx1 and Decoder	1.5 ± 1
CMD Rx2 and Decoder	1.5 ± 1
Torquing Coil	2 ± 1
2. SAR Transponder	1 ± 0.5
Rx1	1 ± 0.5
Tx1	5 ± 2
3. Power Conditioning (Efficiency 80%)	3 ± 1
Primary Power	19 ± 8.5
4. Battery Charge Power	10 ± 3
Total Power Demand	29 ± 11.5
Design Margin 35%	10
Max. Required Power	39
Solar Array	
Beginning of life power *(BOL)	90 watts
End of life power (EOL) (35% degradation over 7 years)	58 watts
Excess Power at BOL	51 watts
Excess Power at EOL	19 watts

* Based on solar constant 135.3 MW/cm^2, cell efficiency 10.3% and power quoted is at equinox (sun line perpendicular to drum).

SPINNING SPACECRAFT - POWER BUDGET

Table 2-3 (From Ref.2)

ITEM		POWER-WATTS
1. Household Power		
TM1 and Encoder		5 ± 2
CMD Rx1 and Decoder		1.5 ± 1
CMD Rx2 and Decoder		1.5 ± 1
2. SAR Transponder		
Rx1		1 ± 0.5
Tx1		5 ± 2
3. Power Conditioning (efficiency 80%)		3 ± 1
	Primary Power	17 ± 7.5
4. Battery Charge Power		10 ± 3
	Total Power Demand	27 ± 10.5
	Design Margin 35%	10
	Max. Required Power	39 watts
Solar Array		
Beginning of life * (BOL)		64 watts
End of life (EOL) (35% Degradation over 7 years)		42 watts
Excess Power at BOL		25 watts
Excess Power at EOL		3 watts

* Based on solar constant 135.3 MW/cm^2, cell efficiency 11.8% and power quoted for worst case orientation.

GRAVITY GRADIENT SPACECRAFT - POWER BUDGET

Table 2-4 (From Ref.2)

3. DCS SYSTEM DESIGN

3.1 Design Requirements/Objectives

Ref. (3) provides a good description of the past history and future planning for data collection and location systems. The NASA ATS/OPLE, NIMBUS/IRLS and French EOLE were experiments with interrogatable DCS systems. However, the disadvantages of cost, complexity and weight of the interrogatable data platforms led to random access systems of which ERTS/DCS and NIMBUS/TWERLE are the first examples. In this study, only random access data collection systems will be considered as specified in the Statement of Work (Appendix A). Table 3-1 presents a list of DCS design requirements/objectives as a framework for consideration.

Random access as opposed to interrogation of DCP's (data collection platforms) greatly simplifies and reduces the cost of both the DCP's and the satellite by eliminating the need for a receiver on each DCP and a command link through the satellite. However, this saving is achieved at the cost of system capacity. The ERTS DCS has been estimated to have a capacity for reliably handling (without excessive message overlap) 1000 DCP's operating with a 1:4700 duty cycle (3). An interrogatable type of DCS with equivalent bandwidth could probably achieve a capacity of 4000-5000 DCP's.

Several different types of data collection systems have been flown on satellites and they each require a different DCP design. For operational systems, there is an urgent need to establish international standards for signal formats and characteristics so that users do not lose their considerable investment in DCP's with every new DCS that is launched. The ERTS DCS has been the most outstanding success to date. Some users have made strong recommendations (4) that future data collection systems be compatible with the ERTS DCP's.

The capacity required for a system serving only Canadian requirements has been estimated during previous studies of the UHF Multi-purpose Satellite (5) and Table 3-2 is a copy of the estimated needs of various users. Leaving aside the Fisheries requirements for 3000 platforms (which may require a substantially different design approach), a capacity of about 2000 platforms is envisaged. Although the ERTS DCS does not provide a location capability, this is required for certain applications in the fields of meteorology, oceanography, hydrology and wildlife management. Approximately 10% of the users are assumed to require location of their DCP's.

Recommendations from ERTS DCS users at a Wallops Flight Center Workshop in May 1973 (6,7) included the following:

REQUIREMENT/OBJECTIVE	NOTES
1. Operates on the random access principle	Preferable
2. Compatible with existing ERTS DCP's	Preferable
3. System capacity - Data Collection 2000 DCP's - DCP Location 200 DCP's	
4. Minimum coverage - each satellite - twice per day per DCP	
5. Data format - nominal 64 data bits, 95 bits total	ERTS - type format DCP memory module to expand data capacity
6. Data delivery - mail - telex - regional terminals	As with ERTS

DCS SYSTEM REQUIREMENTS/OBJECTIVES

TABLE 3-1

- more frequent data sampling is required by about 50% of the users - hourly sampling would be adequate

- data delivery on demand (ie. readout of data platform whenever desired)

The need for more frequent sampling is currently being met for the ERTS DCS by the development of a memory module which allows hourly readings to be stored and readout in one or more sequential data bursts. Data readout on demand requires the use of an interrogatable system in geosynchronous orbit and this need can be met with the SMS/GOES DCS. The low altitude DCS satellite concept considered in this report provides a set of orbital passes over the entire globe once every twelve hours. The altitude of the orbit should be selected so as to enable every DCP, regardless of its location, to be visible to the satellite on at least one orbit pass every 12 hours. Additional satellites (at least two are usually required in an operational system) should be used in an active mode to enable more frequent data samples to be collected.

Department	User Agency	No. of Sites (1980)	Type of Station F - Fixed, M - Moving	Growth in Sites Per Year (%)	Bits/Message	Messages/Day	Acceptable Bit Error Rate (-exp)	Accept. Message Loss (%)	Interrogation Required N-No, Y-Yes, D-Desired	Traffic Multiplier Ratio of actual possible messages	NOTES
DOE	App. Hydrol	200	F	20	50	24	4	10	N	1	
DOE	Forestry	200	F	5	50	4	4	10	N	.4	Seasonal use, 5 months/year
DOE	Wildlife	10	F	10	60	24	5		N	1	
DOE	Fisheries	3000	M	2	300	3	5	2	D	.3	800 to 1000 active at any one time
DOE	Glaciol. Event.	6	F	10	1	1*	4	2	N	1	Activity initiated transmissions
[illegible]	Glaciol. Env.	6	F	10	60	4	4	2	N	1	
DOE	Glaciol. Hyd.	6	F	15	150	1	4	2	N	1	
DOE	Water Quality	9	F	10	72	24	4	5	D	1	
DOE	Pollution Control	50	F	10	240	3*	4	50	D	1	50% increase for Activity initiated transmissions
DOE	At. Envir. Serv. (1)	5	F	10	288	24	4	1	N	1	
DOE	At. Envir. Serv. (2)	25	F	10	288	24	4	5	D	1	
DOE	CCIW	10	M	10	150	2	4	10	D	1	
DOE	Pac. Currents	25	M	10	50	12	4	5	N	1	
DOE	Tidal Survey	140	F	0	100	24	4	5	N	1	
DOE	Frozen Sea	6	M	10	300	50	4	5	N	1	
DOE	Bedford Ocean	5	M	20	80	8*	4	5	N	1	50% increase for Activity initiated transmissions
EMR	Earth Phys.	25	F			24			Y		Long messages, 24,000 channel minutes requ'd
EMR	Geoscience	4	M	10	300	24*		5	N	1	Activity initiated transmissions
[illegible]	Lighthouse	300	F	0	50	30*	4	5	D	1	25% increase for Activity initiated transmissions
Prov.	Forestry	900	F	5	50	4	4	10	N	.4	Estimated by DOE Forestry
	Total	4927									

* Note applies

Sensor Data Retransmission Requirements

Table 3-2

(From Ref.5)

The use of the ERTS data format as indicated in Table 3-1 allows 64 data bits (8 words x 8 bits) to be transmitted with each data burst. This is sufficient for most applications but may be expanded by use of a memory module, now under development for future ERTS type DCP's, which permits the expanded data format to be read out on consecutive data bursts.

Data delivery with the ERTS DCS has involved both mail (computer punch cards) and Telex. In Canada, users may also access their data by computer terminal hookup to the Canada Centre for Remote Sensing. The use of regional terminals to reduce the cost of data delivery to the end user requires an inexpensive ground station design, probably operating at a UHF downlink frequency. There are, however, limitations in the geographic coverage obtainable by regional ground stations as indicated in Chapter 4.

3.2 Basic Design Alternatives

A data collection system contains four major elements:

- data collection platforms (and their associated sensors) which transmit information according to a signal format consisting of a basic frequency, duty cycle, encoding scheme and burst interval
- a communications channel (a satellite-borne transponder)
- receiving stations which detect, demodulate and decode the transponded data signals
- a data distribution system to deliver the data to the end users

The design alternatives for these four system elements are discussed in the following sub-sections.

3.2.1 Data Collection Platforms

A data collection platform consists of a power supply (usually a battery), digital interface circuits to accept data from sensors, control circuits, and a transmitter. In this study, the sensor interfaces with the platform and its electrical /mechanical design are not considered.

It is in the timing of the signals and the data rate that major differences occur among the data collection systems which have been flown or are planned. In Table 3-3, information from Ref. (3) is presented on several data collection systems. A major distinction is noted between systems which provide data collection only and those which also provide location of the

	POSITION LOCATION		NO POSITION LOCATION	
System Characteristics	NIMBUS F	TIROS N	ERTS	SMS/GOES
Multiple Access	Random	Random	Random	Commanded or Self Timed
Coverage	Global	Global	2/3 Western Hemisphere	Earth Disk
Frequency	401.2 MHz	401.65 MHz	401.55 MHz	402 MHz
Bandwidth	30 kHz		68 kHz	
Capacity	200	200	1000	1000/6 hrs
Simultaneous Signals	8		1	1
<u>DCP Characteristics</u>				
Power	600 mwatts	3 watts	5 watts	5 watts
Antenna Gain	2-3 db	2-3 db	2-3 db	13 db
Bit Rate	100 bps	400 bps	2500 bps	100 bps
Duty Cycle	1/60		1/4700	1/6 hrs
Burst Length	0.5 sec		0.038 sec	
Data Words per Burst	4	4-32	8	8
Weight-Electronics	0.45 kg	0.56 kg	4.1 kg	5.5 kg

DCS CHARACTERISTCS

TABLE 3-3

platforms. To determine location, the platforms generally transmit longer data bursts at shorter intervals, as compared to data collection only systems, so that accurate doppler shift measurements may be made on the signals. This usually involves a much lower data rate although the total number of bits of data transmitted in any one signal bursts can be the same as a data collection only system. In addition, since the signals have a much higher duty cycle, greater reliance is placed on frequency diversity and parallel detection to achieve a high system capacity.

The major problem with the selection of an ERTS type DCP for the baseline design lies in the incorporation of a location capability. The ERTS DCS efficiently achieves a high system capacity (1000 DCP's) with a single detection channel by using short, infrequent bursts (1/180 sec) and a high data rate. However, the doppler location technique requires more frequent bursts (once every 20-40 seconds) and accurate frequency measurements. Assuming the 38 msec burst time of an ERTS DCP is adequate for frequency measurement, a duty cycle of one burst every 30 seconds results in each locatable DCP taking up the same system capacity as six standard DCP's. Hence the system capacity requirement for 2000 DCP's of which 10% are locatable is equivalent to 3000 ERTS type DCP's. Three or more parallel detection channels and an increased system bandwidth would also be required.

Informal contacts with NASA GSFC during the course of the study have indicated that it may be possible to make accurate doppler shift measurements on the short signal bursts associated with high data rate DCS systems like ERTS by using sophisticated processing techniques. GSFC has been studying the use of an analog z transform technique to rapidly identify signal frequencies so that a phase lock loop receiver can be immediately commanded to the proper frequency for signal acquisition. It is claimed that a signal frequency in a 500 kHz bandwidth can be measured to an accuracy of 800 Hz in 3 milliseconds. It may be possible to extend this technique to obtain the necessary 1-10 Hz accuracy over the full 38 msec burst time of an ERTS DCP. On the other hand, an accurate measurement of frequency may be made with a conventional phase lock loop receiver providing the signal-to-noise is high enough.

In selecting a system design, a reconciliation must be made between the need to incorporate platform location and the desire (of the users) to make the system compatible with the present ERTS/DCS. Several alternatives are postulated as follows:

a) a dual mode system which handles both ERTS-type DCP's and locatable DCP's of a different design. This, in reality, is two data collection systems operated in parallel even though a single integrated transponder (with two frequency bands) is used for both types of DCP's.

b) A single, low data rate system which provides location for all DCP's and uses only one type of DCP. This approach is less efficient than an ERTS-type data collection system because many of the DCP's do not require location and, in order to accomodate up to 2000 DCP's, many (80-100) parallel channels for detection and processing have to be used.

c) A mixed mode system capable of operating with either ERTS-type DCP's or modified ERTS DCP's which can be located. The modified ERTS DCP's may operate either by emitting an additional location signal in a separate frequency band or by producing a short carrier burst after the normal signal. The repetition interval would be 20-30 seconds instead of 180 seconds. The ERTS-type ground processor would have to be modified to make the necessary doppler shift measurements.

In order to support a firm system design choice in this area, a detailed investigation will have to be made of alternative doppler measurement techniques. In addition, an intensive trade-off study including the results of system simulations and analyses will be required to reconcile the needs for data collection and platform location.

3.2.2 Communications Channel

The basic concept of a satellite data collection system involves use of a transponder on a satellite to communicate the data back to a ground station. The transponder characteristics reflect the overall system design requirements but may be chosen so that it is adaptable to several different types of DCP signal formats. In this manner, it may be considered more of a general purpose communications link; the system design being determined by the DCP's and the signal processing at the ground stations.

Some data collection systems, (eg. NIMBUS RAMS) do not use a communications transponder. Instead the satellite contains a number of parallel, phase lock loop receivers which measure the doppler shifts of the DCP signals directly and store this information and the digital data on a tape recorder for later transmission to an earth station. This method eliminates the flexibility inherent in the communications transponder concept and requires substantially more equipment on the satellite.

However, it gives the capability for global coverage without requiring a large number of ground stations. For Canadian coverage, data storage on board the satellite is unncessary since only 2-3 ground stations are required.

3.2.3 Receiving Stations

There is a need for at least two ground stations to provide adequate coverage to all of Canada as indicated in Chapter 4. Since they would be located near Summerside, PEI and Yellowknife, NWT, it would be costly for many users, who require fast delivery, to obtain their data by daily Telex.

An alternate concept involves the use of relatively low cost regional terminals to collect the data at points closer to the end users. However, the locations of these terminals may prevent full or adequate coverage over all of Canada and it would still be necessary to depend on long distance communications to deliver data to some users. Chapter 4 indicates the coverage zones for several regional terminal locations.

Another alternative is to use two ground stations which transmit all their data in block form by common carrier to regional terminals where it is processed and sorted prior to delivery to the users. These regional terminals may be existing computer utilities, either government-owned or commercial. There could be significant savings in communications with this method if the data is transfered in bulk form rather than separately to individual users. The doppler data processing for position location calculations could be implemented either at these regional terminals or by the user. Detailed cost studies will be required to support a final decision in this area.

3.2.4 Data Distribution

The delivery of data from the ERTS DCS is done both by mail delivery of punched computer cards and by Telex. Canadian users can obtain their data from a special disk file on the computer at the Canada Centre for Remote Sensing (CCRS) by telephone interconnect of a standard computer terminal. The main disadvantages of the present arrangement appears to be the long distance telephone costs to users located distant from Ottawa and the time it takes to get the data from the ground stations to Washington, DC and then to CCRS.

For this system, the methods of data delivery to the end user are expected to be the same as currently used except for the point of distribution. As discussed in Section 3.2.3, data distribution may be from the two basic ground stations, from regional terminals (computer centres) or from regional ground stations serving individuals or small groups of users.

3.3 A Baseline System Design

In a preliminary study of this nature, it is impossible to make an optimum system design selection without the benefit of detailed performance analyses and evaluation of each alternative. However, the principal objective of this study is to determine the feasibility of combining a data collection system with a search and rescue satellite system. Hence, a somewhat arbitrary system design is postulated at this stage to allow meaningful results to be derived for other aspects of the study.

The baseline design assumes the use of ERTS-type DCP's for data collection and modified ERTS DCP's for data collection and location in a mixed mode type of system. The following subsections describe the major elements of the system.

3.3.1 Data Collection Platforms

As mentioned above, the system design assumes the use of ERTS-type DCP's. A specification summary for these DCP's is given in Table 3-4. For location purposes, modifications will be required to the DCP's. Two options are as follows:

a) a stable sub-carrier is added to the transmitter; it is sent for 200-500 msec. every 30 seconds on a frequency 10 kHz from the edge of the transponder band pass; and this signal is modulated with a low rate (100 bps) identification code.

b) the main DCP signal format is altered to in corporate a carrier burst of approximately 20 msec duration after the basic data transmission is finished; the repetition rate is increased to one burst every 20-30 seconds; and the transmitter oscillator is modified to make it stable (ie. low tolerance crystal and temperature compensation).

The second option is probably easier to implement in the existing DCP's. The question which remains, however, is whether the doppler shift can be measured with sufficient accuracy on a short carrier burst. The first option requires more power drain from the DCP and a separate doppler processor capable of handling many simultaneous signals in the ground station. However, it may be slightly more efficient in terms of ultimate system capacity since the multiple narrow band (300-400 Hz) location signals are all put into 20 kHz of bandwidth whereas in the second option, the location signals each tie up about 20 kHz of bandwidth.

To meet some users' requirements for increased amounts of data and/or more frequent data readings, the memory module now under development for ERTS DCP's should provide an adequate solution. It allows data readings to be programmed at frequent

Data Format	8 bit digital words
Data Burst Format	95 bits: sync(15), ID(12), data(64), encoder runout (4)
Data Rate	2500 bps
Encoder	Rate ½ convolutional with constraint length of 5 bits
Converter	Split Phase (Manchester II) biphase level output
Message Format	190 bits, 5 kbps
Frequency	401.55 MHz ±0.0025%
Short term Stability	250 Hz rms
Power	5 Watts (into 50 ohms at 1.5:1 VSWR)
Modulation	FSK
FM deviation	±5 kHz ±5%
Mark to Space Transition	20 ± 10 microseconds
Duty Cycle	30 msec burst every 180 sec (90 optional)
Antenna Gain	Bifolium 1.5 db min at 20° elevation - 2 db min at 90° elevation
Antenna Polarization	Right Circular
Antenna Impedence	50 chms
Antenna Ground Plane	46 inch diamter

ERTS DCP SPECIFICATION

TABLE 3-4

intervals by the DCP clock, stored in the memory and then read-out sequentially on one or more consecutive data bursts.

For some applications, especially those requiring a light weight DCP (e.g. meteorological balloons), the ERTS DCP design is probably too heavy (4.1 kg vs. 0.545 kg for the NIMBUS F DCP's) and a complete repackaging job will have to be done.

In order to accommodate 2000 ERTS-type DCP's, a system bandwidth of about 100 kHz is required. In addition, several parallel detection and decoding channels are required at the ground station. The present ERTS system (which does not provide location) uses approximately 68 kHz of bandwidth and detects only one signal at a time. Frequency diversity is used only to prevent interference of one signal by a second one.

Figure 3-1 shows the spectral distribution of the DCP signals. For option a), the location signals are all concentrated in the upper 20 kHz of the spectrum leaving 80 kHz for the regular data transmissions. Up to eight location signals and two data signals may be present at any one instant. The frequency characteristics of the ERTS DCP's are as follows:

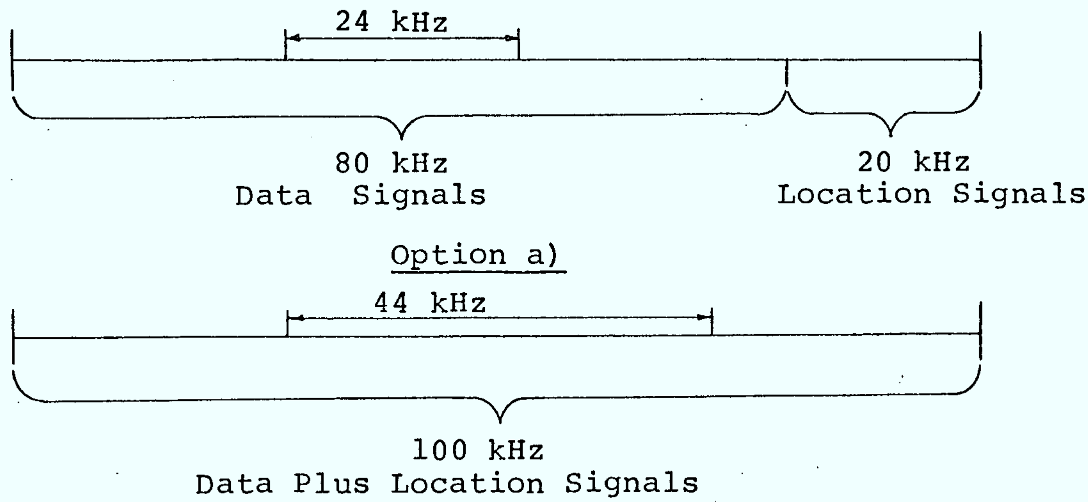
Transmitter Stability (0.0025%)	±10 kHz
Doppler Shift (1000 km altitude, 20 deg. elev. angle)	± 8 kHz
Signal bandwidth (5 kbps, FSK)	20 kHz

The nominal DCP center frequencies should be located over a range of ±12 kHz around the center of the 80 kHz bandwidth. This can be accomplished by crystal selection or by relaxing the tolerance on the crystal to .005%. The locatable DCP's require a very stable oscillator although the center frequency does not have to be precisely known. The oscillator circuit must be temperature compensated to achieve a low drift (5-10 Hz) over periods of 10-15 minutes.

For option b), the full 100 kHz of bandwidth is available for data signals since the location signals occur at the same frequency as the data transmissions. The nominal center frequencies are required to be spread over ±22 kHz. Doppler shift and crystal tolerances ensure that there is a statistical spread over the full 100 kHz bandwidth. The effect of 200 DCP's having an extra 20 msec carrier burst and repeating every 30 seconds is equivalent to 1800 DCP's. Thus the total system loading is effectively 3600 DCP's and up to four signals will often occur simultaneously. Frequency diversity will allow most simultaneous transmissions to be properly received by parallel detection and decoding circuits in the ground stations.

3.3.2 Communications Channel

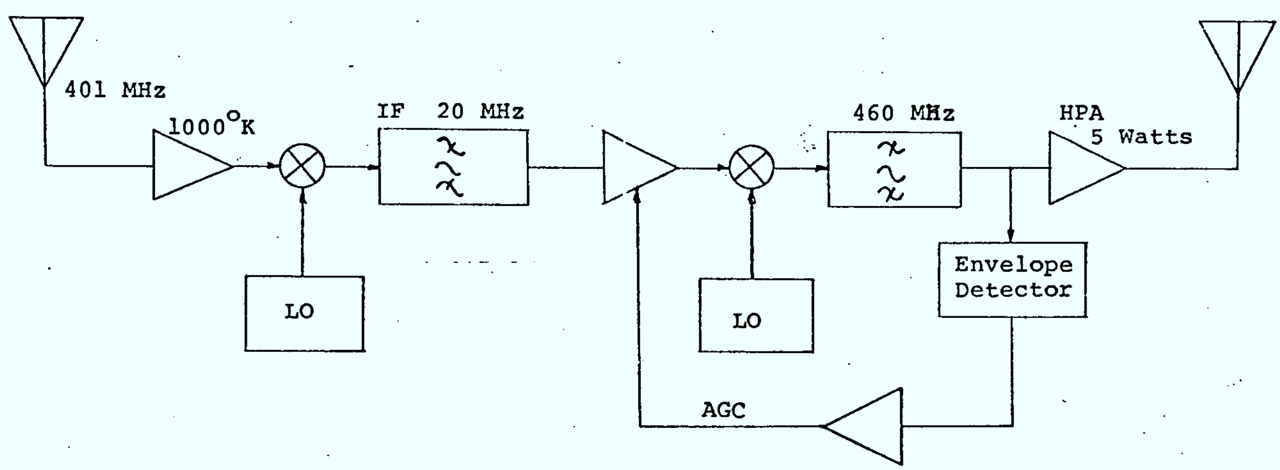
The transponder on the satellite is designed for a 100 kHz bandwidth. The uplink is in the 401 - 403 MHz band while the downlink is nominally set for 460 MHz (272 MHz may be considered



Option b)

Signal Spectrum Allocations

Figure 3-1



Transponder Block Diagram

Figure 3-2

as an alternative). The transponder block diagram is presented in Figure 3-2. The transponder may either use an AGC loop or a soft limiter to maintain interference from intermodulation products to an acceptably low value when multiple transmissions occur simultaneously.

The assumptions used in the uplink and downlink calculations are as follows:

1) Uplink frequency — 400 MHz

2) DCP RF Power Output — 5 Watts

3) DCP Antenna Pattern - Bifolium
   - At 90 deg. elevation angle: Gain > -2 db
   - At 20 deg. elevation angle: Gain > 1.5db
   - At 10 deg. elevation angle: Gain ~ 0.5db

4) Satellite receive antenna pattern - Bifolium (same as DCP)

5) Satellite transmit antenna gain — 0 db

6) Satellite receiver noise temperature — 1000 ^{o}K

7) Downlink frequency — 460 MHz

8) Ground station antenna gain (equivalent 3 m diameter) — 20 db

9) Ground station receiver noise temp. — 300 ^{o}K

10) Orbit altitude — 1100 km

These assumptions yield the uplink parameters as given in Table 3-5.

		DCP ANTENNA ELEVATION ANGLE		
Parameter		10 deg	20 deg	90 deg
Satellite range	km	2900.	2300.	1100.
DCP EIRP	dbw	7.5	8.5	5.
Satellite G/T	db/^{o}K	-29.5	-28.5	-32.
Uplink C/N_o	dbHz	52.9	56.9	56.3

UPLINK PARAMETERS

TABLE 3-5

Note that a bifolium antenna pattern on both the satellite and the DCP results in a fairly constant C/N_o over the elevation angle range of 20-90 deg.

The satellite transponder parameters are given in Table 3-6 for the Option b) signal format.

1) Receiver Bandwidth	100 kHz
2) Noise Power (kTB)	-148.6 dbw
3) Received Signal Power (20 deg elev)	-141.7 dbw
4) S/N (per DCP)	6.9 db
5) HPA RF Output Rating 5 Watts	7. dbw
6) Output Backoff (to minimize intermod)	2. db
7) No. of Simultaneous Signals (option b)	4
8) RF power available per signal	-1. dbw
9) Correction for transponded noise power	-.3 db
10) Net Power per DCP signal	-1.3 dbw

SATELLITE TRANSPONDER PARAMETERS - OPTION b)

TABLE 3-6

For option a), 2 simultaneous data transmission signals are contained in an 80 kHz bandwidth and up to 8 location signals are contained in the remaining 20 kHz bandwidth. To ensure proper power sharing between these two types of signals, channellization of the transponder is recommended. The 5 watt power output is divided equally between the two channels resulting in the parameters given in Table 3-7.

	80 kHz Channel	20 kHz Channel
1) Number of signals	2	8
2) Power available	3.9 dbw	3.9 dbw
3) Power per signal	0.97 dbw	-5.1 dbw
4) Output backoff	-1. db	-2. db
5) Correction for transponder noise	- .5 db	- .1 db
6) Net power per signal	-0.5 dbw	-7.2 dbw

SATELLITE TRANSPONDER PARAMETERS - OPTION a)

TABLE 3-7

At the ground station the following assumptions apply:

1) Minimum elevation angle	5	deg
2) Maximum range	3300	km
3) Ground station G/T	-4.8	db/^{o}K
4) Spacecraft transmit antenna gain	0	db

The signals at the ground station have the characteristics given in Table 3-8.

	Option a)		Option b)
	80 kHz Channel	20 kHz Channel	100 kHz
1) EIRP per signal	-.5 dbw	-7.2 dbw	-1.3 dbw
2) Downlink C/N_o per signal	67.3 dbHz	60.6 dbHz	66.5 dbHz
3) Overall C/N_o	56. dbHz	55.5 dbHz	55.9 dbHz
4) Receiver Bandwidth	20. kHz	500. Hz	20. kHz
5) Receive C/N	13. db	28.5 db	12.9 db
6) Threshold	10. db	10. db	10. db
7) Margin above threshold	3. db	18.5 db	2.9 db

GROUND STATION SIGNAL PARAMETERS

TABLE 3-8

The margins given in Table 3-8 represent a fairly solid signal for data decoding. The location signals of Option a) have a high signal-to-noise due to the narrow bandwidth of the phase lock loop receiver and this allows accurate doppler shift measurements to be made. In option b), the margin above threshold applies only to the 5 kbps data signals. The phase lock loop receiver lines up on the signal during the 38 msec data burst and then makes an accurate measurement of doppler shift using a narrow bandwidth (<100 Hz) during the 20 msec carrier burst. Its margin above threshold with this bandwidth will be approximately 20 db.

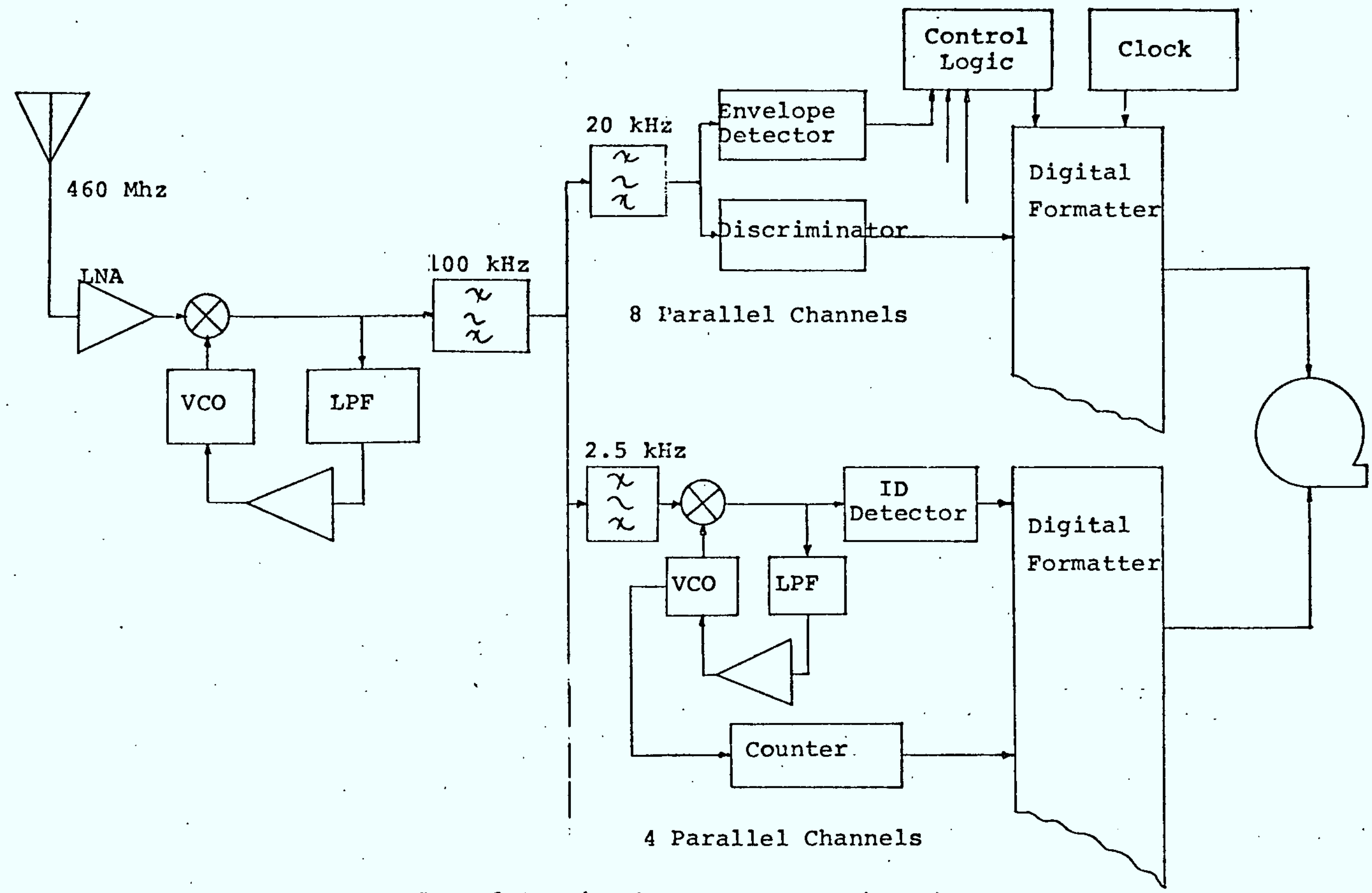
The above link calculations show that a satellite transponder with an actual RF power output of 3 watts (2 db backoff) is quite adequate for handling the signals of either Option a) or b). The total DC power consumption, assuming an efficiency of 30% and allowing for operation of the receiver, is about 15 watts.

3.3.3 Ground Stations

As stated in the RF link budgets of the previous sub-section, the ground station antenna is assumed to have a gain of 20 db which corresponds to a 3 meter diameter dish antenna. In practice, it is more likely that a quad helix array will be used. The corresponding beamwidth is about 15 degrees and therefore, the antenna pointing is done with a simple, program track control loop. Pointing data is sent to each station once per week from the control centre where orbit predictions are calculated.

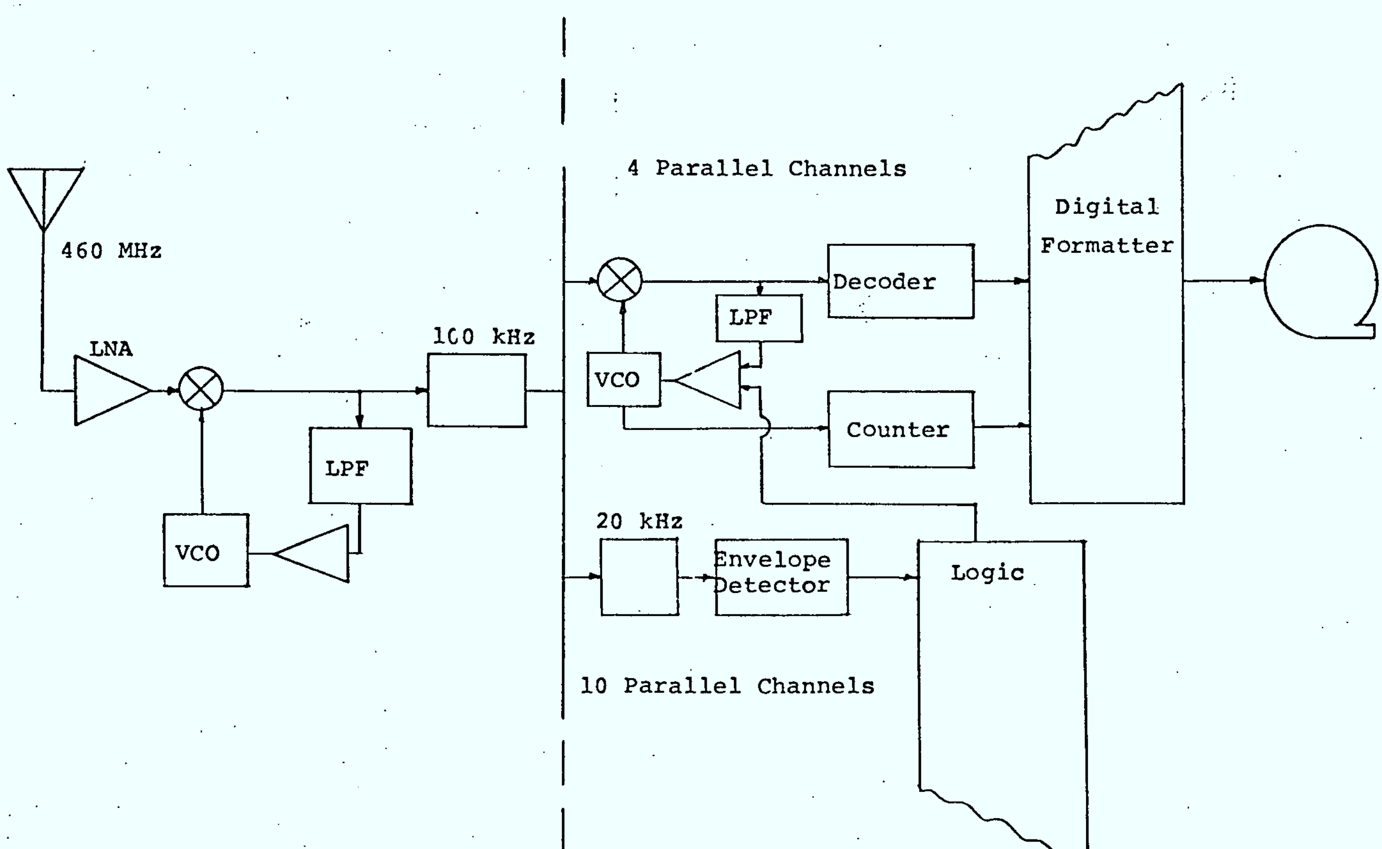
The data detection and decoding hardware configuration will depend on which signal format option is finally chosen. Figures 3-3 and 3-4 present the block diagrams for the two options. In option a), only 2 digital detection and decoding channels are required whereas 4 are required in option b). However, option a) requires 8 parallel phase lock loops for doppler measurements compared to 4 for option b).

The standard ERTS data processor uses non-coherent signal detection by using an array of discriminators fed by a comb filter. Each filter has a 20 kHz bandwidth and overlaps 50% with adjacent filters. Option a) requires 8 discriminators while option b) requires 10. A logic unit monitors the outputs from a square law detector on each discriminator to detect the presence of a signal and assigns the receivers to particular frequencies. This technique is quite fast compared to using a phase lock loop receiver to search the entire spectrum to detect the presence of signals. The receivers domodulate the signals and feed them to digital decoders. The data is tagged with an error flag if discrepancies in the convolutional code are detected. The data is then stored on magnetic tape until the pass is complete.



Ground Station Processor - Option a)

FIGURE 3-3



Ground Station Processor - Option b)

Figure 3-4

The position location signals are treated in a similar manner. The phase lock loop receiver oscillator is read out by a digital counter and, in the case of option a), the identification code is detected. This data is also stored on magnetic tape for later processing.

A promising alternate processor technique involves an all digital approach using a Fast Fourier Transform processor and adaptive matched filtering to extract both the data and the signal doppler shift. This approach would appear to give the potential for handling multiple simultaneous signals in a single processor and would give a fast response to signal inputs. However, at the present time, insufficient work has been done to define the expected performance of this type of processor for a proper comparison to be made with the more conventional approaches described above.

For the baseline design, two ground stations are assumed; they are located at Summerside, PEI and at Yellowknife, NWT as for the Search and Rescue ground stations. Other locations may be considered but system coverage may be degraded (see Chapter 4). The ground stations would sort the data according to user identification codes and assemble the data for block transmission to regional terminals once every 12 hours.

The regional terminals, being general purpose computer centers, would store the data on magnetic tape and from that produce punched cards, paper tape, disk files or line printer output for each user according to a prearranged contractual agreement with each user. The user could have his data delivered in raw form, in engineering units or in histogram format. The computer centers would also be able to run specific application programs for the user to analyze for long term trends, limit flags, etc. and to process the doppler data for position location.

The regional terminals will be located in large population centers such as Halifax, Montreal, Ottawa, Toronto, Winnipeg, Calgary and Vancouver and would be implemented by existing computer utilities. In this manner, the user pays the computer utility for data handling and processing services according to his own needs. The computer utilities would charge the users a prorata share of the data transmission costs from the ground stations but this would likely be significantly less than the cost of dedicated telex messages from the ground station to individual users.

3.3.4 Data Distribution

Under the concept of using computer utilities as regional terminals for data distribution, the normal methods for data delivery are used. Printed outputs such as punched cards, paper tape, lineprinter, calcomp, etc. are delivered by mail or courier service. The user can also obtain data by telephone interconnect of a standard remote computer terminal to obtain his data in printed form on paper tape or on magnetic tape cartridge.

4. MISSION ANALYSIS

4.1 Orbit Compatibility with the SAR Mission

The DCS orbit requirements share many basic characteristics with the SAR requirements. Coverage requirements in either case dictate that the satellite should cover a large area (high satellite altitude) as many times per day as possible (low altitude). The former effect tends to dominate, making the optimum range of orbit altitudes 1000 to 1400 kilometers. If coverage over all of Canada is required in less than 12 hours, it must be provided by a multiple satellite system. (If very frequent coverage is required for all of Canada, say every hour or less, a synchronous or highly elliptical satellite orbit system may be required, which is incompatible with the SAR mission).

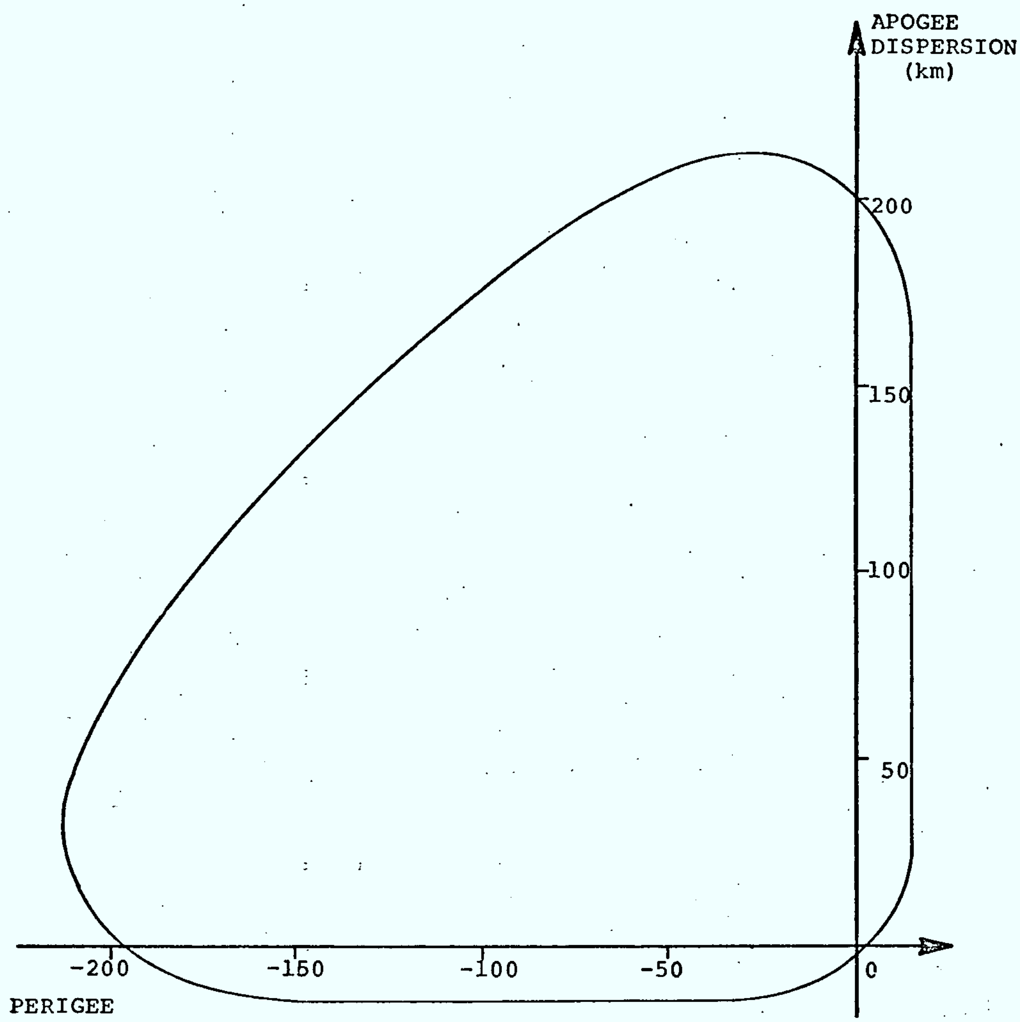
4.2 Effect of Scout Injection Errors on System Coverage

The Scout launch vehicle is capable of injecting the satellite into a polar orbit with a maximum inclination error of ±1.8 degrees (3 sigma). This error will have only a second order effect on data collection performance. The target orbit allows for a passage over the North pole once per orbit, but the coverage swath is so wide that any small inclination deviation will not significantly change the coverage pattern. There will also be a secondary effect on rate of change of ascending node and argument of perigee, but these parameters are not controlled for this mission.

The Scout has poor accuracy for achieving the final injection velocity and therefore large changes in the apogee and perigee heights result. Scout design curves for a 550 km circular orbit are shown in Figure 4-1. These errors will be approximately half again as large for a SAR/DCS mission due to the higher mean altitude. Assuming a nominal altitude for this mission of 1100 kilometers, it is very unlikely (less than 1% probability) that the apogee will ever exceed 1500 kilometers where radiation damage may begin to be significant in a long duration mission. It is also quite unlikely that the perigee will ever drop below 800 kilometers.

Three extreme DCP locations were chosen in order to demonstrate the effect of reduced altitude (800 km) on coverage:

1) 90 degrees North latitude
2) 42 degrees North, 50 degrees West
3) 47 degrees North, 140 degrees West



SCOUT APOGEE-PERIGEE DISPERSIONS
(for 550 km altitude orbit)

Figure 4-1

The two ground station locations, recommended in a previous study (2), were assumed to be Yellowknife, N.W.T. and Summerside, PEI.

Figures 4-2 and 4-3 indicate the coverage for the northernmost DCP for satellite altitudes of 1100 km and 800 km respectively. The three lens shaped coverage zones define the area of mutual satellite visibility from the DCP and the ground station for the three satellite elevation angles of 10 degrees, 15 degrees and 20 degrees as measured at the DCP. A minimum allowable antenna elevation angle of 5 degrees is assumed for the Yellowknife ground station. The DCS is available to the DCP only during the time the satellite is over the coverage zone. At 1100 kilometers altitude, the satellite transponds the DCP signals on about eleven orbits every day (split into two groups of passes about twelve hours apart). At least two passes per day are about 5 minutes long for the 20 degree elevation angle, or about 7 minutes long for the 10 degree elevation angle. At 800 kilometers altitude, both the nominal number of orbits per day and

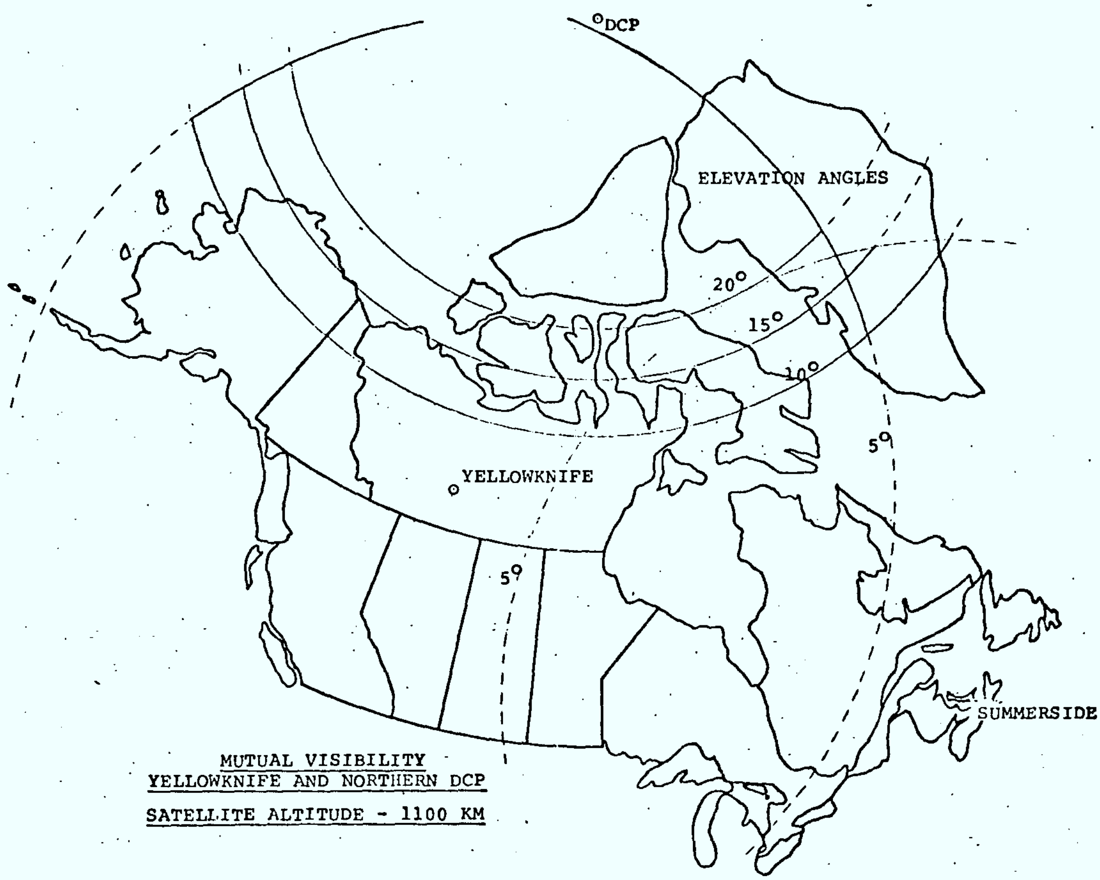


Figure 4-2

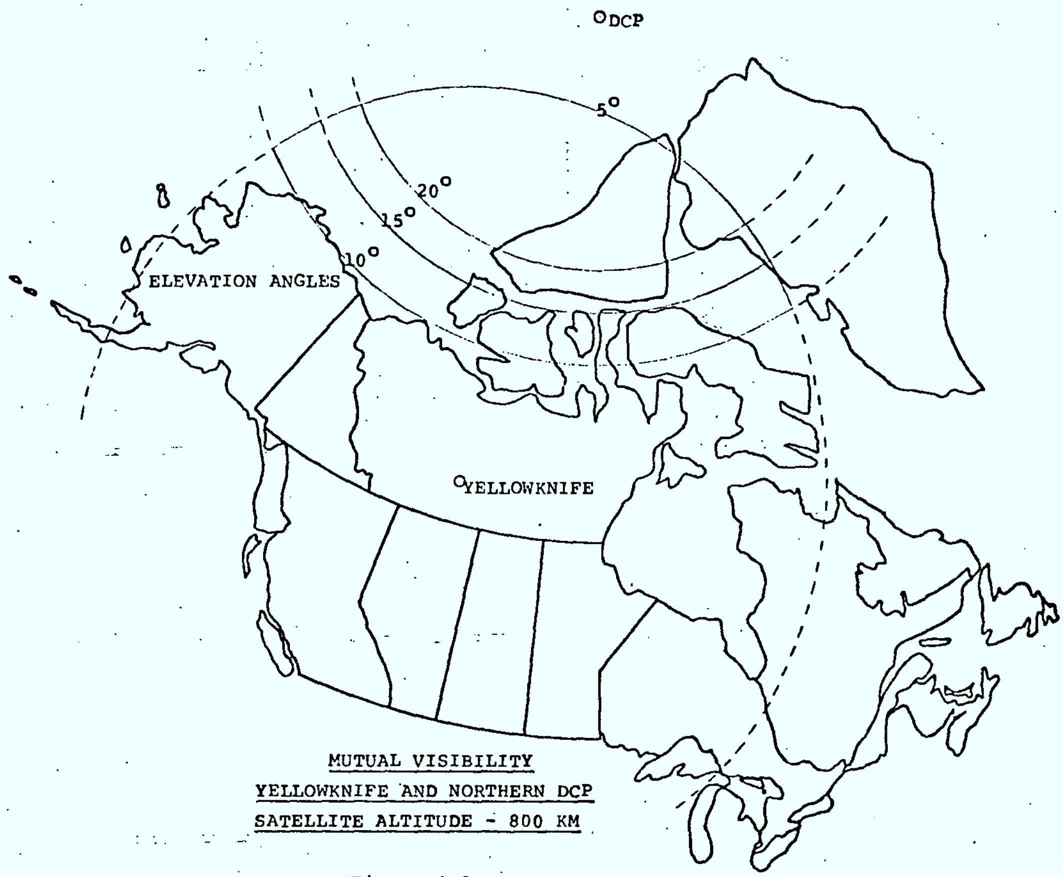


Figure 4-3

the maximum length of pass are reduced. Table 4-1 compares the visibility parameters for both altitudes.

SATELLITE ALTITUDE	DCP MIN. ELEV. ANGLE	NOMINAL PASSES/DAY	MAXIMUM PASS LENGTH (MIN.)
1100 km	20^{o}	11	5
	15^{o}	11	5.75
	10^{o}	11	6.75
800 km	20^{o}	8.5	4.25
	15^{o}	8.5	5
	10^{o}	8.5	5.75

NORTHERN DCP VISIBILITY PARAMETERS

TABLE 4-1

Based on a 180 second long data transmission duty cycle and a 95% chance that a data burst will be successfully transmitted if mutual visibility exists, there is a high probability that there will be at least one successful transmission every twelve hours from the northern DCP even if the orbit dispersions result in an 800 kilometer perigee over the North Pole. For the nominal 1100 km satellite altitude and a 15 degree (or lower) elevation limit, the northernmost DCP is covered primarily by Yellowknife although Summerside also has a small area of mutual visibility. (Figure 4-2). At a satellite altitude of 800 km the Summerside visibility disappears.

Figures 4-4 and 4-5 show the coverage of the easternmost DCP for satellite altitudes of 1100 and 800 km. The area of mutual visibility between Summerside (antenna elevation limit 5 degrees) and the eastern DCP is almost as large as the DCP visibility limit alone. The nominal number of passes per day and maximum length of pass are shown in Table 4-2. Because of the very long passes it is very probable that there will be at least one successful data transmission every 12 hours. For the nominal 1100 km satellite altitude and a 15 degree (or lower) elevation limit, the easternmost DCP is covered primarily by Summerside although Yellowknife also has a small area of mutual visibility (Figure 4-4). The Yellowknife visibility disappears if the satellite altitude drops to 800 kilometers.

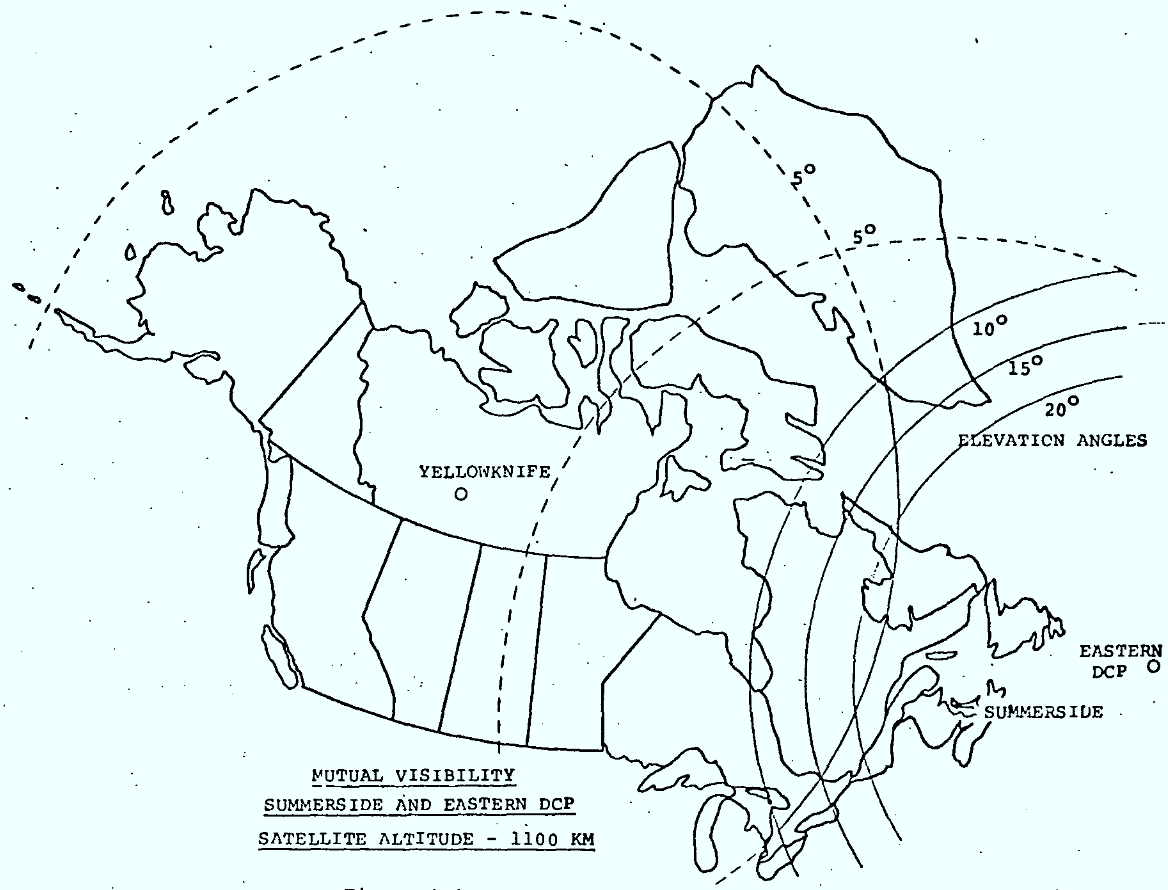


Figure 4-4

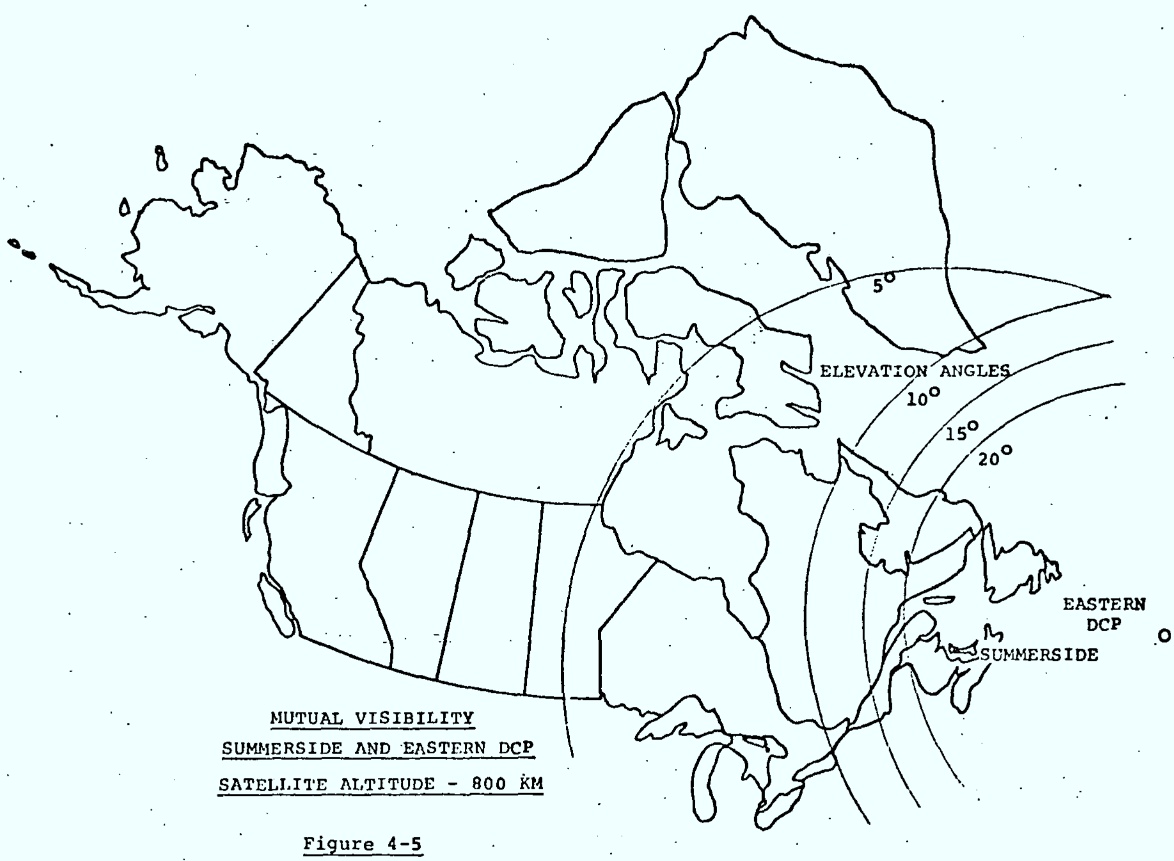


Figure 4-5

SATELLITE ALTITUDE	DCP MIN. ELEV. ANGLE	NOMINAL PASSES/DAY	MAXIMUM PASS LENGTH (MIN.)
1100 km	20^o	3	10
	15^o	3.5	11.5
	10^o	4	13
800 km	20^o	2.75	7.5
	15^o	3	8.5
	10^o	3.25	9.5

EASTERN DCP VISIBILITY PARAMETERS

TABLE 4-2

Figures 4-6 and 4-7 show the coverage of the westernmost DCP for satellite altitudes of 1100 km and 800 km. A large area of mutual visibility with Yellowknife results for either altitude. Visibility parameters are listed in Table 4-3.

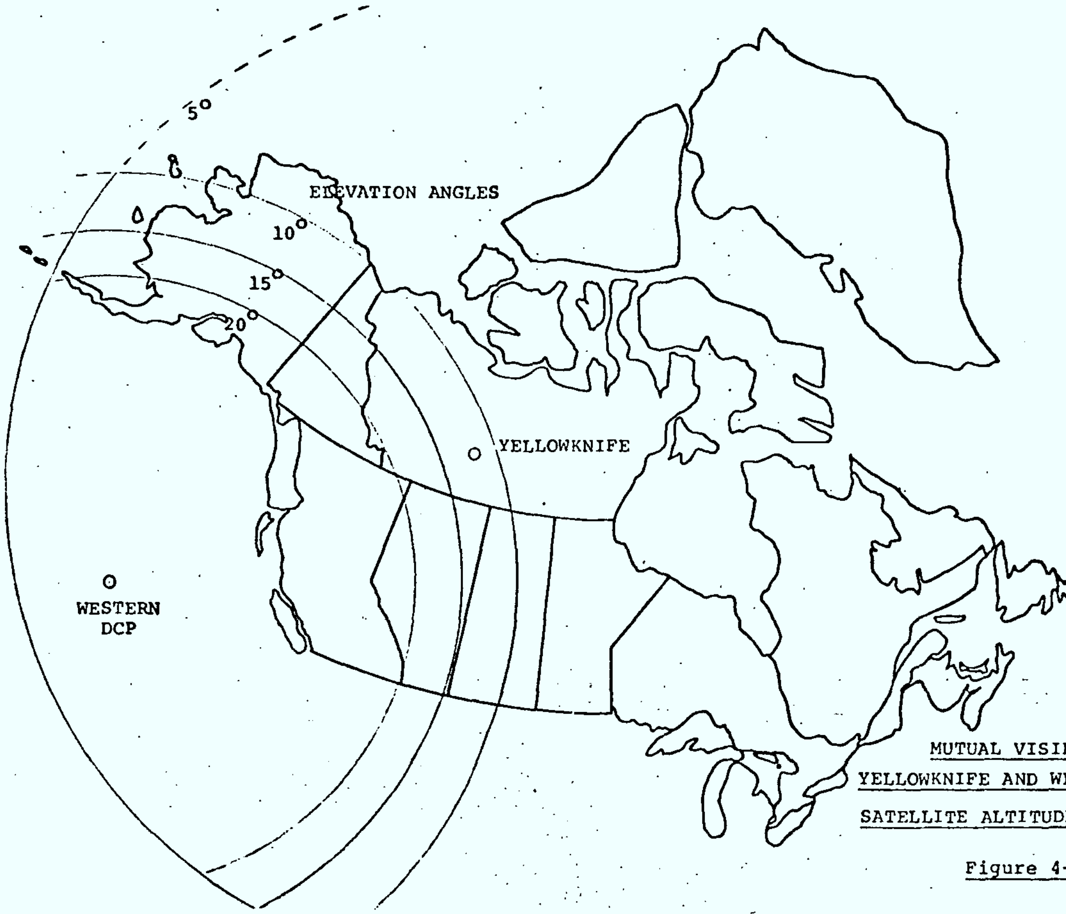
SATELLITE ALTITUDE	DCP MIN. ELEV. ANGLE	NOMINAL PASSES/DAY	MAXIMUM PASS LENGTH (MIN.)
1100 km	20^o	3.25	6.25
	15^o	4	7.25
	10^o	4.5	8.25
800 km	20^o	2.5	5
	15^o	3.25	5.75
	10^o	3.75	6.75

WESTERN DCP VISIBILITY PARAMETERS

TABLE 4-3

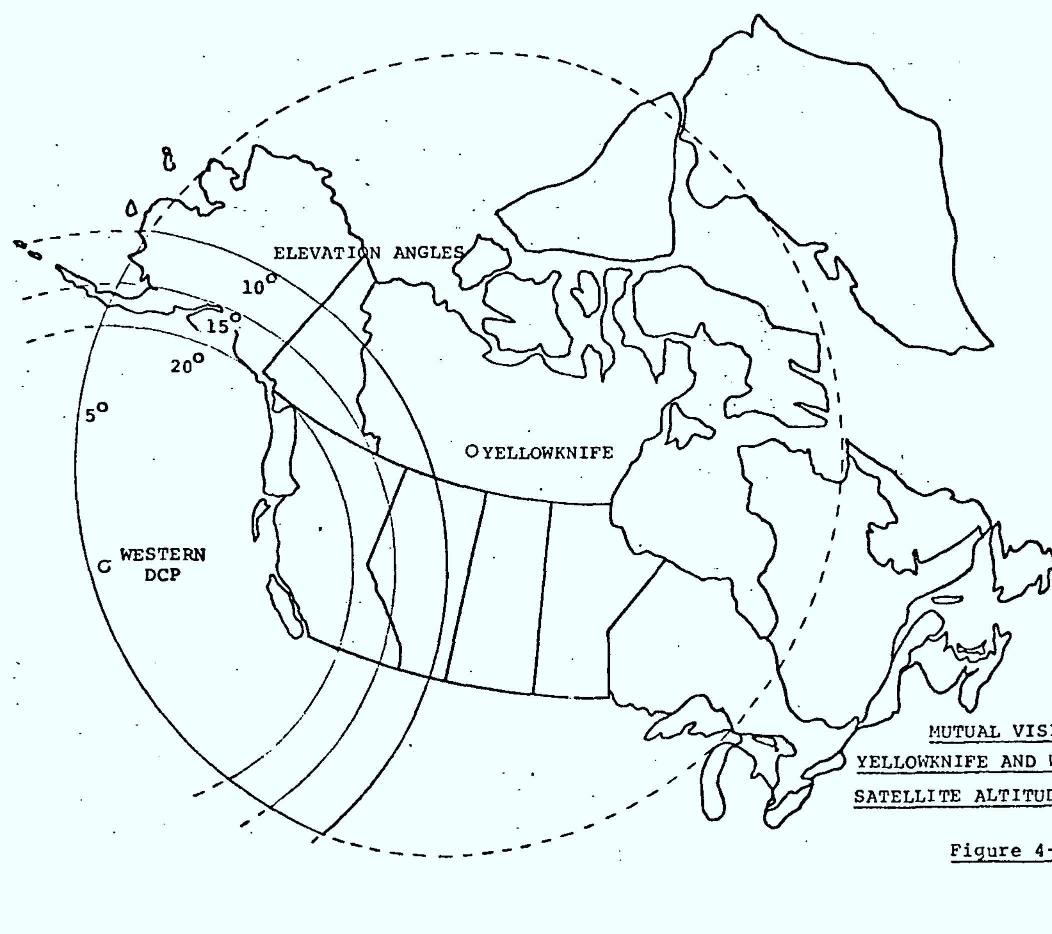
For the Western DCP there is a high probability that at least one data burst will be successfully transmitted every 12 hours.

In summary, it has been shown in Figures 4-2 to 4-7 that adequate visibility of the satellite is obtained for three extreme DCP locations even when the satellite altitude is as low as 800 km. Table 4-4 summarizes the visibility data for the three extreme DCP locations based on a 15 degree satellite elevation angle at the DCP.



MUTUAL VISIBILITY
YELLOWKNIFE AND WESTERN DCP
SATELLITE ALTITUDE - 1100 KM

Figure 4-6



MUTUAL VISIBILITY
YELLOWKNIFE AND WESTERN DCP
SATELLITE ALTITUDE - 800 KM

Figure 4-7

DCP Location	Satellite Altitude 1100 km Passes/Day	Pass Length (min)	800 km Passes/Day	Pass Length (min)
Northern	11	5.75	8.5	5
Eastern	3.5	11.5	3	8.5
Western	4	7.25	3.25	5.75

- based on a 15 degree satellite elevation angle at the DCP

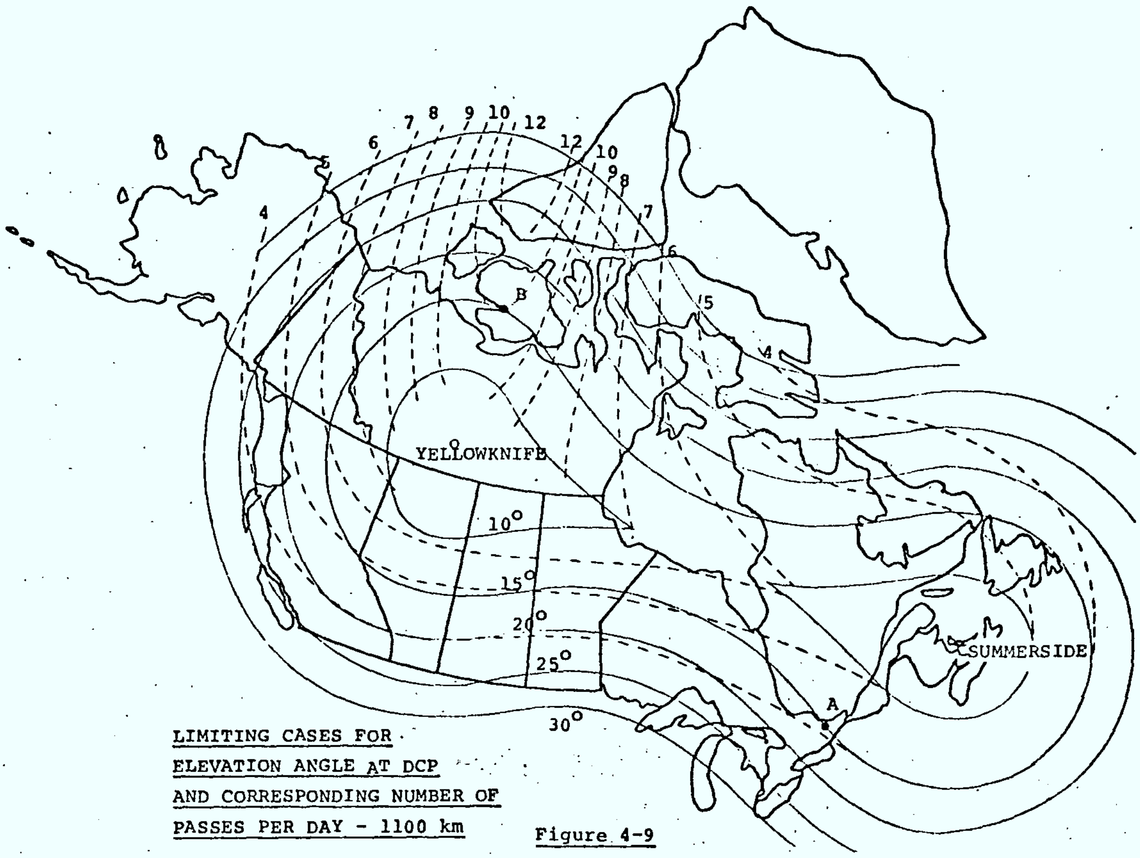
SUMMARY OF SATELLITE VISIBILITY FOR THREE EXTREME DCP LOCATIONS

TABLE 4-4

4.3 Nominal DCP and Earth Station Coverage

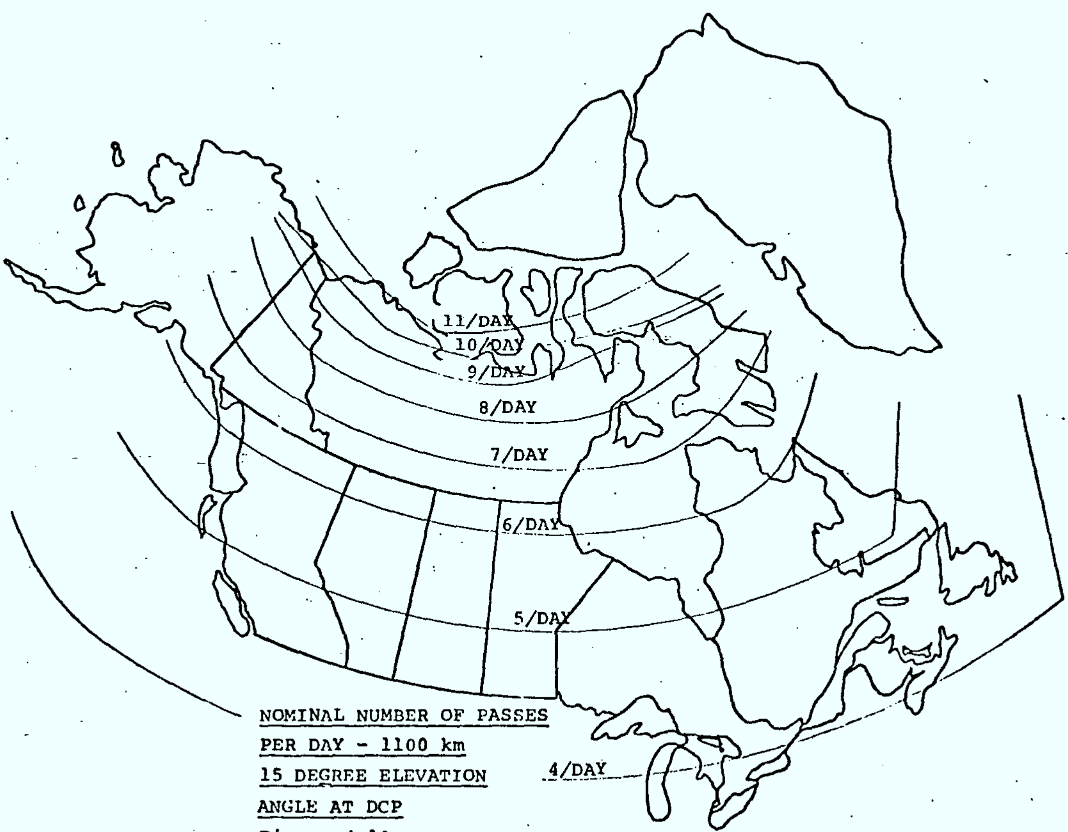
The coverage analysis given in Section 4.2 deals with extreme DCP locations and orbit altitudes ranging from 800 - 1100 km. At the nominal satellite altitude of 1100 km, and for locations on the Canadian land mass or nearby coastal waters, the system coverage is generally much better than for the cases given in the previous section.

Coverage is dependent upon two basic parameters - the solid angle subtended at the centre of the earth by the mutual visibility patterns (such as those shown in Figures 4-2 to 4-7) and the number of passes per day intercepting the solid angle. Figure 4-8 shows the solid angle coverage by the DCP alone as a function of the minimum satellite elevation angle at the DCP for which the system will operate. The solid angle drops off very rapidly with increasing angle. Also shown on the graph is another important parameter - the maximum possible pass length. (Neither of these curves includes an allowance for coverage limitations imposed by ground station antenna elevation angle restrictions). The length of a pass is important both to increase the probability of a successful data transmission and to maximize the doppler shift range for platform position determination. The range of locations in Canada for which the data in Figure 4-8 applies is shown by the "dog bone curves" of Figure 4-9. These curves represent limits of the areas within which the Yellowknife and Summerside stations do not cut off any portion of the DCP pattern. A substantial area of Canada is covered by the assumed nominal 15 degree minimum satellite elevation angle at the DCP which (from Figure 4-8) will result in passes up to 11.6 minutes long. Outside the 15 degree contour, a DCP with a 15 degree minimum elevation angle will suffer a loss in pass length and/or in the number of passes per day.

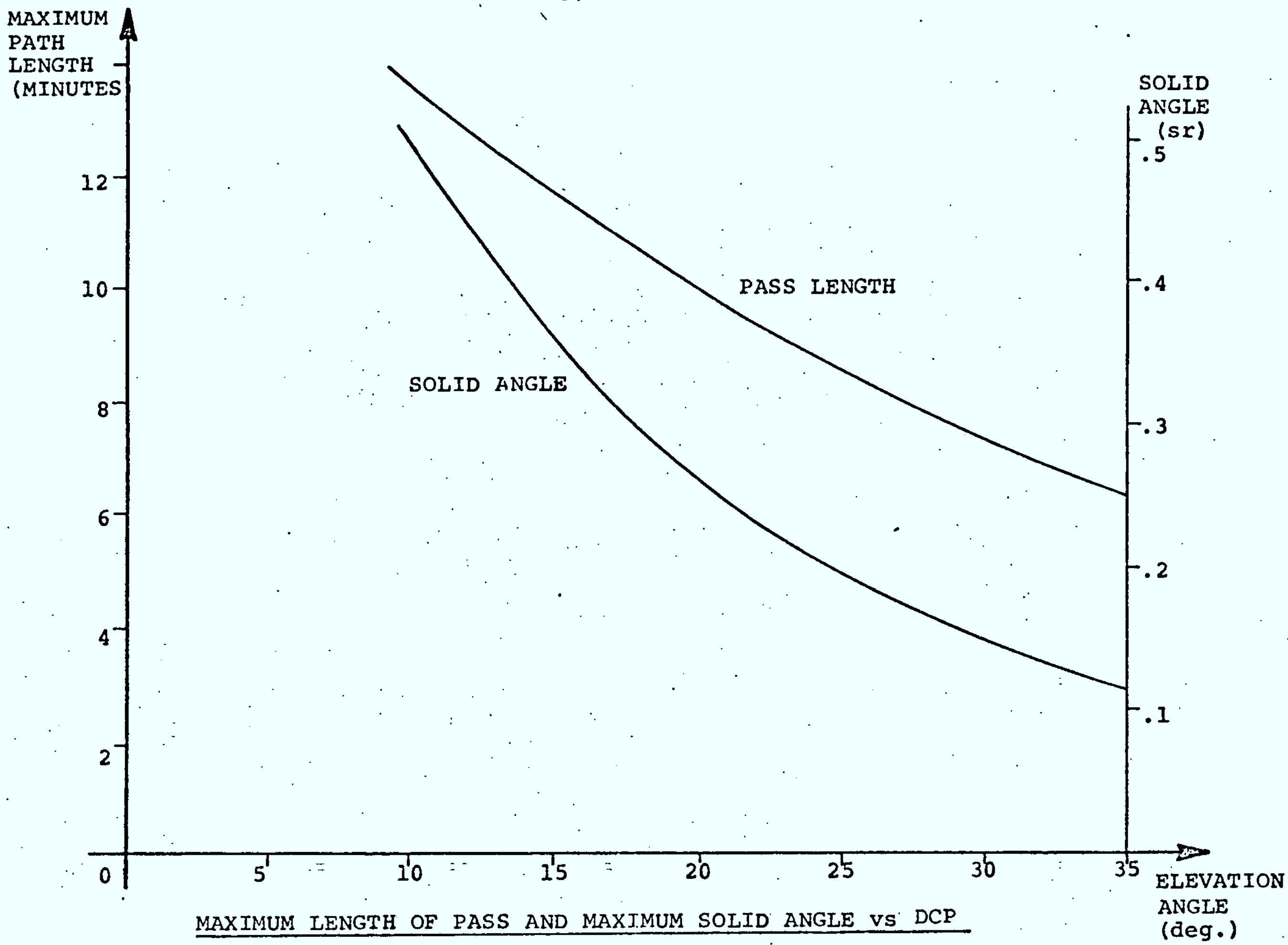


LIMITING CASES FOR
ELEVATION ANGLE AT DCP
AND CORRESPONDING NUMBER OF
PASSES PER DAY - 1100 km

Figure 4-9



NOMINAL NUMBER OF PASSES
PER DAY - 1100 km
15 DEGREE ELEVATION
ANGLE AT DCP
Figure 4-10



MAXIMUM LENGTH OF PASS AND MAXIMUM SOLID ANGLE vs DCP ANTENNA ELEVATION ANGLE

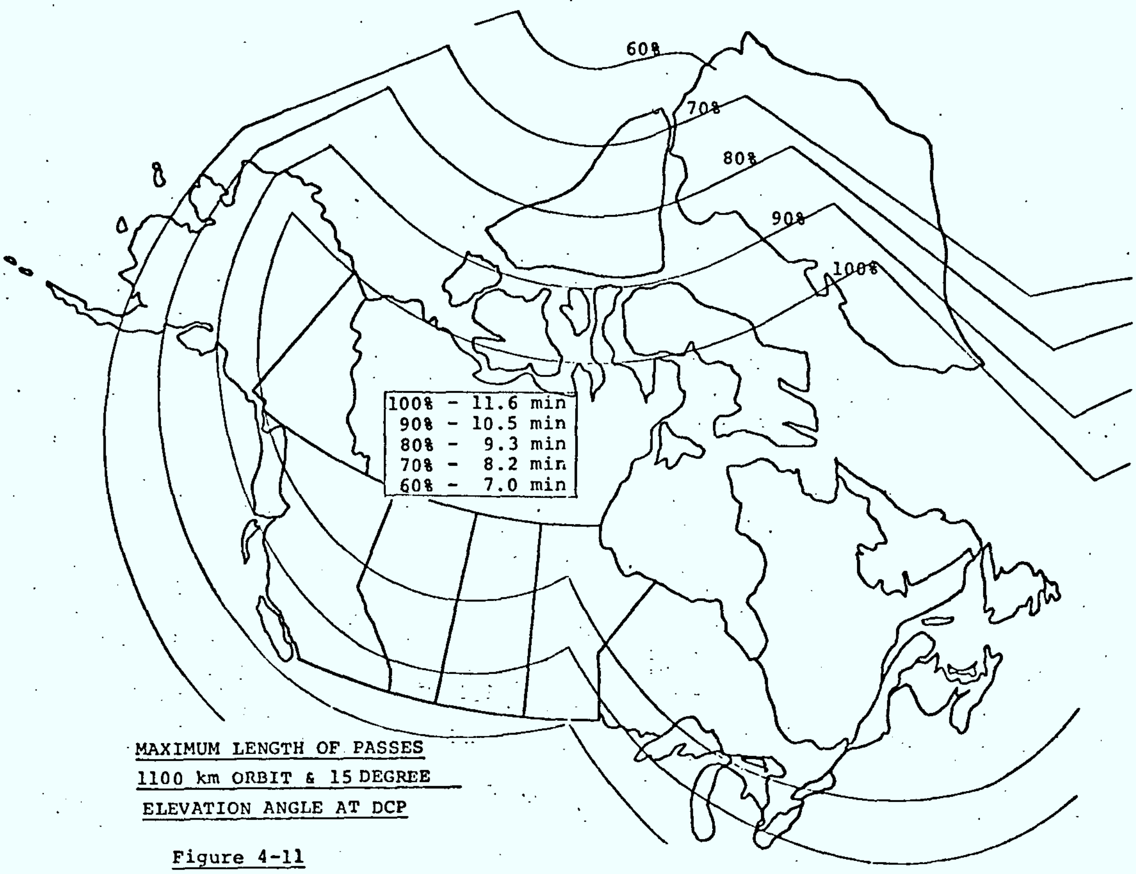
FIGURE 4-8

The dashed lines in Figure 4-9 represent the nominal number of passes per day visible to a station with the indicated elevation angles. So, for example, DCP A near Ottawa with a 15 degree minimum elevation angle, has no restrictions in solid angle due to ground station (Summerside) coverage restrictions and sees the satellite about four times per day. DCP B, also with a 15 degree minimum elevation angle and located on Victoria Island in the Arctic is also unrestricted and has the same maximum pass length, but it will view the satellite about 11 times per day.

Note that Figure 4-9 indicates only the limiting cases of unrestricted DCP view angle. If DCP A had a minimum elevation angle of 10 degrees, its solid angle would be restricted by the Summerside view angle. Its total solid angle would still be larger than the 15 degree case, as would its maximum pass length and nominal number of passes per day but these coverage parameters would not be as large as if it were located inside the 10 degree contour. In general, the nearer Yellowknife or Summerside a DCP is, the less likely it is to have its solid angle restricted, and the nearer the pole, the greater is the nominal number of passes per day (since the sub-satellite tracks converge on the pole).

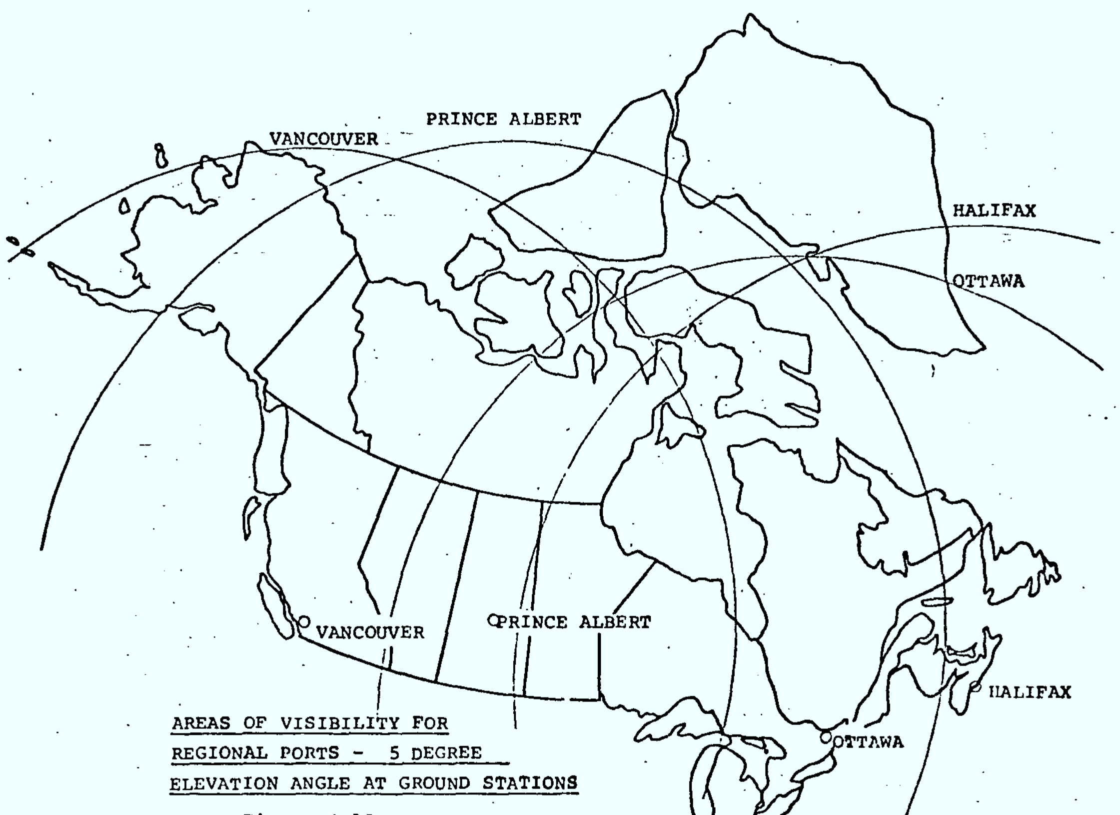
From the point of view of total solid angle, the SAR ground station configuration is weakest in the area of the Davis Strait, where some loss in DCP solid angle is inevitable. However, this loss is countered by the large number of passes per day and maximum pass lengths if a 15 degree minimum elevation angle is achievable. Figure 4-10 gives contours of the nominal number of passes per day over Canada assuming a 15 degree elevation angle at the DCP. Figure 4-11 shows the maximum pass lengths available for a DCP with a 15 degree elevation angle. The contours of pass length are expressed as a percentage of the maximum possible pass length of the DCP without ground station coverage restrictions. This 100% value is equivalent to a satellite pass of 11.6 minutes. Almost all of the Canadian land mass is covered within the 80% contour giving the conclusion that there is a good probability of getting at least one long pass per day, everywhere in or near the Canadian land mass except for the high Arctic.

The possibilities of using "regional ports" was also examined. Figure 4-12 shows the resulting coverage patterns for regional ports at Vancouver, Prince Albert, Ottawa and Halifax. The coverage of any one of these stations is of course poorer than that provided by the SAR configuration although it may serve special limited coverage requirements. Even the combination of all four regional ports is unable to provide Northern coverage as well as the SAR configuration.



MAXIMUM LENGTH OF PASSES
1100 km ORBIT & 15 DEGREE
ELEVATION ANGLE AT DCP

Figure 4-11



AREAS OF VISIBILITY FOR
REGIONAL PORTS - 5 DEGREE
ELEVATION ANGLE AT GROUND STATIONS

Figure 4-12

5. SATELLITE/PAYLOAD DEFINITION

This chapter deals with the specific question of the feasibility of combining a data collection system and a search and rescue satellite system on a single satellite. For this purpose, the search and rescue satellite baseline design as described in Chapter 2 (based on Ref. 2) is used as a starting point. The three areas of weight, power and antenna are examined closely for compatibility. Since a detailed spacecraft configuration layout does not exist, questions regarding unit envelope, mounting and thermal control are not addressed. However, for the size of spacecraft, the weights and the powers involved, there does not appear to be any fundamental constraints that indicate a potential problem in these areas.

5.1 Power

The data collection transponder is capable of a rated 5 watts saturated RF power output. Assuming a 30% efficiency, this requires 16.6 watts of DC power. In actual practice, the transmitter will be backed off from saturation by about 2 db to keep intermod levels down. Depending on the design of the transmitter, this may reduce DC power consumption somewhat. However, for the purposes of the power budget, the full 16.6 watts will be used. The receiver and frequency translation section requires only a very small amount of power. A figure of 1.5 watts is assumed. The total transponder power consumption is therefore about 18 watts.

Based on the data given in Tables 2-3 and 2-4 for the Search and Rescue Satellite baseline design, Table 5-1 presents a revised spacecraft power budget which includes both the data collection and search and rescue transponder requirements. Power conditioning and battery charge powers are adjusted to account for the larger primary load. No increase in power for the telemetry and command is assumed since the amount would be negligible.

From Tables 2-3 and 2-4, the solar panel power outputs (at Beginning of Life-BOL) for the spinning and gravity gradient spacecraft configurations are 90 watts and 64 watts respectively. The spinning spacecraft power output should be adjusted to 80 watts for summer solstice conditions.

For the spinning spacecraft configuration, the margin of 5 watts (7%) is insufficient to cover solar panel degradation over a 7 year lifetime. A higher solar cell efficiency level than the 10.3% assumed in Table 2-3 would provide an adequate margin. Several new types of solar cells have recently been developed ('violet cell', 'black cell') which achieve output efficiencies of 13-15%. However, by selecting standard solar cells from the production line, an efficiency level 11.8% is obtainable and this gives a 22% margin for degradation over the mission lifetime. Adding additional solar panel area may be difficult without resorting to deployable panels since the cylindrical spacecraft body size is constrained by the Scout launch vehicle fairing.

For the gravity gradient spacecraft configuration, the power output is clearly insufficient even with the 11.8% solar cell efficiency level assumed in Table 2-4. The solution in this case is to enlarge the solar panels. An extra 10 lbs. in solar array weight will yield an additional 40 watts (assuming 11.8% cell efficiency) which results in a power margin of 38%.

In summary, the spacecraft designs of Ref. 2 appear to be able to handle the power requirements of a combined search and rescue and data collection mission only with certain modifications. It appears that power will be the constraining factor in spacecraft development and every effort should be made to minimize power consumption in the payload.

ITEM	POWER - WATTS
1. Telemetry and Command	10
2. SAR Transponder	7
3. DCS Transponder	18
4. Power Conditioning (80% efficiency)	7
Primary Power Demand	42
5. Battery Charge Power (50%)	21
6. Design Margin (20%)	12
Total Power Demand	75

SAR/DCS POWER BUDGET

TABLE 5-1

5.2 Weight

The spacecraft weight budgets given in Tables 2-1 and 2-2 for the spinning and gravity gradient spacecraft configurations are used as the basis for estimating the weight budget of a combined data collection and search and rescue satellite. Changes were made in the areas of transponder, telemetry and command, wiring harness, and power to accommodate the data collection subsystem. Table 5-2 presents the estimated weight budgets for a combined SAR/DCS satellite. For both the spinning and gravity gradient spacecraft configuration, adequate weight margins exist for the current Scout launch vehicle payload capacity into an 1100 km circular orbit.

ITEM	CONFIGURATION	
	SPINNING	GRAVITY GRADIENT
1. Structure	35 lbs	30 lbs
2. Thermal	10	10
3. Solar Array	18	25
4. Power Conditioning	5	5
5. Batteries	18	18
6. TM and Command	17	17
7. SAR Transponders	14	14
8. DCS Transponders	18	18
9. Antennas, SAR, DCS, TM, CMD	11	11
10. Wiring Harness	6	6
11. Torquing Coils	2	2
12. Gravity Boom and Damper	-	10
Total	154 lbs	166 lbs
Scout Payload (1100 km orbit)	177 lbs	188 lbs
Design Margin	15%	13%

SAR/DCS WEIGHT BUDGETS

TABLE 5-2

The data collection transponder consists of a receiver, a frequency translating section, a transmitter and an antenna as indicated in the block diagram of Figure 3-2. The receiver and translation section are assumed to occupy a single unit. The antenna is used in conjunction with a duplexer for both transmit and receive. In an operational mission, a redundant transponder will be required. The antenna and duplexer will not be duplicated but allowance is made for two RF switches. Figure 5-1 shows the redundant transponder configuration. It is estimated that 19 lbs are required for the full transponder configuration. A weight breakdown is as follows:

Antenna plus duplexer	0.7 lbs
RF switches (2)	0.3
Receiver plus translation section (2)	4.0
Transmitter (5W output rating) (2)	14.0
Total Weight	19.0 lbs

The antenna, duplexer and RF switches are listed in with the other antenna weights in Table 5-2.

The transponder also requires certain telemetry and command functions. They are as follows:

Telemetry

1) Transmitter 1 Voltage (indicates unit 'ON')

2) Transmitter 1 or 2 Temperature

3) Transmitter 2 Voltage (indicates unit 'ON')

Command

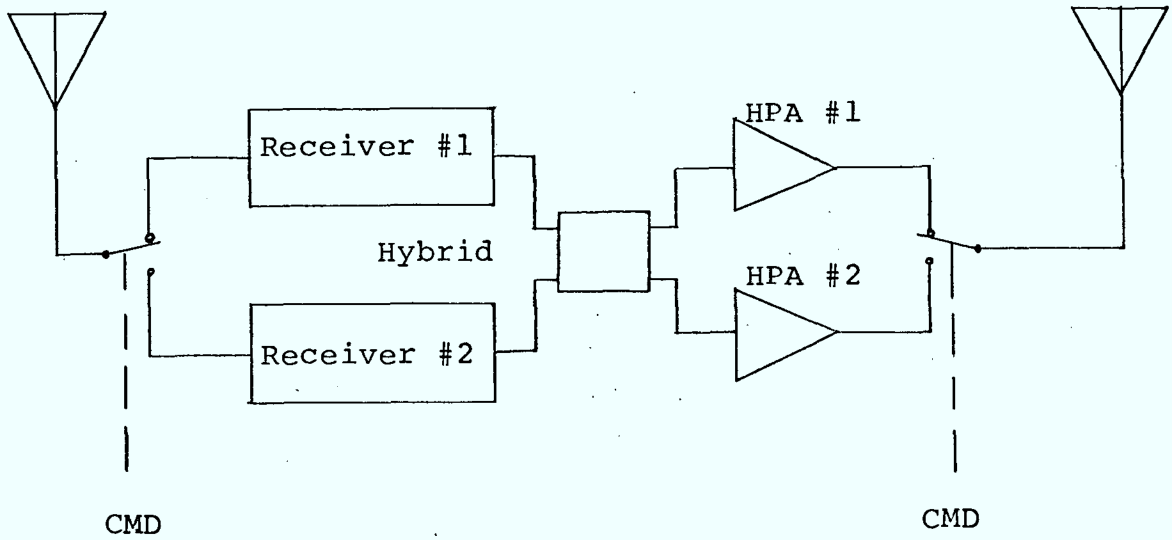
1) Transmitter 1 'ON', 2 'OFF'

2) Transmitter 1 'OFF', 2 'ON'

3) Receiver 1 'ON', 2 'OFF'

4) Receiver 1 'OFF', 2 'ON'

5) Subsystem 'OFF' (disconnects all units from power bus)



Redundant Transponder Configuration

Figure 5-1

The commands allow cross-strapping of the receiver and transmitter sections thereby improving redundancy. These extra telemetry and command functions can be accomodated with a minor weight impact. An allowance of 1 lb. is made in the telemetry and command weight budget and a further 1 lb. is allowed for increase in wiring harness weight.

The original battery weights assumed for the search and rescue satellite mission were quite conservative. The 18 lbs. allocated to NiCd batteries are sufficient to support the primary power demand of 42 watts plus the 20% design margin of 12 watts during eclipse with only a 15% depth of discharge.

5.3 Antennas

One of the more difficult problems with a combined search and rescue and data collection mission is the integration of all the antenna requirements. These are listed below:

Receive	Frequency
Command	UHF
SAR	121.5 HMz
SAR	243. MHz
DCS	401. MHz
Transmit	
Telemetry	UHF
SAR	UHF
DCS	UHF (460 MHz)

It appears logical to try and group as many functions as possible onto one or two basic antennas and to separate the functions by means of duplexers. Ref. (2) proposed a quarter turn double helix operating over the 120 - 243 MHz range. Ref. (8) postulated a double, cross-drooped dipole arrangement to operate in the region of both 121.5 and 243 MHz. This arrangement may be suitably modified to add a third set of elements operating in the 400 - 460 MHz range. Figure 5-2 shows one possible arrangement and indicates in block diagram form how the various units would be connected to the antennas.

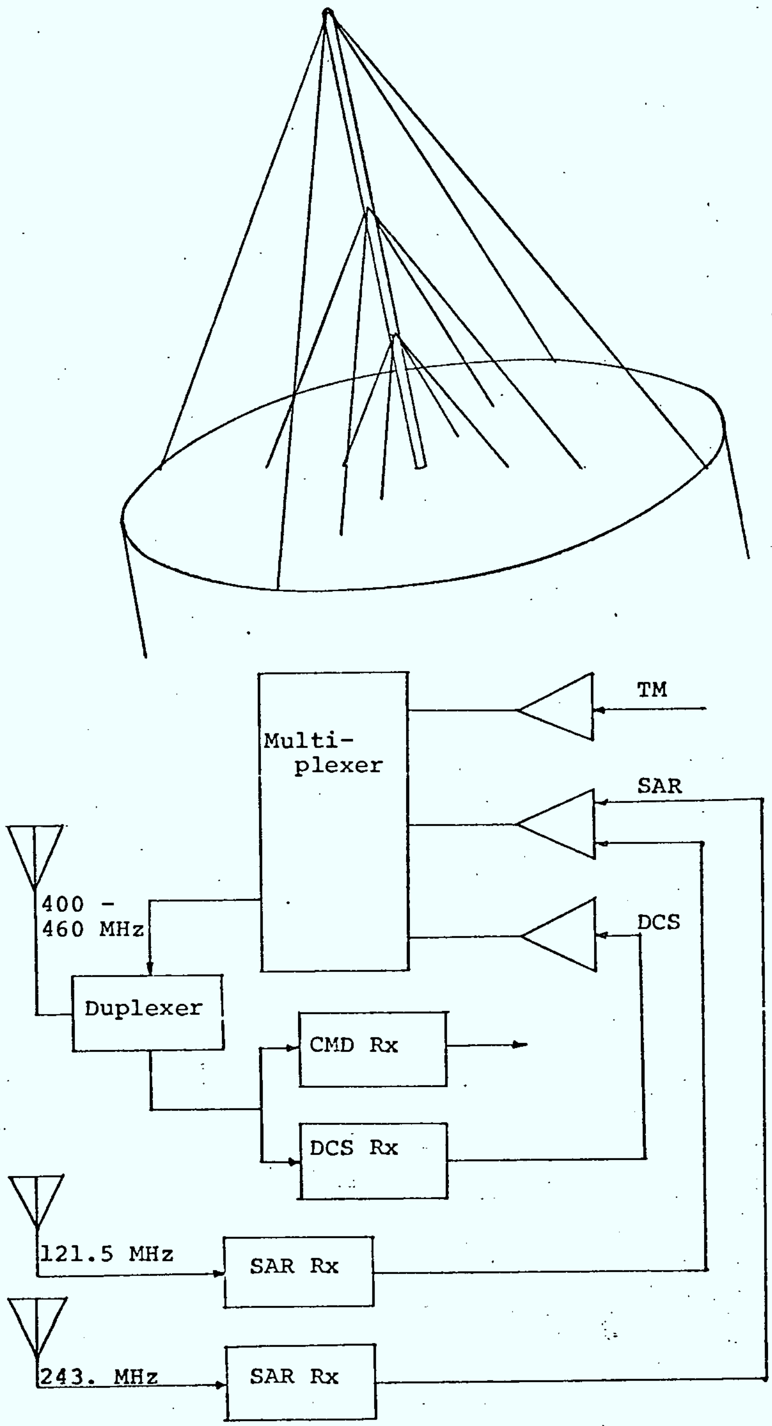
It would be desirable, if Radio Regulations permit, to have all transmitters operating in the same frequency band so that a common transmitting antenna may be used as indicated in Figure 5-2. This approach may even be extended to the transmitter stages for DCS, SAR and telemetry functions to provide further savings in weight and, possibly, power.

Further work will be required to examine the type of pattern which may be obtained by the multiple, nested, cross drooped dipole antenna. A bifolium gain pattern was assumed in Chapter 3 for the RF link calculations since it gives a uniform signal strength; the changes in antenna gain with look angle compensate for variations in range to the satellite as it passes over the DCP locations. An additional problem involves the nesting of three antennas, each designed to operate at a different frequency, and the possible interaction between them. Analytical work supported by practical test measurements is recommended.

5.4 Summary

The data collection subsystem, in this preliminary evaluation, appears to be a compatible payload on a satellite providing search and rescue functions. The combined SAR/DCS mission requires a doubling in the spacecraft primary power demand to 42 watts over the SAR only mission. This is accommodated in the spinning spacecraft configuration by use of slightly higher efficiency solar cells (11.8% vs 10.3%) and by adding solar panel area to the gravity gradient spacecraft configuration. The extra weight required to accommodate the DCS hardware is readily available with either spacecraft configuration. The total spacecraft weights are 154 lbs for the spinning configuration and 166 lbs for the gravity gradient configuration giving design margins of 15% and 13% respectively.

The most difficult area technologically, appears to be the design of the antenna configuration which must operate at two SAR receive frequencies (121.5 and 243 MHz) and in the 400 - 460 MHz band for the DCS and other functions including SAR and telemetry downlinks. Additional work in the antenna design area is recommended.



Antenna Sub-system Configuration

Figure 5-2

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3. Space Data Relay Systems, Charles E. Cote, NASA GSFC, Wallops Flight Center Workshop, May 1973.

4. USDI Requirements and Programs, John M. DeNoyer, United States Geological Survery, Wallops Flight Center Workshop, May 1973.

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APPENDIX A

STATEMENT OF WORK

Feasibility Study on a Communications Satellite providing Search and Rescue and Data Collection Services

Requirements of Study

The Contractor shall conduct a study on the feasibility of combining a Search and Rescue Alert (SAR) Service and a Data Collection (DC) Service on a single satellite of a near-polar orbiting satellite system. The study is to be restricted to a satellite configuration able to be launched into an appropriate orbit with a Scout launch vehicle from the Western Test Range.

Baseline system and satellite designs for a system providing only a SAR service shall be documented as the initial activity of the system. This first activity shall represent a consolidation of information already in the possession of the Contractor. It shall not include the development of new information. Follow-on study activity shall include the extension of the SAR service baseline designs to accommodate the DC service. System considerations, mission analyses and payload/satellite definition shall be given emphasis in the approximate ratio of 1:1:2.

System considerations shall emphasize a random-access collection system from fixed and moving data platforms, relaying this data to regional acquisition terminals. Provision for determination of platform location shall be considered a system requirement. The platform-to-satellite uplink frequency shall be assumed to lie between 401 and 403 MHz. An optimum satellite-to-earth downlink frequency shall be selected as part of the study. If allocated resources permit, trade-offs relevant to a requirement to relay data to regional user terminals shall be investigated.

Mission analysis activities shall identify appropriate orbits for satellites providing both SAR and DC services and characterize these orbits in terms of parameters significant to each of the services. The effect of injection errors, stabilization errors and lifetime effects on these parameters shall also be characterized if significant.

Payload/satellite definition activities shall include definition of the application payload in block-diagram form in sufficient detail to provide good weight, power and performance estimates. Other support subsystems shall be defined in sufficient detail to provide good weight and power estimates. The definition activities shall include a comparison to the subsystem level with one or more similar satellites.

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