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# EXECUTIVE SUMMARY OF FEASIBILITY STUDY ON A TWO BAND UHF COMMUNICATIONS SATELLITE

DECEMBER 1972

Prepared for
Department of Communications
Ottawa, Canada
under
Contract No. PL 3610-1-0622
Serial OPL2-0005

RCA Research Laboratories

RCA Limited | Ste-Anne-de-Bellevue, Québec

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Approved By: M.P. Bachynski
~~Dr.~~ M.P. Bachynski
Director of Research

Dated: DECEMBER 1972

RCA Limited | Ste-Anne-de-Bellevue | Quebec | Canada

## NOTE

In the course of this program and in the preparation of this report, extensive use has been made of RCA Limited's background data and material, some of which is of a proprietary nature. In order to protect RCA Limited's commercial position, it is respectfully requested that the Government of Canada take this into consideration in dissemination of this report.

# FEASIBILITY STUDY OF A TWO-BAND UHF COMMUNICATIONS SATELLITE

## Executive Summary

### 1. Introduction

The work summarized here was performed under DSS Contract PL 3610-1-0622 Serial OPL 2-0005, under the design authority of the Department of Communications. The program extends a previous study which showed that it is feasible to develop, under specific constraints, a communications system "intended for low capacity voice telephone services to remote areas of Canada" and presented alternative design concepts which could be implemented in either the 225-400 MHz band or in the 1500 MHz band. The study reported here extended the general concept and developed designs appropriate to simultaneous operation in the 225-400 MHz and 2.5 GHz bands.

The traffic model provided by the D.O.C. designates four classes of user as shown in Table 1. Thus at the lower band, capability was to be provided to serve mobile and

| Band | Service | Eclipse | Carriers | Frequency Assignments | Channels |
|---|---|---|---|---|---|
| 225-400 MHz | Mobile | 100 % | 1 | 1 | 1 Half Duplex |
| | Transportable | 50 % | 20 | 20 | 10 Duplex |
| 2.5 GHz | Fixed | 50 % | 20 | 40 | 20 Duplex |
| | Program | 100 % | 2 | 2 | 2 Simplex |

Table 1 - Traffic Model

transportable stations with differing satellite EIRP's (Effective Isotropic Radiated Power), while at the higher band radio program distribution and higher quality fixed station telephony was required.

In conjunction with the Design Authority and considering the 1977 time frame for implementation, it was decided to design to the projected Thor-Delta launch vehicle capability of 1890 lbs in transfer orbit. This capability was considered to have a high probability of being available without an excessive non-recurrent cost penalty to the program. After appropriate allowances for interstage adaptor, apogee motor fuel etc. this resulted in designs to an initial on station weight of 963 lbs.

## 2. System Concepts

While the program constraints indicated a geostationary orbit, the specific operating frequencies and dual band nature of the requirements, coupled with the statistical nature of the major portion of the traffic (telephony) gave the possibility of several new modes of operation, and in turn permitted application of unique spacecraft techniques. In order to prevent major economic and/or technological penalties to the implementation program additional design objectives were established. These objectives were:

- All flight spacecraft to be identical
- Operational use of in-orbit spares
- Operational use of spacecraft early-life resources
- Non-tracking ground stations
- Maximum reliability of system.

In order to meet these objectives, the conceptual design work which is normally carried out at the single spacecraft level was instead carried out on the total space segment level as it would exist at various times in the mission i.e. single operational spacecraft, two spacecraft in orbit, early life power, end of life power, single point failures, eclipse vs sunlight operation etc. etc. In accordance with guidance of D.O.C. the traffic model quoted was considered to be the minimum acceptable for a viable service, and the design emphasis was placed on protecting the minimum traffic in all foreseeable circumstances but exceeding it to the maximum extent possible under "normal" operating conditions.

The opportunities for application of new concepts are the result of the statistical nature of the major portion of the traffic coupled with the requirement that the ground station antennas be of small diameter (4-6 feet). Thus at the lower band the ground station beam widths are such that spacecraft at quite widely separated orbital stations can be simultaneously illuminated by the up link beam. As a result, with only slight signal loss, the low band services can be split between two spacecraft spaced about $18^{\circ}$ apart in longitude. Thus, the two spacecraft are never eclipsed simultaneously and, in principle, communications traffic can be maintained without secondary (battery) power. This "Sequential Eclipse" offers savings in weight which can be applied to increased communications, additional fuel etc.

However, the two spacecraft cannot operate at the same frequencies simultaneously when in the view of a common source. Thus it is necessary that the "identical" satellites exhibit different frequency plans, preferably without major hardware penalties. (In the detailed design portion of the study this objective has been achieved.)

In principle, it is also possible to split service, with each spacecraft operating in only one frequency band (although supplied with transponders at both frequencies) and carrying no redundancy. Then in the case of a transponder failure the functions of the two satellites are reversed to maintain service. This "Criss-Cross Redundancy" provides high protection against transponder failures although obviously not against failures of the spacecraft supporting subsystems.

While at the higher band (2.5 GHz) the ground station directivity is such that time spaced eclipse cannot be utilized, the spacecraft can be illuminated adequately by a fixed pointing antenna over reasonable excursions from its station. Thus "Reduced Inclination Control" when coupled with a technique of "Biased Inclination Insertion" provides additional savings in fuel weight. The antenna directivity also demands that this traffic be through a single satellite.

In order to make use of the early life power available in the spacecraft yet avoid substantial hardware difficulties e.g. in signal combining, the concept of "Non-identical Substitution" is incorporated providing a variable communications capability (fitting the available power) and also fulfilling the redundancy requirements. Where identical substitution is required, as might occur near the end of spacecraft life, it is available through the criss-cross redundancy feature.

By appropriate allocation of hardware and functions, it has proven possible to develop design concepts which incorporate these features yet fulfill the single satellite requirements. Thus the practical system fulfills the traffic model requirements for a single satellite and greatly exceeds it for the full system.

## 3. Spacecraft Alternatives

Whereas in the previous study it was found that low band services tended to be maximized in a 3 axis spacecraft configuration while the high band services were optimized in a dual spin configuration, it was not obvious which was the most suitable configuration for a dual band system. In the course of this study four basic concepts were examined as to feasibility with two detailed to a greater extent.

a) Electrically Despun - Dual Spin

At the request of the Design Authority, this concept was examined, although beyond the scope of the original tasks. The design was developed as a hybrid arrangement utilizing, at the lower band, electrical despin of an antenna array over the surface of the cylindrical solar array, with the high band services provided through a mechanically despun erectable antenna at the top of the spacecraft. The low band antenna was a more complex and higher gain version of the LES 6 antenna but still failed to provide sufficient gain, when coupled with the power available at the end of life, to fulfill the (single satellite) minimum traffic model.

The design concept was developed to the stage of basic configuration and budgets, but not pursued in the absence of more detailed predictions of antenna performance.

b) 3 Axis - Rigid Deployable Solar Array

This concept was put forward by the contractor as being of interest for use where the prime power demand is in excess of that available from dual spin concepts but somewhat less than from a flexible array such as CTS uses. The design developed was based on the ITOS/TIROS designs as adapted by RCA Astro-Electronics Division and proposed for the U.S. Domestic Program. Again basic budgets were developed but in the absence of detailed design and costing information the concept was not pursued, although the concept is considered a valid candidate for this mission.

c) Dual Spin

Dual spin concepts were examined in depth for this mission, with several differing designs traded off as to lifetime, inclination control, eclipse capability etc. The general conclusion is that the dual spin concept offers a wide range of design options which fulfill the general mission requirements, and allow incorporation of the features developed in the course of the study. Further, this concept appears to be the one which could most readily encompass changes in launch capability should they occur and, in particular, should the 1890 lb. transfer capability not be attained in the time frame of interest.

The design limitation for the dual spin configurations tends to be available power although both the power and weight margins tend to zero out almost simultaneously. This means the design makes full use of both resources. (A basic implementation margin equal to 5% of transfer orbit weight is carried separately in accordance with good design practice.)

The dual spin concept was developed in some detail and is the basis of the budgetary costs presented.

d) 3 Axis - Flexible Solar Array

A 3 axis concept utilizing a large extensible solar array was developed based on the extensive CTS data available. The general concept of such configurations is applicable where the mission demands on power are large considering the launch vehicle involved (as for CTS). In the present mission, the trade-offs tend to become weight limited by virtue of the secondary power demands in eclipse (if extensive use is made of the available primary power) and because of the large weight assignments to solar array extension and orientation.

This 3 axis configuration is considered viable for this mission although there is somewhat less range of tradeoffs than for the dual spin design, and it is also somewhat more sensitive to launch vehicle capabilities.

This concept was developed to some depth and cost differentials relative to the dual spin implementation indicated.

4. Communications

The transponder portion of the communications sub-system is the key to the operational flexibility of the overall system. As shown in Figures 2 and 3 there are two completely separate transponders, one at each band. In fact, in the dual spin design the only element of commonality is the antenna reflector while in the 3 axis design there is no point of dual function.

The low band transponder (Figure 1) shows the broad band low level receiver followed by a local oscillator mixer unit. The local oscillator is designed to put out either of two frequencies as determined by ground command. This allows the incoming signals from either one of two bands to be down converted to a set (80) of channelized I.F. strips. Thus two identical spacecraft can utilize a maximum of 160 frequency assignments (i.e. 80 each) without carrying additional I.F. hardware or violating the requirement to be identical. A number of these I.F. amplifiers have a gain change of 10 dB available, to provide the high EIRP down link signals.

After I.F. limiting and amplification, the signals are up converted and sent to one of two power amplifiers selected by command from an assortment of different types. As shown, there are broadband power stages carrying up to 3 high power carriers or up to 30 low power signals. It must be noted that only one of the power amplifiers in each of the multiplexer input arms can be powered up at one time, but because of their differing capabilities the demand on spacecraft resources can be varied.

The 2.5 GHz transponder (Figure 2) is more conventional in concept. It is a single translation, all r.f. repeater having two channels. Program material is carried in a transistor power amplifier capable of either 2 or 3 carriers. The telephony traffic is carried through a 20 watt Travelling Wave Tube amplifier (1 for 1 redundancy). The TWT proposed is an adaptation of a tube developed for S Band operation in the Apollo mission. It features dual mode operation (10 or 20 watts) and thus the demand on spacecraft resources can be reduced for eclipse or similar purposes.

The transponder specifications are summarized in Table 2.

The antenna portion of the sub-system differs according to the spacecraft configuration under consideration. In a dual spin design (Figure 3) the antenna consists of an erectable rib and mesh parabolic reflector 130" in diameter. This is about the largest diameter which can be carried in the fairing without complex mechanical arrangements. The feed is a structural amalgamation of a horn-type linear feed at 2.5 GHz with a reflector backed crossed dipole feed providing circularly polarized low band illumination.

For the 3 axis design the antennas are separate at high and low bands. The high band is a simple parabola with horn feed while at 300 MHz the antenna is a quad helix array (Figure 4).

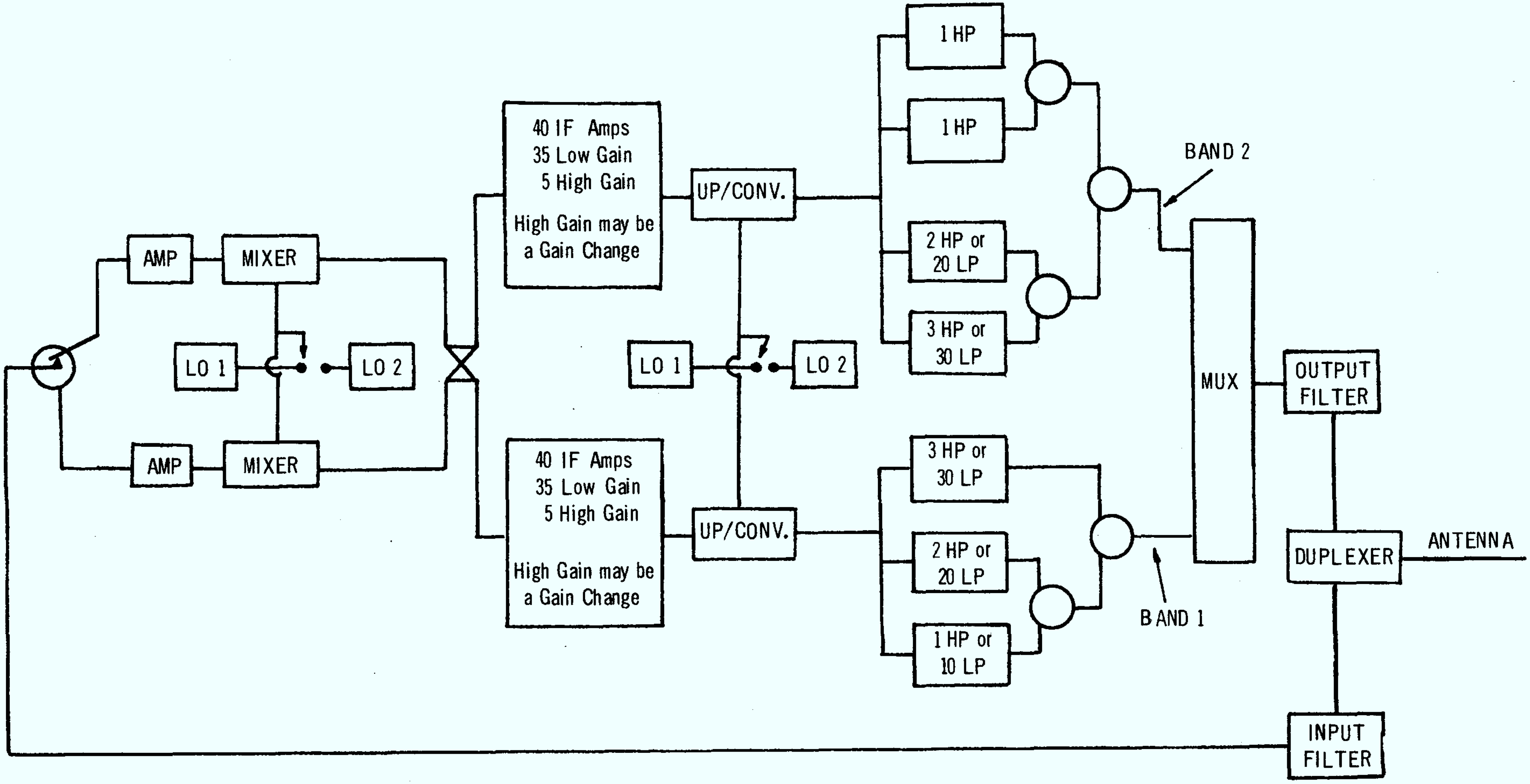


**Figure 1 – Block diagram for the 300 MHz transponder**

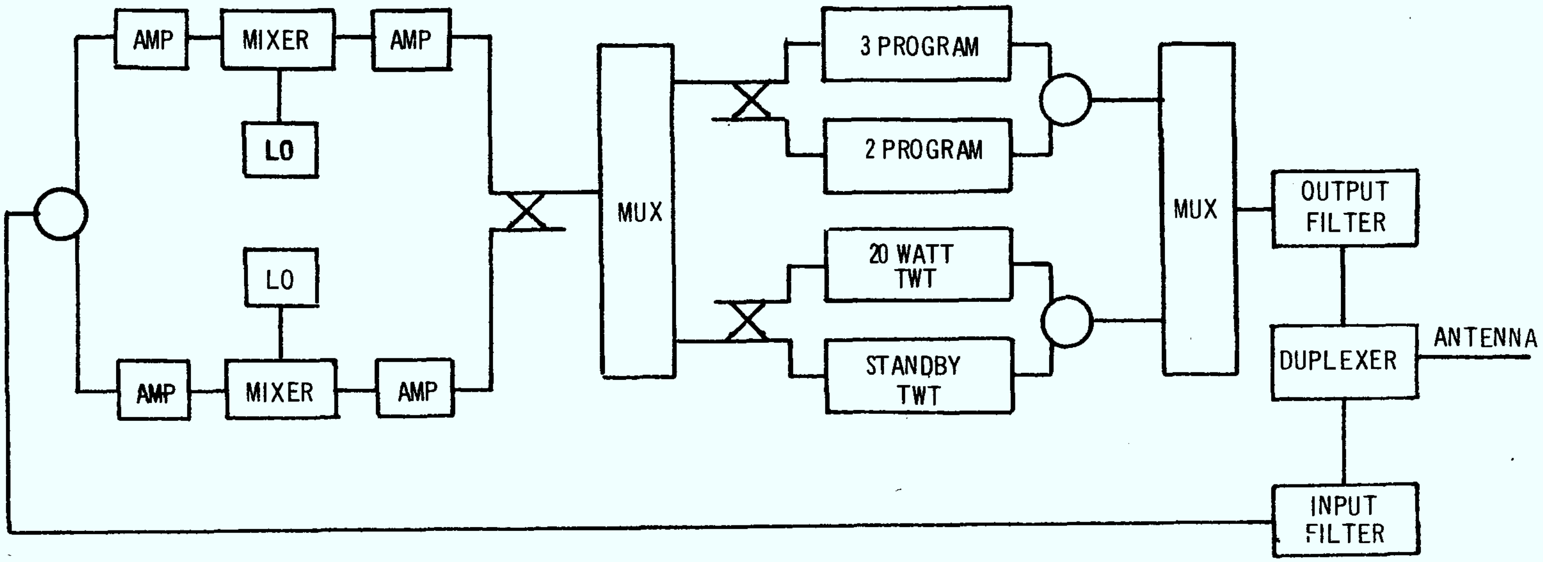


**Figure 2 – Block diagram for the 2.5 GHz transponder**

| 2.5 GHz SUBSYSTEM | | |
|---|---|---|
| Type | Single Frequency Conversion | |
| Operation | F.D.M.A. | |
| Input | Uncooled Paramp | |
| Multiplexing | Graphite Fiber Epoxy Composite Waveguide Filters | |
| Weight | 20 lbs. | |
| Services | Telephony | Broadcast |
| Number of Carriers | 90 | 3 |
| Output Device | TWT | Transistor |
| Output Power (dBW) | 9.2 | 3.9 |
| Eclipse | 50 % | 67 % |

| 300 MHz SUBSYSTEM | | |
|---|---|---|
| Type | Dual Frequency Conversion Fully Channelized at I.F. | |
| Operation | F.D.M.A. | |
| Input | Low Noise Amplifier | |
| Multiplexing | Interdigital Filters | |
| Weight | 70 lbs. | |
| Services | Mobile | Transportable |
| Number of Carriers (Max.) | 3 | 30 |
| Number of Carriers (E.O.L.) | 1 | 20 |
| Output Device | Transistor | Transistor |
| Output Power (dBW) (Max.) | 16.1 | 16.1 |
| Eclipse | 1 | 10 |

Table 2 – Specifications for the Dual-Frequency Transponder
(Single Satellite Service)

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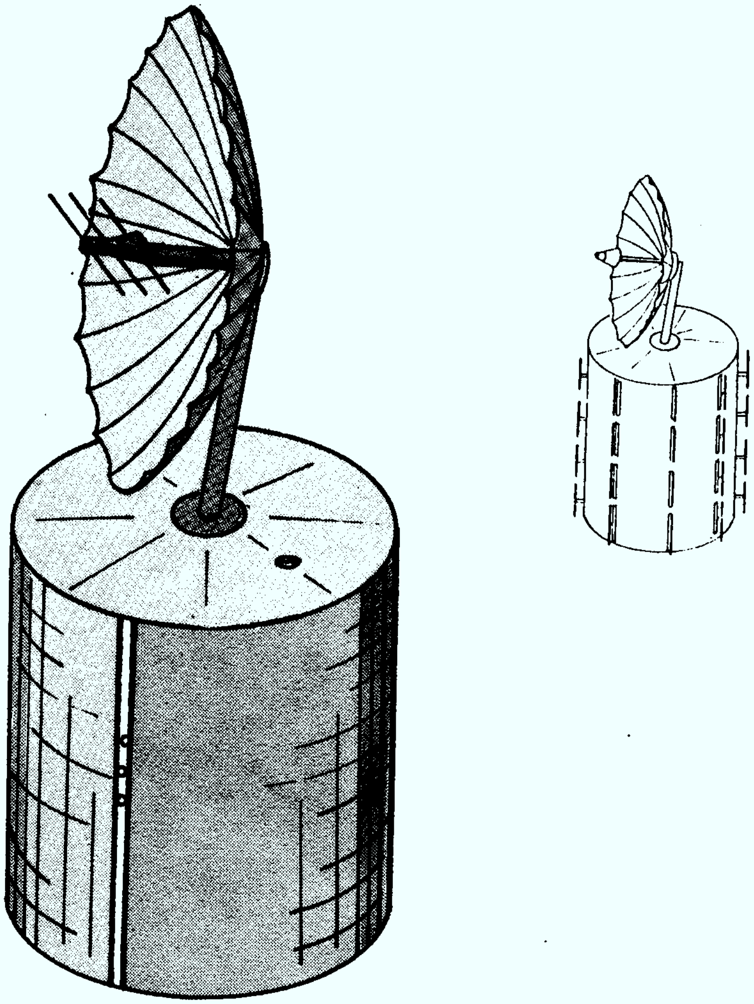
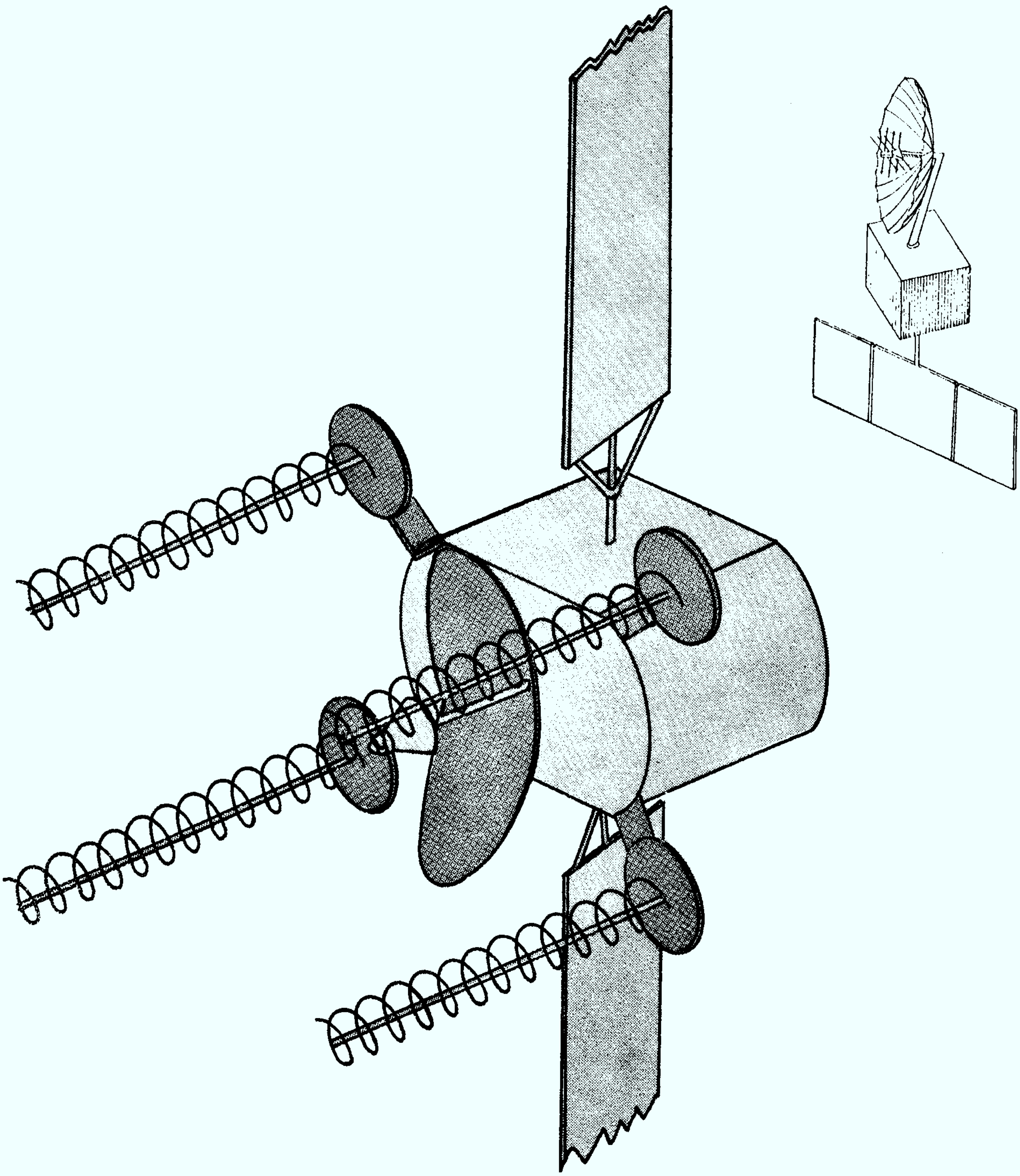


DUALBAND-DUAL SPIN SPACECRAFT

Figure 3



3 AXIS STABILIZED SPACECRAFT – CTS BASED

Figure 4

## 5. Conclusions and Recommendations

On the basis of the study it is concluded that not only is a dual band spacecraft feasible within the constraints of this mission, but that, by unique spacecraft design, attractive operating modes can be incorporated in the system, improving the cost effectiveness. Table 3 summarizes the traffic model achieved for the two design concepts detailed in the course of the study, while Table 4 gives their respective "top level" specifications.

The dual spin configuration (Figure 3) shows the greatest range of viable trade offs of the four concepts examined and thus the greatest adaptability to other mission constraints which might be developed. The design presented comes close to limiting simultaneously across all constraints imposed by the launch vehicle (weight, fairing limits on power, antenna height etc.) and thus appears to be simultaneously close to an optimum and an upper limit under the chosen and given constraints.

The 3 axis CTS based configuration (Figure 4) also fulfills the basic mission requirements but lacks some of the dual spin flexibility in design. It is basically weight limited and only limited advantage can be taken of the large power per pound coefficient (for power increases) made possible by the flexible solar array.

The other configurations examined show antenna gain limitations in the case of the electrical despinning or for the 3 axis ITOS configuration capabilities intermediate to those of the preferred designs. On the basis of the limited depth examination either of these last two configurations could probably fulfill the basic mission requirements.

Because of the proposed system operating modes all the designs have more severe thermal problems than normally encountered in communications spacecraft, in that the thermal sub-system must maintain the appropriate equipment environment despite a highly variable heat load developing at different locations within the spacecraft. This problem, particularly in the 3 axis configurations may require application of active thermal control techniques.

Budgetary cost estimates have been developed for a program based on procurement to a performance specification and following good commercial space practice. For a fully protected 10-year system (3 operational spacecraft plus standby) the spacecraft costs including development and profits are estimated to be \$52.9 M.

| | | 300 MHz | | 2.5 GHz | |
|---|---|---|---|---|---|
| | | High Power | Low Power | Broadcast | Low Power |
| Single Satellite | Sun BOL | 3 | 30 | 3 | 90 |
| | Sun EOL, S.S. | 1 | 30 | 3 | 90 |
| | Min. Eclipse | – | – | 2 | 45 |
| Dual Satellite System | Sun | 4 | 60 | 3 | 90 |
| | Min. Eclipse | 1 | 30 | 2 | 45 |

(a) 3-Axis

| | | 300 MHz | | 2.5 GHz | |
|---|---|---|---|---|---|
| | | High Power | Low Power | Broadcast | Low Power |
| Single Satellite | Sun BOL | 3 | 30 | 3 | 90 |
| | Sun EOL, S.S. | 1 | 20 | 3 | 90 |
| | Eclipse | 1 | 10 | 2 | 45 |
| Dual Satellite | Sun | 3 | 50 | 3 | 90 |
| | Eclipse | 3 | 30 | 3 | 90 |

(b) Dual Spin

Table 3 – Traffic Capability Channels

- Diameter: 86"   • Height: 157.5" / 227.5"
- 1820 lbs. in transfer; Initial on orbit 963 lbs.; End of Life: 813 lbs.
- Dual Band Transponder
- Canadian Coverage
- Power: 360 Watts E.O.L. (S.S.); Eclipse: 243 Watts
- 8-Year Life

Table 4(a) – Spacecraft Characteristics – Spin Stabilized Configuration

- Diameter: 71" ● Height: 116" / 116"
- 1820 lbs. in transfer; Initial on orbit 948 lbs. End of Life: 800 lbs.
- Dual Band Transponder
- Canadian Coverage
- Power: 437 Watts E.O.L. (S.S.); Eclipse: 160 Watts
- 8-Year Life

Table 4(b) – Spacecraft Characteristics – 3-Axis Configuration

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