EXECUTIVE SUMMARY

SPARE SATELLITE

POSITIONING STUDY

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SUMMARY

Different sparing philosophies are optimum for the different types of services offered by communication satellites. Satellites for international fixed satellite services are appropriately spared in the current manner using a fully operational satellite position. The spare is loaded with revenue producing but pre-emptable traffic and takes peaks in traffic loading. This type of sparing is also appropriate for regional fixed services provided sufficient pre-emptable traffic is available to justify the fully operational spare in the face of the needs of other regional satellite systems.

If such pre-emptable traffic is not available then it is possible to spare a regional fixed satellite system by means of an interstitial spare position or a spare co-located with one of the operating spacecraft. In the former case, the spare can be tested at full power using a small fraction of the total time provided allowance is made for this additional interference in the CCIR recommendations. Station keeping fuel must be expended to move the spare into position in the event of a failure. In the latter case, some additional hardware is required on both the spacecraft and the ground station used for testing purposes. This allows the spare to be tested at full power without interference with the co-located operational satellite. If the spare backs up more than one operational satellite then station keeping fuel must be expended to move the spare to the second location. For this reason plus the fact that the interstitial spare requires no special hardware or test procedures, the interstitial spare is preferred over the co-located spare for the regional fixed satellite service.

Testing of the interstitial spare is restricted in time if not in function and it may be difficult to carry out the extensive test schedule usually performed in order to commission a newly launched satellite. To alleviate this problem special commissioning slots were considered into which newly launched satellites would be placed for this extensive test schedule before moving on to their assigned interstitial position. However, such commissioning slots would be located at the edges of the congested regions and would entail rather long subsequent drift paths. The penalty in station keeping fuel required to first move the satellite to a commissioning slot and then move it on to its assigned position is considered unacceptable and therefore this procedure is not recommended. These initial commissioning tests must be carried out in the interstitial position in the allotted time interval.

Current plans for a direct broadcast satellite system utilize only one operational orbital position. Thus the co-located spare becomes appropriate. In addition, for some time to come it is expected that there will be down time every night allowing adequate time to perform both the periodic tests and the initial commissioning tests on the spare satellite.

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1.0 INTRODUCTION

This executive summary is a review of the highlights of the work performed on the DOC contract for a "Study on the Feasibility of Positioning Satellites in Geostationary Orbit" under Contract No. 07SU36100-8-1131. The main report on the program is entitled "Spare Satellite Positioning Study" dated May 1979. Mr. Rob Milne was the Scientific Authority.

The study addresses the problem of providing in orbit spare satellites in an increasingly congested orbit without occupying an authorized operational position with a non-operating spare. Figure 1 shows the number and placement in the orbit of 4/6 GHz and 12/14 GHz existing or projected satellites. The imminent congestion in the regions over the major land masses is clearly illustrated.

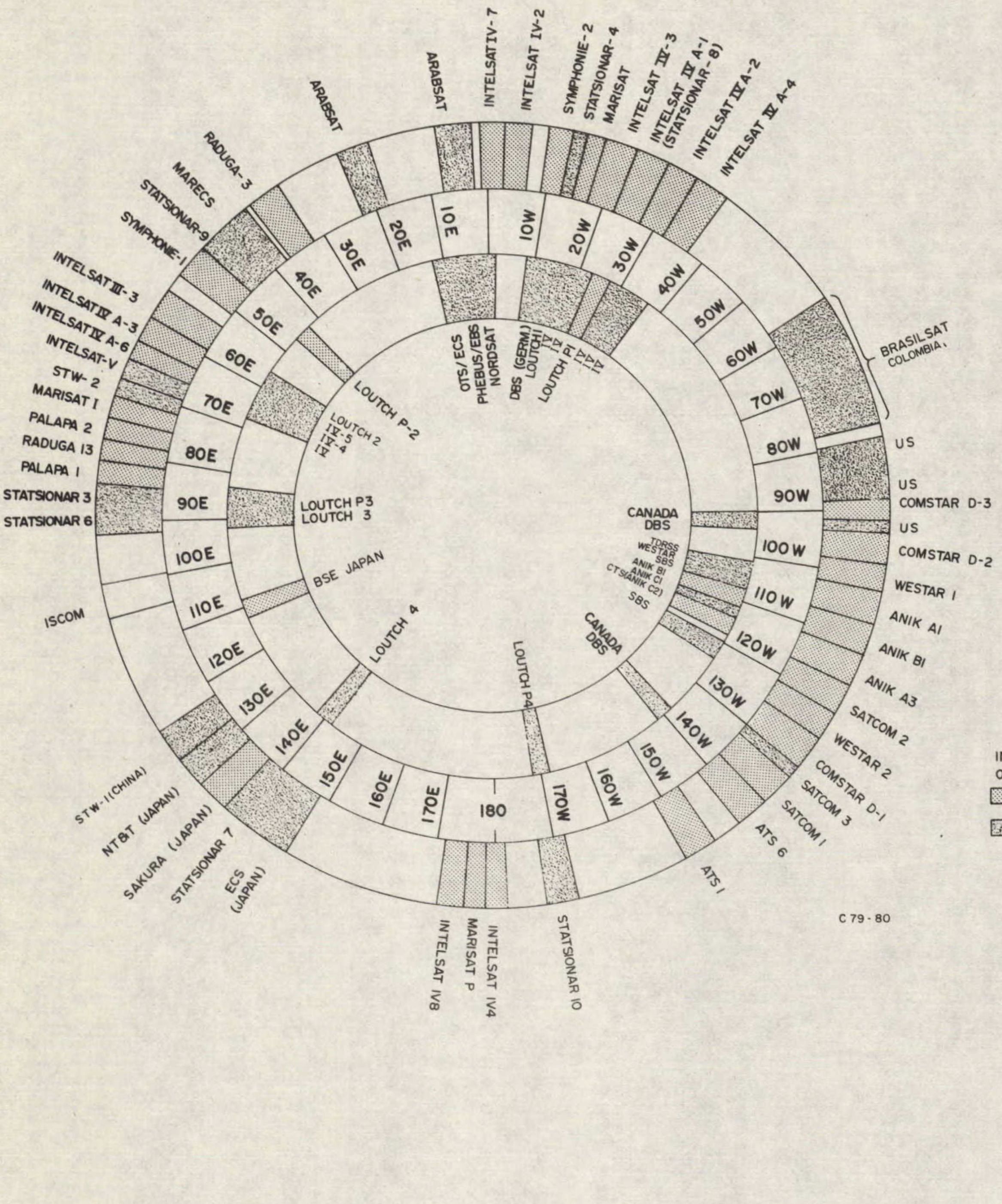
In the event that an inactive spare satellite is not permitted to occupy a fully operational position then it may be located either in an interstitial position between two operational satellites or co-located with an operational satellite. In either position the level of radiation it may emit without undue interference with operational spacecraft is strictly limited. The objective of the study is to determine methods for periodically checking the health of the satellite for the recommended sparing philosophies.

There are a number of recognized satellite communications services ranging from low power UHF maritime communications to high power 12 GHz direct broadcast service. Sparing requirements for each service are different resulting in a different optimum sparing philosophy for each service. The recommended sparing philosophy for each type of service is summarized in Table 1. It is considered that International Communication satellites, some high capacity, high priority regional satellites and maritime satellites are appropriately spared in their current manner. Direct broadcast satellites are likely to be shutdown for sufficient periods each day to allow health monitoring of the co-located spare satellite. However, regional communication satellites, being generally situated in the congested part of the orbit may require special sparing philosophies. Out of those available, two have been selected as potentially useful, 1) where the spare is placed interstitially between two operational orbital positions and 2) where the spare is co-located with an operational satellite.

SERVICE / SPARE ARRANGEMENT	FIXED				DBS	MARITIME
	REGIONAL			INTERNATIONAL		
	HEAVY ROUTE	THIN ROUTE	MULTI BEAM			
- FULLY OPERATIONAL SPARE (WITH PRE-EMPTIBLE USERS)	X			X		
- DEDICATED DORMANT SPARE SLOT (INTERSTITIAL)		X				
- SHARED DORMANT SPARE SLOT (INTERSTITIAL)						
- CO-LOCATED WITH OPERATIONAL SATELLITE		X	X		X	
- OTHER						X(1)

(1) SPARING USING OVERLAP OF COVERAGE AREAS AND/OR REDUCED CAPACITY TRANSPONDER ON OTHER SATELLITES

TABLE 1 - SUMMARY OF SPARING METHODS



INNER RING 14/12 GHz
OUTER RING 6/4 GHz
PRESENTLY IN ORBIT
PROJECTIONS

FIGURE 1 - PRESENT AND PROJECTED OCCUPANCY OF THE ORBITAL ARC

2.0 TESTING PROCEDURES

When a satellite is first launched an extensive test program is undertaken terminating in the commissioning of the spacecraft. Subsequently, in the case of a spare spacecraft some parameters are periodically measured at intervals of about one year to verify the continued operation of all systems. Some such tests are performed by means of telemetered data only. Others require RF power in the signal path and would result in increased interference into adjacent satellites unless precautions are undertaken. In the following, two procedures are described which allow quantitative monitoring of the transmission path with acceptably low levels of interference to other spacecraft in adjacent orbital positions.

2.1 Interstitial Spare Satellite

There are current proposals for modifications to the CCIR recommendation number 466-2 which would recognize the fact that noise level is variable and would allow higher levels of interference for shorter periods of time. The adoption of such a recommendation would allow testing of an interstitial spare satellite placed half way between two operating satellites providing the testing was carried out in a sufficiently short length of time. The currently proposed modification is to allow 2000 picowatts of noise from a single interfering source provided the interference is limited to 0.3%, amounting to 2.2 hours in any month. Since other sources of interference must be accommodated within the 2.2 hours the testing on any one channel must be carried out in much less than two hours. This can be accomplished by automatic testing procedures and by limiting power levels for those tests where TWTA saturation is not required.

2.2 Co-located Spare Satellite

The co-located spare satellite is considered to be at the same position as the operating satellite it is intended to replace, within approximately the 1 dB beamwidth of the ground station. In this position it is not able to radiate energy within the channel bandwidth. To test the satellite it is proposed to use the command carrier, amplitude modulated at a low rate. With a small amount of additional hardware this carrier can be routed through the receiver, bypassing the channel filters but accessing the TWTA's by means of the TWTA redundancy switches. The signal then returns to the ground station via the telemetry path. A simplified block diagram illustrating the signal path is given in Figure 2. In this way changes in channel performance can be observed and absolute performance determined by calibrating the difference between in band and test performances with prelaunch measurements.

Modifications will also be required to the telemetry and command ground station. Figure 3 shows one possible scheme for implementing the ground station for spare satellite testing.

A small amount of extra hardware is required on the satellite. This is in the form of additional switches plus some additional filters to isolate the test signal. The amount of extra hardware and the details of the implementation depends upon the initial redundancy switching configuration. Table 2 gives the estimated weights for two redundancy configurations. The first is the 24 channel Anik D configuration with 4 for 4 redundancy switching and the second is another 24 channel configuration using "R" type switches for TWTA redundancy. The total hardware increment is 4.3 kg for the former and 1.5 kg for the latter. Also shown is an estimate of the weight of the redundancy switches for the unmodified system in each case. It is seen that the "R" switch configuration is initially heavier but requires less additional hardware so that the net weight difference is quite small. In the "R" switch case none of the additional hardware is in the communications path so that no degradation in reliability is expected.

Table 2 - Weight Estimates for On-board Testing Hardware

Item	24 Channel ANIK-D	24 Channel 2 R-Switches
TWTA Redundancy Switching, kg	4.1	7.6
Additional Hardware for Testing, kg	4.3	1.5
Total, kg	8.4	9.1

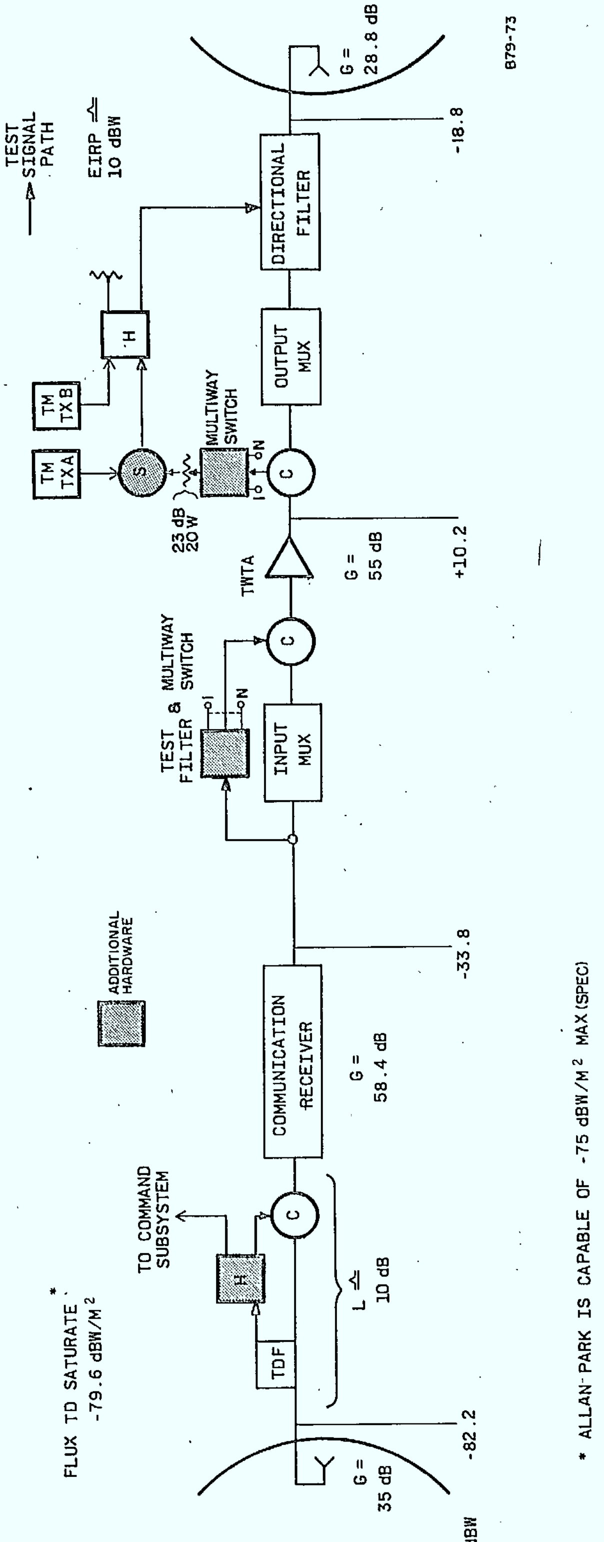


FIGURE 2 - TEST SIGNAL ROUTING AND LEVEL DIAGRAM

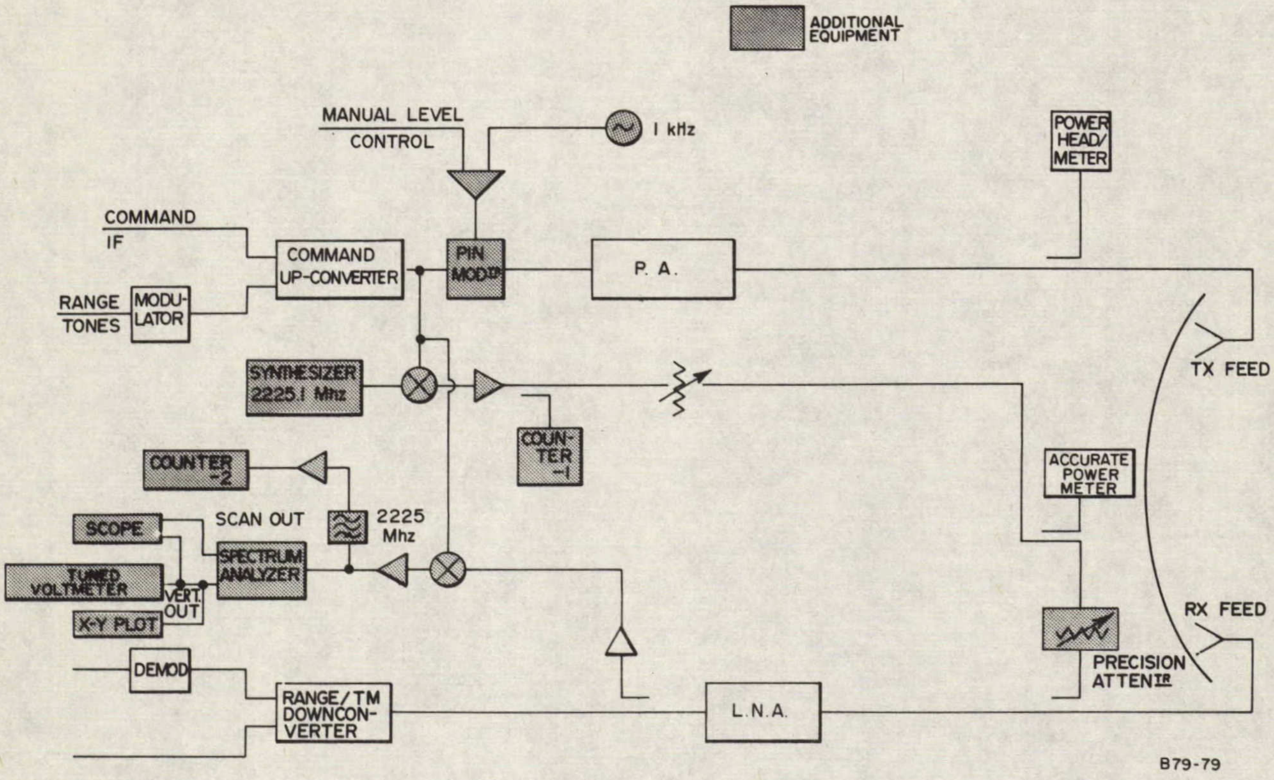


FIGURE 3 - EARTH STATION MODIFICATIONS
FOR TESTING CO-LOCATED SPARE

3.0 BACKUP DATA

3.1 Fuel Consumption

One of the penalties associated with storing a satellite in an interstitial position is that it must be moved before it can be placed in service. This is also true of a co-slotted spare if the spare satellite provides backup for more than one operational spacecraft. The amount of fuel used is greater as the drift velocity is increased. The relation between drift angle, drift time and the amount of fuel expenditure measured in decrease of satellite lifetime is presented in Figure 4. It is seen that moving a satellite from one location to another in one or two days requires a considerable expenditure of fuel even when the angle is as small as five degrees.

3.2 Collision Avoidance

For co-located satellites the possibility exists that two spacecraft will collide causing sufficient damage so that one or both satellites are inoperative. Using simplifying assumptions, such as random motion of the satellites, a low probability of collision can be estimated. However, the satellite motion is far from random and the possibility exists of controlling the orbits so that collisions are avoided. Two basic concepts are suggested by which conceptually all collisions can be avoided. These are:

a) by means of ground measurement, accurately control the separate orbits so that satellites never occupy the same cell at the same time,

b) using proximity detectors, control hydrazine jets in such a way that collisions are avoided.

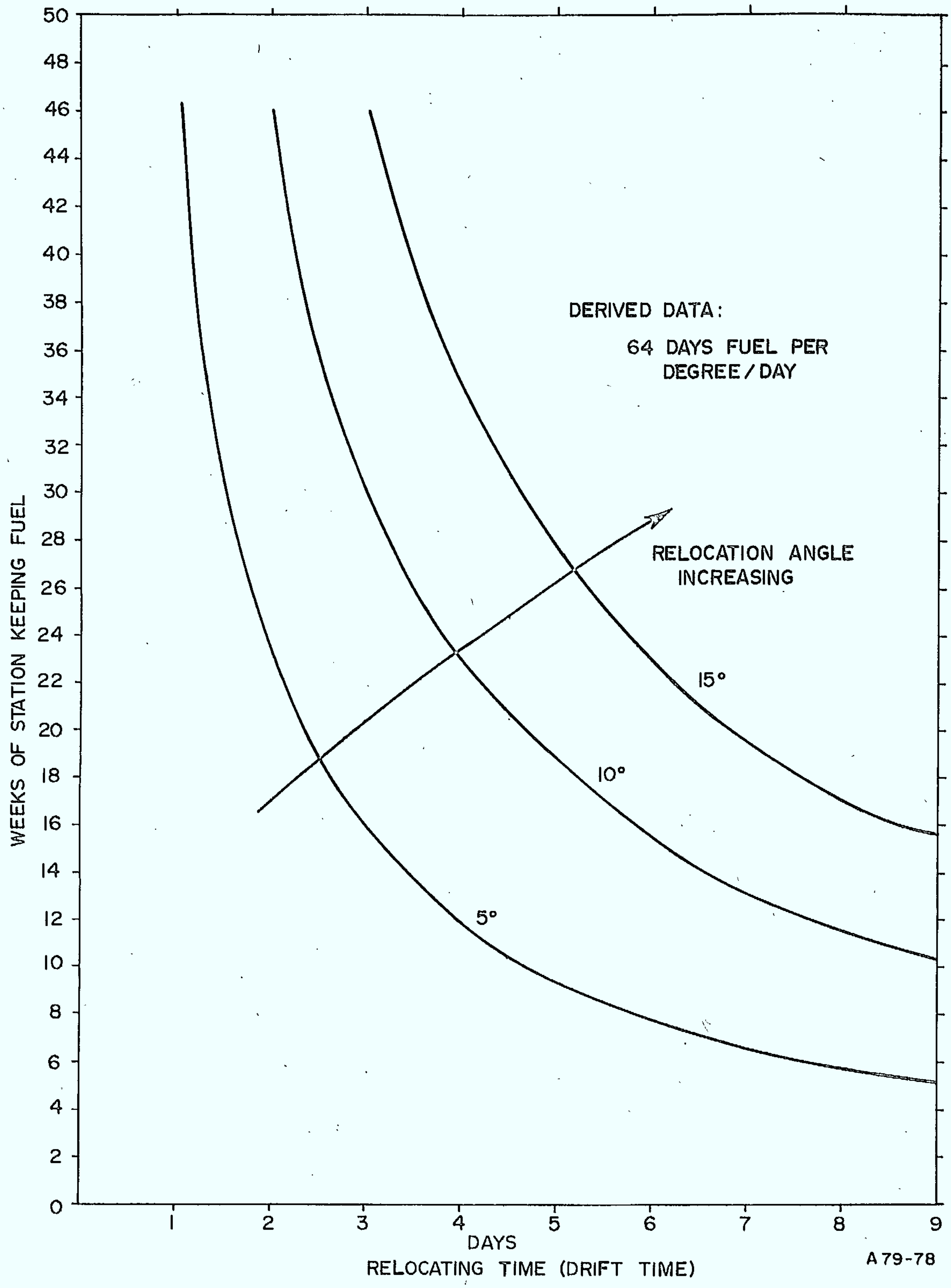


FIGURE 4 - SATELLITE FUEL CONSUMPTION FOR LONGITUDINAL RELOCATION

3.3 Space Segment Cost Tradeoffs

Space segment cost tradeoffs for a direct broadcast satellite system have been performed using a CRC modeling program called COMSATMOD. The modeling was carried out for a four beam system with eight channels in each beam for a total of 32 channels. The objective of the tradeoff was to determine the cost differential between three systems, the first consisted of one operational satellite carrying all 32 channels plus an identical spare, the second consisted of two operational satellites each carrying 16 channels plus one identical spare, and the third consisted of four primary satellites each carrying 8 channels plus an identical spare.

The results of the tradeoff are shown in Figure 5 for a range of TWTA power levels. Two break points are evident, the very large spacecraft require the large, expensive IUS interstage, medium sized spacecraft use the less expensive SSUS-A (PAM-A), while the smaller satellite use the SSUS-D (PAM-D). It is seen that for the lower power levels three half size spacecraft are less expensive than either two full size or five quarter size satellites. Thus, two operating satellites each carrying 16 channels plus one spare capable of backing up either primary satellite is the preferred configuration. In the interests of identical satellites and minimum complexity on the ground the two operating satellites must be in the same orbital position providing a strong incentive to co-locate the spare with the two primary satellites.

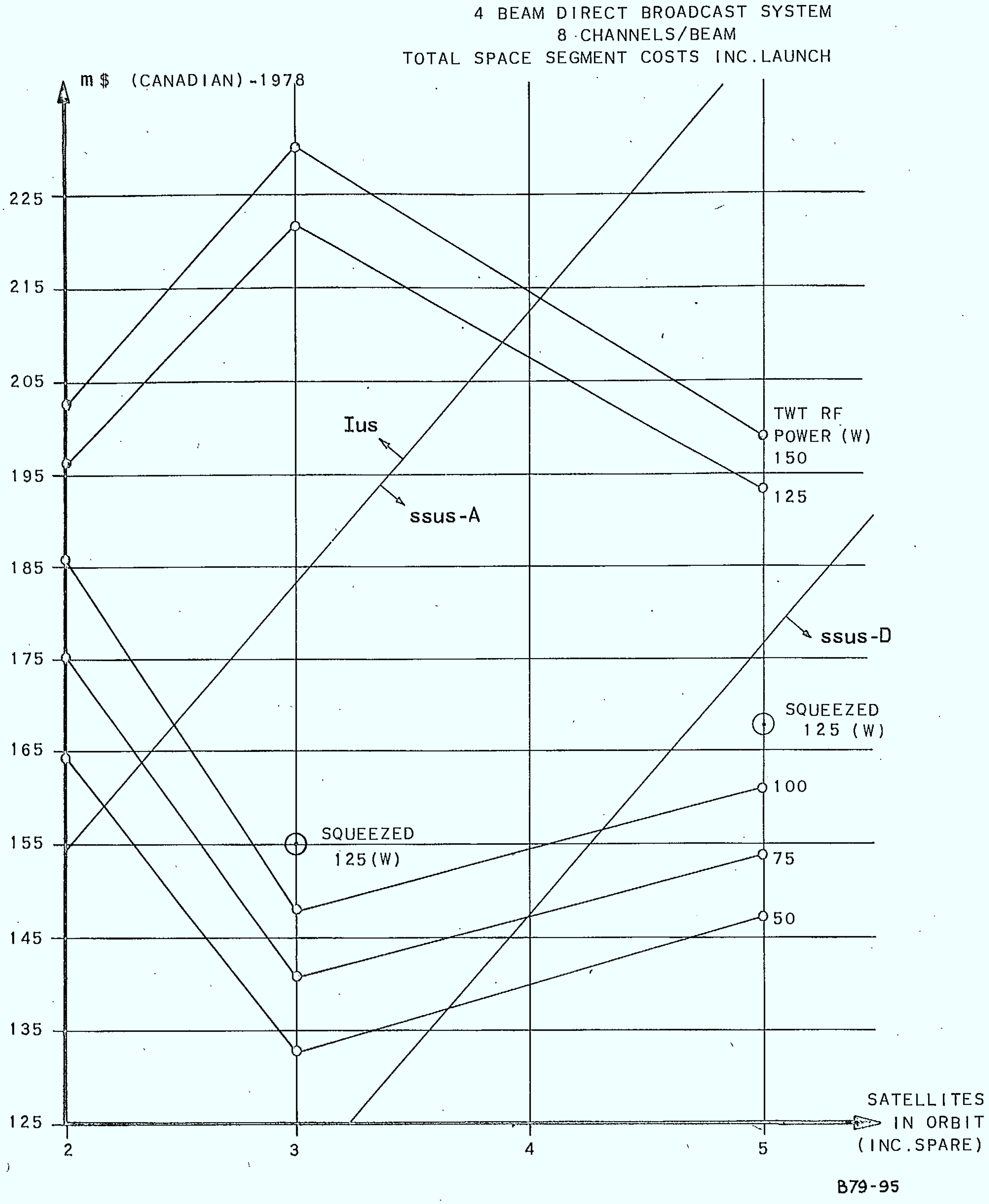


FIGURE 5 - SPACE SEGMENT COST TRADEOFF CURVES FOR A DIRECT BROADCAST SATELLITE SYSTEM

4.0 CONCLUSIONS AND RECOMMENDATIONS

a) Retaining a spare satellite in a fully operational position can be justified for a regional satellite system provided a sufficient volume of pre-emptable traffic or peak traffic loading is available. If such traffic is available, this appears to be the preferred method of sparing.

b) A spare satellite can be retained in an interstitial position between two fully operational satellites. Periodic health monitoring can be carried out in this position provided the time at full power for each channel is much less than two hours. Post launch commissioning test can be carried out in the same manner provided the time restriction is adhered to. This appears to be the second most preferred method of satellite sparing.

c) Positioning the spare satellite in the same orbital slot as the primary satellite is feasible for the fixed regional services but requires some additional hardware on the spacecraft. Tests are carried out using the out of channel command beacon. The difference between in channel and out of channel performance must be calibrated by ground tests or post launch commissioning tests.

d) A dedicated orbital position for post launch commissioning tests for all satellites was considered. However, because of the penalty in station keeping fuel to move the satellite from this position to its final position this procedure is not recommended. The absence of this commissioning slot leaves the method of post launch testing of the co-located spare for fixed regional services unresolved. One possibility is to stop the satellite in the adjacent interstitial location and subsequently move it into the co-located position.

e) Co-located spare satellites are recommended for the direct broadcast service. It is considered that in the foreseeable future there is sufficient system down time in the middle of every night to allow fully testing the spare without additional hardware or other penalty.

f) The fuel expended to move a satellite from one orbit location to another increases as the drift time decreases. The remaining useful lifetime can be maximized by making the drift time equal to the loss of life due to the expenditure of station keeping fuel.

g) Techniques are proposed which should ensure that collisions do not occur between co-located satellites.

h) A more detailed examination of the testing procedures for an interstitial satellite is required. The tests to be performed should be confirmed for both the initial commissioning tests and the periodic health monitoring. The time required to carry out the tests in both instances is critical and needs to be minimized. The optimum spectral characteristics of the test signal need to be established and the ground station test equipment outlined. The content and wording of the proposed modification to CCIR Recommendation 466-2 needs to be reviewed in the context of the new requirement.