TABLE 9

Interference (pWpO)

Satellite	Downlink	Uplink	Total
TCI	170	220	390
RCA	680	1, 170	1, 850
H	610	490	1, 100
WU	1, 650	550	2, 200
F	510	10, 600	11, 110
ATT	370	80	450
CS	4, 230	2, 740	6, 970
MCI	4, 190	870	5, 060

output of 1 kW per channel with a corresponding main beam EIRP of 92.5 dBW while Fairchild proposes a power output of 12 W with an EIRP of 73 dBW in the main beam. This means that AT&T would have an additional 19.5 dB discrimination against the interference from the Fairchild earth stations and, furthermore, AT&T would cause 20 dB greater interference to other uplinks than Fairchild would. This situation is apparent from table 9. AT&T has a total uplink interference of only 80 pWpO while Fairchild has a totally unacceptable 10,600 pWpO.

Another complicating factor in the uplink interference case is the Canadian plans. They indicate that they may occassionally transmit from remote sites using antennas as small as 26 ft.

If a maximum power limit and a minimum antenna size of 98 ft was imposed on the applicants, then the interference situation would be that summarized in table 10. For these calculations the Canadian system was assumed to use 26 ft antennas and 83 dBW EIRP for its earth stations. Under these conditions the interference levels are generally satisfactory. The total interference for Hughes and Fairchild exceed the CCIR Recommendation slightly (less than 1 dB), but this is not considered serious. The uplink interference to the Hughes satellite is predominantly from the link to its other satellite spaced 3° away. The interference in the case of Fairchild is predominantly from the Canadian satellites. Since Fairchild uses spot beams and since this additional discrimination toward Canada was not included in the calculations, the interference should be less.

TABLE 10

Interference (pWpO)

98-ft antennas and adjusted Earth Station EIRP

Satellite	Downlink	Uplink	Total
TCI	70	90	160
RCA	270	130	400
H	610	590	1200
WU	330	170	500
F	510	720	1230
ATT	370	270	640
CS	530	230	760
MCI	520	210	730

It should be reiterated that the basic issue behind the analysis contained herein involves the optimum tradeoffs between cost, performance, and orbit/ spectrum utilization. There is no absolute limit to the number of satellites that can be accommodated in the orbit. If one is willing to impose additional constraints (costs) on the applicants and/ or permit additional interference on the communication links more satellites can be accommodated and, hence, more intensive use can be made of the geostationary orbit. Conversely, if one is willing to be extravagent in the use of the orbit/ spectrum resource, fewer, but higher performance (lower interference) or lower cost systems can be permitted. It should be made clear that the change in performance need not affect the individual user of a satellite voice circuit, for example, in as much as the number of such circuits per channel (transponder) can be adjusted to give equivalent performance. Increasing the number of satellites increases the cost to maintain a given level of performance or decreases the capacity of the individual systems. Such changes in cost or capacity may or may not significantly affect the economic viability of the proposals. Since the preliminary economic analysis done by SRI indicates considerable excess capacity, decreasing the capacity of individual systems in order to gain the advantages of a larger number of competitors is a possible alternative - if such a step is even necessary.

This paper does not directly address these more basic issues. It deals, instead, with the question: "Can the satellites of the current applications be accommodated in the geostationary orbit as proposed?" Since the applicants propose in several instances to use the same orbital slot, it is obvious that at least minimal changes will be necessary. This analysis does indicate the need for constraints on Earth Station transmitter power and antenna size. These trade-offs will be investigated in more detail in subsequent papers. These will deal with different orbital arrangements, other services (e.g., video), different antenna sizes, and actual earth station locations.

SC 4

SC4

October 26, 1971

PSD/DMH

DOMSAT Orbit/Spectrum Utilization
Working Paper

Lt. Col. S. A. Lasher

Enclosed is the supplement to the working paper dated October 12. It includes additional analysis of tradeoffs, FM-TV distribution, and interference to/from the Canadian Telesat system. I am presently writing a "summary and conclusions" section for the original working paper and this supplement. I will bring it with me next week.

I am also enclosing a copy of the short computer program for computing interference which was written by Dwight Irwin of ITS. We are converting it for use on the Time-share computer.

Dale N. Hatfield

OT
ITS
Chrono.
Subject
bcc
DNH/pm (10-26-71)

RKS

DOMESTIC SATELLITE ORBIT/SPECTRUM UTILIZATION

Working Paper Supplement

Draft - Dale N. Hatfield October 22, 1971

1. INTRODUCTION

In a previous working paper dated October 12, 1971, specific locations were proposed for the satellites of each DOMSAT applicant and 4/6 GHz interference calculations for the configuration were presented for FDM/FM systems. In this paper, the interference calculations are extended to include different system parameters (particularly different earth station antenna sizes and transmitter power), FM television distribution, and the Canadian Telesat system. These calculations were made using a relatively simple computer program. In order to check the program, the calculations which were made manually in the earlier paper were redone using the computer. The revised calculations are given in table 1. The changes are not particularly significant and are due principally to manually scaling protection ratios from the graph contained in the paper. These results are more complete in that the interference is shown for all satellites, not just the assumed worst case.

As noted in the earlier paper, the downlink performance is generally acceptable (using the 1,000 pWpO total interference power criterion) except for the satellites of Western Union, COMSAT, and MCI. It was further noted that under the assumption that only RCA would serve Alaska, all of COMSAT's remaining CONUS stations would use 98 ft antennas, and under these conditions, the downlink interference would be acceptable. The remaining two, WU and MCI, propose relatively small antennas - 45 ft and 32 ft, respectively.

Table 1a. Interference (pWpO)

Satellite	4 GHz Downlink	6 GHz Uplink	Total
TCI1	93	43	136
TCI2	152	60	212
RCA1	617	1,014	1,631
RCA2	700	1,157	1,857
H1	512	466	978
H2	585	803	1,388
RCA3	553	1,260	1,813
WU1	1,374	509	1,883
WU2	1,447	591	2,038
WU3	1,638	410	2,048
F1	456	8,691	9,147
F2	414	10,286	10,400
ATT1	403	74	477
CS1	3,730	2,984	6,714
MCI1	3,697	859	4,556
ATT2	391	174	565
CS2	3,616	3,205	6,821
MCI2	3,526	845	4,371
ATT3	350	154	504
CS3	1,889	1,455	3,344

Table 1b. Interference (pWpO).

Satellite	4 GHz Downlink	6 GHz Uplink	Total
TCI1	93	41	134
TCI2	152	57	209
RCA1	617	1,004	1,621
RCA2	700	1,146	1,846
H1	512	462	974
H2	585	799	1,384
RCA3	553	1,245	1,798
WU1	1,374	503	1,874
WU2	1,447	584	2,031
WU3	1,638	395	2,033
F1	456	8,413	8,869
F2	414	9,586	10,000
ATT1	403	38	441
CS1	398	2,942	3,340
MCI1	3,697	596	4,293
ATT2	391	131	522
CS2	386	3,133	3,519
MCI2	3,526	578	4,104
ATT3	350	112	462
CS3	201	1,413	1,614

The WU downlink interference is not totally unacceptable in that it is small enough to be compensated for in other parts of the system. The complicating factor appears to be that WU claims a 10 dB greater protection ratio for its 45 ft antenna than the value computed by the generally accepted engineering methods used in this analysis and by the other applicants. WU calculations are on page A-4 of their proposal. If they can, in fact, get 10 dB better performance, then the interference would be clearly acceptable. If, instead, this is an error on their part, their use of 45 ft antennas for FDM/ FM message service is suspect and an increase to 60 ft or even 98 ft antennas - as used by other applicants in this service - may be necessary. The MCI interference calculations are somewhat sketchy and it is not clear if the 1,000 pWpO is met with the 5° spacing and 32 ft antennas that they propose. A factor in their favor is that they propose an 800 voice-circuit per transponder system as opposed to 1200 circuit system assumed in the analysis. The 800 channel system, of course, is more tolerant of noise/ interference. As stated in the earlier paper, it could be argued that since the spacing proposed here is consistent with the spacing that they themselves propose, it should be acceptable. The effect of 800 channel interference on 1200 channel systems, and vice versa, will be given a brief evaluation in a subsequent analysis.

One further note is that RCA proposes 98 ft antennas at certain locations. At these earth stations the downlink interference would be 231, 263, and 207 pWpO for RCA1, RCA2, and RCA3, respectively.

Since the 98 ft antenna assumption for COMSAT is more consistent with the original assumption that RCA would exclusively serve Alaska, table 1b was prepared. This table, then, should be regarded as showing the interference for 1200 channel telephone FDM/ FM service, for the described orbital arrangement (with the RCA

Alaskan service assumption), and with the applications otherwise essentially as proposed.

The 6 GHz uplink interference situation is different than that of the downlink in one important aspect. The downlink EIRP, as pointed out in the earlier paper, is constrained by the maximum power flux density permitted by international agreement. Since the downlink is so constrained, the system engineer will attempt to use higher uplink EIRPs so that the maximum margin is available for the downlink. For example, suppose the uplink and downlink SNRs were both 56 dB. The overall SNR would then be 53 dB. If the unconstrained uplink EIRP was raised 10 dB, the uplink SNR would be 66 dB in which case the overall SNR would be only slightly less than 56 dB. If he does this by an increase in transmitter power, he will produce 10 dB greater interference to other users and get 10 dB greater margin over the interference they cause him. It is clearly to his own advantage to use a level of power detrimental to other users of the orbit/ spectrum resource. Furthermore, the higher powers may significantly complicate frequency sharing with terrestrial microwave systems. Specific examples of the wide-range of transmitter powers and EIRPs were given in the earlier paper.

Because of this variation and the widely different transmitting antenna sizes, the uplink interference is not generally as acceptable. The tradeoffs involved in getting more acceptable performance are treated in section 3.

2. DOWNLINK INTERFERENCE VS. ANTENNA SIZE

One tradeoff mentioned in the previous paper was interference power versus antenna size. To illustrate this tradeoff, table 2 was prepared. It shows the downlink performance as a function of earth

Table 2. Downlink Interference vs. Antenna Size

	Interference (pWpO)			
	Antenna Size			
Satellite	32	45	60	98
TCI1	326	165	93	35
TCI2	534	270	152	57
RCA1	2,163	1,094	615	231
RCA2	2,461	1,245	700	263
H1	4,794	2,425	1,363	512
H2	5,480	2,772	1,558	585
RCA3	1,938	980	551	207
WU1	2,714	1,373	772	290
WU2	2,857	1,445	812	305
WU3	2,232	1,635	919	345
F1	4,270	2,160	1,214	456
F2	3,887	1,966	1,105	415
ATT1	3,774	1,909	1,073	403
CS1	3,729	1,886	1,060	398
MCI1	3,689	1,866	1,049	394
ATT2	3,661	1,852	1,041	391
CS2	3,616	1,829	1,028	386
MCI2	3,521	1,781	1,001	376
ATT3	3,278	1,658	932	350
CS3	1,882	952	535	201

station antenna size. A regulated minimum antenna size is not particularly relevant for the receive-only (RO) case since other users of the orbit/ spectrum are not affected and only the effect is decreased performance to the user of the smaller antenna. On the other hand, close orbital spacing may, as a practical matter, limit the minimum antenna size. This is of the most concern to those applicants proposing distribution of video signals to many, small RO terminals (e.g., educational TV). FM/ TV distribution is discussed in section 5.

Examination of table 2 reveals several interesting factors. First, the downlink performance for FDM/ FM and this orbital arrangement is entirely satisfactory with 98 ft antennas. The interference power does not exceed 500 pWpO except for the Hughes satellites (512 and 585 pWpO) which receive the majority of the interference from their own opposite link. Five out of the eight applicants propose the use of 98 ft antennas at least at certain locations. These include those who are most concerned with this type of service (e.g., AT&T and GT&E). Going from 98 ft antennas to 60 ft antennas increases the interference about 2.7 times (4.25 dB). In some instances these size antennas would provide acceptable 1200 channel per transponder FDM/ FM service while in other cases (1) adjustments in system parameters (particularly the number of channels per transponder) or (2) reallocation of the noise budget would be necessary. Going from 60 ft to 45 ft antennas would increase the interference by another 2.5 dB and going from 45 ft to 32 ft would increase it another 3.0 dB.

3. UPLINK INTERFERENCE VS. ANTENNA SIZE WITH ADJUSTED EARTH STATION EIRPs

Since the uplink interference power shown in table 1b is unacceptable in several instances, the interference was recomputed assuming equal earth station EIRPs. This should not be interpreted as a requirement that all earth stations have equal EIRPs. Instead, a minimum transmitting antenna size <u>and</u> maximum transmitter power output would be specified. The equal EIRP case then would correspond to all users having minimum antennas and maximum power. An applicant deviating from this case could help himself (by going to larger antennas) or help others (by using less power) but in no case could he cause others to have poorer calculated performance than that computed by assuming the equal EIRPs corresponding to minimum antenna and maximum power.

The results of the computations with equal EIRPs are shown in table 3. The situation is generally improved from the standpoint that the variation in uplink interference is reduced and several cases that were categorically unacceptable are now more reasonable. For several satellites, however, the uplink performance is still poorer than the downlink performance due to their proximity to other satellites with the smaller earth station antennas. The uplinks of RCA, Hughes, and, in particular, Western Union suffer from the interference from the smaller Canadian stations (26/ 32 ft antennas), although RCA and Western Union contribute to it as well through the use of 32 and 45 ft antennas, respectively. COMSAT and AT&T receive considerable uplink interference from the MCI (32 ft) earth stations. Ironically, the MCI uplink performance is among the best because of the use of 98 ft antennas by COMSAT and AT&T.

While the total interference for many of the satellites still exceed the arbitrary 1,000 pWpO standard, they are within the range that could probably be accommodated by the relatively minor adjustments in systems parameters mentioned in section 2. The exceptions, MCI and, to a lesser degree, Western Union, were discussed in section 2 as well.

Table 3. Uplink Interference with Equal EIRPs

Satellite	Uplink Interference (pWpO)	Total (Using Downlink Valves from Table 1 - pWpO)
TCI1	64	157
TCI2	97	249
RCA1	916	1,533
RCA2	1,025	1,725
H1	569	1,081
H2	1,123	1,708
RCA3	528	1,081
WU1	874	2,248
WU2	658	2,105
WU3	450	2,088
F1	945	1,401
F2	443	857
ATT1	392	795
CS1	809	1,207
MCI1	251	3,948
ATT2	854	1,245
CS2	845	1,231
MCI2	220	3,746
ATT3	742	1,092
CS3	212	413

Table 4 shows the uplink interference (for equal EIRPs) versus earth station antenna size assuming 32 ft antennas for the Canadian earth stations. The interference from the Canadian station produces marginal interference performance even with a 60 ft transmitting antenna (minimum) associated with the U.S. DOMSAT systems. The coordination situation with Canadian Telesat system will be addressed in more detail in section 6.

4. TOTAL INTERFERENCE VS. ANTENNA SIZE

Table 5 shows total interference (uplink and downlink) as a function of antenna size with earth station EIRPs equal. These results merely summarize tables 2 and 4 and are for 32 ft Canadian antennas. The total interference is clearly acceptable for 1200 voice-circuit FDM/FM links using 98 ft antennas. With 45 or 60 ft antennas the performance generally exceeds the 1,000 pWpO recommendation, but probably not excessively in the latter case. In this particular orbit arrangement, the Hughes eastern-most satellite (H2) has the highest interference due to the fact that it uses the same antenna polarity and channel offset as Canadian system with a satellite 5° away. An increase in this spacing is possible while still keeping all satellites within the useful arc.

5. TELEVISION DISTRIBUTION

All applicants propose some form of 525 line television distribution using FM modulation with one 40 MHz transponder per video signal. FM-TV distribution is less demanding than the FDM/FM message service assumed up to this point. It is so undemanding that AT&T, for example, does not even bother to show performance calculations for links with 98 ft antennas at each earth station. For

Table 4. Uplink Interference vs. Antenna Size (32 ft Canadian Antennas)

	Interference (pWpO)			
	Antenna Size (ft)			
Satellite	32	45	60	98
TCI1	145	89	63	43
TCI2	237	130	97	62
RCA1	964	487	274	103
RCA2	1,094	554	312	117
H1	2,133	1,182	757	415
H2	2,439	1,525	1,117	788
RCA3	864	442	254	102
WU1	1,208	622	773	149
WU2	1,272	654	378	155
WU3	1,440	734	418	164
F1	1,902	1,101	742	454
F2	1,729	922	561	270
ATT1	1,681	873	512	221
CS1	1,658	852	491	201
MCI1	1,643	840	480	191
ATT2	1,628	829	472	184
CS2	1,607	817	463	179
MCI2	1,567	796	451	173
ATT3	1,458	740	419	160
CS3	840	427	242	94

Table 5. Total Interference vs. Antenna Size

	Interference (pWpO)			
	Antenna Size (ft)			
Satellite	32	45	60	98
TCI1	471	254	156	78
TCI2	771	400	249	119
RCA1	3,127	1,581	889	334
RCA2	3,555	1,799	1,012	380
H1	6.927	3,607	2,120	927
H2	7,919	4,297	2,675	1,373
RCA3	2,802	1,422	805	309
WU1	3,922	1,995	1,545	439
WU2	4,129	2,099	1,190	460
WU3	4,672	2,369	1,337	509
F1	6,172	3,261	1,956	910
F2	5,616	2,888	1,666	685
ATT1	5,455	2,782	1,585	624
CS1	5,387	2,738	1,551	599
MCI1	5,332	2,706	1,529	585
ATT2	5,289	2,681	1,513	575
CS2	5,223	2,646	1,491	565
MCI2	5,088	2,577	1,452	549
ATT3	4,736	2,398	1,351	510
CS3	2,722	1,379	777	295

television distribution to a large number of RO earth stations, which is typical of this service, minimizing the size of antennas becomes an important factor. Thus the principal concern in this analysis will be the performance afforded RO earth stations as a function of antenna size.

Each applicant proposes a peak-to-peak signal-to-RMS noise objective of about 56 dB. This translates into a carrier-to-noise requirement of about 16.5 dB. Most applicants do not address the carrier-to-interference power (C/I) requirements when the undesired signal is FDM/FM message or another FM-TV service. AT&T refers to tests which show that if the cochannel interference is another FM-TV signal, then it is satisfactorily low if it is 19.9 dB weaker than the desired signal. For offset channels, the corresponding figure is 11.9 dB. They go on to state that further tests showed that FDM/FM telephone signals were less interfering to TV signals than were other television signals.

For this analysis, the C/I for each downlink was computed and tabulated in table 6, assuming 32 ft antennas. The results are generally satisfactory. The worst-case C/I is 28 dB for the Hughes H2 satellite. The interfering signal, in this case, would be 11.5 dB less than the noise (assuming the 16.5 dB ppSNR requirement was just being met) and some 8.1 dB better than the tests referred to by AT&T would require. This seems entirely adequate, even allowing for further uplink degradation. For certain applications, e.g., schoolhouse RO terminals, even smaller antennas would be possible because of this margin and less stringent requirements. In the study by NSL for the Corporation for Public Broadcasting, a 45 dB ppSNR objective is used for "School Service" as opposed to the 55 dB for "Network Service", indicating the relaxed requirement.

Table 6. Downlink FM-Television Performance - 32 ft Antennas

Satellite		C/I (dB)
TCI1	---	42
TCI2	---	40
RCA1	.715	30
RCA2	.809	30
H1	1.546	28
H2	1.764	28
RCA3	.665	30
WU1	.909	30
WU2	.953	30
WU3	1.049	30
F1	1.353	30
F2	1.230	29
ATT1	1.196	29
CS1	1.180	29
MCI1	1.169	29
ATT2	1.158	29
CS2	1.143	29
MCI2	1.115	30
ATT3	1.038	30
CS3	.597	30

6. CANADIAN TELESAT SYSTEM

Up until this point, the proposed Canadian satellites have not been considered except as a source of uplink interference. The purpose of this section is to specifically analyze the interference coordination problem between the Canadian and U.S. Domestic Satellite Systems. The assumptions regarding the Canadian system are based on a recent paper entitled, "Summary-Technical Characteristics of Canadian Domestic Communication-Satellite System". The Canadian system will use the same 4/6 GHz bands as the U.S. systems.

Fortunately, the Canadian Telesat system uses similar technology to the U.S. 12 transponder systems. This simplifies considerably the coordination problem. On the other hand, they propose occasional use of transmitting antennas as small as 26 ft which tends to complicate the problem. They propose regular use of 32 ft antennas although 98 ft antennas are proposed for Heavy Route earth stations which will provide 960 circuit per transponder telephone service.

For the 98 ft Canadian stations, the U.S. systems would contribute 178 pWpO out of an acceptable downlink total of 313 pWpO for the C1 link, 160 pWpO out of 298 for C2, and 44 pWpO out of 104 for C3. On the uplink side the corresponding figures are 106 of 955, 51 of 1494, and 66 of 955. The greater than 1,000 pWpO totals are due to their own use of 32 ft antennas.

Because of the interference produced by the Canadian system in the U.S. uplinks for this orbit arrangement, table 7 was prepared to show the uplink and total interference to U.S. DOMSAT systems as a function of the Canadian earth station antenna size. U.S. earth stations are assumed to be 98 ft. With a Canadian antenna size of 60 ft or greater, the total interference on the H2 links would be less than 1,000 pWpO. Further analysis of the characteristics of the transmissions that Canada is planning to make from the 26/32 ft earth stations is needed.

Table 7. Uplink and Total Interference vs. Canadian Earth Station Antenna Size

	Interference (pWpO) - Uplink/ Total			
	Antenna Size (ft)			
Satellite	26	32	60	98
TCI1	58/ 91	43/ 78	21/ 56	15/ 50
TCI2	83/ 140	62/ 119	33/ 90	25/ 82
RCA1	103/ 334	103/ 334	103/ 334	103/ 334
RCA2	117/ 379	117/ 379	117/ 379	117/ 379
H1	523/ 1,035	415/ 927	265/ 776	227/ 739
H2	1,092/ 1,677	788/ 1,373	365/ 950	260/ 844
RCA3	108/ 315	102/ 309	94/ 301	92/ 299
WU1	160/ 450	149/ 439	133/ 423	129/ 419
WU2	167/ 472	155/ 460	140/ 445	136/ 441
WU3	170/ 515	164/ 509	156/ 501	154/ 449
F1	599/ 1,055	454/ 910	253/ 709	203/ 659
F2	319/ 734	270/ 685	201/ 616	184/ 599
ATT1	245/ 648	221/ 624	188/ 591	179/ 582
CS1	215/ 613	201/ 599	182/ 579	177/ 575
MCI1	200/ 594	191/ 585	178/ 572	175/ 569
ATT2	191/ 582	184/ 575	176/ 566	174/ 564
CS2	184/ 570	179/ 565	173/ 558	171/ 556
MCI2	177/ 553	173/ 549	168/ 544	167/ 543
ATT3	163/ 513	160/ 510	156/ 506	155/ 505
CS3	97/ 298	94/ 295	90/ 292	89/ 291

5 - 5

SC5

October 28, 1971

PSD/ DNH

DOMSAT Orbit/ Spectrum Utilization

Lt. Col. S. A. Lasher

Attached is a brief statement of the conclusions I have reached as a result of the analysis contained in the Working Paper and Supplement that I recently sent to you in draft form.

Dale N. Hatfield

Chrono.
Subject
bcc
DNH/ pm (10-28-71)

Conclusions

DNH - 10/28/71

The more detailed analysis contained in the Working Paper supports the conclusion that mutually satisfactory technical arrangements could be made to accommodate the U. S. and Canadian domestic satellites in the available geostationary orbit.

Specifically, all of the currently proposed domestic satellites (including three Canadian satellites but excluding ground spares) could be allocated orbit space so that each satellite transponder could provide acceptable 1200 channel, FDM-FM telephony service with 30 ft earth station antennas. From this, acceptable performance for other services can be expected.

Interference levels would be sufficiently low that "Network Service" quality TV distribution could be provided with 32-ft or smaller receiving antennas.

For efficient orbit utilization, the maximum earth station transmitter power (as well as the minimum transmitting antenna size) should be limited.

Interference levels to the Canadian Telesat system appear aceeptable.

There would be considerable difficulty in accommodating additional U. S. domestic satellites without exploiting bands other than 4/ 6 GHz.

Chrono.
Subject
bcc
DNH/ pm (10-28-71)

OFFICE OF TELECOMMUNICATIONS POLICY
EXECUTIVE OFFICE OF THE PRESIDENT
WASHINGTON, D.C. 20504

October 28, 1971

DIRECTOR

Honorable Dean Burch
Chairman
Federal Communications Commission
Washington, D.C. 20554

Dear Dean:

The unrealized potential of satellite communication systems for U.S. domestic services continues to be a source of serious concern to the Administration. Prospective suppliers of these services have been delayed for more than six years while various parts of the Government have examined and reexamined the question of public policy guidelines.

In January 1970, the Administration recommended that domestic satellite communications be allowed to develop under a basic policy of open entry. Under this policy, any financially qualified entity which sought to establish a domestic satellite system, including common carriers, would be authorized to do so, subject only to antitrust considerations and essential technical coordination.

The Commission responded favorably to this approach, but chose to solicit applications and comments from all prospective satellite operators before proceeding further. The private sector has since responded to this initiative with seven proposals for full-service satellite systems and several proposals for partial service offerings -- all to be offered on a privately financed commercial basis.

The Office of Telecommunications Policy has carefully reviewed the major applications to determine whether they raise questions about any of the principles and premises set forth in the Administration's original recommendation. We have examined questions of technical and economic feasibility, particularly those relating to spectrum and orbit utilization and to the existence of economies of scale or other natural monopoly conditions. We also have reviewed the several legal and procedural issues raised. In no area did we find evidence which would negate the Administration's previous policy recommendation.

Indeed, the opposite is true. There are customers waiting for satellite services and prospective suppliers with the capital and the will to offer them on a commercial basis. We see no reason for the government to continue keeping these groups apart. No further study, sifting of applications, or enforced commercial arrangements would be as constructive for the using public or for the industry as the prompt opening up of this new and exciting field.

As you know, the President recently established measures designed to alleviate the problems of our nation's economy. The prompt authorization of domestic satellite systems would aid substantially in this effort by stimulating up to $450 million in investments, and associated employment, in the aerospace and electronic industries -- two segments of the economy which have been hit particularly hard by cutbacks in Federal spending. The authorization would also provide lower transmission costs and thereby help reduce upward pressure on common carrier rates.

I urge the Commission to examine carefully the enclosed recommendations and to adopt an open entry policy as promptly as possible.

I am available, as is my staff, to discuss this subject in whatever depth you may desire.

Sincerely,

Tom

Clay T. Whitehead

Enclosure

Domestic Satellite Communications

Summary OTP Findings and Policy Recommendations

The several applications from prospective domestic satellite operators now pending before the Federal Communication Commission indicate clearly that such facilities can play a significant and increasing role in enhancing the nation's communications capability and broadening the range of economic services.

The Administration recommended in January 1970, that domestic satellite operations be established under a basic public policy of open entry and competitive operation. Under this policy, any financially qualified entity which sought to establish a domestic satellite system for public or private use could do so, subject only to antitrust considerations and essential technical coordination.

The Office of Telecommunications Policy has examined the applications now before the FCC to determine whether the Administration's policy recommendation continues to be appropriate. This examination shows there are no technical, economic, or legal considerations which preclude the approval of any proposed system. Conversely, there is substantial evidence that a policy of open entry and competitive operation would produce benefits in terms of innovative systems and services, cost reductions, and economies of specialization for the communications user.

The available orbit space will readily accommodate all proposed U.S. and Canadian satellites using 4 and 6 GHz spectrum allocations without fear of harmful interference, even in the rather unlikely event that all proposed systems would be built. This can be achieved with an average satellite separation of about 3°, which is shown to be more than adequate by several applicants (Hughes, WTCI, COMSAT, and WU) and our own analysis, provided adjacent satellites are alternately polarized. Furthermore, there are numerous engineering and operating options which would allow additional systems to be built as this becomes necessary, even using existing technology and these spectrum bands.

It also appears that noninterfering sites can be found for all proposed earth stations under established coordination procedures. Sample calculations for the New York City area indicate there are many sites which, according to the ITU coordination criteria, qualify for detailed coordination with specific terrestrial relay stations, even in this congested area.

Further technological developments, such as the use of multiple satellite antenna beams, will permit the installation of additional satellites of increased capacity in coming years. In conjunction with the use of other frequency allocations of substantially greater extent than the 4 and 6 GHz bands, these developments will multiply both the number of satellites which can be established and the capacity of each severalfold, providing a substantial reserve capacity to meet future growth in demand.

There are no significant economies of scale in the proposed systems which would preclude the feasibility of multiple systems or result in substantial inefficiencies. The annual cost per in-orbit channel is virtually the same for the 12, 24, and 48 channel satellite configurations proposed, and the small differences which exist are well within the range of uncertaintly of the cost estimates. There are some economies of scale for particular types of earth stations (e.g., multipurpose, multichannel), but these are rapidly overcome by economies of specialization for special-purpose systems; even when economies of scale appear, they are bounded due to the limited channel capacity available through a single earth station/satellite path.

There is no <u>a priori</u> evidence that multipurpose systems are more economic or more suited to user demands than single-purpose systems. There are substantial cost savings for some systems which provide specially tailored services (e.g., network TV distribution). Similarly, there may be economies in providing a given type of service at different quality levels. As in the case of the specialized common carriers, there is reason to believe that the marketplace can best resolve the tradeoffs between service and cost, particularly in an era of dynamic technological development.

The demand for service identified in the applications will support several -- although probably not all -- of the proposed systems. There appears to be a near-term need for about 100 satellite channels (5-10 satellites, depending on capacity), whereas the applications encompass a total of 336 channels in 12 primary satellites plus another 264 channels in 8 spare/secondary satellites. Even so, there is no evidence to indicate that selection of the successful operator(s) by the government is either necessary or preferable on public interest grounds to a marketplace determination. The cost of these systems is great(typically in the $50-200 million range), and investors will weigh their prospects carefully before making final commitments to systems without an adequate traffic base or competitive advantage.

The American people should and can receive a dividend from U.S. investments in space technology through domestic satellite services. However, a discriminatory tax on this mode of communications for any purpose, including support of public television, is an inefficient, inequitable, and largely counterproductive approach to the realization of that objective. By raising the cost and thus deterring the commercial use of satellite services, this tax would simply encourage less cost-effective technologies and stifle innovation in satellite technology. If a subsidy for worthwhile public services is required, it should be granted by the Congress and supported by a tax that does not burden a particular mode of communications.

Numerous legal and procedural questions have been raised in the applications and comments before the FCC. Our examination indicates that the Commission has adequate legal authority and precedents for adopting an open-entry policy, as urged by the Administration, without further administrative proceedings.

There are many measures consistent with existing rules and procedures which the Commission could adopt to expedite the authorization of domestic satellite communication systems and avoid unnecessary comparative hearings. The following is an illustrative example of one approach:

(1) Issue a ruling, as in the case of specialized carriers, that arguments of economic exclusivity alone will not be considered grounds for comparative hearings in situations where competitive supply of services appears feasible.

(2) Require all applicants to undertake prior coordination of satellite and earth station locations and frequency assignments to avoid possible interference situations -- again as in the specialized carrier procedures.

(3) Require each applicant to specify the desired orbit location, frequency bands, antenna polarization, and expected implementation date for each proposed satellite, and to define a <u>service arc</u> within which the proposed service can be satisfactorily provided, as set forth in the regulations of the World Administrative Radio Conference.

(4) Provide a 60-90 day period following issuance of a policy statement, within which applicants may revise their proposals and undertake the coordination of technical parameters as noted in (2).

(5) Routinely approve all applications for which there is no basic conflict in orbit location and spectrum usage (i.e., no common-frequency satellite proposed by a different entity within 3° of the location requested), subject to relocation within the service arc at the discretion of the Commission in order to accommodate additional systems.

(6) Set comparative hearings for all applications for specific orbit locations which are in conflict and which cannot be resolved through consultation with the FCC staff and affected parties. Such hearings would deal with matters

of both technical compatability and economic exclusivity, but would be limited to the particular satellites in conflict.

(7) Rule that the cost of relocating satellites (including associated earth station costs) within the stated service arc to accommodate additional systems shall be borne by the system operator until 120 days prior to satellite launch, after which all such costs shall be borne by the new entrant.

While some antitrust questions have been raised in the proceedings, in our view they should be resolved in favor of liberal entry and unrestricted initial operation. None of the proposed systems, including those contemplated by COMSAT, COMSAT/AT&T, and Hughes/GTE, appear to pose a serious anti-competitive threat at this time, either individually or in combination. (Nor do we see any legal reason for excluding COMSAT from either activity they have proposed). Any measures necessary to prevent anti-competitive behaviour can be taken if and when such practices appear; to establish them at the outset without firm assurance that they are necessary would have the effect of precluding rather than fostering competitition in this new field.

Service to Alaska and Hawaii, as proposed by several applicants, poses a different and more complex set of legal issues, having to do both with the distinction between U.S. domestic and international carriers and services and with international agreements to which we are a signatory. We conclude that applications to provide service to these areas should be approved subject to appropriate consultation with INTELSAT as required in the definitive agreements. Similarly, we find no valid basis for denying traffic to a domestic satellite system which would otherwise be served by trans-oceanic cables, except to the extent such facilities offer lower costs or are more effective in meeting the specific requirement.

In conclusion, we find there are no unique circumstances or public interest considerations which require that domestic satellites be treated differently than any other new technological development. The Commission has established rules and procedures for dealing with private radio communication systems, specialized communications carriers, and common carriers which should be applicable to the domestic satellite proposals now before it, or likely to emerge in the near future. These rules and procedures, interpreted in the light of the Administration policy recommendations concerning entry and operation, and augmented by procedural arrangements such as those previously identified, should allow the prompt authorization of all proposed systems and an early development of this exciting new communications capability.

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OFFICE OF TELECOMMUNICATIONS

December 3, 1971

Lt. Col. S. A. Lasher
Office of Telecommunication Policy
Executive Office of the President
Washington, D. C. 20504

Dear Seb,

In the past few days since receiving the SRI report, I have worked out the following analysis which I would propose to include in our report. I would appreciate comments on both its content and appropriateness.

With 24 transponder systems at 4/6 GHz, a 1,000 pWOp interference limit, 98 ft earth station antennas, and homogeneous system parameters, 23 satellites can be accommodated in the 85° of available orbit. (This is well confirmed.) Thus using just 4/6 GHz, 24 times 23 or 552 transponders could be placed. Including a like number of transponders at 12/13 GHz on each satellite would double this, making a total of 1104, 40 MHz transponders.

The analysis by SRI indicates that the expected demand by the mid-1970s is about 100 transponders. Using the 4/3 ratio of active to in-orbit spare satellites represented by the applications, the total requirement is 175 transponders. Adding Canada's requirements for 36 transponders in the same time period gives a total of 211 transponders which is only 40% of the number that could be accommodated using just 4/6 GHz and only 20% of those that could be accommodated if the higher bands were included. Furthermore since 3/7 of these are in-orbit spares, the demand for active transponders requires only 17% and 8% of the total capacity, respectively. Even if the useful arc is considered to be just 70° to insure elevation angles greater than 10° in CONUS, these figures would only change to 20% and 10%, respectively.

The total capacity proposed by the applicants is 588 transponders in orbit (336 active plus 252 spare). Adding the Canadian transponders produces a total of 624; but 96 of these use the higher bands, leaving a total of 528 which can be accommodated.

SURNAME	DATE	SURNAME	DATE

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The conclusions are:

* The orbit/spectrum capacity so vastly exceeds the demand that (a) open entry is indeed feasible, (b) systems with varying designs to suit specialized requirements could be accepted, and (c) later entrants could be accommodated.

* All 624 proposed transponders could be immediately accommodated in the unlikely event that all systems are built.

The latter conclusion should not be construed to mean that there would not be practical difficulties in producing an arrangement acceptable to all applicants. Shifts to the riskier 12/13 GHz bands, increases in antenna size, and limitations on earth station power might be necessary--all of which may increase costs.

Sincerely yours,

Dale N. Hatfield
Policy Support Division

DOMESTIC SATELLITE ORBIT/SPECTRUM UTILIZATION

Working Paper

Dale N. Hatfield

December 13, 1971

DOMESTIC SATELLITE ORBIT/SPECTRUM UTILIZATION

Working Paper

1. INTRODUCTION

The objective of this paper is to evaluate the geostationary orbit/spectrum utilization aspects of the U.S. Domestic Communication Satellite (DOMSAT) System applications. In particular, the goal is to provide information for considering the scarcity of the orbit/spectrum resource in DOMSAT policy recommendations. This is only one of many economic, legal, and technical aspects that must be evaluated. A closely related study of earth station siting is one of the latter.

This paper has been divided into several sections. Section 2 contains a brief summary of the principal findings of the study. Section 3 provides a general background on the orbit/spectrum allocation problem and section 4 contains a short review of the DOMSAT applications. Section 5 is devoted to a general analysis of the tradeoffs involving orbit spacing, performance, and system parameters typical of those proposed by the applicants. Section 6 contains an analysis of orbit capacity versus indicated demand and Section 7 discusses proposed capacity and certain factors affecting orbit/spectrum requirements. Section 8 contains an analysis for a specific orbital configuration to accommodate all of the current applicants. Finally, the Appendix contains a description and a listing of the computer program used in calculating the interference.

2. PRINCIPAL FINDINGS

- The average spacing required to accommodate all 23 of the initial U.S. and Canadian satellites in the available orbit is not inconsistent with the spacings analyzed and proposed in the applications.

- The ultimate capacity of the available geostationary orbit using (and reusing) 2000 MHz of spectrum so vastly exceeds the indicated initial demand that scarcity of this resource is not a compelling issue in policy determination.

- Both a general analysis and an analysis of a specific, hypothetical orbit/spectrum allocation to applicants indicate that all 23 satellites could be accommodated in the unlikely event that all systems are built, albeit certain adjustments in system parameters may be necessary.

- Major technical changes to accommodate all applicants would center on adjustments to uplink antenna sidelobe radiation and/or minimum earth station antenna sizes. Minor changes would involve polarization and frequency plans.

3. BACKGROUND

Technical factors affecting the utilization of the orbit/ spectrum resource have received considerable attention both nationally and internationally. For a more detailed, general analysis of these factors, the reader is referred to the papers by Bradley (1968), Hult, et al. (1968), Beyer, et al. (1968), Jansky and Jeruchim (1971), Jeruchim and Sayer (1969), and a number of CCIR documents.

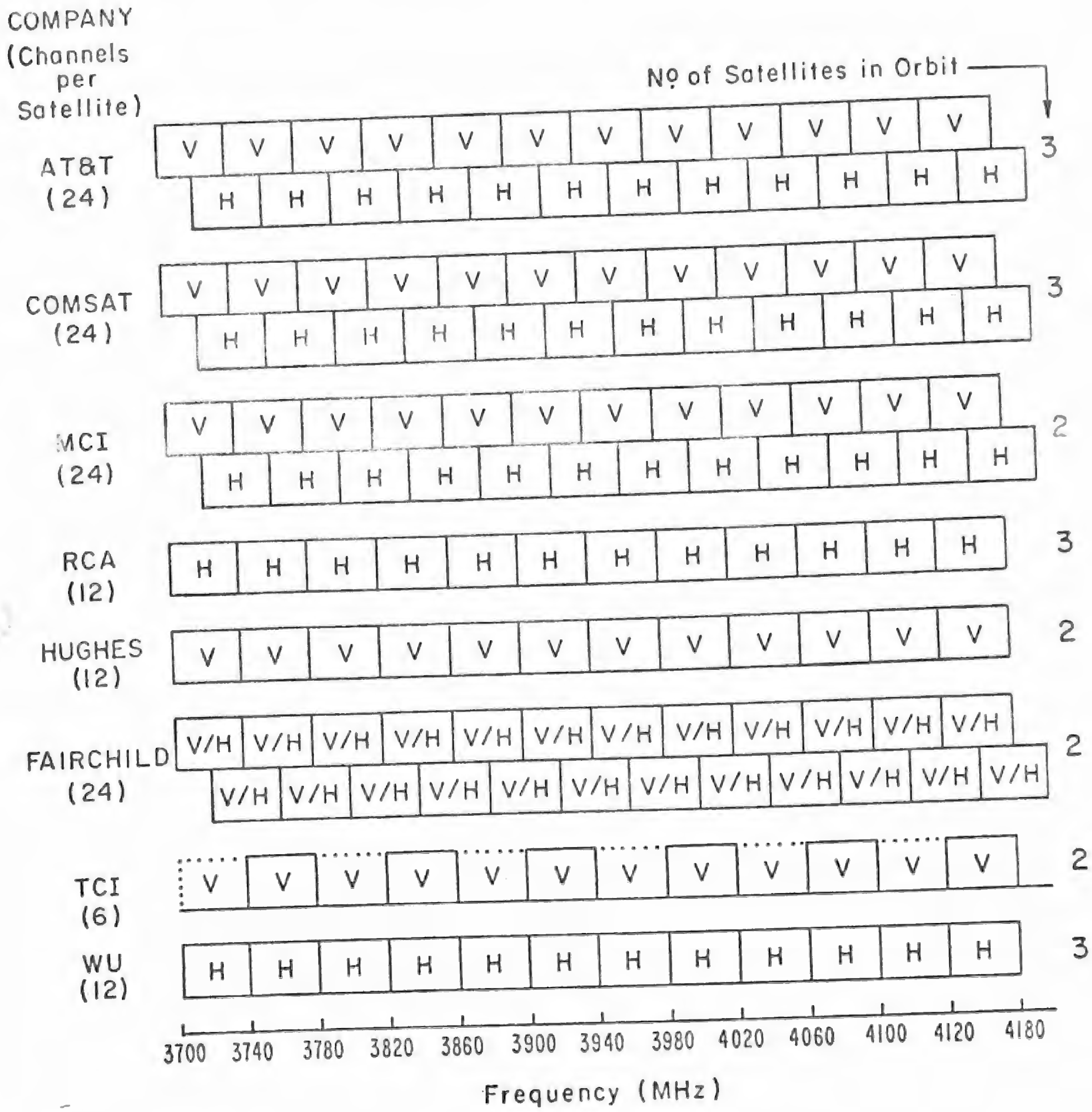
If each satellite in the geostationary orbit could use different portions of the frequency spectrum, then many of them could occupy the same orbital "slot" since the problem is not one of physical space. Because of the relative scarcity of available spectrum, this is not possible and reuse of the spectrum is necessary and prudent. In the case of the DOMSAT system, each applicant proposes to make use of two separate bands of frequencies near 4 and 6 GHz. These bands, used for downlinks and uplinks respectively, must also be shared with terrestrial systems as well. In addition, certain applicants propose the use of similar bands near 12 and 13 GHz. This multiple use of the same band is based upon the ability of each system to discriminate against or reject the signals of other systems. This discrimination can come from several sources but one of the principal ones is antenna directivity. Thus a basic factor determining the minimum spacing between satellites using the band is the directivity of the antennas employed. These sources of discrimination are discussed in more detail in section 5. The point to be made here is that the basic issue is one involving tradeoffs among costs, performance, and orbit/ spectrum utilization. The use of more directive (costly) antennas would yield higher system performance (in terms of less interference) and/ or allow more satellites to be accommodated in the orbit. Conversely, extravagant use of the orbit/ spectrum would permit fewer (but higher performance) or lower cost systems. The limits on orbit/ spectrum utilization are basically economic. The applicants themselves are very much concerned with both the cost and performance of their system. They may be less concerned with the efficient use of the "free" but valuable orbit/ spectrum resource. This paper does not directly address these more basic issues which are the subject of a separate study. Instead, it deals with the following question:

> Can the satellites of the current applicants be accommodated in the available geostationary orbit with acceptable performance and without imposing significant additional constraints (costs)?

4. REVIEW OF APPLICATIONS

The DOMSAT applications have been summarized in several different places. A MITRE Corporation report (Eldridge, et al., 1971) is devoted specifically to this subject and the FCC has summarized certain factors in Public Notice 65963 dated April 13, 1971. For completeness, the characteristics which are particularly important to the orbit/ spectrum utilization question are repeated here. There are certain features that are common to all applicants. Each propose the use of 40 MHz transponders. With the exception of Western Telecommunications (WTCI), they use 12 or 24 such transponders in the 500 MHz of available uplink and downlink bandwidth. For the 24 transponder systems, the 12 "even" channels are offset 20 MHz and cross-polarized with respect to the "odd", thus enabling the reuse of the spectrum. The channeling plans proposed for the 4 GHz downlinks are summarized in figure 1. Corresponding plans are used for the 6 GHz uplinks. Because of international maximum power flux density

4 GHz (DOWNLINK) FREQUENCY PLANS



V = Polarization Parallel to Spin Axis
H = Polarization Perpendicular to Spin Axis
(or equivalent)

Each block corresponds to one transponder

Note: The Canadian Telestat plan is the same as that of Hughes

DNH 9-8-71

restrictions, the applicants all propose nearly the same satellite downlink EIRP - about 36 dBW.

4.1 RCA

RCA Global Communications and RCA Alaska Communications (hereafter referred to as RCA) propose the initial deployment of two satellites at 121°W and 125°W longitude. Each satellite would have 12 transponders at 4/6 GHz. When the growth of traffic warrants it, they propose to place a third satellite in orbit at 114°W longitude and at the same time move the satellite from 121°W to 118°W longitude. A final configuration would put satellites at 114°W, 118°W, 122°W, and 126°W longitude. The satellites proposed would have a G/T of -7.4 dB/°K at 6 GHz.

RCA proposes earth stations with different size antennas and different uplink EIRPs. These range from stations with 32 ft antennas and 3 KW transmitter power output (87.8 dBW mainbeam EIRP) to a station with a 60 ft antenna and a power output of 300 W (83.8 dBW mainbeam EIRP) to, finally, a station with a 98 ft antenna and 100 W power output (82.5 dBW mainbeam EIRP). These would have a G/T of 32, 37, and 41 dB/°K respectively.

Each transponder would handle one FM-TV signal, 1000 FDM-FM voice circuits, or a 3.6×10^7 bps data signal.

4.2 WTCI

Western Tele-Communications (WTCI) proposes a two-satellite system. These would be placed at 113°W and 116°W longitude. Their system is somewhat unique in that they propose to use only six transponders per satellite in the 4/6 GHz bands with each satellite using only every other channel. They propose to employ a similar scheme at 12/13 GHz. They would have a G/T of 1.9 dB/°K.

Transmit/Receive (TR) earth stations would employ 32 ft antennas at 12/13 GHz and 60 ft antennas at 4/6 GHz. At 4/6 GHz the transmitter power output would be 700 W for a mainbeam EIRP of 84 dBW. The G/T for 6 GHz would be 36 dB/°K. They also propose Receive Only (RO) stations with antennas as small as 18 ft.

FM-TV, FDM-FM telephone, and data trasmission are proposed.

4.3 Hughes

Hughes proposes to use two satellites with 12 transponders each at 100°W and 103°W longitude. Hughes will lease certain of these transponders to General Telephone and Electronics (GTE). They will have a G/T of -7 dB/°K.

All T/R earth stations (both Hughes and GTE) using the Hughes satellites will use 98/100 ft antennas. Hughes proposes to use a transmitter power of 600 W and GTE proposes 3 kW for mainbeam EIRPs of 83 dBW and 92 dBW, respectively. Corresponding G/Ts would be 37 and 43 dB/°K. Hughes also proposes RO terminals with 35 ft antennas and G/T of 28 dB/°K.

FM-TV, FDM-FM telephone, and data transmission are proposed. One FM-TV signal or 1,320 voice channels (GTE) per transponder is indicated.

4.4 Western Union

Western Union (WU) proposes three satellites at 95°W, 102°W, and 116°W longitude. Each satellite would have 12 transponders at 4/6 GHz and the 6 GHZ G/T is -7 dB/°K.

The T/R earth stations would employ 45 ft antennas with a transmitter power output of 330 W for a mainbeam EIRP of 83 dBW. The G/T is indicated as 32 dB/°K. Capacity per transponder is either 1 FM-TV signal, 1200 FDM-FM voice channels, or 5×10^7 bps data.

4.5 ATT

American Telephone and Telegraph and the Communications Satellite Corporation (referred to as simply ATT in the remainder of this report) proposes a 24 transponder per satellite 4/6 GHz system with satellites located at 94°W, 104°W, and 119°W longitude. The G/T for the COMSAT-supplied satellites is indicated as -7 dB/°K.

The five major earth stations would employ 100 ft antennas with a transmitter power output of 1 kW giving a mainbeam EIRP of 92 dBW. The G/T would be 41 dB/°K. Capacity is either one FM-TV signal, 900 FDM-FM voice channels, or 3.5×10^7 bps per channel.

4.6 COMSAT

The Communications Satellite Corporation (COMSAT) proposes the same type satellite with 24 transponders each at 4/6 GHz. The three satellites would be placed at 99°W, 114°W, and 124°W longitude. Indicated G/T is -7 dB/°K.

All T/R earth stations would employ 97 ft antennas except those in Alaska which would use 32 ft. Power output per channel would be 630 W for the 97 ft antenna stations with a corresponding mainbeam EIRP of 90 dBW. The 32 ft stations would have a transmitter power output of 450 W with a maximum EIRP of 80.5 dBW in the mainbeam. The G/T is 32 and 41 dB/°K for the 32 ft and 97 ft sites, respectively. RO stations with 42 ft antennas and a G/T of 35 dB/°K are also proposed. Capacity proposed is either one FM-TV signal, 1200 FDM-FM voice channels, or 5×10^7 bps data per transponder.

4.7 MCI

MCI-Lockheed Corporation (MCI) proposes two satellites at 114°W and 119°W longitude. Each satellite would have 24 transponders at 4/6 GHz and 24 at 12/13 GHz. G/T is 1.9 dB/°K

Earth stations with an antenna diameter of 32 ft are proposed at all locations. A transmitter power of 3.0 kW with a mainbeam EIRP of 85 dBW at 6 GHz is given for these stations. The 4/6 GHz G/T is 33 dB/°K. The capacity per transponder is listed as either one FM-TV channel, 800 voice channel FDM-FM, or 5×10^7 bps data.

4.8 Fairchild

Fairchild Hiller Corporation (Fairchild) proposes two satellites at 104°W and 115°W longitude. Through the use of spot beams (in addition to cross polarization and interleaved carriers), they would have 96 transponders at 4/6 GHz and 24 at 7/13 GHz. The G/T at 6 GHz is 15.2 dB/°K.

At 4/6 GHz, the applicant proposes earth stations with 97 ft antennas, a transmitter power output of only 12 W, a corresponding EIRP of 73 dBW, and a G/T of 36 dB/°K. Each transponder would have a capacity of either 1 FM-TV signal, 1200 FDM-FM voice channels, or 3.5×10^7 bps data.

5. GENERAL ACTIONS

5.1 Useful Orbital Arc for U.S. and Canadian Coverage

The coverage of a synchronous satellite varies with its location in the geostationary orbit and the restrictions on minimum elevation angles at the earth stations. The minimum elevation angle restrictions arise from technical factors such as the increase in noise temperature and increased coordination problems with terrestrial systems at the lower angles. For elevation angles greater than 5° (the FCC guideline), the useful arc for coverage of the contiguous U.S. (CONUS) ranges from about 53° W to 138° W longitude. Thus there is approximately 85° total. The portion of the arc visible from a given earth location decreases with increasing latitude, hence the corresponding range for Canada is from about 82° W to 122° W. For coverage of Alaska with the same 5° restriction, the satellite must be located west of about 114° W.

Elevation angles from various cities in which the applicants propose earth stations to the 53° W and 138° W extremes of the useful orbit are summarized in table 1. If the elevation angle restriction is increased to 10°, the useful arc is reduced to approximately 70°.

5.2 Average Spacing

There are applications for 24 orbital slots, but four of these are designated for ground spares. In addition, Canada's plans to launch three satellites must be included, making a total of 23 slots that must be initially allocated - including the third RCA and the third Canadian satellites which would not be immediately launched. Thus an average spacing of approximately 3.7° is indicated, i.e., 85° divided by 23. If the 10° minimum elevation angle were imposed, the average

Table . Elevation angles from earth station locations to the extremes of the geostationary orbit visible from Conus.

Long. of Earth Stn.	Lat. of Earth Stn.	Elevation Angle with Satellite at 53 W	Elevation Angle with Satellite at 138 W	Nearby City
73.50	40.40	38.74	10.60	New York City
72.42	41.45	38.16	9.49	Hartford
71.05	42.20	37.94	8.27	Boston
78.55	42.52	34.53	13.56	Buffalo
75.10	40.00	38.42	11.93	Philadelphia
76.54	40.17	37.60	12.95	Harrisburg
77.00	38.55	38.84	13.85	Washington, D.C.
80.00	40.26	35.81	15.49	Pittsburg
81.41	41.30	34.18	16.09	Cleveland
80.50	35.03	39.93	17.84	Charlotte, N.C.
81.00	34.00	40.46	18.61	Columbia, S.C.
81.40	30.20	43.16	20.27	Jacksonville
80.15	25.45	47.62	20.59	Miami
84.23	33.45	38.75	21.47	Atlanta
84.30	39.10	34.38	19.15	Cincinnati
83.05	42.23	32.55	16.86	Detroit
90.03	30.00	36.79	27.76	New Orleans
87.45	41.50	30.68	20.27	Chicago
88.00	44.32	28.23	19.18	Greenbay
93.10	45.00	24.87	22.01	St. Paul
92.17	34.42	32.44	27.38	Little Rock
94.37	39.05	27.99	26.43	Kansas City, Kan
96.00	41.15	25.59	26.24	Omaha
68.47	44.49	36.46	5.81	Bangor
96.48	32.47	30.25	31.80	Dallas/Ft. Worth
95.25	29.45	32.85	32.43	Houston
105.00	39.45	20.24	33.09	Denver
118.15	34.00	11.89	45.12	Los Angeles
122.27	37.45	7.71	43.55	San Francisco
122.40	45.32	5.68	35.57	Portland
122.20	47.35	5.27	33.45	Seattle
157.50	21.50	21.55	56.51	Oahu, Hawaii
134.20	58.20	*****	23.78	Juneau
132.00	55.00	*****	27.05	Ketchikan
148.00	70.00	10.25	11.16	Prudoe Bay
150.09	52.20	12.81	29.25	Talkeetna
147.50	64.50	10.47	16.81	Fairbanks
66.08	18.29	63.83	8.55	San Juan
150.00	61.10	11.87	20.06	Anchorage

Note: The Bangor, Maine station was added to provide a point at extreme northeast of Conus. Asterisks indicate elevation angle $< 0°$.

spacing would be slightly greater than 3°. Average spacings of this magnitude appear feasible based on the analysis presented by the applicants themselves. These analyses are discussed briefly in the next section. It should be kept in mind that the 12 transponder satellites employing cross polarization and interleaved carriers between adjacent satellites can be spaced closer than the 24 channel systems which employ these techniques within each satellite.

5.3 Spacing Requirements As Stated by Applicants

In the original material furnished to the applicants by the FCC, earth station antennas of 32 ft and satellite spacings of 5° were suggested as minimums. In general, there seems to be several forces at work in choosing spacings. Wider spacings are favored by those applicants arguing for a monopoly position, although this may also result from the fact that they are associated with the larger capacity satellites. The forces toward narrower spacing result from (1) the efforts of applicants to cover two satellites using a single antenna with dual feeds - thereby reducing costs and (2) those favoring open entry who want to demonstrate that the satellites of all applicants could be accommodated.

In the 12 transponder (4/6 GHz) per satellite class, WTCI and Hughes both propose 3° spacing for their systems. Of these two, the Hughes' analysis is more detailed. It concludes that 3° spacing is adequate for their own satellites, and that their satellites could be located "within 3 to 5° of other satellite systems using the same frequency bands (depending upon the other satellite system design)". WTCI references the North American-Rockwell Coordination Analyses and states that: "Several additional satellites are permitted by 3° spacing and system calculations indicate this to be feasible". The RCA application proposed 4° spacing of its satellites. This spacing is based on a tradeoff analysis involving minimizing sun outage time and reducing interference on one hand (requiring a wider spacing) and staying within the requirements for covering both satellites with a dual feed, single antenna on the other. Western Union uses 7° spacing but notes that 2.5° spacing would be feasible with cross polarization. The COMSAT and ATT (24 transponder) applications propose alternating their satellites at 5° spacing (in accordance with the FCC guidelines). COMSAT has a detailed analysis and a summary table which shows required satellite spacing as a function of the type of signal and for typical earth station equipment. The spacings range from 1.3° to 4.3°, but the 4.3° is footnoted with the comment that "it reduces to 3.0° by cross polarization with respect to the interfering satellite... (and) that ±2.5° orbital spacing between satellites would be theoretically possible." The ATT proposal contains a detailed analysis for 4.5° which shows protection margins consistent with the analysis given by COMSAT. The MCI proposal also uses 5° spacing, but they indicate that 3.4° spacing is possible.

Thus, the applicants themselves either support the contention that average spacings in the range from 3-4° are possible or, as a minimum, they do not present any strong arguments that they are not sufficient.

5.4 Tradeoffs for Representative Systems

The purpose of this section is to critically examine spacing requirements using systems parameters typical of those proposed. This is necessary because in many cases the applicants' analyses considered only other interfering systems which were identical to their own. Furthermore, examination of the tradeoffs will provide some insight into orbit capacity and the effect of certain system constraints such as minimum antenna size.

5.4.1 Assumptions

Certain assumptions are necessary for the following analysis.

First, only the 4 GHz downlink and 6 GHz uplink interference is considered. This is the most critical case because (1) the antenna discrimination at 12/13 GHz is substantially greater for the same antenna size and (2) fewer applicants propose the use of the higher frequency bands thus reducing the potential interference.

Second, satellite spacing is acceptable if the total added noise from interference on the satellite/earth station link, in the worst-case voice channel, is less than 1,000 pW0p (pico-watts, psophometrically weighted). This noise is only part of a total noise budget of 10,000 pW0p if CCIR Recommendations are followed. The choice of the 1,000 pW0p limit for interference in the satellite link is, of course, arbitrary. In fact, several applicants exceed this limit - compensating for it in other parts of the system or in offered performance.

Third, it is assumed that the angle between two satellites as observed at an earth station is equal to the satellite spacing as measured in degrees of equatorial arc. This is a conservative assumption in that the former angle is always greater than the latter.

Fourth, as a baseline for this analysis a nominal 1200-voice circuit per channel (transponder), FDM/FM system with an RMS modulation index of 0.6 and a top baseband frequency of 5.5 MHz is assumed. This nominal system is the same as that given by COMSAT in their Comments dated 12 May 1971, and it is generally representative of voice circuit systems. It is conservative from the standpoint that no applicant proposes a greater number of voice channels per 40 MHz transponder. It is assumed (with precedent) that acceptable performance in this case would permit acceptable performance in other services.

Antennas proposed for DOMSAT earth stations are parabolic dishes ranging in size from 32 ft to 100 ft in diameter. It is assumed that the on-axis gain (G) of these antennas is given by:

$$G = 20 \log \frac{\pi D}{\lambda} - 3 \text{ dB}$$

where D is the diameter and λ is the wavelength - both in the same units. The -3 in the expression accounts for the assumed 50% efficiency. It is assumed further that the gain of the antenna at an off-angle Θ degrees from the mainbeam is given by the expression 32 - 25 log (Θ) dBi for $1 \leq \Theta \leq 48$ and, for $\Theta > 48$, it is a constant -10 dBi. Thus the protection ratio (PR) offered by the spatial directivity of the antennas is:

$$PR = 20 \log \frac{\pi D}{\lambda} - 35 + 25 \log (\Theta) \text{ dB}$$

for $1° \leq \Theta \leq 48$. For receiving, this expression is simply the strength of the desired signal relative to the strength of the undesired signal coming from an off-angle Θ from the main beam. For transmitting, this expression gives the signal strength transmitted in the desired direction relative to the signal strength in the undesired direction Θ. This equation is plotted for 4/ 6 GHz and popular antenna sizes in figure 2, which is taken from a recent COMSAT report. The gain and sidelobe suppression indicated are consistent with CCIR Recommendations and the specifications in the applications.

Sixth, it is assumed that if the desired and undesired signals are cross polarized with respect to each other, then there is an additional 10 dB of discrimination when the undesired signal lies outside the main beam. This assumption is also consistent with

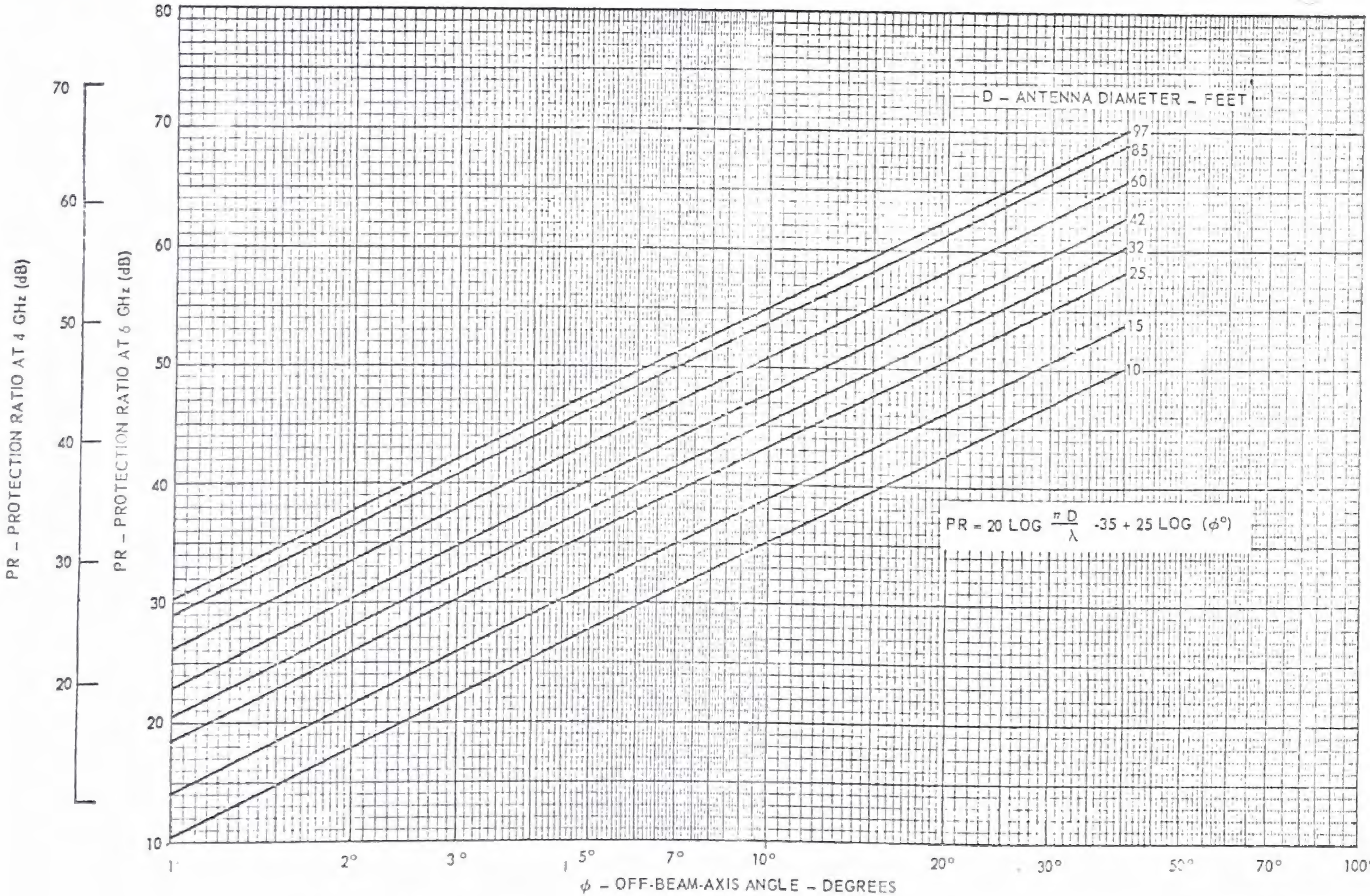


Figure 2. Protection ratio vs. off-beam-axis angle assuming 50% antenna efficiency and [32 - 25 log (θ)] sidelobes (from COMSAT Report DS-1-68).

CCIR Recommendations and is generally supported by the applications.

Seventh, it is assumed that the total baseband noise produced by multiple interfering signals can be calculated by simply summing their individual contributions.

Eighth, it is assumed that the basic transmission loss (BTL) from a satellite in geostationary orbit to an earth station is independent of the earth station location over the area of concern in this analysis. Because of the great distance of the geostationary arc compared with the diameter of the earth, this is a good assumption.

The test tone signal-to-weighted noise power ratio (SNR) in the worst-case (top) telephone channel is related to the carrier-to-interference ratio (CIR) at the input of the receiver by an expression

$$SNR = CIR + B \quad \text{dBm0p}$$

where B is the "Interference Reduction Factor". As defined here, B includes noise weighting and top channel pre-emphasis advantage. It depends upon the modulation characteristics of the wanted and unwanted signals and the separation of their carrier frequencies (offset). For the parameters of the FDM/ FM system assumed in this analysis, B is computed to be approximately 25 dB when the carrier frequencies are the same. If the interfering signal is offset 20 MHz (half the channel width), then B is approximately 42 dB. In such a situation, the desired channel may receive noise from both the 20 MHz higher and the 20 MHz lower interfering channel, and hence this must be reduced 3 dB to 39 dB. These figures were computed independently in accordance with a COMSAT report. With no offset, the 25 dB figure is consistent with that assumed by the applicants, i.e., AT&T, 24.7; RCA, 26.8; and GT&E, 24. The slight differences in systems (1200, 1000, and 1320 voice channel/ transponder, respectively), account for the variation. The additional isolation produced by offsetting (interleaving) the channels is open to more question. Many applicants do not address this issue since they do not propose interleaving. The 42 dB figure is, however, consistent with that given in the COMSAT Comments and is 2.2 dB less than the figure used by AT&T. The noise (N_i) in pW0p in the top baseband channel is related to the SNR by the expression $SNR = 10 \log \frac{10^9}{N_i}$.

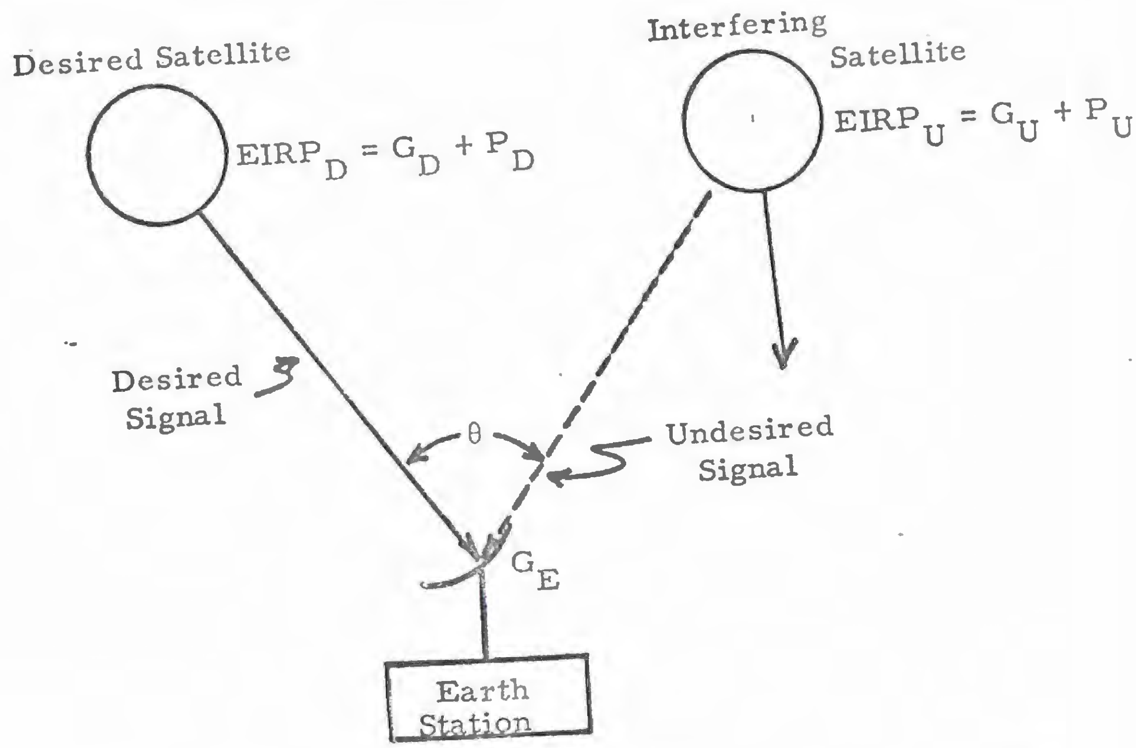
Tenth, the orbit spacings used in the analysis are the nominal values. The applicants propose stationkeeping accuracies of $\pm 0.1°$ which means under worst-case conditions the satellites could be .2° closer. These conditions were not included in this analysis because (1) the probability of both satellites being at their extremes at the same time is small, (2) at the close spacings (2.5°) the increase in interference would be 1 dB or less, and (3) an increase in interference by movement to one side is often offset by a decrease in interference from the other side.

Eleventh, only a single applicant will be permitted to serve Alaska. Hence only that applicant's satellites must be located west of 114°W longitude. For the purposes of this analysis, this applicant is assumed to be RCA.

5.4.2 Interference Relationships

The equations for computing the downlink interference for a single interfering satellite and for uplink interference for a single interfering earth station are developed in figures 3 and 4, respectively. From the carrier-to-interference ratio, the noise in the worst-case telephone channel can be computed as described in the previous section. This is done for each interference source and the total uplink or downlink noise is just the sum of such contributions using assumption seven. The total noise is just the sum of the uplink and downlink noise.

Figure 3. Downlink Interference



$$\begin{aligned} CNR &= G_E + G_D + P_D - (G_U + P_U) - [32 - 25 \log_{10}(\theta)] + P \quad \text{dB} \\ &= G_E - [32 - 25 \log_{10}(\theta)] + (G_D + P_D) - (G_U + P_U) + P \quad \text{dB} \\ &= G_E - [32 - 25 \log_{10}(\theta)] + [EIRP_D - EIRP_U] + P \quad \text{dB} \end{aligned}$$

Antenna Suppression (Figure 3) — Relative EIRP Adjustment — Polarization Isolation

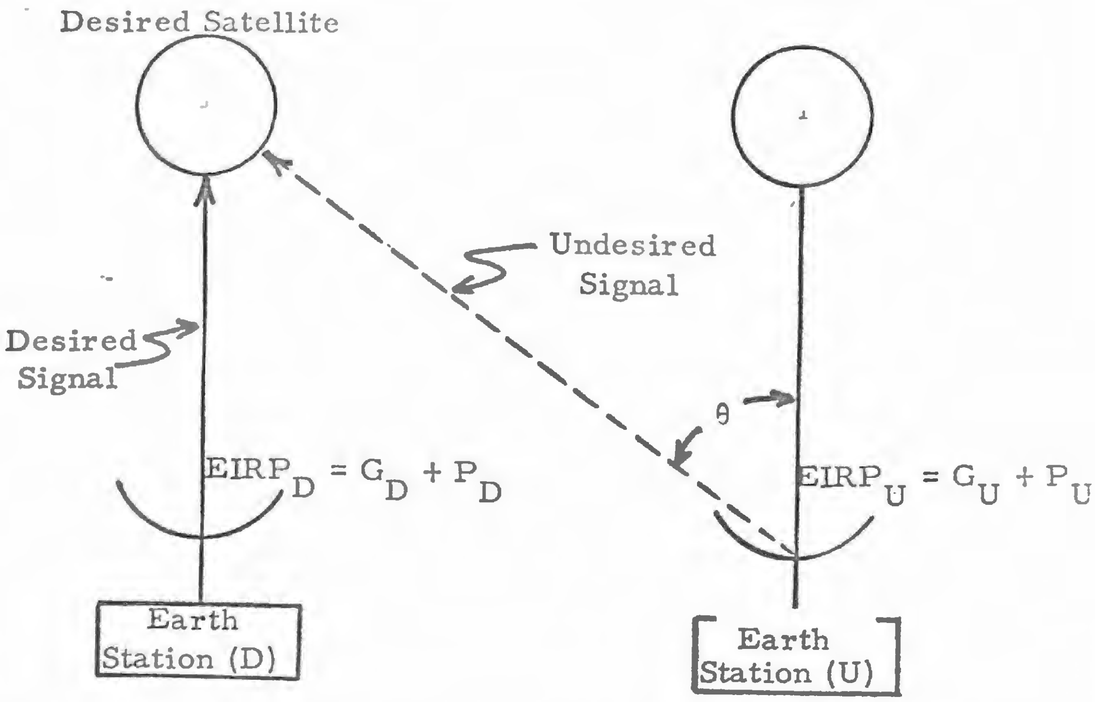
where

- CNR = Carrier-to-noise (interference) ratio
- G_E = Earth station antenna gain (on-axis) - dBi
- G_D = Antenna gain of desired satellite - dBi
- P_D = Desired satellite transmitter power output - dBW
- G_U = Antenna gain of undesired (interfering) satellite - dBi
- P_U = Undesired satellite transmitter power output - dBW
- θ = Orbit spacing angle (degrees)
- $[32 - 25 \log_{10}(\theta)]$ = Earth station antenna gain at off-axis angle θ - dBi
- P = Polarization Isolation - dB

Assume no satellite antenna directivity, i.e., undesired signal =

$$EIRP_U = G_U + P_U$$

Figure 4. Uplink Interference



$$CNR = G_D + P_D - [P_U + 32 - 25 \log_{10} (\theta)] + P \quad \text{but} \quad P_U = EIRP_U = G_U$$

$$= EIRP_D - [EIRP_U - G_U + 32 - 25 \log_{10} (\theta)] + P \qquad dB$$

$$= (EIRP_D - EIRP_U) + G_U - [32 - 25 \log_{10} (\theta)] + P \qquad dB$$

Relative EIRP Adjustment	Antenna Suppression (Interfering Station)	Polarization Isolation

where

CNR = Carrier-to-noise ratio - dB

G_D = Desired earth station antenna gain - dBi

P_D = Desired earth station transmitter power output - dBW

P_U = Undesired (interfering) earth station transmitter power output - dBW

θ = Orbit spacing angle (degrees)

$[32 - 25 \log_{10} (\theta)]$ = Earth station antenna gain at off-axis angle θ - dBi

P = Polarization isolation - dB

Assume no satellite antenna directivity to discriminate between Desired and Interfering earth stations

In the following four sections, the noise in pW0p is computed for a uniformly spaced distribution of 13 satellites with 12 transponders operating at 4/ 6 GHz and for 10 satellites with 24 transponders. This corresponds to the mix represented in the application with the three Canadian satellites included in the 12 transponder systems. The 12 transponder satellites are labelled as C12A through C12M and the 24 transponder satellites are labelled C24A through C24J.

5.4.3 Minimum Spacing Versus Antenna Size

One of the most important parameters in determining minimum spacing is the earth station antenna sizes. The following table summarizes the spacing required for 12 and 24 transponder systems assuming equal satellite and earth station EIRPs, alternating polarization and offset carriers for adjacent 12 transponder satellites, and the total noise objective of 1, 000 pW0p.

	Minimum Spacing (Degrees)			
	Antenna Size (ft)			
	98	60	45	32
24-transponder	3.6	5.2	6.6	8.8
12-transponder	1.8	2.6	3.3	4.4

The details of the 98 ft antenna, 12-transponder system calculation are given in table 3 as an example of how these minimums were established. Using the figures in the table above, the 13 12-transponder satellites would require 23.4° and the 10 24-transponder satellites would require 36° of orbit for a total of 59.4°. For 60 ft antennas the total would be 85.8°. Thus if all proposed systems were homogeneous (except for 12/ 24 transponder difference) and if they

Table 3a. Interference power for 12-transponder systems with uniform parameters and 98 ft earth station antennas

Satellite	Spacing (Degrees)	Downlink	Uplink	Total
C12A	0.0	344	153	497
C12B	1.8	347	154	501
C12C	1.8	607	270	877
C12D	1.8	603	268	871
C12E	1.8	649	288	937
C12F	1.8	641	285	926
C12G	1.8	657	292	949
C12H	1.8	641	285	926
C12I	1.8	649	288	937
C12J	1.8	603	268	871
C12K	1.8	607	270	877
C12L	1.8	347	154	501
C12M	1.8	344	153	497

Table 3b. Details of interference calculations of satellite C12G

DATA

[illegible]

RESULTS

[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible].7	[illegible]	55.[illegible]	.[illegible]	.[illegible]
2	[illegible]	[illegible].1	67.[illegible]	[illegible]	.[illegible]	.[illegible]
3	[illegible]	[illegible]	66.[illegible]	[illegible]	.[illegible]	.[illegible]
4	[illegible]	[illegible].9	[illegible]	51.[illegible]	.[illegible]	.[illegible]
5	[illegible]	13.[illegible]	62.6	[illegible]	.[illegible]	.[illegible]
6	[illegible]	15.[illegible]	[illegible]	47.1	.[illegible]	.[illegible]
7	[illegible]	15.1	57.5	[illegible]	.[illegible]	.[illegible]
8	[illegible]	[illegible].5	[illegible].7	[illegible].5	.[illegible]	.[illegible]
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible].5	[illegible]	[illegible].5	.[illegible]	.[illegible]

[illegible]

all used the same size earth station antennas, then the minimum antenna size would be about 60 ft. The antennas actually proposed include all four of the nominal sizes shown in the table. Since some are larger, equal, and smaller than 60 ft, then the question remains as to what mix of antenna sizes can be accommodated.

In the 24 transponder systems, COMSAT, Fairchild, and AT&T each propose TR sites with 98/100 ft antennas except in Alaska where COMSAT proposes 32 ft antennas. Assuming RCA is given this coverage, then only 98/100 ft antennas would be involved. MCI, with the only remaining 24-transponder system, proposes 32 ft antennas for use with its two satellites. Using the spacings from the table, the 8 COMSAT, Fairchild, and AT&T satellites would require 28.8° of orbit, and the 2 MCI would require 17° for a total of 45.8°. The interference calculations for this distribution are given in table 4.

For the 12-transponder systems, the earth station antenna mix is as follows:

Ant. Size (ft)	No. of Systems
98	2
60	2
45	3
32	6

Again using the spacings given previously, this mix would require a total of 46° of orbit space as shown in table 5. The total orbit for both the 12 and 24 transponder systems would be 91.8° - exceeding the 85° available. However all of the systems are not 1200 channel/transponder systems and these could be spaced closer as examined in

Table 4a. Interference power for 24-transponder systems with antenna mix as proposed

Satellite	Spacing (Degrees)	Antenna Diam. (ft)	Interference Downlink	Uplink	Total
C24A	3.6	98	342	157	499
C24B	3.6	98	600	274	874
C24C	3.6	98	643	296	939
C24D	3.6	98	657	306	963
C24E	3.6	98	658	313	971
C24F	3.6	98	650	321	971
C24G	3.6	98	614	332	946
C24H	3.6	98	376	300	676
C24I	8.5	32	846	153	999
C24J	8.5	32	432	133	565

Table 4b. Details of interference calculation for satellite C24I

DATA

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	1
2	[illegible]	1.	1.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	1.	[illegible]	[illegible]	[illegible]	[illegible]	1	1
4	[illegible]	1.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	1.[illegible]	7.[illegible]	[illegible]	[illegible]	[illegible]	1	1
6	[illegible]	1.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	1.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	1
8	[illegible]	1.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	1.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]
10	[illegible]	1.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	[illegible]
11	[illegible]	1.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	1
12	[illegible]	1.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	[illegible]	1.	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]

RESULTS

TOTAL [illegible] INTERFERENCE IS 657.[illegible]
TOTAL [illegible] INTERFERENCE IS [illegible]
TOTAL INTERFERENCE IS 9[illegible].5[illegible]

INDEX	[illegible]	ELEV.	[illegible]	[illegible]	SATELLITE	[illegible]	[illegible]
1	[illegible]	10.[illegible]	56.[illegible]	52.9	.0	.0	[illegible]
2	[illegible]	9.[illegible]	52.3	56.[illegible]	.0	.0	[illegible]
3	[illegible]	7.[illegible]	51.9	[illegible]	.0	.0	[illegible]
4	[illegible]	5.4	48.3	45.3	.0	.0	[illegible]
5	[illegible]	3.6	44.4	40.9	.0	.0	[illegible]
6	[illegible]	1.8	37.8	33.3	.0	.0	[illegible]
7	[illegible]	*****	*****	*****	*****	*****	[illegible]
8	[illegible]	1.[illegible]	36.[illegible]	33.3	.0	.0	[illegible]
9	[illegible]	3.6	44.4	40.9	.0	.0	[illegible]
10	[illegible]	5.4	48.[illegible]	45.3	.0	.0	[illegible]
11	[illegible]	7.[illegible]	51.9	[illegible]	.0	.0	[illegible]
12	[illegible]	9.[illegible]	52.3	56.9	.0	.0	[illegible]
13	[illegible]	10.[illegible]	56.[illegible]	52.[illegible]	.0	.0	[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	.0	.[illegible]	81.[illegible]	77.	[illegible]	[illegible]
2	[illegible]	10.	14.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	10.[illegible]	14.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	.[illegible]	[illegible]	69.[illegible]	[illegible]	11[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	10.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	.0	.0	69.[illegible]	65.9	11[illegible]	[illegible]
10	[illegible]	10.0	14.0	97.[illegible]	94.3	[illegible]	[illegible]
11	[illegible]	.0	.0	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	10.[illegible]	14.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	[illegible]	.[illegible]	.0	[illegible]	[illegible]	[illegible]	[illegible]

Table 5a. Interference power for 12-transponder systems with antenna mix as proposed

Satellite	Spacing (Degrees)	Antenna Diam. (ft)	Interference Downlink	Interference Uplink	Interference Total
C12A	0.0	32	371	155	526
C12B	4.3	32	376	156	532
C12C	4.3	32	657	269	926
C12D	4.3	32	661	268	929
C12E	4.3	32	729	232	961
C12F	4.3	32	830	245	1075
C12G	4.3	45	535	295	830
C12H	3.3	45	576	281	857
C12I	3.3	45	781	267	1048
C12J	3.3	60	472	223	695
C12K	2.6	60	679	279	958
C12L	2.6	98	131	183	314
C12M	1.8	98	191	255	446

Table 5b. Details of interference calculations for satellite C12F

DATA

[illegible]	[illegible]	[illegible]	[illegible]	[illegible] C12F	[illegible]	[illegible]	[illegible]	[illegible]
1	C12[illegible]	.0	.0	5[illegible].0	[illegible].0	4.0	1	1
[illegible]	[illegible]	[illegible]	4.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	C12[illegible]	4.3	[illegible].0	[illegible]	[illegible].0	[illegible]4.0	1	1
4	C12[illegible]	4.3	1[illegible]	[illegible].0	[illegible].0	[illegible]4.0	[illegible]	[illegible]
5	C12[illegible]	4.3	17.0	[illegible].0	[illegible].0	[illegible]4.0	1	1
6	C12[illegible]	4.3	[illegible]1.[illegible]	[illegible].0	[illegible].0	[illegible]4.0	[illegible]	[illegible]
7	C12[illegible]	4.3	[illegible]	4[illegible]	[illegible].0	[illegible]4.0	1	1
[illegible]	C12[illegible]	[illegible]	[illegible].1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	C12[illegible]	[illegible].0	[illegible].4	4[illegible].0	[illegible].0	[illegible]4.0	1	1
10	C12[illegible]	[illegible].3	[illegible].7	60.0	[illegible].0	[illegible]4.0	[illegible]	[illegible]
11	C12[illegible]	[illegible].6	[illegible].3	60.0	[illegible].0	[illegible]4.0	1	1
12	C12[illegible]	[illegible]	40.[illegible]	9[illegible].0	[illegible].0	[illegible]4.0	[illegible]	[illegible]
13	C12[illegible]	1.[illegible]	4[illegible].7	[illegible]	[illegible].0	[illegible]	1	1

RESULTS

TOTAL [illegible] IS [illegible]0.1[illegible]
TOTAL [illegible] IS [illegible]4[illegible].[illegible]
TOTAL [illegible] IS 1[illegible].4[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] SATELLITE	[illegible]	[illegible]
1	C12[illegible]	[illegible]1.5	54.1	56.5	.0	.0	[illegible]
2	C12[illegible]	17.[illegible]	51.6	48.1	.0	.0	[illegible]
3	C12[illegible]	12.9	48.5	45.0	.0	.0	[illegible]
4	C12[illegible]	8.6	44.1	40.6	.0	.0	[illegible]
5	C12[illegible]	4.3	36.0	35.1	.0	.0	[illegible]
6	C12[illegible]	*****	*****	*****	*****	*****	[illegible]
7	C12[illegible]	4.3	39.5	3[illegible].1	.0	.0	[illegible]
8	C12[illegible]	7.6	45.7	[illegible].0	.0	.0	[illegible]
9	C12[illegible]	10.[illegible]	49.4	4[illegible].0	.0	.0	[illegible]
10	C12[illegible]	14.[illegible]	55.[illegible]	46.0	.0	.0	[illegible]
11	C12[illegible]	16.[illegible]	[illegible]	47.[illegible]	.0	.0	[illegible]
12	C12[illegible]	19.4	6[illegible].7	49.4	.0	.0	[illegible]
13	C12[illegible]	[illegible]1.[illegible]	6[illegible].6	56.4	.0	.0	[illegible]

[illegible]	SATELLITE [illegible]	[illegible] SUPPRESSION	[illegible] SUPPRESSION	NET SUPPRESSION [illegible]	[illegible]	[illegible]	[illegible]
1	C12[illegible]	10.0	14.0	10[illegible].1	[illegible]	.[illegible]	[illegible]
2	C12[illegible]	.0	.0	74.[illegible]	[illegible].1	[illegible]1.[illegible]	[illegible]
[illegible]	C12[illegible]	1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	C12[illegible]	.0	.0	[illegible].1	[illegible].6	1[illegible]	[illegible]
5	C12[illegible]	10.0	14.0	[illegible]	[illegible].1	[illegible]	[illegible]
6	C12[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	C12[illegible]	10.[illegible]	14.[illegible]	[illegible]	[illegible].1	1.[illegible]	[illegible]
[illegible]	C12[illegible]	.0	.0	[illegible]	[illegible]	4.[illegible]	[illegible]
9	C12[illegible]	10.0	14.0	[illegible].6	9[illegible].[illegible]	.1	[illegible]
10	C12[illegible]	.0	.0	[illegible].0	71.0	10.0	[illegible]
11	C12[illegible]	10.0	14.0	10[illegible]	[illegible]	.0	[illegible]
12	C12[illegible]	.0	.0	[illegible].7	[illegible].4	1.[illegible]	[illegible]
13	C12[illegible]	10.[illegible]	14.[illegible]	[illegible]	[illegible].4	.[illegible]	[illegible]

section 5.4.5. If a 45 ft diameter minimum was imposed so that 45 ft antennas were substituted for all 32 ft antennas, the 23 satellites would fit.

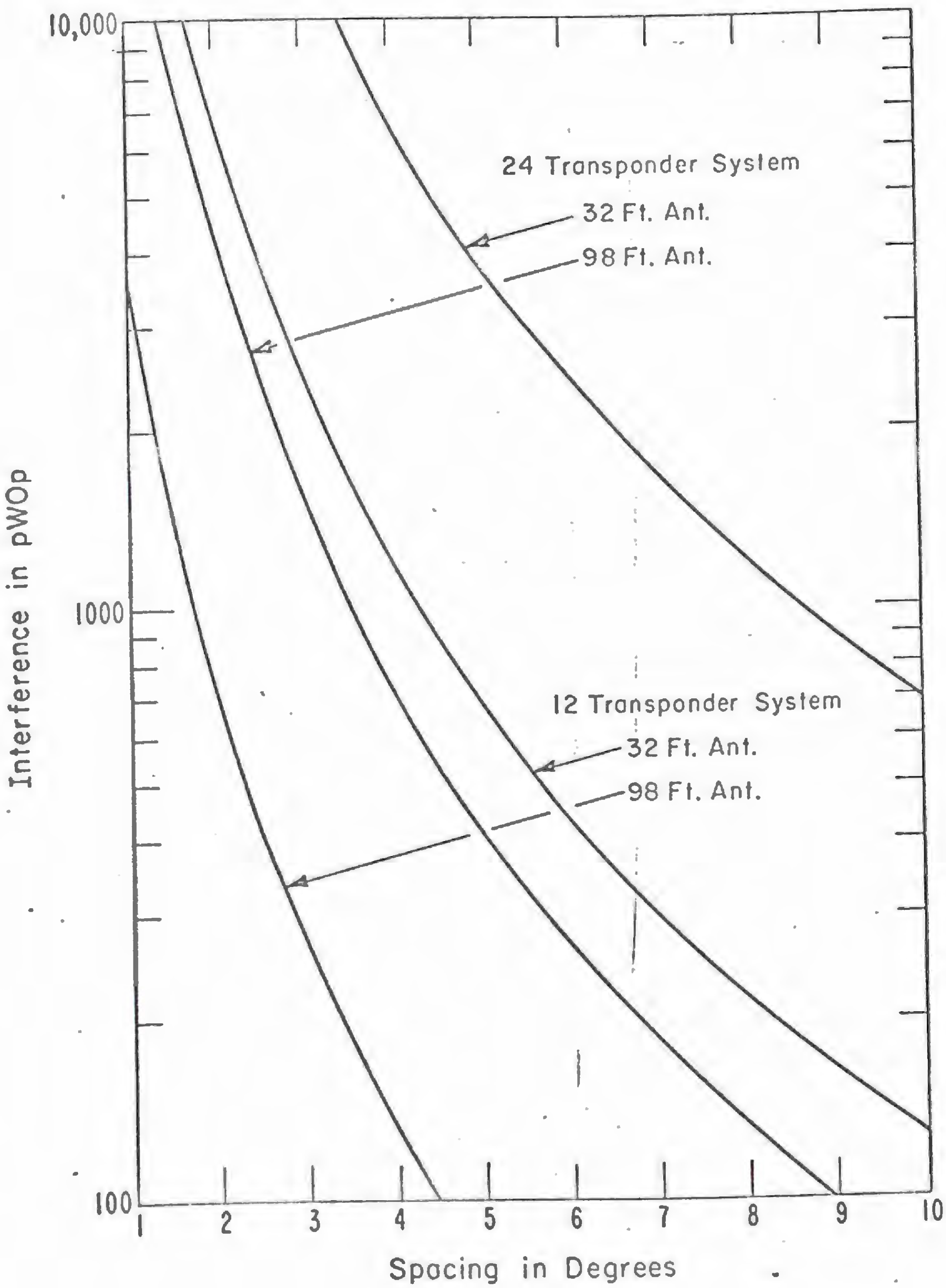
To recapitulate, if the 12 and 24 transponder systems were otherwise homogeneous 1200 voice-channel per transponder systems, (1) all 23 satellites could be accommodated with all earth stations using 60 ft antennas or (2) all 23 could be accommodated if a 45 ft minimum were established and larger antennas remained as proposed.

5.4.4 Spacing vs. Allowable Noise from Interference

The 1,000 pW0p noise limit for uplink and downlink interference is arbitrary as pointed out in section 5.4.1. This 1,000 pW0p is only a portion of an overall, end-to-end objective of 10,000 pW0p for telephone channels. This 10,000 pW0p is also a CCIR recommended value and it must include thermal noise, intermodulation noise, and noise on the terrestrial end links, for example. The thermal noise is the other major source of interference that is a function of earth station/satellite link parameters. Thus within the 10,000 pW0p overall objective, there is a basic tradeoff between thermal noise and interference noise. The most effective use of the orbit occurs when all noise is budgeted to interference, or stated another way, the systems are interference limited. With the total noise constrained any increase in interference noise must be offset by a decrease in thermal noise, other factors remaining constant. The thermal noise is directly related to cost since decreases are made by lowering receive noise temperatures, increasing transmitter power, or employing larger antennas.

The variation of interference noise as a function of spacing for the 1,200 voice channel, baseline system is shown in figure 5 .

Figure 5. Interference Noise in Top Telephone Channel vs. Satellite Spacing



It includes curves for both the 12-transponder and 24-transponder systems for 32 and 98 ft earth station antennas.

5.4.5 Spacing vs. Capacity per Transponder

The "Interference Reduction Factor", which relates the input carrier-to-noise (interference) ratio to the signal-to-noise ratio in the worst case telephone channel in an FDM/FM system, is a function of the modulation index of the desired signal. The modulation index is limited by the highest baseband frequency, which is a function of the number of voice channels, and the maximum allowable RF bandwidth. With the 40 MHz wide channels, most applicants use a bandwidth of 34-36 MHz. For a constant bandwidth, increasing the number of voice channels (and hence the maximum baseband frequency) must be compensated for by a decrease in modulation index and coversely. The smaller the modulation index, the more susceptible the signal is to interference or, put another way, the smaller the Interference Reduction Factor (IRF). If the interfering signal is also an FDM/FM signal with the same characteristics the IRF can be computed from the following equation:

$$IRF = 18.8 + 10 \log \left[1 + 9.5 \times \frac{1}{10} \left(\frac{BW}{.0084 \times N} - 1 \right)^{3} \right] \text{ dB}$$

where BW is the bandwidth and N is the number of voice channels ($N \geq 240$). This relation is derived in Appendix A from the equations given in the paper by Jansky and Jerechum (1970). For a bandwidth of 34 MHz the IRF as a function of the number of voice channels is plotted in figure 6 using the foregoing relationship.

The applicants propose capacities ranging from 800 voice channels/transponder (MCI) to 1320 voice channels/transponder

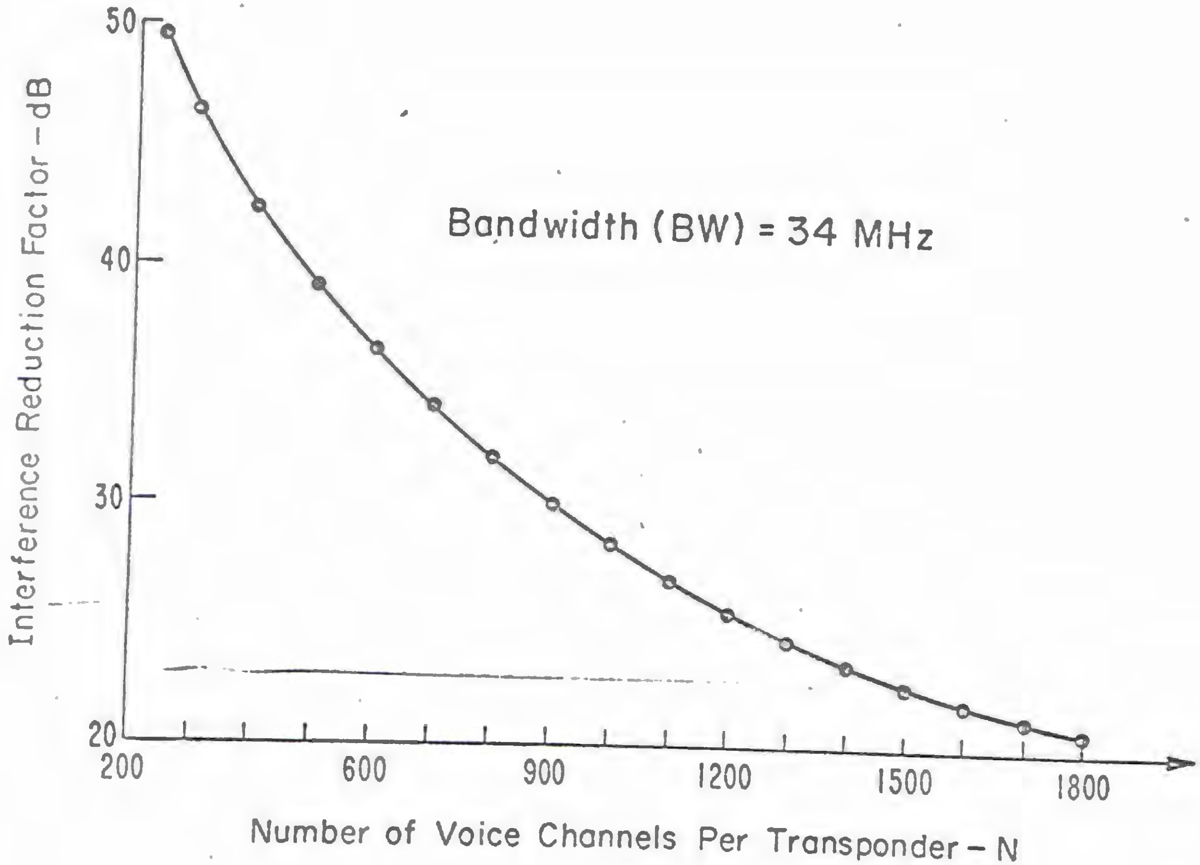


Figure 6. Interference Reduction Factor vs. Number of Voice Channels per Transponder

(Hughes-GTE). Figure 6 shows that the IRF would vary from 32 dB to 24.5 dB. Between 1200 and 800 the variation is about 6 dB. This means that the noise powers computed with the 25 dB IRF for the 1200 channel/transponder would be reduced by a factor of 4 for an 800 channel system. This is equivalent to doubling the earth station antenna diameters, allowing the interference noise budget to increase to 4000 pW0p, or changing the spacing from 3.6° to 2.5° for the 24 transponder systems using 98 ft antennas.

5.4.6 Spacing and EIRP Differences

The difference between the EIRP of the desired and undesired satellite appears in the relationship for downlink interference shown in section 5.4.2. Similarly, the difference between the EIRP of the desired and undesired earth station appears in the uplink case. If these differences are not zero (i.e., if the systems are not homogeneous in this respect), the required spacing is increased. This can be seen by the following example. Suppose two homogeneous systems were using adjacent orbital positions at a spacing such that the total noise in the worst-case telephone channel of each system was 1,000 pW0p and suppose 333 pW0p of this was in the uplink. Now consider the situation where one system increases its earth station power by a factor of 10 (10 dB) so that its EIRP is also increased by a like amount. Its uplink carrier-to-interference ratio would be increased 10 dB so that its uplink noise would be decreased to only 33 pW0p. But the carrier-to-interference ratio on the uplink of the other system would decrease 10 dB resulting in an uplink noise of 3,330 pW0p - or a total of 4,000 pW0p which is 6 dB over the 1,000 pW0p objective. Thus for <u>both</u> systems to meet the objective, the orbit spacing must be increased. A similar argument can be made for the downlink case.

As noted in section 3, the satellite EIRPs are fairly uniform at about 36 dBw in the main beam because of the maximum power flux density limits imposed by international regulations. The earth station EIRPs, on the other hand, vary widely. AT&T proposes an EIRP of 93 dBw using 100 ft antennas while Fairchild proposes an EIRP of 73 dBw with the same size antenna - a 20 dB difference. Fairchild incorporates higher gain, spot beam antennas on their satellite which decreases significantly the earth station EIRP requirements. Since AT&T and Fairchild both propose earth stations in some common metropolitan areas (e.g., New York City), the additional satellite antenna directivity will not aid in reducing this 20 dB greater interference. The remainder of the applicants propose more similar technology but the variation in earth station EIRPs is still 10 dB.

The increase in spacing due to this variation can be minimized by grouping like systems in the same part of the orbit.

5.4.7 General Analysis Summary

To summarize section 5, it has been shown that (a) the average spacing required to accommodate all 23 of the U.S. and Canadian satellites is not inconsistent with the spacings analyzed and proposed in the applications, and (b) a mix of thirteen 12-transponder and ten 24-transponder satellites, with parameters representative of the systems proposed, can be accommodated in the available orbit, albeit certain adjustments may be necessary in minimum earth station antenna sizes, noise budgets, channel capacity per transponder, or earth station mainbeam EIRPs.

6. ORBIT CAPACITY RELATIVE TO INDICATED DEMAND

With 24-transponder systems, a 1000 pW0p noise objective, 1200 voice channels per transponder, 98 ft earth station antennas, and homogeneous parameters, 23 satellites could be accommodated in the 85° of available arc. Thus using just 4/6 GHz, 552 transponders (23x24) could be placed. Including a like number of transponders at 12/13 GHz would double this, making a total of 1104, 40 MHz transponders.

The analysis in a report by Stanford Research Institute (Allan, et al., 1971) indicates that the expected demand for transponders by the mid-1970s is about 100. Using the 4/3 ratio of active to in-orbit spare satellites represented by the applications, the total U.S. requirement is 175 transponders. Adding Canada's requirement for 36 transponders gives a total of 211 transponders which is only 40% of the number that could be accommodated using just 4/6 GHz and only 20% of those that could be accommodated if the higher bands were included. Furthermore, since 3/7 of these are in-orbit spares, the demand for active or primary transponders requires only 17% and 18%, respectively. Even if the useful arc is considered to be just 70° to insure that elevation angles are greater than 10° in the contiguous U.S., these figures would only change to 20% and 10%, respectively.

Since the ultimate capacity so vastly exceeds the indicated demand, the scarcity of the orbit/spectrum resource is not a compelling consideration at this time. In fact, there is sufficient capacity that systems with varying designs to suit specialized applications can be accepted and later entrants could be accommodated.

7. CAPACITY PROPOSED AND OTHER FACTORS AFFECTING ORBIT REQUIREMENTS

The total initial capacity proposed by the applicants is 588 transponders (336 active and 252 spare) using figures from the SRI report. Adding the Canadian transponders produces a total of 624; but 96 of these use higher bands, leaving a total of 528 which must be accommodated at 4/ 6 GHz. This is within the capacity indicated in section 6, from which it can be concluded that all 624 proposed transponders could be immediately accommodated in the unlikely event that all systems are built.

Any residual concern about the practicality of accommodating all applicants is at least partially alleviated by the following:

1. It will probably prove most economical for successful applicants to share orbiting spares and/ or to enter into agreements calling for other applicants to handle the service of a system experiencing a major failure - thereby decreasing the number of secondary/ spare satellites in orbit. This would seem especially true in view of the proposed supply and indicated demand.
2. Only 11 of the proposed satellites are designated as "primary" and less interference protection could be given to "secondary" satellites.
3. There is some flexibility of moving the satellites in orbit to reduce interference on a case-by-case basis.
4. The possibilities of using other bands has not been fully exploited.
5. The Canadian satellites have satellite antennas covering a different geographic area, and this should diminish the sharing problem with them. This was not included in either the foregoing or subsequent analysis.

6. There may be certain operational procedures and detailed engineering design improvements (e.g., better antenna sidelobe suppression) that can be pursued.

8. ANALYSIS OF A SPECIFIC ORBITAL ARRANGEMENT

In this section, specific orbital locations for the satellites of each applicant are assigned, and 4/6 GHz interference levels are computed for the nominal 1200-voice channel per transponder, FDM/FM system described previously. This particular orbital arrangement uses the assumption that only a single applicant (RCA) would be required to serve Alaska. This arrangement should not be construed as an optimal, recommended, or necessarily equitable allocation. It is advanced solely to indicate the nature of the problems to be addressed in negotiating the technical arrangements for accommodating all applicants.

8.1 Orbit Locations

The specific orbit locations proposed for this analysis are illustrated in figure 7. The assignments were made in a largely arbitrary fashion with the following exceptions:

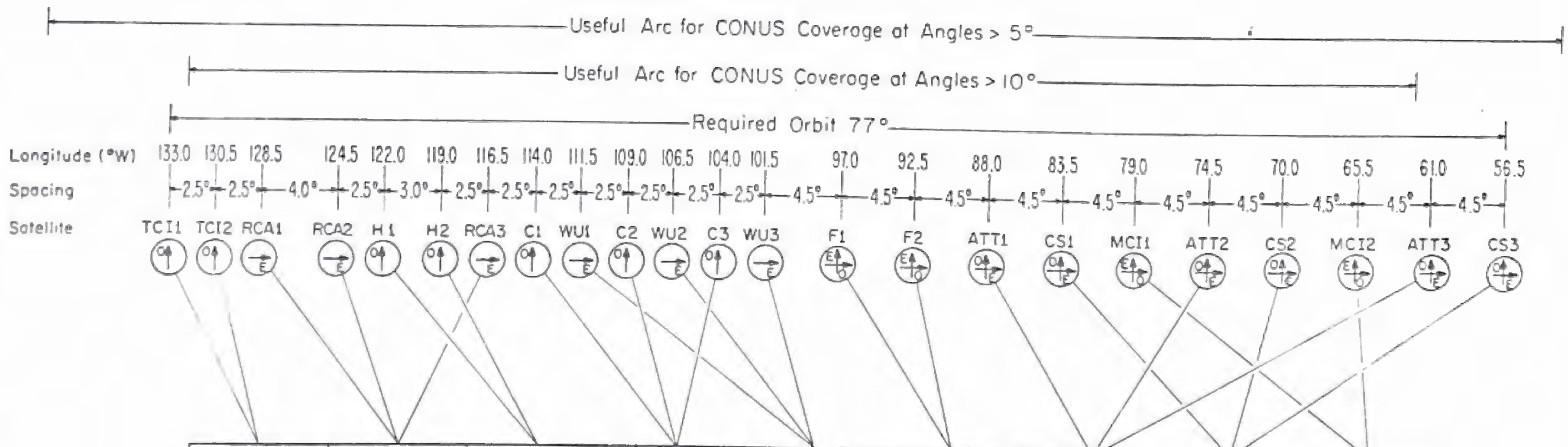
(a) the 12-channel and 24-channel systems were separated

(b) RCA was given locations consistent with the assumption that they would be awarded the Alaskan service

(c) the Canadian Telesat orbit locations were determined from their published descriptions

(d) systems employing bands higher than 4/6 GHz were placed nearer the center where possible.

Fig. 7 ORBIT ARRANGEMENT AND EARTH STATION PARAMETERS



Western Tele-Communications (TCI)	RCA	Hughes (H)	Canada (C) -Reference Only-	Western Union (WU)	Fairchild (F)	AT + T (ATT)	COMSAT (CS)	MCI
R/T Ant EIRP	R/T Ant EIRP	R/T Ant EIRP	R/T Ant EIRP	R/T Ant EIRP	R/T Ant EIRP	R/T Ant EIRP	R/T Ant EIRP	R/T Ant EIRP
60' 88 dBw	98' 83 dBw	98' 83 dBw	98' 83 dBw	45' 83 dBw	100' 73 dBw	100' 93 dBw	98' 90 dBw	32' 85 dBw
45' 87 dBw	60' 84 dBw	100' 92 dBw	32' 83 dBw				32' 81 dBw	
	35' 88 dBw		26' 81 dBw					
RO Ant G/T	RO Ant G/T	RO Ant G/T	RO Ant G/T	RO Ant G/T	RO Ant G/T	RO Ant G/T	RO Ant G/T	RO Ant G/T
-- --	-- --	35' --	-- --	32' --	-- --	-- --	42' --	-- --

Earth Station Characteristics

B-96362

The arrows inside the satellite representations show the assumed polarization of the satellite and the "O" and "E" refer to the "odd" and "even" carrier frequencies, respectively, where the even transponder carriers are offset 20 MHz from the odd ones. In some instances these are different than that proposed by the particular applicant, but such modifications are of a minor importance. Also shown on the figure are the earth station EIRPs and the antenna sizes for Receive/ Transmit (R/ T) and Receive Only (RO) sites.

8.2 Interference Calculations

The uplink, downlink, and total interference noise for each satellite is shown in table 6. The interference situation for each applicant is discussed in the following sections.

8.2.1 MCI

The two satellites of this applicant are located adjacent to one another at the western edge of the useful arc. WTCI proposes the use of dual beam dish antennas so that both satellites can be simultaneously covered by a single antenna. This necessitates that their two satellites lie within a few degrees of each other. The 60 ft diameter antenna with an EIRP of 84 dBw was used in the calculations. The increase in the Interference Reduction Factor (IRF) due to the use of alternating carrier frequencies on each satellite was also included.

The table shows that the interference is 152 pWpO on the downlink and 57 pWpO on the uplink, the eastern most satellite (WTCI2). The total of 209 pWpO is well within the 1000 pWpO limit.

WTCI also proposes Receive Only (RO) stations with antennas as small as 20 ft. This would decrease the antenna suppression by

Table 6. Interference (pWpO)

Satellite	4 GHz Downlink	6 GHz Uplink	Total
TCI1	93	41	134
TCI2	152	57	209
RCA1	617	1,004	1,621
RCA2	700	1,146	1,846
H1	512	462	974
H2	585	799	1,384
RCA3	553	1,245	1,798
WU1	1,374	503	1,874
WU2	1,447	584	2,031
WU3	1,638	395	2,033
F1	456	8,413	8,869
F2	414	9,586	10,000
ATT1	403	38	441
CS1	398	2,942	3,340
MCI1	3,697	596	4,293
ATT2	391	131	522
CS2	386	3,133	3,519
MCI2	3,526	578	4,104
ATT3	350	112	462
CS3	201	1,413	1,614

as much as 14 dB with a corresponding increase in noise power. It is assumed that the service requirements of these terminals is consistent with the degradation in performance.

8.2.2 RCA

Two of the satellites of this applicant are located adjacent to each other and east of the two WTCI satellites as shown in figure 7. The third satellite is located to the east of the two Hughes satellites. These locations are consistent with the assumption that RCA will serve Alaska. The spacing between the two adjacent RCA satellites (RCA_1 and RCA_2) is 4° as they requested. Even at 4° their analysis indicates total interference power greater than 1000 pWpO for 32 ft antennas, and they make little comment about this fact. For the purpose of this analysis, 60 ft antennas (which are also proposed by RCA) are assumed. In other sections evaluating interference caused by RCA earth stations, 32 ft antennas are substituted.

The uplink interference is 1, 146 pWp0 and the downlink interference is 700 pWpO, resulting in a total of approximately 1, 846 pWpO for RCA_2. This is approximately 2.5 dB greater than the 1000 pWpO limit referenced earlier. This interference is largely due to signals from RCA's own satellites. For example, the 4 GHz downlink interference for RCA_1 consists of about 500 pWpO of interference from RCA_2 and only about 200 pWpO from other systems. In RCA's own analysis they assume slightly greater antenna suppression and a 26.8 dB Interference Reduction Factor (for their 1000 voice channel per transponder system), which gives almost 50% lower interference. Since the allocation (spacing) is in accordance with RCA's application, since the interference is predominantly from

RCA's own system, and because their calculations were based on a more detailed analysis of their own system, this level of interference is probably not objectionable. Furthermore, RCA proposes 98 ft antennas at certain locations. At these earth stations the downlink interference would be reduced to 231, 263, and 207 pWpO for RCA_1, RCA_2, and RCA_3, respectively.

8.2.3 Hughes

Between RCA_2 and RCA_3 are the two satellites of Hughes. They are spaced at 3° in accordance with their application and they are cross-polarized and frequency interleaved with the RCA satellites. The Hughes interference analysis is in terms of signal-to-noise ratios for video transmission. The calculations for FDM/FM are contained in the GT&E applications for earth stations which will use the Hughes satellites. Those calculations and the calculations in this section are based on the 98 ft earth station antennas proposed for FDM/FM transmission. Hughes also proposes the use of smaller antennas for use at video RO sites.

The total interference predicted for H_2 is about 1384 pWpO. This is slightly in excess of the arbitrary limit. The downlink interference is primarily from the companion Hughes satellite (400 pWpO out of the total of 585 pWpO). Since the spacing between the two satellites is in accordance with their application, since the downlink interference is predominantly from their own satellite, and since the differences in geographic coverage of the Canadian and Hughes satellite will tend to diminish the interference from that source, this level of interference appears reasonable.

8.2.4 Western Union

The three satellites of this applicant have been alternated with the three Canadian satellites and are cross-polarized and frequency interleaved with them. WU proposes the use of 45 ft antennas for T/R Earth Stations and 32 ft antennas at RO terminals. The calculations in this section are based on the 45 ft antennas with a mainbeam EIRP of 83 dBw. The indicated interference is 1638 pWOp on the downlink and 395 pWOp on the uplink for the WU_3 satellite. About 1200 pWOp (3/4) of the downlink interferece is contributed by WU_2 and the western-most Fairchild satellite (F_1). The WU downlink interference is not totally unacceptable in that it is small enough to be compensated for in other parts of the system. The complicating factor appears to be that WU claims a 10 dB greater protection ratio for its 45 ft antenna than the value computed by the generally accepted engineering methods used in this analysis and by the other applicants. WU calculations are on page A-4 of their proposal. If they can, in fact, get 10 dB better performance, then the interference would be clearly acceptable. If, instead, this is an error on their part, their use of 45 ft antennas for 1200 voice channel FDM/FM service is suspect and an increase to 60 ft or even 98 ft antennas - as used by other applicants in this service - may be necessary.

8.2.5 Fairchild

In this proposed arrangement, the two satellites of this applicant are spaced 4.5° apart between the 12 transponder and 24 transponder groups. Earth Stations with 98 ft antennas and a mainbeam EIRP of 73 dBw are proposed and used in the interference analysis. No polarization isolation or interleaving advantage is assumed.

The downlink interference is calculated to be 456 pWpO. As noted in the general analysis, it is often assumed that if the downlink interference is acceptable then the uplink interference will also be acceptable because of the additional antenna directivity at 6 GHz. This is not the case in this situation because of the lack of homogenity in uplink parameters. In the present case, the uplink interference is totally unacceptable for Fairchild since it is over 10 dB above the criterion.

8.2.6 AT&T

The applications of AT&T, COMSAT, and MCI-Lockheed are for similar 24 transponder systems and they have been grouped together in the eastern part of the orbit. AT&T also proposes 98 ft antennas. The interference results are shown in the table.

The downlink interference power is 391 pWpO and the uplink interference power is 131 pWpO for a total of 522 pWpO for $AT\&T_2$. The uplink interference is low because of the relative EIRP being proposed for the earth stations (93 dBw) especially in relation to the stations of the adjacent Fairchild satellite (73 dBw).

8.2.7 COMSAT

The interference computations for COMSAT assume their use of 98 ft antennas with a mainbeam EIRP of 90 dBw. For the middle satellite (CS_2) the downlink interference is computed to be 386 pWOp and the uplink interference is computed to be 3133 pWOp for a total of 3519 pWOp. Again the uplink interference power is unacceptable because of the variation in earth station parameters and, in particular, because of use of small (32 ft) antennas by the earth stations of the nearby MCl satellites.

8.2.8 MCI

The downlink and uplink interference for a 32 ft antenna and an EIRP of 85 dBw are computed to be 3697 and 596 pWpO, respectively, for the western-most MCI satellite. Since MCI proposes to use the 32 ft antennas at all locations, this is the best performance that can be expected. The great majority of the downlink interference comes from the four closest satellites. However, it should be recalled that MCI proposes an 800 voice channel per transponder system as opposed to the 1200 channels assumed here. For a constant bandwidth of 34 MHz, the IRF increases approximately 6 dB when the number of channels is reduced from 1200 to 800. The corresponding decrease in interference power by one-fourth would put the total in an acceptable range.

8.3 Overall Downlink Performance

The overall 4 GHz downlink performance for this allocation appears to be adequate in all but two cases - Western Union and MCI. The Western Union case is clouded by their apparent assumption of better sidelobe suppression for their 45 ft antennas. An increase in antenna size to 60 ft would reduce the interference from 1650 to 528 pWOp, an acceptable level. The MCI spacing is adequate for the 800 voice channel per transponder system they propose. Hence it can be concluded that only minor negotiations would be required to arrive at a mutually acceptable orbit arrangement and set of system parameters for downlink interference.

8.4 Overall Uplink Performance

The 6 GHz uplink interference situation is different than that of the downlink in one important aspect. The downlink EIRP, as pointed out in the general analysis, is constrained by the maximum power flux density permitted by international agreement. Since the downlink is so constrained, the system engineer will attempt to use higher uplink EIRPs so that the maximum margin is available for the downlink. For example, suppose the uplink and downlink SNRs were both 56 dB. The overall SNR would then be 53 dB. If the unconstrained uplink EIRP was raised 10 dB, the uplink SNR would be 66 dB in which case the overall SNR would be only slightly less than 56 dB. If he does this by an increase in transmitter power, he will produce 10 dB greater interference to other users and get 10 dB greater margin over the interference they cause him. It is clearly to his own advantage to use a level of power detrimental to other users of the orbit/ spectrum resource. Furthermore, the higher powers may significantly complicate frequency sharing with terrestrial microwave systems. Specific examples of the wide-range of transmitter powers and EIRPs were given in earlier sections of this paper.

Because of this variation and the widely different transmitting antenna sizes, the uplink interference is not generally as acceptable. The tradeoffs involved in getting more acceptable performance are treated in the following paragraphs.

Since the uplink interference power shown in table 6 is unacceptable in several instances, the interference was recomputed assuming equal earth station EIRPs. This should not be interpreted as a requirement that all earth stations have equal EIRPs. Instead, a minimum transmitting antenna size and maximum transmitter power output would be specified. The equal EIRP case then would correspond to all users having minimum antennas and maximum power. An applicant deviating from this case could help himself (by going to larger antennas) or help others (by using less power) but in no case could he cause others to have poorer calculated performance than that computed by assuming the equal EIRPs corresponding to minimum antenna and maximum power.

The results of the computations with equal EIRPs are shown in table 7. The situation is generally improved from the standpoint that the variation in uplink interference is reduced and several cases that were categorically unacceptable are now more reasonable. For several satellites, however, the uplink performance is still poorer than the downlink performance due to their proximity to other satellites with the smaller earth station antennas. The uplinks of RCA, Hughes, and, in particular, Western Union suffer from the interference from the smaller Canadian stations (26/32 ft antennas), although RCA and Western Union contribute to it as well through the use of 32 and 45 ft antennas, respectively. COMSAT and AT&T receive considerable uplink interference from the MCI (32 ft) earth stations. Ironically, the MCI uplink performance is among the best because of the use of 98 ft antennas by COMSAT and AT&T.

While the total interference for many of the satellites still exceed the arbitrary 1000 pWpO standard, they are within the range that could probably be accommodated by the other relatively minor adjustments in systems parameters. The exceptions, MCI and, to a lesser degree, Western Union, were discussed in section 8.3 as well. The MCI interference would be acceptable if the IRF for 800 channels were used as discussed in that section. An increase in antenna size from 45 ft to 60 ft by Western Union would produce an acceptable level of interference for them and reduce interference to others as well.

In conclusion, negotiations to achieve mutually acceptable uplink performance would be more difficult than for the downlink, but

Table 7. Uplink Interference with Equal EIRPs

Satellite	Uplink Interference (pWpO)	Total (Using Downlink Valves from Table 1 - pWpO)
TCI1	64	157
TCI2	97	249
RCA1	916	1,533
RCA2	1,025	1,725
H1	569	1,081
H2	1,123	1,708
RCA3	528	1,081
WU1	874	2,248
WU2	658	2,105
WU3	450	2,088
F1	945	1,401
F2	443	857
ATT1	392	795
CS1	809	1,207
MCI1	251	3,948
ATT2	854	1,245
CS2	845	1,231
MCI2	220	3,746
ATT3	742	1,092
CS3	212	413

there is no reason to doubt they would be successful. They would involve steps to equalize EIRPs and increase minimum antenna sizes.

8.5 Television Distribution

All applicants propose some form of 525 line television distribution using FM modulation with one 40 MHz transponder per video signal. FM-TV distribution is less demanding than the FDM/FM message service assumed up to this point. It is so undemanding that AT&T, for example, does not even bother to show performance calculations for links with 98 ft antennas at each earth station. For television distribution to a large number of RO earth stations, which is typical of this service, minimizing the size of antennas becomes an important factor. Thus the principal concern in this analysis will be the performance afforded RO earth stations as a function of antenna size.

Each applicant proposes a peak-to-peak signal-to-RMS noise objective of about 56 dB. This translates into a carrier-to-noise requirement of about 16.5 dB. Most applicants do not address the carrier-to-interference power (C/I) requirements when the undesired signal is FDM/FM message or another FM-TV service. AT&T refers to tests which show that if the cochannel interference is another FM-TV signal, then it is satisfactorily low if it is 19.9 dB weaker than the desired signal. For offset channels, the corresponding figure is 11.9 dB. They go on to state that further tests showed that FDM/FM telephone signals were less interfering to TV signals than were other television signals.

For this analysis, the C/I for each downlink was computed and tabulated in table 8, assuming 32 ft antennas. The results are generally satisfactory. The worst-case C/I is 28 dB for the Hughes

Table 8. Downlink FM-Television Performance - 32 ft Antennas

Satellite		C/I (dB)
TCI1	---	42
TCI2	---	40
RCA1	.715	30
RCA2	.809	30
H1	1.546	28
H2	1.764	28
RCA3	.665	30
WU1	.909	30
WU2	.953	30
WU3	1.049	30
F1	1.353	30
F2	1.230	29
ATT1	1.196	29
CS1	1.180	29
MCI1	1.169	29
ATT2	1.158	29
CS2	1.143	29
MCI2	1.115	30
ATT3	1.038	30
CS3	.597	30

H_2 satellite. The interfering signal, in this case, would be 11.5 dB less than the noise (assuming the 16.5 dB ppSNR requirement was just being met) and some 8.1 dB better than the tests referred to by AT&T would require. This seems entirely adequate, even allowing for further uplink degradation. For certain applications, e.g., schoolhouse RO terminals, even smaller antennas would be possible because of this margin and less stringent requirements. In the study by NSL for the Corporation for Public Broadcasting, a 45 dB ppSNR objective is used for "School Service" as opposed to the 55 dB for "Network Service", indicating the relaxed requirement.

8.6 Canadian Telesat System

Up until this point, the proposed Canadian satellites have not been considered except as a source of uplink interference. The purpose of this section is to specifically analyze the interference coordination problem between the Canadian and U.S. Domestic Satellite Systems. The assumptions regarding the Canadian system are based on a recent paper entitled, "Summary-Technical Characteristics of Canadian Domestic Communication-Satellite System". The Canadian system will use the same 4/6 GHz bands as the U.S. systems.

Fortunately, the Canadian Telesat system uses similar technology to the U.S. 12 transponder systems. This simplifies considerably the coordination problem. On the other hand, they propose occasional use of transmitting antennas as small as 26 ft which tends to complicate the problem. They propose regular use of 32 ft antennas although 98 ft antennas are proposed for Heavy Route earth stations which will provide 960 circuit per transponder telephone service.

For the 98 ft Canadian stations, the U.S. systems would contribute 178 pWpO out of an acceptable downlink total of 313 pWpO for the C_1 link, 160 pWpO out of 298 for C_2, and 44 pWpO out of 104 for C_3. On the uplink side the corresponding figures are 106 of 955, 51 of 1494, and 66 of 955. The greater than 1000 pWpO totals are due to their own use of 32 ft antennas, but assumes the 1200 circuit per transponder system rather than the 960 they actually propose.

Because of the interference produced by the Canadian system in the U.S. uplinks for this orbit arrangement, table 9 was prepared to show the uplink and total interference to U.S. DOMSAT systems as a function of the Canadian earth station antenna size. U.S. earth stations are assumed to be 98 ft. With a Canadian antenna size of 60 ft or greater, the total interference on the H_2 links would be less than 1000 pWpO. Further analysis of the characteristics of the transmissions that Canada is planning to make from the 26/32 ft earth stations is needed.

Table 9. Uplink and Total Interference vs. Canadian Earth Station Antenna Size

	Interference (pWpO) - Uplink/ Total			
	Antenna Size (ft)			
Satellite	26	32	60	98
TCI1	58/ 91	43/ 78	21/ 56	15/ 50
TCI2	83/ 140	62/ 119	33/ 90	25/ 82
RCA1	103/ 334	103/ 334	103/ 334	103/ 334
RCA2	117/ 379	117/ 379	117/ 379	117/ 379
H1	523/ 1,035	415/ 927	265/ 776	227/ 739
H2	1,092/ 1,677	788/ 1,373	365/ 950	260/ 844
RCA3	108/ 315	102/ 309	94/ 301	92/ 299
WU1	160/ 450	149/ 439	133/ 423	129/ 419
WU2	167/ 472	155/ 460	140/ 445	136/ 441
WU3	170/ 515	164/ 509	156/ 501	154/ 449
F1	599/ 1,055	454/ 910	253/ 709	203/ 659
F2	319/ 734	270/ 685	201/ 616	184/ 599
ATT1	245/ 648	221/ 624	188/ 591	179/ 582
CS1	215/ 613	201/ 599	182/ 579	177/ 575
MCI1	200/ 594	191/ 585	178/ 572	175/ 569
ATT2	191/ 582	184/ 575	176/ 566	174/ 564
CS2	184/ 570	179/ 565	173/ 558	171/ 556
MCI2	177/ 553	173/ 549	168/ 544	167/ 543
ATT3	163/ 513	160/ 510	156/ 506	155/ 505
CS3	97/ 298	94/ 295	90/ 292	89/ 291

9. REFERENCES

Bradley, W. E., Communication strategy of geostationary orbit, Astronautics and Aeronautics, Vol. 6, No. 4, April 1968.

Hult, J. L., et al., The technology potentials for satellite spacing and frequency sharing, Memorandum RM-5785-NASA, the Rand Corporation, October 1968.

Beyer, J. P., et al., Some orbital spacing considerations for geostationary communications satellites (Using the 4 and 6 GHz frequency bands), COMSAT Report DS-1-68, October 1968.

Jansky, D. M. and M. C. Jeruchim, Technical factors and criteria affecting geostationary orbit utilization, Communication Satellites for the 70's: Systems, edited by N. E. Feldman and C. M. Kelly, MIT Press, 1971.

Jeruchim, M. C. and T. C. Sayer, Orbit/spectrum utilization study - Interim Report, Doc. No. 69SD4270, General Electric Co., 1969.

OT FORM 10
(1-71)

OFFICE OF TELECOMMUNICATIONS

December 29, 1971

SC9

PSD/DNH

Communications Satellite Launching Costs

R. K. Salaman

At the BPSD meeting on November 30, I mentioned several specific tasks that might be done for us by ITS in the Communications Satellite area. Mr. Crombie identified two of these as being of particular interest to ITS and circulated a memorandum to the ITS staff on December 1 outlining the tasks and requesting responses. Burgette Hart of Dr. Dougherty's group contacted me and said that she was interested in looking into launching costs. I gave her a go-ahead to take an initial look at the problem. Last week she returned with the attached list of questions and comments. I discussed the material with Don Ewing and I recommend that we have her undertake the remainder of the study on a part time basis with a total level of effort of one man-month. I have also attached a copy of a memorandum I wrote in response to her questions and comments.

Dale N. Hatfield

Attachments

FILE COPY

SURNAME	DATE	SURNAME	DATE

OT FORM-10
(1-71)

OFFICE OF TELECOMMUNICATIONS

December 29, 1971

PSD/DNH

Satellite Launching Costs

Burgette Hart, ITS

Confirming our recent conversation, I am very much interested in having you continue the study of satellite launching costs. In response to your specific questions, I would like to have you concentrate on launch costs for communications satellites into the geostationary orbit although costs for allied types of satellites are also of interest if they can be acquired with a minimum of extra effort. I am basically interested in a curve of cost versus payload and we will take care of relating payload to number of voice channels, etc., elsewhere. The cost of the satellite itself should not be included. We do not need costs in fine detail. I can't really answer the latter parts of your second question and I suggest we wait until we look at other models of launch costs that have been used. Perhaps they will discuss a reasonable approach.

I would like to see the following accomplished with one man-month of effort:

(A) Review of existing models.

Computer Science Corporation, General Electric, General Dynamics, and perhaps others, have computer models for Communications Satellite design. These include launch cost models. Each of these models should be briefly investigated and summarized. Les Berry can give you the name of a person to contact at CSC and Jean Adams (ITS) has a GE contact and reports. Mr. Pat Bergan can be contacted at General Dynamics in San Diego. Jean Adams also has reports on the GD model.

(B) Follow up on contacts at NASA and COMSAT.

All of the contacts you listed at NASA and COMSAT seem worthy of pursuit--especially to verify the models of (A).

SURNAME	DATE	SURNAME	DATE

FILE COPY

(C) Preparation of staff paper on results.

This informal paper should include

1. A recommended model, basically a curve of cost vs. payload for launch into the geostationary orbit.

2. A brief review of the limitations of the recommended model, and, in particular, what costs are or are not included.

3. A brief discussion of the CSC, GE, and GD models.

4. Recommendations for keeping the selected model updated.

5. A summary of relevant past launch costs.

I anticipate that the model/information would be included in the OT computer based information center. I have attached a curve taken from a recent GE report on TV distribution via satellite.

Dale N. Hatfield
Policy Support Division

cc: HTDougherty
DDCrombie

FILE COPY

SURNAME	DATE	SURNAME	DATE

Table 5-1. Launch Vehicle Selection Model

Launch Vehicle No.	Name	Net Payload Into Orbit (lbs)	Total Cost Per Launch ($M)	Launch Cost per Pound In Orbit ($K)
1	TAT/Delta/TE 364 (1440)	365	5.6	15.4
2	TAT (6C)/Delta/TE 364 (1440)	420	5.8	13.8
3	TAT (3A+6C)/Delta (Tr. St. Eng.)/TE 364 (2250)	640	6.2	9.7
4	TAT (3A+6C)/Delta (Tr. St. Eng)/TE 364 (2250)/AKM	790	7.0	8.9
5	Titan IIIB/Ascent Agena/AKM	1355	12.6	9.3
6	SLV-3C/Centaur/BII (2300)	1840	15.5	8.4
7	SLV-3C/Centaur/AKM	2030	16.1	7.9
8	Titan IIIB/Centaur/AKM	2200	20.4	9.3
9	Titan IIIC	2400	25.1	10.4
10	Titan IIID/Centaur	8200	26.6	3.2
11	Titan IIID (7)/Centaur	10900	29.7	2.7

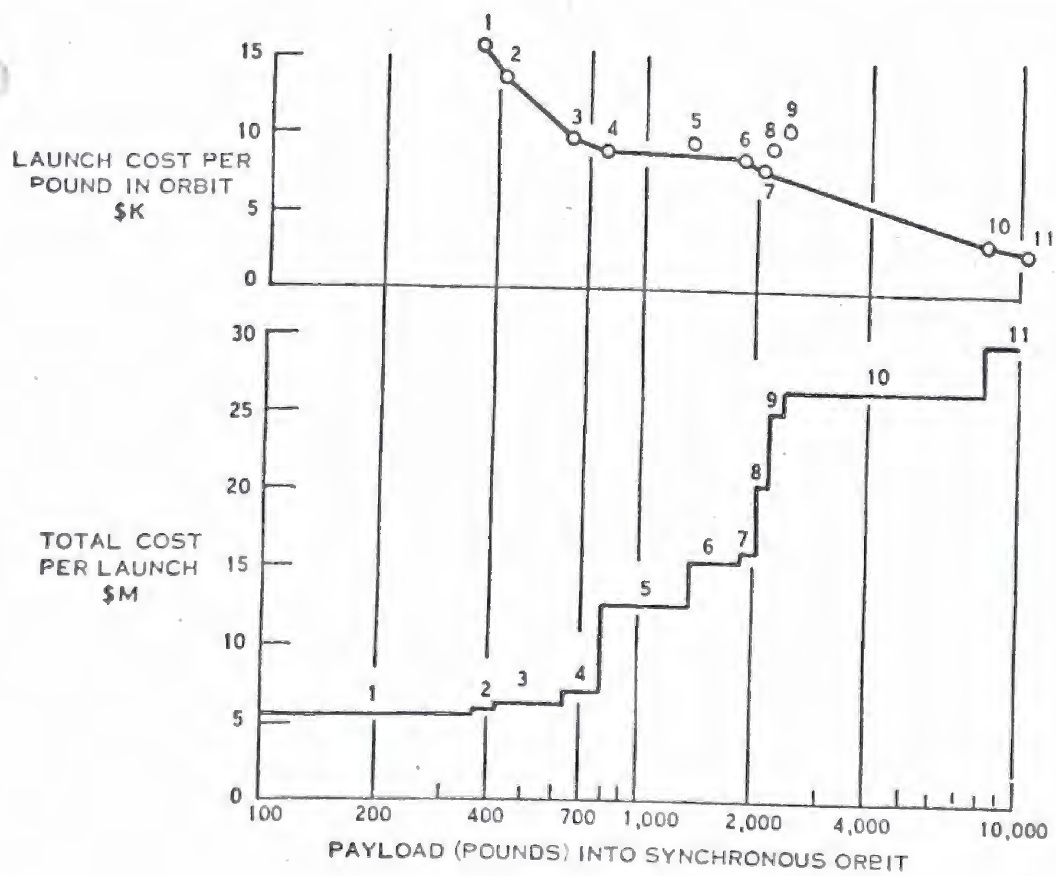


Figure 5-4. Launch Costs

Roger: I gave her go ahead on this.

DMH

SC 10

FORM CD-14 (3-9-59) U.S. DEPT. OF COMM.

TRANSMITTAL SLIP

DATE: 1/17/77

TO: D. Hatfield

REF. NO. OR ROOM, BLDG.:

FROM: B. Hart

REF. NO. OR ROOM, BLDG.: X3929

ACTION

- [ ] NOTE AND FILE
- [ ] NOTE AND RETURN TO ME
- [ ] RETURN WITH MORE DETAILS
- [ ] NOTE AND SEE ME ABOUT THIS
- [ ] PLEASE ANSWER
- [ ] PREPARE REPLY FOR MY SIGNATURE
- [ ] TAKE APPROPRIATE ACTION
- [ ] PER OUR CONVERSATION
- [ ] PER YOUR REQUEST
- [ ] FOR YOUR APPROVAL
- [ ] FOR YOUR INFORMATION
- [x] FOR YOUR COMMENTS
- [ ] SIGNATURE
- [ ] INVESTIGATE AND REPORT

COMMENTS:

Using the enclosed guide I am comparing the GE and GD computer programs. The CSC program is not available yet, but I will talk to Mr. Illgen of CSC and get what info I can. Am I on the right track?

GPO : 1959 O—499871 USCOMM-DC 789-P

COMMENTS:

I am also:

1. Obtaining costs of all past Intelsat launches and payload capabilities.
2. Comparing launch costs (from 2 or 3 sources) of approximately 25 different launch vehicles.
3. Listing satellites (which have been launched into geostationary orbits) with corresponding payloads and launch vehicles (from 1963 to present)

GPO : 1959 O—499871 USCOMM-DC 789-P

Discussion of computer model will include these topics (when information is available):

1. Computer program

   a. To which computers is the program acceptable--with what modifications and in what types of computer language?

   b. What is the relationship of launch cost model to basic program (e.g., subroutine in space segment input, or other?)

   c. How adaptable is the program for different situations--how much of the basic program is necessary to obtain a launch vehicle cost model output?

2. Accuracy and detail of launch cost input

   a. How inclusive is the input--how many launch vehicles are included in the basic selection indices?

   b. How are the vehicles selected--by volume and/or antenna configuration of satellite as well as payload?

   c. How current and accurate is the information in the indices--where are they obtained--what provisions for updating and revising--based on what fiscal year--any provisions for differences in overhead (gov't vs non-gov't, increases due to decreased production or dollar devaluation, etc.)?

   d. What does each cost include--launch vehicle development, fairing and shrouds, mission or payload integration, field services, apogee kick motor development costs, or aerospace ground equipment? What is not included in the cost--how significant are these?

   e. What factors are inherent in the cost calculation--all related to launch costs on the Eastern Test Range--prorated on the basis of expected satellite life--provision for ground spares or launch losses--based on what concurrency (expected future production and launch rate)?

3. Type of launch cost output

   a. What subtotals are given--recurring and non-recurring (or development) costs--space segment subtotal?

   b. How are the costs evaluated--per pound of payload weight--per year of operating costs--if not, are the necessary figures available in other space segment output data?

OT FORM_10
(1-71)

OFFICE OF TELECOMMUNICATIONS

SC 11

January 19, 1972

PSD/DNH

Comments on the Ross TEC Report

Lt. Col. S. A. Lasher, OTP

Last week I asked Phil Rice of ITS to review the Ross TEC report. I was favorably impressed with it but I felt it would be useful if I got another opinion. Mr. Rice, of course, was a co-author of NBS Tech Note 101 which is used in the analysis. I am attaching a copy of his memorandum to me.

This also served to stimulate further ITS interest in our work and I think the contents of Phil's memorandum reflects that. I will send another memorandum later this week with my own specific comments.

Dale N. Hatfield
Policy Support Division

Attachment

FILE COPY

SURNAME	DATE	SURNAME	DATE

U.S. DEPARTMENT OF COMMERCE
Office of Telecommunications
INSTITUTE FOR TELECOMMUNICATION SCIENCES
Boulder, Colorado 80302

Date: January 17, 1972

Reply to Attn of: PR

Subject: Comments on "Analysis of Earth Station Siting for the Proposed Domestic Satellite Systems," Ross Telecommunications Engineering Corporation, Washington, D. C. 3 Jan 1972.

To: Dale Hatfield, PSD/OT

The foreword to this final report under contract OTP-SE-72-104 between the Office of Telecommunications Policy and Ross TEC commends the high quality of the recent Domestic Satellite applications before the FCC. I think that this report is to be commended as well. It goes beyond merely summarizing the technical characteristics and some of the costs of these DomSat applications. The objectives of the report, stated as a summary on pages 96 and 97, are clear and reasonable, and the conclusions listed on page 99 are specific, moderate, and well-supported by arguments and data.

Yes, 100 km may be large for a minimum coordination distance, though natural from a propagation point of view. Yes, as much as or more than 100-200 watts should not be needed for an earth station transponder channel. More effort must be expended to define and understand costs; benefits, and probabilities. And, yes, the FCC should reconsider the 13 dBW figure for maximum terrestrial microwave power, and procedures to allow for off-path scatter need more attention. To these conclusions I would add a few more, noted later in this memo. Two observations found on page 86 are fair conclusions, too, it seems to me, - that about 20 miles works out often as the optimum distance of an earth station from a city center, and that receive - only stations can be located within cities.

Comparing Dom Sat applications is no easy task. We tried it more than a year ago with some that were sent here by Don Jansky and Wilfred Dean. The objectives of the applications differ even more than the systems do.

Besides comparing the feasibility of proposed earth station siting and investigating the sensitivity of the interference situation to system design parameters, Ross Tec developed a computer program to perform coordination distance calculations more or less independent of those in the applications; included off-path scatter calculations; compared FCC and WARC procedures; listed options available for the control of interference levels; and determined the range of some of the related "economic penalties" or costs, as well as the costs and some of the benefits of Dom Sat systems parameters cataloged in the report.

Beyond this, the most important contributions, I think, are the presentations that enable siting and interference factors to be compared between systems, and the description of a probabilistic siting model. I believe that the comparisons are weak in assessing objectives and probable benefits, as well as amortization aspects of the proposals. It is important to evolve quantitative measures of the dollar values of benefits minus costs, and to attach service and "interference" probabilities to them, expanding the definitions of service and interference to include social, socio-economic, fiscal, legal and political aspects as well as technical aspects. There are, it seems to me, a great many more technical aspects to the calculation of an interference probability than those included in the useful and attractive statistical model illustrated in section 6.4. Page 99 recommends refinements to this model and an increase of its scope.

President Johnson's Task Force reports, the JTAC book Spectrum Engineering, K. A. Norton's The Silent Crisis Screams, a number of Rand reports, and other reports that we have studied and used include a wealth of ideas for how to quantify overall studies.

Let's get started with what is in the Ross TEC and related reports. First, boil down the material still further, evolving a model or map of the most important features of benefits and costs related to proposed Dom Sat systems and competing non-satellite systems. Make an administratively confidential study that attempts to order the existing proposals according to a total dollar value of society benefits and costs, rejecting any component of this "effective service sum" that is associated with less than a 95% service probability. Publish the conceptual outline of such a procedure, either outside of any politically sensitive context, or else as a way of evolving and broadcasting additional Dom Sat options in a hypothetical future social context where the nation and the world may have developed a recognizable public philosophy. (This was a favorite term with Walter Lippman, and is very much out of fashion right now. There are, of course, self-fulfilling aspects to prophecies of future needs and resources, if they are well thought out.)

The Ross TEC report, particularly in Section 4.2.4, concludes that all of the Dom Sat applications are feasible even if only dB are juggled. But we can change social (etc.) contexts, objectives, input parameters, probabilities, and interference criteria and reach either the same conclusion or the opposite conclusion without changing technical system characteristics very much.

Incidentally, ITS experience with the available magnetic tape data bases makes us very suspicious of conclusions derived from them. The agreement on pages 56 and 57 between estimates of "number of conflicts" versus coordination distance for five of the Dom Sat proposals is impressive. As a co-author of NBS Tech Note 101, I should be pleased with the use made of it. But for many of these applications it is cumbersome and out-of-date.

Much better allowances for terrain effects, site shielding for instance, can be derived from the more recent work of A. G. Longley of ITS and some models developed in Japan. Natural shielding can amount to more than 40 dB sometimes, in the absence of off-path scatter problems, which it reduces as well. Also, a wide and flat reflecting surface in front of a low antenna reduces unwanted field strengths below free-space values, though there may be awkward fading of these signal levels. Paragraph 2, page 21 of the Ross TEC report makes a valid point, that a free-space propagation path from a shielded site to a scatter volume and a line-of-sight terrain-reflection multipath path from an unshielded site represent satisfactory assumptions.

Throughout the literature on the subject of this report, as well as in committee meetings that I have attended, and implicit in such criteria as those of Table 3.1, page 11, there seems to be an unreasonable amount of confusion about the concepts of thermal and non-thermal noise, long-term vs short term, percentage of time vs percentage of times or occasions, and "worst case" vs confidence bands relative to median values for a "worst case condition."

For instance, the CCIR "long-term" and "short-term" criteria in Table 3.1 list allowable interference levels that differ by 20 dB at 4 GHz between .005% and 20% of "the time" for total power in a band, and by 27 dB at 6 GHz between 0.0025% and 20% for power spectral density or system noise temperature in any 4 kHz band. But the related phenomena do not differ on the average with frequency or between total power and watts/4 kHz. Also, page 330 of the CCIR Special Joint Meeting Report, February 1971, estimates that the difference between 0.005% and 20% field strengths exceeds 30 dB, on the average, for "Region B."

The reasons for these and other oddities are sometimes simple and sometimes complex, but not having the reasons available often makes intelligent use of the interference criteria impossible, it seems to me.

I would appreciate the opportunity to do more work in this area. Preparing this memo, including the study that went with it, required five hours.

Phil C Rice

Philip L. Rice
Division 2

cc:
J. Hull
R. Salaman

U.S. DEPARTMENT OF COMMERCE
Office of Telecommunications
INSTITUTE FOR TELECOMMUNICATION SCIENCES
Boulder, Colorado 80302

Date: January 28, 1972

Reply to Attn of: PSD/DNH

Subject: Trip to Washington, D. C. January 25-27, 1972

To: Roger K. Salaman

These are my abbreviated notes from the subject trip:

1. Discussed the Ross TEC report with Lasher and Nelson at OTP. Evaluated comments of Kelleher.

2. Called Sam Fordyce at NASA regarding their report on DOMSAT Orbit/Spectrum Utilization for FCC. He appeared hostile but agreed to send copies to WRH and us.

3. Discussed the mobile area with Hal Millie and got his notes on previous meeting you attended. I will start detailed project planning steps and technical summaries.

4. Prepared material for use in Contract Procurement on Mobile Economic Benefit Study and discussed it with Mr. Bull of DOC Procurement Group.

5. Attended Motorola briefing at OTP with Millie and Polishuk. I was very impressed with the discussion led by George Mansur.

Dale N. Hatfield

U.S. DEPARTMI : OF COMMERCE
Office of Telecommunications
INSTITUTE FOR TELECOMMUNICATION SCIENCES
Boulder, Colorado 80302

SC 13

Date: February 1, 1972

Reply to Attn of: GGA/ITS

Subject: Development of a computer subroutine for calculating the interference reduction factor for FDM/FM systems

To: Dale N. Hatfield

In partial response to your DOMSAT Interference Study Work Statement the indicated subroutine has been written and checked out. The subroutine does not handle the general case and is restricted to the following assumptions:

1. Both wanted and unwanted carriers are "wideband" (rms modulation indices near unity or better), i.e., have Gaussian-shaped spectra with negligible residual carrier component.

2. The interfering carrier is "small" with respect to the wanted carrier.

3. The wanted carrier's receiver passes the wanted and unwanted spectra without distortion even when the carriers are offset.

Under these conditions the interference reduction factor reduces to a relatively simple function. The subroutine merely solves equation 2-26a from the following report:

General Electric, "Orbit/Spectrum Utilization Study," Vol. IV, Doc. No. 70SD4293, 31 Dec. 1970.

Some degree of confidence in the results one gets from this routine was obtained by comparison with what one obtains from the figures in CCIR Annex 8-3 of the S.J.M. Report (Geneva, 1971).

Interference reduction factors were computed for several r.m.s. multichannel modulation indices (in the range $0.65 < M < 1.28$) for the wanted and unwanted carriers for both the cochannel and offset channel (20 MHz) cases. Agreement was generally closer than $\pm$ 1 dB with the worst difference being 1.7 dB.

A comparison was also made to the two examples (exs. 1 & 2) in Mr. Crombie's note entitled "Calculation of Interference Noise in FDM-FM Systems" submitted to the minutes of the November 3, 1971, OT/OTP meeting. My results differed from these by 0.6 dB for ex. 1 and by 1.8 dB for ex. 2.

It should be noted that a general solution to this problem covering all possibilities is by no means simple. It basically involves computation of the r-f spectra for both the wanted and unwanted signals, modification of these by any filtering and convolution of these spectra to obtain the interference spectrum that results in the baseband of the wanted signal system. The tough part is in the computation of the r-f spectra. To my knowledge no simple solutions exist for these spectra for low modulation indices.

Gene G. Ax

cc:
D. D. Crombie
G. W. Haydon

U.S. DEPARTMENT OF COMMERCE
Office of Telecommunications
INSTITUTE FOR TELECOMMUNICATION SCIENCES
Boulder, Colorado 80302

SC 14

Date: February 9, 1972

Reply to Attn of: PSD/DNH

Subject: Trip Report

To: R. K. Salaman

1) I submitted DOMSAT Orbit/Spectrum paper on Monday and began review of complete OTP, OR, Ross TEC, and SRI paper.

2) Wrote two project descriptions for WRH.

3) Received copy of letter from Jack Kelleher to SAL regarding DOMSAT paper.

4. Talked with Art Cooke and he said he had paved the way for me to contact SRI about their computer simulation model and mobile communications data base. I agreed to submitting revised project/task descriptions by Wednesday or Thursday.

5. Had lunch with WRH and discussed his visit next week. Also discussed my future role in mobile versus help to him. He said he would discuss it at OT-OTP Tuesday meeting.

Dale N. Hatfield
Dale N. Hatfield

SC 14

A GENERAL ANALYSIS OF DOMESTIC SATELLITE ORBIT/SPECTRUM UTILIZATION

Policy Support Division
Office of Telecommunications
U.S. Department of Commerce
Boulder, Colorado 80302

December 13, 1971

A GENERAL ANALYSIS OF DOMESTIC SATELLITE ORBIT/SPECTRUM UTILIZATION

1. INTRODUCTION

The objective of this paper is to evaluate the geostationary orbit/spectrum utilization aspects of the U.S. Domestic Communication Satellite (DOMSAT) System applications. In particular, the goal is to provide information for considering the scarcity of the orbit/spectrum resource in DOMSAT policy recommendations. A much more detailed analysis will be needed to select a final orbit/spectrum sharing arrangement. This study is only one of many economic, legal, and technical aspects that must be evaluated. A closely related study of earth station siting is considered in a companion paper.

This paper has been divided into several sections. Section 2 contains a brief summary of the principal findings of the study. Section 3 provides a general background on the orbit/ spectrum allocation problem and section 4 contains a short review of the DOMSAT applications. Section 5 is devoted to a general analysis of the tradeoffs involving orbit spacing, performance, and system parameters typical of those proposed by the applicants. Section 6 contains an analysis of orbit capacity versus indicated demand and Section 7 discusses proposed capacity and certain factors affecting orbit/ spectrum requirements.

2. PRINCIPAL FINDINGS

- The average spacing required to accommodate all 23 of the initial U.S. and Canadian satellites in the available orbit is not inconsistent with the spacings proposed and analyzed in the applications.
- A general analysis indicates that 23 satellites with characteristics typical of those proposed could be accommodated in the unlikely event that all systems are built, albeit certain adjustments in system parameters may be necessary.
- The ultimate capacity of the available geostationary orbit using (and reusing) 2000 MHz of spectrum so vastly exceeds the indicated initial demand that scarcity of this resource is not a compelling issue in DOMSAT policy determination.

3. BACKGROUND

Technical factors affecting the utilization of the orbit/ spectrum resource have received considerable attention both nationally and internationally. For a more detailed analysis of these factors, the reader is referred to the papers by Bradley (1968), Hult, et al. (1968), Beyer, et al. (1968), Jansky and Jeruchim (1971), Jeruchim and Sayer (1969), and a number of CCIR documents.

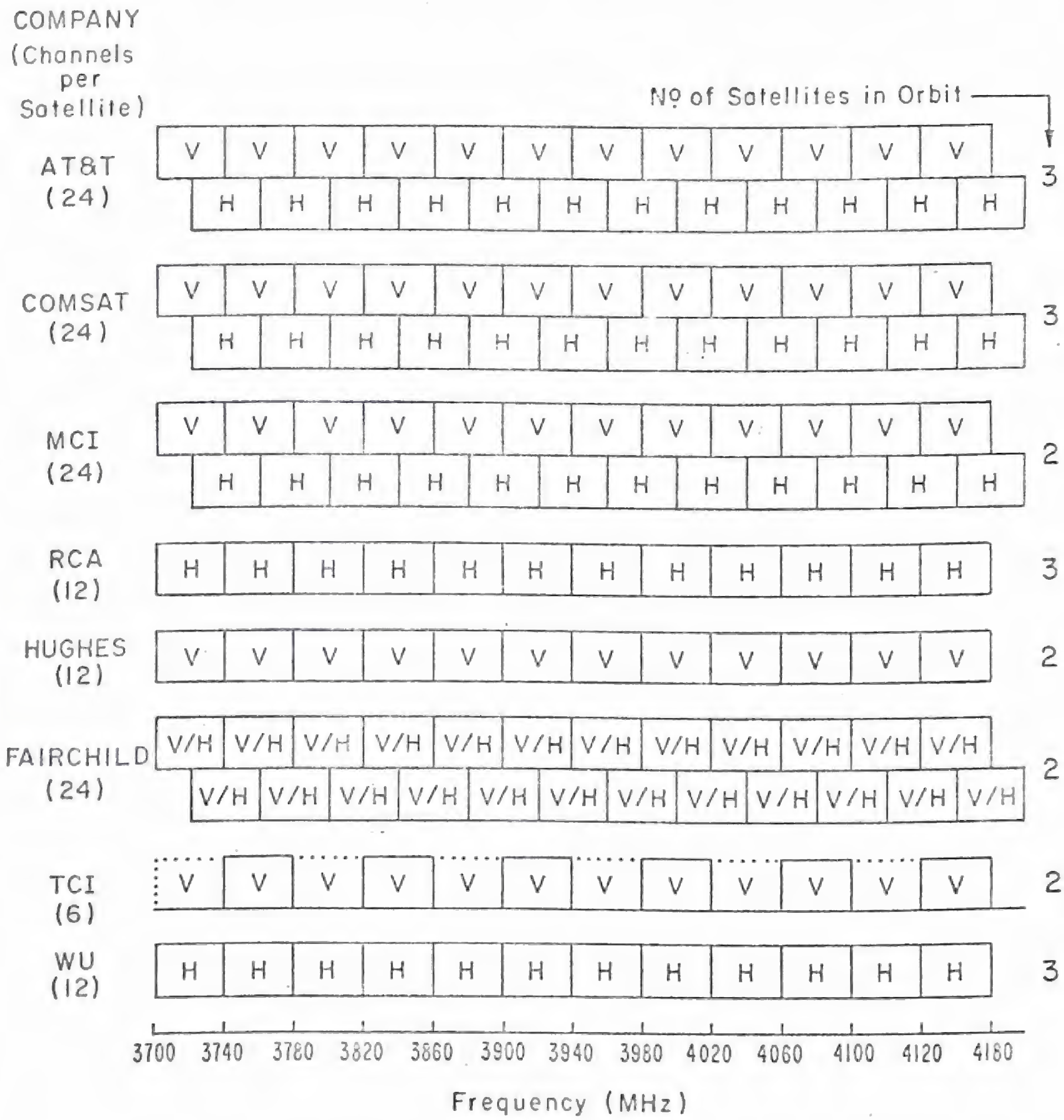
If each satellite in the geostationary orbit could use different portions of the frequency spectrum, then many of them could occupy the same orbital "slot" since the problem is not one of physical space. Because of the relative scarcity of available spectrum, this is not possible and reuse of the spectrum is necessary and prudent. In the case of the DOMSAT system, each applicant proposes to make use of two separate bands of frequencies near 4 and 6 GHz. These bands, used for downlinks and uplinks respectively, must also be shared with terrestrial systems as well. In addition, certain applicants propose the use of bands near 12 and 13 GHz. This multiple use of the same band is based upon the ability of each system to discriminate against or reject the signals of other systems. This discrimination can come from several sources but one of the principal ones is antenna directivity. Thus a basic factor determining the minimum spacing between satellites using the band is the directivity of the antennas employed. These sources of discrimination are discussed in more detail in section 5. The point to be made here is that the basic issue is one involving tradeoffs among costs, performance, and orbit/ spectrum utilization. The use of more directive (costly) antennas, for example, would yield higher system performance (in terms of less interference) and/or allow more satellites to be accommodated in the orbit. Conversely, extravagant use of the orbit/ spectrum would permit fewer (but higher performance) or lower cost systems. Thus the limits on orbit/spectrum utilization are basically economic.

4. REVIEW OF APPLICATIONS

The DOMSAT applications have been summarized in several different places. A MITRE Corporation report (Eldridge, et al., 1971) is devoted specifically to this subject and the FCC has summarized certain factors in Public Notice 65963 dated April 13, 1971. For completeness, the characteristics which are particularly important to the orbit/ spectrum utilization question are repeated here. There are certain features that are common to all applicants. Each propose the use of 40 MHz wide channels with one transponder per channel on the satellite. With the exception of Western Tele-Communications

Figure 1

4 GHz (DOWNLINK) FREQUENCY PLANS



V = Polarization Parallel to Spin Axis
H = Polarization Perpendicular to Spin Axis
(or equivalent)

Each block corresponds to one transponder

Note: The Canadian Telesat plan is the same as that of Hughes

(WTCI), they use 12 or 24 such transponders in the 500 MHz of available uplink and downlink bandwidth. For the 24 transponder systems, the 12 "even" channels are offset 20 MHz and cross-polarized with respect to the "odd", thus enabling the reuse of the spectrum. The channeling plans proposed for the 4 GHz downlinks are summarized in figure 1. Corresponding plans are used for the 6 GHz uplinks. Because of international maximum power flux density restrictions, the applicants all propose nearly the same satellite downlink EIRP--about 36 dBW.

4.1 RCA

RCA Global Communications and RCA Alaska Communications (hereafter referred to as RCA) propose the initial deployment of two satellites at 121°W and 125°W longitude. Each satellite would have 12 transponders at 4/6 GHz. When the growth of traffic warrants it, they propose to place a third satellite in orbit at 114°W longitude and at the same time move the satellite from 121°W to 118°W longitude. A final configuration would put satellites at 114°W, 118°W, 122°W, and 126°W longitude. The satellites proposed would have a G/T of -7.4 dB/°K at 6 GHz.

RCA proposes earth stations with different size antennas and different uplink EIRPs. These range from stations with 32 ft antennas and 3 KW transmitter power output (87.8 dBW mainbeam EIRP) to a station with a 60 ft antenna and a power output of 300 W (83.8 dBW mainbeam EIRP) to, finally, a station with a 98 ft antenna and 100 W power output (82.5 dBW mainbeam EIRP). These would have a G/T of 32, 37, and 41 dB/°K respectively.

Each transponder would handle one FM-TV signal, 1000 FDM-FM voice circuits, or a 3.6×10^7 bps data signal.

4.2 WTCI

Western Tele-Communications (WTCI) proposes a two-satellite system. These would be placed at 113°W and 116°W longitude. Their system is somewhat unique in that they propose to use only six transponders per satellite in the 4/6 GHz bands with each satellite using only every other channel. They propose to employ a similar scheme at 12/13 GHz. They would have a G/T of 1.9 dB/°K.

Transmit/Receive (TR) earth stations would employ 32 ft antennas at 12/13 GHz and 60 ft antennas at 4/6 GHz. At 4/6 GHz the transmitter power output would be 700 W for a mainbeam EIRP of 84 dBW. The G/T for 6 GHz would be 36 dB/°K. They also propose Receive Only (RO) stations with antennas as small as 18 ft.

FM-TV, FDM-FM telephone, and data trasmission are proposed.

4.3 Hughes

Hughes proposes to use two satellites with 12 transponders each at 100°W and 103°W longitude. Hughes will lease certain of these transponders to General Telephone and Electronics (GTE). They will have a G/T of -7 dB/°K.

All T/R earth stations (both Hughes and GTE) using the Hughes satellites will use 98/100 ft antennas. Hughes proposes to use a transmitter power of 600 W and GTE proposes 3 kW for mainbeam EIRPs of 83 dBW and 92 dBW, respectively. Corresponding G/Ts would be 37 and 43 dB/°K. Hughes also proposes RO terminals with 35 ft antennas and G/T of 28 dB/°K.

FM-TV, FDM-FM telephone, and data transmission are proposed. One FM-TV signal or 1,320 voice channels (GTE) per transponder is indicated.

4.4 Western Union

Western Union (WU) proposes three satellites at 95°W, 102°W, and 116°W longitude. Each satellite would have 12 transponders at 4/6 GHz and the 6 GHZ G/T is -7 dB/°K.

The T/R earth stations would employ 45 ft antennas with a transmitter power output of 330 W for a mainbeam EIRP of 83 dBW. The G/T is indicated as 32 dB/°K. Capacity per transponder is either 1 FM-TV signal, 1200 FDM-FM voice channels, or 5×10^7 bps data.

4.5 ATT

American Telephone and Telegraph and the Communications Satellite Corporation (referred to as simply ATT in the remainder of this report) proposes a 24 transponder per satellite 4/6 GHz system with satellites located at 94°W, 104°W, and 119°W longitude. The G/T for the COMSAT-supplied satellites is indicated as -7 dB/°K.

The five major earth stations would employ 100 ft antennas with a transmitter power output of 1 kW giving a mainbeam EIRP of 92 dBW. The G/T would be 41 dB/°K. Capacity is either one FM-TV signal, 900 FDM-FM voice channels, or 3.5×10^7 bps per channel.

4.6 COMSAT

The Communications Satellite Corporation (COMSAT) proposes the same type satellite with 24 transponders each at 4/6 GHz. The three satellites would be placed at 99°W, 114°W, and 124°W longitude. Indicated G/T is -7 dB/°K.

All T/R earth stations would employ 97 ft antennas except those in Alaska which would use 32 ft. Power output per channel would be

630 W for the 97 ft antenna stations with a corresponding mainbeam EIRP of 90 dBW. The 32 ft stations would have a transmitter power output of 450 W with a maximum EIRP of 80.5 dBW in the mainbeam. The G/T is 32 and 41 dB/°K for the 32 ft and 97 ft sites, respectively. RO stations with 42 ft antennas and a G/T of 35 dB/°K are also proposed. Capacity proposed is either one FM-TV signal, 1200 FDM-FM voice channels, or 5×10^7 bps data per transponder.

4.7 MCI

MCI-Lockheed Corporation (MCI) proposes two satellites at 114°W and 119°W longitude. Each satellite would have 24 transponders at 4/6 GHz and 24 at 12/13 GHz. G/T is 1.9 dB/°K

Earth stations with an antenna diameter of 32 ft are proposed at all locations. A transmitter power of 3.0 kW with a mainbeam EIRP of 85 dBW at 6 GHz is given for these stations. The 4/6 GHz G/T is 33 dB/°K. The capacity per transponder is listed as either one FM-TV channel, 800 voice channel FDM-FM, or 5×10^7 bps data.

4.8 Fairchild

Fairchild Hiller Corporation (Fairchild) proposes two satellites at 104°W and 115°W longitude. Through the use of spot beams (in addition to cross polarization and interleaved carriers), they would have 96 transponders at 4/6 GHz and 24 at 7/13 GHz. The G/T at 6 GHz is 15.2 dB/°K.

At 4/6 GHz, the applicant proposes earth stations with 97 ft antennas, a transmitter power output of only 12 W, a corresponding EIRP of 73 dBW, and a G/T of 36 dB/°K. Each transponder would have a capacity of either 1 FM-TV signal, 1200 FDM-FM voice channels, or 3.5×10^7 bps data.

5. GENERAL ANALYSIS

5.1 Useful Orbital Arc for U.S. and Canadian Coverage

The coverage of a synchronous satellite varies with its location in the geostationary orbit and the restrictions on minimum elevation angles at the earth stations. The minimum elevation angle restrictions arise from technical factors such as the increase in noise temperature and increased coordination problems with terrestrial systems at the lower angles. For elevation angles greater than 5° (the FCC guideline), the useful arc for coverage of the contiguous U.S. (CONUS) ranges from about 53° W to 138° W longitude. Thus there is approximately 85° total. The portion of the arc visible from a given earth location decreases with increasing latitude, hence the corresponding range for Canada is from about 82° W to 122° W. For coverage of Alaska with the same 5° restriction, the satellite must be located west of about 114° W.

Elevation angles from various cities in which the applicants propose earth stations to the 53° W and 138° W extremes of the useful orbit are summarized in table 1. If the elevation angle restriction is increased to 10°, the useful arc is reduced to approximately 70°.

5.2 Average Spacing

There are applications for 24 orbital slots, but four of these are designated for ground spares. In addition, Canada's plans to launch three satellites must be included, making a total of 23 slots that must be initially allocated - including the third RCA and the third Canadian satellites which would not be immediately launched. Thus an average spacing of approximately 3.7° is indicated, i.e., 85° divided by 23. If the 10° minimum elevation angle were imposed, the average

Table 1. Elevation angles from earth station locations to the extremes of the geostationary orbit visible from Conus.

Long. of Earth Stn.	Lat. of Earth Stn.	Elevation Angle with Satellite at 53° W	Elevation Angle with Satellite at 138° W	Nearby City
73.50	40.40	38.74	10.60	New York City
72.42	41.45	38.16	9.49	Hartford
71.05	42.20	37.94	8.27	Boston
78.55	42.52	34.53	13.56	Buffalo
75.10	40.00	38.42	11.93	Philadelphia
76.54	40.17	37.60	12.95	Harrisburg
77.00	38.55	38.84	13.85	Washington, D. C.
80.00	40.26	35.81	15.49	Pittsburg
81.41	41.30	34.18	16.09	Cleveland
80.50	35.03	39.93	17.84	Charlotte, N. C.
81.00	34.00	40.46	18.61	Columbia, S. C.
81.40	30.20	43.16	20.27	Jacksonville
80.15	25.45	47.62	20.59	Miami
84.23	33.45	38.75	21.47	Atlanta
84.30	39.10	34.38	19.15	Cincinnati
83.05	42.23	32.55	16.86	Detroit
90.03	30.00	36.79	27.76	New Orleans
87.45	41.50	30.68	20.27	Chicago
88.00	44.32	28.23	19.18	Green Bay
93.10	45.00	24.87	22.01	St. Paul
92.17	34.42	32.44	27.38	Little Rock
94.37	39.05	27.99	26.43	Kansas City, Kan.
96.00	41.15	25.59	26.24	Omaha
68.47	44.49	36.46	5.81	Bangor
96.48	32.47	30.25	31.80	Dallas/Ft. Worth
95.25	29.45	32.85	32.43	Houston
105.00	39.45	20.24	33.09	Denver
118.15	34.00	11.89	45.12	Los Angeles
122.27	37.45	7.71	43.55	San Francisco
122.40	45.32	5.68	35.57	Portland
122.20	47.35	5.27	33.45	Seattle
157.50	21.50	*****	56.51	Oahu, Hawaii
134.20	58.20	4.04	23.78	Juneau
132.00	55.00	2.39	27.05	Ketchikan
148.00	70.00	*****	11.16	Prudhoe Bay
150.09	52.20	*****	29.25	Talkeetna
147.50	64.50	*****	16.81	Fairbanks
66.08	18.29	63.83	8.55	San Juan
150.00	61.10	*****	20.06	Anchorage

Note: The Bangor, Maine station was added to provide a point at extreme northeast of Conus. Asterisks indicate elevation angle $< 0°$.

spacing would be slightly greater than 3°. Average spacings of this magnitude appear feasible based on the analysis presented by the applicants themselves. These analyses are discussed briefly in the next section. It should be kept in mind that the 12 transponder satellites employing cross polarization and interleaved carriers between adjacent satellites can be spaced closer than the 24 channel systems which employ these techniques within each satellite.

5.3 Spacing Requirements As Stated by Applicants

In the original material furnished to the applicants by the FCC, earth station antennas of 32 ft and satellite spacings of 5° were suggested as minimums. In general, there seems to be several forces at work in choosing spacings. Wider spacings are favored by those applicants arguing for a monopoly position, although this may also result from the fact that they are associated with the larger capacity satellites. The forces toward narrower spacing result from (1) the efforts of applicants to cover two satellites using a single antenna with dual feeds - thereby reducing costs and (2) those favoring open entry who want to demonstrate that the satellites of all applicants could be accommodated.

In the 12 transponder (4/6 GHz) per satellite class, WTCI and Hughes both propose 3° spacing for their systems. Of these two, the Hughes' analysis is more detailed. It concludes that 3° spacing is adequate for their own satellites, and that their satellites could be located "within 3 to 5° of other satellite systems using the same frequency bands (depending upon the other satellite system design)". WTCI references the North American-Rockwell Coordination Analyses and states that: "Several additional satellites are permitted by 3° spacing and system calculations indicate this to be feasible". The RCA application proposed 4° spacing of its satellites. This spacing is based on a tradeoff analysis involving minimizing sun outage time and reducing interference on one hand (requiring a wider spacing) and staying within the requirements for covering both satellites with a dual feed, single antenna on the other. Western Union uses 7° spacing but notes that 2.5° spacing would be feasible with cross polarization. The COMSAT and ATT (24 transponder) applications propose alternating their satellites at 5° spacing (in accordance with the FCC guidelines). COMSAT has a detailed analysis and a summary table which shows required satellite spacing as a function of the type of signal and for typical earth station equipment. The spacings range from 1.3° to 4.3°, but the 4.3° is footnoted with the comment that "it reduces to 3.0° by cross polarization with respect to the interfering satellite... (and) that ±2.5° orbital spacing between satellites would be theoretically possible." The ATT proposal contains a detailed analysis for 4.5° which shows protection margins consistent with the analysis given by COMSAT. The MCI proposal also uses 5° spacing, but they indicate that 3.4° spacing is possible.

Thus, the applicants themselves either support the contention that average spacings in the range from 3-4° are possible or, as a minimum, they do not present any strong arguments that they are not sufficient.

5.4 Tradeoffs for Representative Systems

The purpose of this section is to critically examine spacing requirements using systems parameters typical of those proposed. This is necessary because in many cases the applicants' analyses considered only other interfering systems which were identical to their own. Furthermore, examination of the tradeoffs will provide some insight into orbit capacity and the effect of certain system constraints such as minimum antenna size.

5.4.1 Assumptions

Certain assumptions are necessary for the following analysis.

First, only the 4 GHz downlink and 6 GHz uplink interference is considered. This is the most critical case because (1) the antenna discrimination at 12/13 GHz is substantially greater for the same antenna size and (2) fewer applicants propose the use of the higher frequency bands thus reducing the potential interference.

Second, satellite spacing is acceptable if the total added noise from interference on the satellite/earth station link, in the worst-case voice channel, is less than 1,000 pW0p (pico-watts, psophometrically weighted). This noise is only part of a total noise budget of 10,000 pW0p if CCIR Recommendations are followed. The choice of the 1,000 pW0p limit for interference in the satellite link is, of course, arbitrary. In fact, several applicants exceed this limit - compensating for it in other parts of the system or in offered performance.

Third, it is assumed that the angle between two satellites as observed at an earth station is equal to the satellite spacing as measured in degrees of equatorial arc. This is a conservative assumption in that the former angle is always greater than the latter.

Fourth, as a baseline for this analysis a nominal 1200-voice circuit per channel (transponder), FDM/FM system with an RMS modulation index of 0.6 and a top baseband frequency of 5.5 MHz is assumed. This nominal system is the same as that given by COMSAT in their Comments dated 12 May 1971, and it is generally representative of voice circuit systems. It is conservative from the standpoint that only Hughes/GTE proposes a greater number of voice channels per 40 MHz transponder. It is assumed (with precedent) that acceptable performance in this case would permit acceptable performance in other services.

Antennas proposed for DOMSAT earth stations are parabolic dishes ranging in size from 32 ft to 100 ft in diameter. It is assumed that the on-axis gain (G) of these antennas is given by:

$$G = 20 \log\left(\frac{\pi D}{\lambda}\right) - 3 \text{ dB}$$

where D is the diameter and λ is the wavelength - both in the same units. The -3 in the expression accounts for the assumed 50% efficiency. It is assumed further that the gain of the antenna at an off-angle θ degrees from the mainbeam is given by the expression $32 - 25 \log (\theta)$ dBi for $1 \leq \theta \leq 48$ and, for $\theta > 48$, it is a constant -10 dBi. Thus the protection ratio (PR) offered by the spatial directivity of the antennas is:

$$PR = 20 \log\left(\frac{\pi D}{\lambda}\right) - 35 + 25 \log (\theta) \text{ dB}$$

for $1° \leq \theta \leq 48$. For receiving, this expression is simply the strength of the desired signal relative to the strength of the undesired signal coming from an off-angle θ from the main beam. For transmitting, this expression gives the signal strength transmitted in the desired direction relative to the signal strength in the undesired direction θ. This equation is plotted for 4/ 6 GHz and popular antenna sizes in figure 2, which is taken from a recent COMSAT report. The gain and sidelobe suppression indicated are consistent with CCIR Recommendations and the specifications in the applications.

Sixth, it is assumed that if the desired and undesired signals are cross polarized with respect to each other, then there is an additional 10 dB of discrimination when the undesired signal lies outside the main beam. This assumption is also consistent with

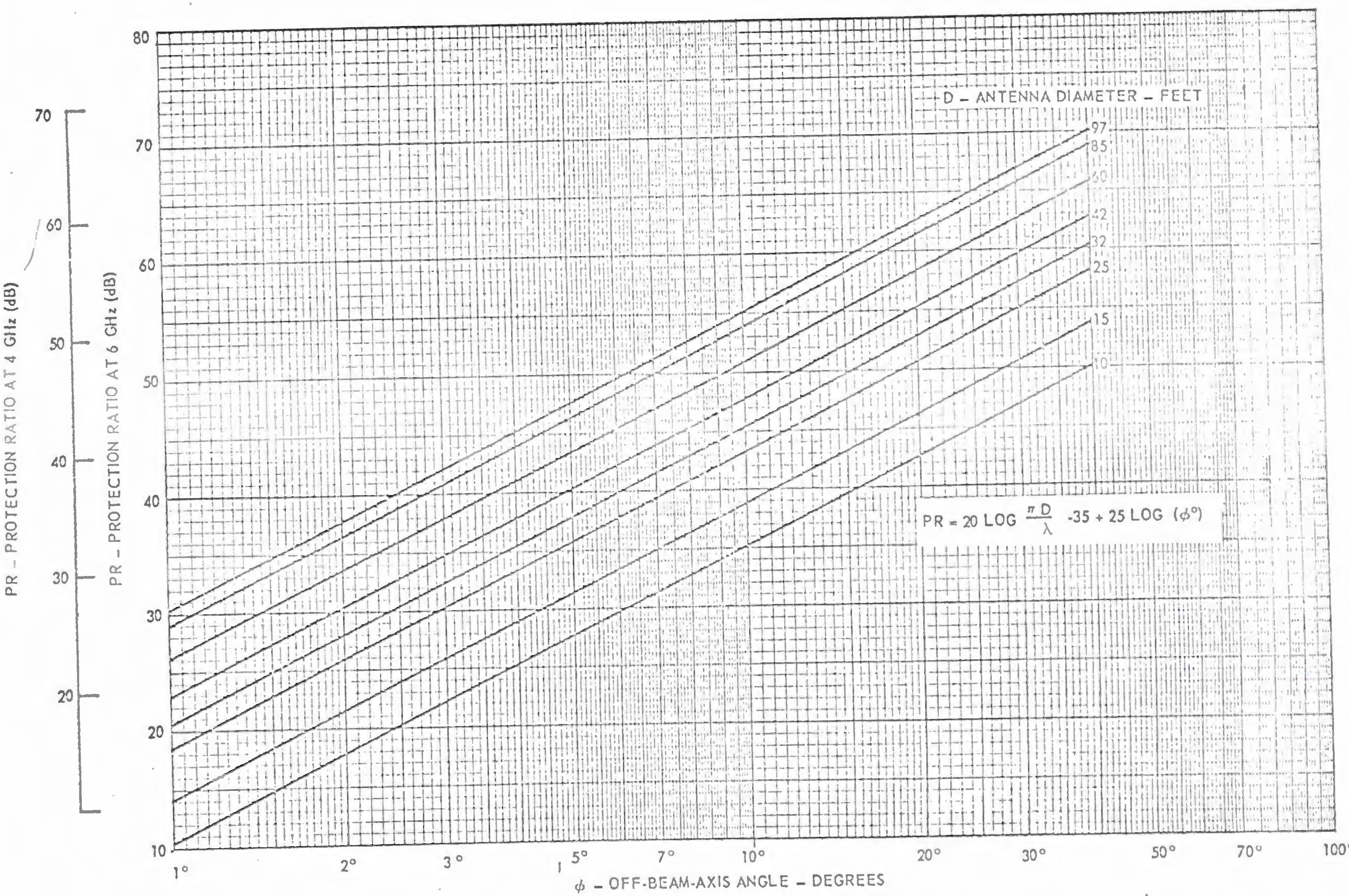


Figure 2. Protection ratio vs. off-beam-axis angle assuming 50% antenna efficiency and [32 - 25 log (θ)] sidelobes (from COMSAT Report DS-1-68).

CCIR Recommendations and is generally supported by the applications.

Seventh, it is assumed that the total baseband noise produced by multiple interfering signals can be calculated by simply summing their individual contributions.

Eighth, it is assumed that the basic transmission loss from a satellite in geostationary orbit to an earth station is independent of the earth station location over the area of concern in this analysis.

The test tone signal-to-weighted noise power ratio (SNR) in the worst-case (top) telephone channel is related to the carrier-to-interference ratio (CIR) at the input of the receiver by an expression

$$\mathrm{SNR} = \mathrm{CIR} + B \quad \mathrm{dBm0p}$$

where B is the "Interference Reduction Factor". As defined here, B includes noise weighting and top channel pre-emphasis advantage. It depends upon the modulation characteristics of the wanted and unwanted signals and the separation of their carrier frequencies (offset). For the parameters of the FDM/ FM system assumed in this analysis, B is computed to be approximately 26.5 dB when the carrier frequencies are the same. If the interfering signal is offset 20 MHz (half the channel width), then B is approximately 41.6 dB. These figures were computed independently in accordance with a report by Jeruchim and Kane (1970). With no offset, the 26.5 dB figure is consistent with that assumed by the applicants, i.e., AT&T, 24.7; RCA, 26.8; and GT&E, 24. The slight differences in systems (1200, 1000, and 1320 voice channel/transponder, respectively), account for the variation. The additional isolation produced by offsetting (interleaving) the channels is open to more question. Many applicants do not address this issue since they do not propose interleaving. The figure used is, however, consistent with that given in the COMSAT Comments and the value used by AT&T. The noise (N_i) in pW0p in the top baseband channel is related to the SNR by the expression: $SNR = 10 \log \frac{10^9}{N_i}$.

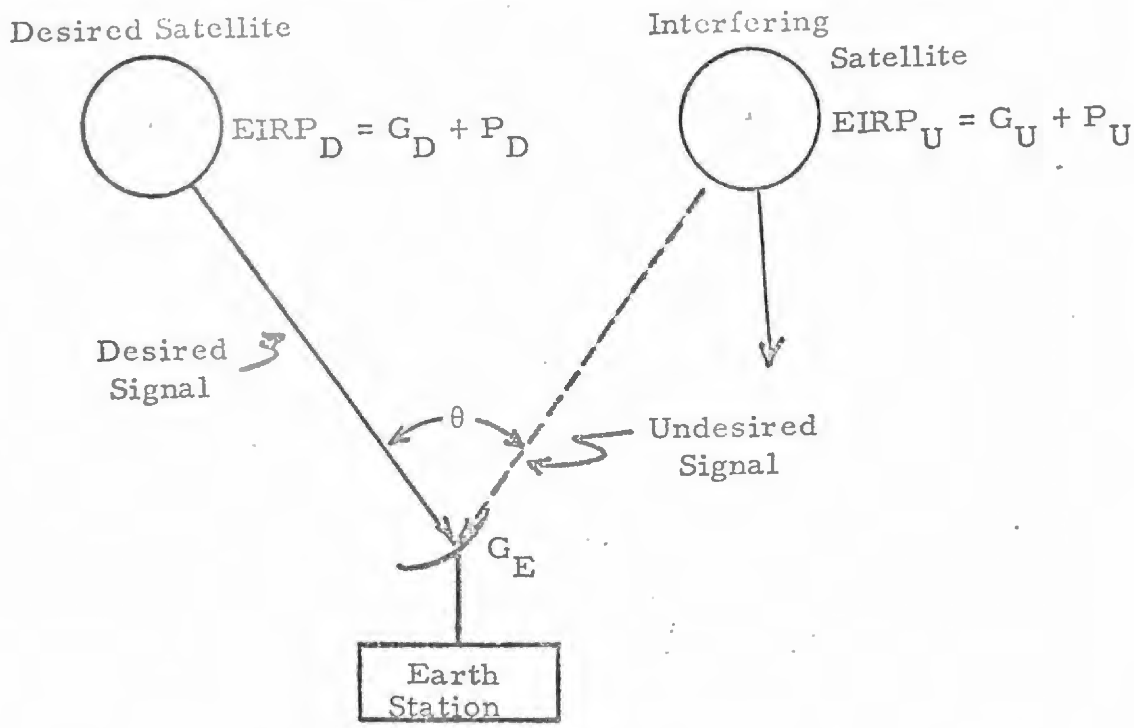
Tenth, the orbit spacings used in the analysis are the nominal values. The applicants propose stationkeeping accuracies of $\pm 0.1°$ which means under worst-case conditions the satellites could be .2° closer. These conditions were not included in this analysis because (1) the third assumption tends to nullify it, (2) the probability of both satellites being at their extremes at the same time is small, (3) at the close spacings (2.5°) the increase in interference would be 1 dB or less, and (4) an increase in interference by movement to one side is often offset by a decrease in interference from the other side.

Eleventh, only a single applicant will be permitted to serve Alaska. Hence only that applicant's satellites must be located west of 114°W longitude.

5.4.2 Interference Relationships

The equations for computing the downlink interference for a single interfering satellite and for uplink interference for a single interfering earth station are developed in figures 3 and 4, respectively. From the carrier-to-interference ratio, the noise in the worst-case telephone channel can be computed as described in the previous section. This is done for each interference source and the total uplink or downlink noise is just the sum of such contributions using assumption seven. The total noise is just the sum of the uplink and downlink noise.

Figure 3. Downlink Interference



$$CNR = G_E + G_D + P_D - (G_U + P_U) - [32 - 25 \log_{10} (\theta)] + P \quad dB$$

$$= G_E - [32 - 25 \log_{10} (\theta)] + (G_D + P_D) - (G_U + P_U) + P \quad dB$$

$$= G_E - \underbrace{[32 - 25 \log_{10} (\theta)]}_{\text{Antenna Suppression (Figure 3)}} + \underbrace{[EIRP_D - EIRP_U]}_{\text{Relative EIRP Adjustment}} + \underbrace{P}_{\text{Polarization Isolation}} \quad dB$$

where

CNR = Carrier-to-noise (interference) ratio

G_E = Earth station antenna gain (on-axis) - dBi

G_D = Antenna gain of desired satellite - dBi

P_D = Desired satellite transmitter power output - dBW

G_U = Antenna gain of undesired (interfering) satellite - dBi

P_U = Undesired satellite transmitter power output - dBW

θ = Orbit spacing angle (degrees)

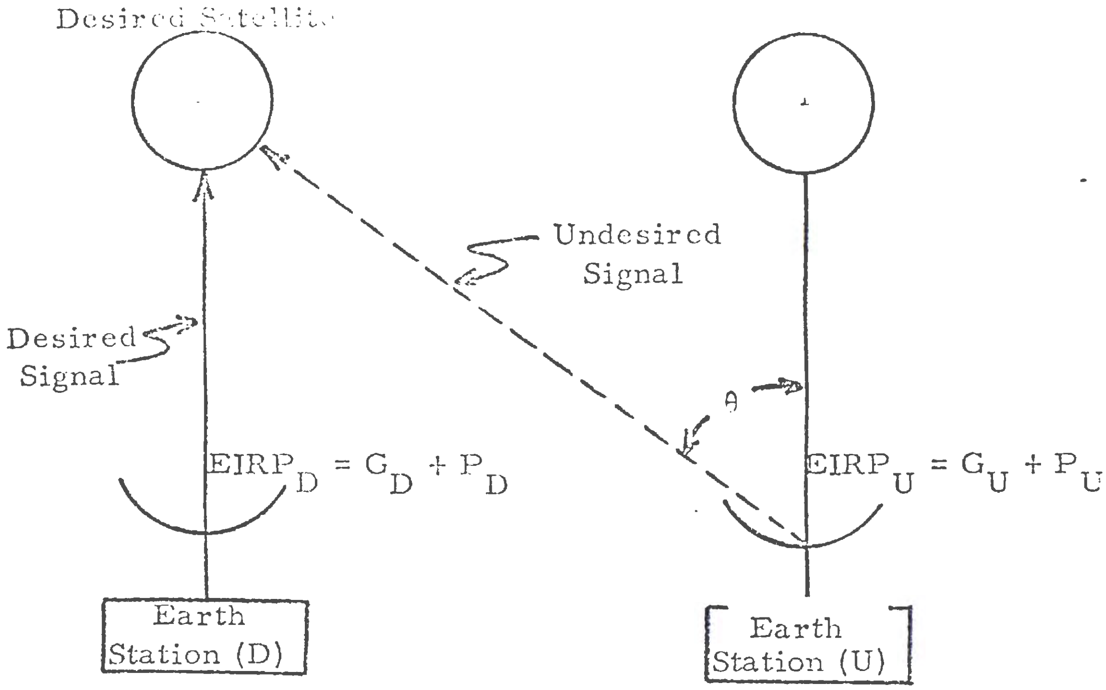
$[32 - 25 \log_{10} (\theta)]$ = Earth station antenna gain at off-axis angle θ - dBi

P = Polarization Isolation - dB

Assume no satellite antenna directivity, i.e., undesired signal =

$EIRP_U = G_U + P_U$

Figure 4. Uplink Interference



$$CNR = G_D + P_D - [P_U + 32 - 25 \log_{10} (\theta)] + P \quad \text{but} \quad P_U = EIRP_U = G_U$$

$$= EIRP_D - [EIRP_U - G_U + 32 - 25 \log_{10} (\theta)] + P \quad dB$$

$$= \underbrace{(EIRP_D - EIRP_U)}_{\text{Relative EIRP Adjustment}} + G_U - \underbrace{[32 - 25 \log_{10} (\theta)]}_{\text{Antenna Suppression (Interfering Station)}} + \underbrace{P}_{\text{Polarization Isolation}} \quad dB$$

where

CNR = Carrier-to-noise ratio - dB

G_D = Desired earth station antenna gain - dBi

P_D = Desired earth station transmitter power output - dBW

P_U = Undesired (interfering) earth station transmitter power output - dBW

θ = Orbit spacing angle (degrees)

$[32 - 25 \log_{10} (\theta)]$ = Earth station antenna gain at off-axis angle θ - dBi

P = Polarization isolation - dB

Assume no satellite antenna directivity to discriminate between Desired and Interfering earth stations

In the following four sections, the noise in pW0p is computed for a uniformly spaced distribution of 13 satellites with 12 transponders operating at 4/6 GHz and for 10 satellites with 24 transponders. This corresponds to the mix represented in the application with the three Canadian satellites included in the 12 transponder systems. The 12 transponder satellites are labelled as C12A through C12M and the 24 transponder satellites are labelled C24A through C24J.

5.4.3 Minimum Spacing Versus Antenna Size

One of the most important parameters in determining minimum spacing is the earth station antenna sizes. The following table summarizes the spacing required for 12 and 24 transponder systems assuming equal satellite and earth station EIRPs, alternating polarization and offset carriers for adjacent 12 transponder satellites, and the total noise objective of 1,000 pW0p.

Minimum Spacing (Degrees)

	Antenna Size (ft)			
	98	60	45	32
24-transponder	3.1	4.6	5.7	7.6
12-transponder	1.5	2.3	2.9	3.8

The details of the 98 ft antenna, 12-transponder system calculation are given in table 3 as an example of how these minimums were established. Using the figures in the table above, the 13 12-transponder satellites would require 19.5° and the 10 24-transponder satellites would require 31° of orbit for a total of 50.5°. For 60 ft antennas the total would be 75.9°. Thus if all proposed systems were homogeneous (except for 12/24 transponder difference) and if they

Table 3a. Interference power for 12-transponder systems with uniform parameters and 98 ft earth station antennas

Satellite	Spacing (Degrees)	Interference (pW0p) Uplink	Downlink	Total
C12A	0.0	171	384	555
C12B	1.5	172	386	557
C12C	1.5	301	677	978
C12D	1.5	299	672	971
C12E	1.5	322	723	1045
C12F	1.5	318	714	1032
C12G	1.5	326	733	1059
C12H	1.5	318	714	1032
C12I	1.5	322	723	1045
C12J	1.5	299	672	971
C12K	1.5	301	677	978
C12L	1.5	172	386	557
C12M	1.5	171	384	555

The method for computing the interference is illustrated on the next page for satellite C12G (Table 3b).

Table 3b. Details of Interference Calculations for Satellite C12G

Satellite	Off-Axis Angle from C12G(°)	Ant. Protection Ratio (dB) Uplink (6 GHz)	Ant. Protection Ratio (dB) Downlink (4 GHz)	Polarization Discrimination (dB)	Interference Reduction Factor (dB)	Interference (dBm0p) Uplink	Interference (dBm0p) Downlink	Interference Power (pW0p) Uplink	Interference Power (pW0p) Downlink
C12A	9.0	54.3	50.8	.0	26.5	-80.8	-77.3	8.3	18.7
C12B	7.5	52.3	48.8	10.0	41.6	-103.9	-100.4	.0	.1
C12C	6.0	49.9	46.4	.0	26.5	-76.4	-72.9	22.9	51.4
C12D	4.5	46.8	43.3	10.0	41.6	-98.4	-94.9	.1	.3
C12E	3.0	42.4	38.9	.0	26.5	-68.9	-65.4	129.3	290.9
C12F	1.5	34.9	31.3	10.0	41.6	-86.5	-82.9	2.3	5.1
C12H	1.5	34.9	31.3	10.0	41.6	-86.5	-82.9	2.3	5.1
C12I	3.0	42.4	38.9	.0	26.5	-68.9	-65.4	129.3	290.9
C12J	4.5	46.8	43.3	10.0	41.6	-98.4	-94.9	.1	.3
C12K	6.0	49.9	46.4	.0	26.5	-76.4	-72.9	22.9	51.4
C12L	7.5	52.3	48.8	10.0	41.6	-103.9	-100.4	.0	.1
C12M	9.0	54.3	50.8	.0	26.5	-80.8	-77.3	8.3	18.7
						Totals		325.8	733.0

Total Uplink and Downlink Noise = 1059 pW0p

Notes: The above calculations show the noise contribution of all other satellites (downlink) and all other earth stations (uplink). Adjacent satellites are frequency interleaved and cross polarized. Equal earth station EIRPs are assumed for uplink calculations and equal satellite EIRPs are assumed for downlink. The Interference Reduction Factors are for the baseline system described in the text. The Interference column is the sum of the Antenna Protection Ratio, the Polarization Discrimination, and the Interference Reduction Factor columns.

all used the same size earth station antennas, then the minimum antenna size would be somewhat less than 60 ft. The antennas actually proposed include all four of the nominal sizes shown in the table. Since some are larger, equal, and smaller than 60 ft, then the question remains as to what mix of antenna sizes can be accommodated.

In the 24 transponder systems, COMSAT, Fairchild, and AT&T each propose TR sites with 98/100 ft antennas except in Alaska where COMSAT proposes 32 ft antennas. Assuming RCA is given this coverage, then only 98/100 ft antennas would be involved. MCI, with the only remaining 24-transponder system, proposes 32 ft antennas for use with its two satellites. Using the spacings from the table, the eight COMSAT, Fairchild, and AT&T satellites would require 24.8° of orbit, and the 2 MCI would require 15.2° for a total of 40°. The interference calculations for this distribution are given in table 4.

For the 12-transponder systems, the earth station antenna mix is as follows:

Ant. Size (ft)	No. of Systems
98	2
60	2
45	3
32	6

Again using the spacings given previously, this mix would require a total of 37.6° of orbit space as shown in table 5. The total orbit for both the 12 and 24 transponder systems would be 77.6° --which is within the 85° available.

Table 4a. Interference power for 24-transponder systems with antenna mix as proposed

Satellite	Spacing (Degrees)	Antenna Diam. (ft)	Interference (pW0p) Uplink	Downlink	Total
C24A	3.1	98	162	352	515
C24B	3.1	98	282	619	901
C24C	3.1	98	305	664	969
C24D	3.1	98	315	677	992
C24E	3.1	98	322	679	1001
C24F	3.1	98	329	670	999
C24G	3.1	98	338	632	970
C24H	3.1	98	296	384	680
C24I	7.6	32	144	806	950
C24J	7.6	32	125	409	934

The method for computing the interference is illustrated on the next page for satellite C24E.

Table 4b. Details of Interference Calculations
for Satellite C24E

Satellite	Off-Axis Angle from C24E (°)	Ant. Protection Ratio (dB) Uplink (6 GHz)	Ant. Protection Ratio (dB) Downlink (4 GHz)	Polarization Discrimination (dB)	Interference Reduction Factor (dB)	Interference (dBm0p) Uplink	Interference (dBm0p) Downlink	Interference Power (pW0p) Uplink	Interference Power (pW0p) Downlink
C24A	12.4	57.8	54.3	.0	26.5	-84.3	-80.8	3.7	8.4
C24B	9.3	54.7	51.2	.0	26.5	-81.2	-77.6	7.6	17.2
C24C	6.2	50.3	46.8	.0	26.5	-76.8	-73.2	21.1	47.4
C24D	3.1	42.8	39.2	.0	26.5	-69.2	-65.7	119.1	268.0
C24F	3.1	42.8	39.2	.0	26.5	-69.2	-65 7	119.1	268.0
C24G	6.2	50.3	46.8	.0	26.5	-76.8	-73.2	21.1	47.4
C24H	9.3	54.7	51.2	.0	26.5	-81.2	-77.6	7.6	17.2
C24I	16.9	51.4	57.6	.0	26.5	-77.9	-84.1	16.1	3.9
C24J	24.5	55.5	61.7	.0	26.5	-82.0	-88.2	6.4	1.5
							Totals	321.8	678.9

Total uplink plus downlink noise = 1001 pW0p

Notes: The above calculations show the noise contribution of all other satellites (downlink) and all other earth stations (uplink). Equal earth station and equal satellite EIRPs are assumed. The Interference Reduction Factor is for the baseline system described in the text. Earth station antenna sizes are shown on previous page.

Table 5a. Interference power for 12-transponder systems with antenna mix as proposed

Satellite	Spacing (Degrees)	Antenna Diam. (ft)	Interference (pW0p) Uplink	Downlink	Total
C12A	0.0	32	358	149	507
C12B	3.8	32	361	150	511
C12C	3.8	32	633	259	892
C12D	3.8	32	637	258	895
C12E	3.8	32	703	223	926
C12F	3.8	32	803	237	1040
C12G	2.9	45	520	285	805
C12H	2.9	45	560	272	832
C12I	2.9	45	761	259	1020
C12J	2.9	60	455	216	671
C12K	2.3	60	679	274	953
C12L	2.3	98	126	176	301
C12M	1.5	98	194	258	452

The method for computing the interference is illustrated on the next page for satellite C12F (Table 5b).

Table 5b. Details of Interference Calculations for Satellite C12F

Satellite	Off-Axis Angle from C12F (°)	Ant. Protection Ratio (dB) Uplink (6 GHz)	Ant. Protection Ratio (dB) Downlink (4 GHz)	Polarization Discrimination (dB)	Interference Reduction Factor (dB)	Interference (dBm0p) Uplink	Interference (dBm0p) Downlink	Interference Power (pW0p) Uplink	Interference Power (pW0p) Downlink
C12A	19.0	52.7	49.2	10.0	41.6	-104.3	-100.8	.0	.1
C12B	15.2	50.3	46.8	.0	25.6	-76.8	-73.3	21.0	47.2
C12C	11.4	47.2	43.6	10.0	41.6	-98.8	-95.2	.1	.3
C12D	7.6	42.8	39.2	.0	25.6	-69.3	-65.7	118.7	267.1
C12E	3.8	35.2	31.7	10.0	41.6	-86.8	-83.3	2.1	4.7
C12G	3.8	38.2	31.7	10.0	41.6	-89.8	-83.3	1.0	4.7
C12H	6.7	44.4	37.9	.0	25.6	-70.8	-64.4	82.3	366.0
C12I	9.6	48.3	41.8	10.0	41.6	-99.9	-93.4	.1	.5
C12J	12.5	53.6	44.6	.0	25.6	-80.1	-71.1	9.7	77.0
C12K	14.8	55.5	46.5	10.0	41.6	-107.1	-98.1	.0	.2
C12L	17.1	61.3	48.0	.0	25.6	-87.8	-74.5	1.7	35.2
C12M	18.6	62.2	49.0	10.0	41.6	-113.8	-100.6	.0	.1
						Totals		236.7	802.9

Total uplink plus downlink noise = 1040 pW0p

Notes: See notes on Table 3b. Earth station antenna sizes are shown on previous page.

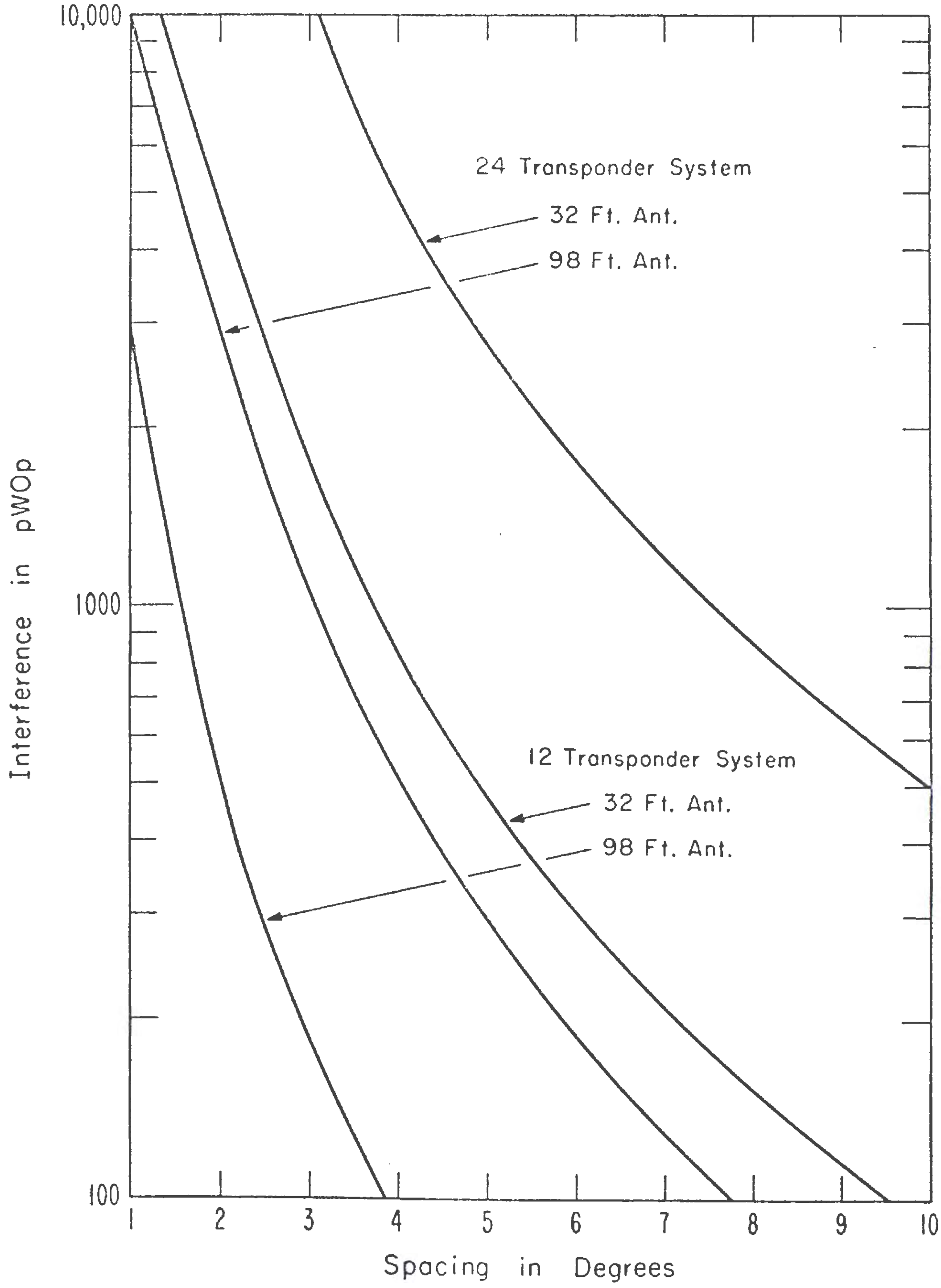
To recapitulate, if the 12 and 24 transponder systems were otherwise homogeneous 1200 voice-channel per transponder systems, all 23 satellites could be accommodated with a mix of earth station antennas representative of those proposed by the applicants.

5.4.4 Spacing vs. Allowable Noise from Interference

The 1,000 pW0p noise limit for uplink and downlink interference is arbitrary as pointed out in section 5.4.1. This 1,000 pW0p is only a portion of an overall, end-to-end objective of 10,000 pW0p for telephone channels. This 10,000 pW0p is also a CCIR recommended value and it must include thermal noise, intermodulation noise, and noise on the terrestrial end links, for example. The thermal noise is the other major source of interference that is a function of earth station/ satellite link parameters. Thus within the 10,000 pW0p overall objective, there is a basic tradeoff between thermal noise and interference noise. The most effective use of the orbit occurs when all noise is budgeted to interference, or stated another way, the systems are interference limited. With the total noise constrained any increase in interference noise must be offset by a decrease in thermal noise, other factors remaining constant. The thermal noise is directly related to cost since decreases are made by lowering receive noise temperatures, increasing transmitter power, or employing larger antennas.

The variation of interference noise as a function of spacing for the 1,200 voice channel, baseline system is shown in figure 5 . It includes curves for both the 12-transponder and 24-transponder systems for 32 and 98 ft earth station antennas.

Figure 5. Interference Noise in Top Telephone Channel vs. Satellite Spacing



5.4.5 Spacing vs. Capacity per Transponder

The "Interference Reduction Factor", which relates the input carrier-to-noise (interference) ratio to the signal-to-noise ratio in the worst case telephone channel in an FDM/ FM system, is a function of the modulation index of the desired signal. The modulation index is limited by the highest baseband frequency, which is a function of the number of voice channels, and the maximum allowable RF bandwidth. With the 40 MHz wide channels, most applicants use a bandwidth of 34-36 MHz. For a constant bandwidth, increasing the number of voice channels (and hence the maximum baseband frequency) must be compensated for by a decrease in modulation index and conversely. The smaller the modulation index, the more susceptible the signal is to interference or, put another way, the smaller the Interference Reduction Factor (IRF). If the interfering signal is also an FDM/ FM signal with the same characteristics the IRF can be computed from the following equation:

$$IRF = 18.8 + 10 \log \left\{ 1 + 9.5 x \left[\frac{1}{\sqrt{10}} \left(\frac{BW}{.0084xN} - 1 \right) \right]^3 \right\} dB$$

where BW is the bandwidth and N is the number of voice channels ($N \geq 240$). This relation was derived from the equations given in the paper by Jansky and Jeruchim (1970). For a bandwidth of 34 MHz the IRF as a function of the number of voice channels is plotted in figure 6 using the foregoing relationship.

The applicants propose capacities ranging from 800 voice channels/ transponder (MCI) to 1320 voice channels/ transponder (Hughes-GTE).* Figure 6 shows that the IRF would vary from 32 dB to 24.5 dB. Between 1200 and 800 the variation is about 6 dB.

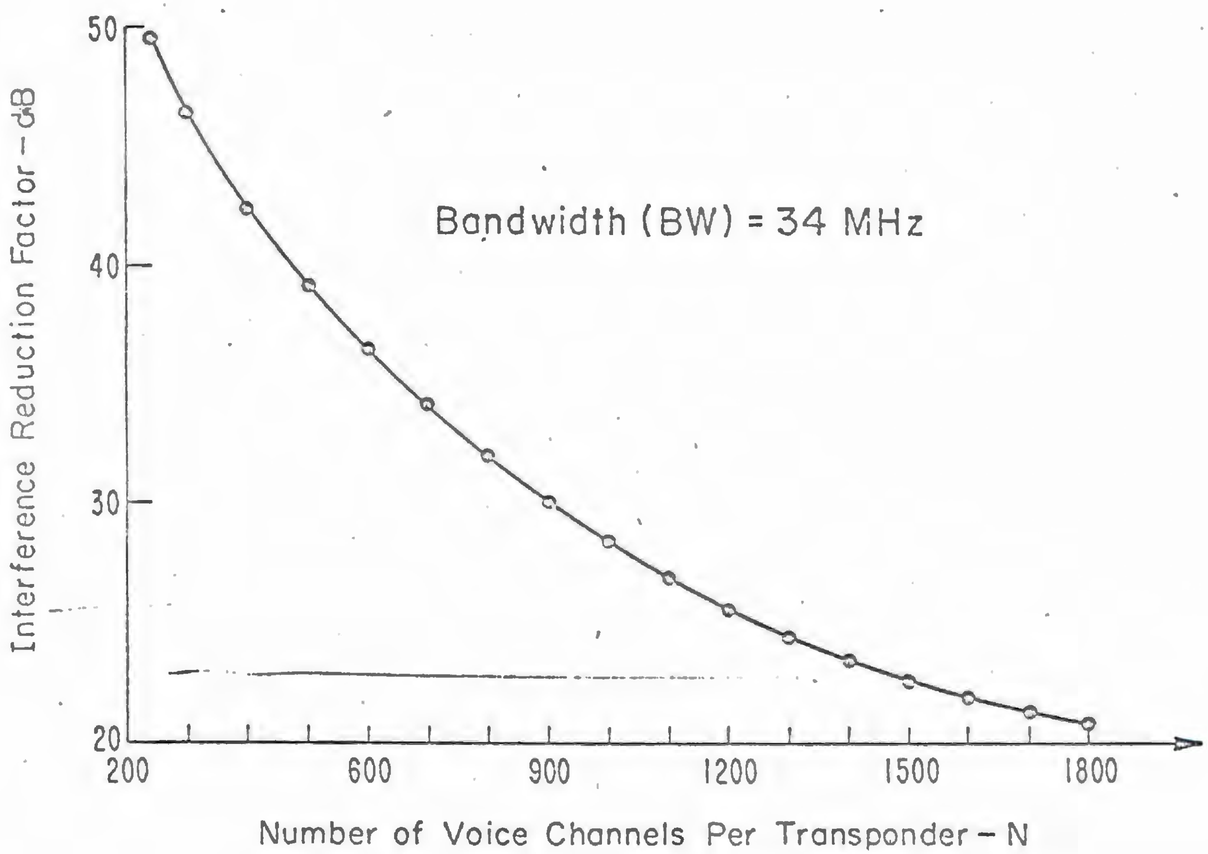


Figure 6. Interference Reduction Factor vs. Number of Voice Channels per Transponder

This means that the noise powers computed with the 26.5 dB IRF for the 1200 channel/transponder would be reduced by a factor of 4 for an 800 channel system. This is equivalent to doubling the earth station antenna diameters, allowing the interference noise budget to increase to 4000 pW0p, or changing the spacing from 3.1° to less than 2° for the 24 transponder systems using 98 ft antennas.

5.4.6 Spacing and EIRP Differences

The difference between the EIRP of the desired and undesired satellite appears in the relationship for downlink interference shown in section 5.4.2. Similarly, the difference between the EIRP of the desired and undesired earth station appears in the uplink case. If these differences are not zero (i.e., if the systems are not homogeneous in this respect), the required spacing is increased. This can be seen by the following example. Suppose two homogeneous systems were using adjacent orbital positions at a spacing such that the total noise in the worst-case telephone channel of each system was 1,000 pW0p and suppose 333 pW0p of this was in the uplink. Now consider the situation where one system increases its earth station power by a factor of 10 (10 dB) so that its EIRP is also increased by a like amount. Its uplink carrier-to-interference ratio would be increased 10 dB so that its uplink noise would be decreased to only 33 pW0p. But the carrier-to-interference ratio on the uplink of the other system would decrease 10 dB resulting in an uplink noise of 3,330 pW0p - or a total of 4,000 pW0p which is 6 dB over the 1,000 pW0p objective. Thus for <u>both</u> systems to meet the objective, the orbit spacing must be increased. A similar argument can be made for the downlink case.

As noted in section 3, the satellite EIRPs are fairly uniform at about 36 dBw in the main beam because of the maximum power flux density limits imposed by international regulations. The earth station EIRPs, on the other hand, vary widely. AT&T proposes an EIRP of 93 dBw using 100 ft antennas while Fairchild proposes an EIRP of 73 dBw with the same size antenna - a 20 dB difference. Fairchild incorporates higher gain, spot beam antennas on their satellite which decreases significantly the earth station EIRP requirements. Since AT&T and Fairchild both propose earth stations in some common metropolitan areas (e.g., New York City), the additional satellite antenna directivity will not aid in reducing this 20 dB greater interference. The remainder of the applicants propose a more uniform technology but the variation in earth station EIRPs is still 10 dB.

The increase in spacing due to this variation can be minimized by grouping like systems in the same part of the orbit.

5.4.7 General Analysis Summary

To summarize section 5, it has been shown that (a) the average spacing required to accommodate all 23 of the U.S. and Canadian satellites is not inconsistent with the spacings analyzed and proposed in the applications, and (b) a mix of thirteen 12-transponder and ten 24-transponder satellites, with parameters representative of the systems proposed, can be accommodated in the available orbit.

6. ORBIT CAPACITY RELATIVE TO INDICATED DEMAND

With 24-transponder systems, a 1000 pW0p noise objective, 1200 voice channels per transponder, 98 ft earth station antennas, and homogeneous parameters, 27 satellites could be accommodated in the 85° of available arc. Thus using just 4/6 GHz, 648 transponders (27x24) could be placed. Including a like number of transponders at 12/13 GHz would double this, making a total of 1296, 40 MHz transponders. Approximately twice as many 12-transponder satellites using 4/6 GHz could be accommodated so that the orbit capacity would be the same.

The analysis in a report by Stanford Research Institute (Allan, et al., 1971) indicates that the expected demand for transponders by the mid-1970s is about 100. Using the 4/3 ratio of active to in-orbit spare satellites represented by the applications, the total U.S. requirement is 175 transponders. Adding Canada's requirement for 36 transponders gives a total of 211 transponders which is only 32% of the number that could be accommodated using just 4/6 GHz and only 16% of those that could be accommodated if the higher bands were included. Furthermore, since 3/7 of these are in-orbit spares, the demand for active or primary transponders requires only 14% and 7%, respectively. Even if the useful arc is considered to be just 70° to insure that elevation angles are greater than 10° in the contiguous U.S., these figures would only change to 17% and 8%, respectively.

Since the ultimate capacity so vastly exceeds the indicated demand, the scarcity of the orbit/spectrum resource is not a compelling consideration at this time. In fact, there is sufficient capacity that systems with varying designs to suit specialized applications can be accepted and later entrants could be accommodated.

7. CAPACITY PROPOSED AND OTHER FACTORS AFFECTING ORBIT REQUIREMENTS

The total initial capacity proposed by the applicants is 588 transponders (336 active and 252 spare) using figures from the SRI report. Adding the Canadian transponders produces a total of 624; but 96 of these use higher bands, leaving a total of 528 which must be accommodated at 4/6 GHz. This is within the capacity indicated in section 6, from which it can be concluded that all 624 proposed transponders could be immediately accommodated in the unlikely event that all systems are built.

Any residual concern about the practicality of accommodating all applicants is at least partially alleviated by the following:

1. It may prove most economical for successful applicants to share orbiting spares and/or to enter into agreements calling for other applicants to handle the service of a system experiencing a major failure - thereby decreasing the number of secondary/spare satellites in orbit. This would seem especially true in view of the proposed supply and indicated demand.
2. Only 11 of the proposed satellites are designated as "primary" and less interference protection could be given to "secondary" satellites.
3. There is some flexibility of moving the satellites in orbit to reduce interference on a case-by-case basis.
4. The possibilities of using other bands has not been fully exploited.
5. The Canadian system has satellite antennas covering a different geographic area, and this should diminish the sharing problem with them. This was not included in the foregoing analysis.

6. There may be certain operational procedures and detailed engineering design improvements (e.g., better antenna sidelobe suppression) that can be pursued.

9. REFERENCES

Bradley, W.E., Communication strategy of geostationary orbit, Astronautics and Aeronautics, Vol. 6, No. 4, April 1968.

Hult, J.L., et al., The technology potentials for satellite spacing and frequency sharing, Memorandum RM-5785-NASA, the Rand Corporation, October 1968.

Beyer, J.P., et al., Some orbital spacing considerations for geostationary communications satellites (Using the 4 and 6 GHz frequency bands), COMSAT Report DS-1-68, October 1968.

Jansky, D.M. and M.C. Jeruchim, Technical factors and criteria affecting geostationary orbit utilization, Communication Satellites for the 70's: Systems, edited by N.E. Feldman and C.M. Kelly, MIT Press, 1971.

Jeruchim, M.C. and T.C. Sayer, Orbit/spectrum utilization study - Interim Report, Doc. No. 69SD4270, General Electric Co., 1969.

Jeruchim, M. C. and D. A. Kane, Orbit/spectrum utilization study - Vol. IV, Doc. No. 70SD4293, General Electric Co., 1970

Satellite

SC 15

OFFICE OF TELECOMMUNICATIONS POLICY
EXECUTIVE OFFICE OF THE PRESIDENT
WASHINGTON, D.C. 20504

March 20, 1972

Mr. Dale Hatfield
Office of Telecommunications
Department of Commerce
Boulder, Colorado 80302

Dear Dale:

Mr. Hinchman has asked me to advise you that we have released your Domestic Satellite study, and those of SRI and RossTec, through the National Technical Information Service. I spoke to your secretary on Friday and indicated to her that the report had been made available.

I am enclosing a copy of the Press Release which we sent out announcing the release of the studies.

Also enclosed is a copy of one of the letters we sent out requesting agenda items for the Pacific Telecommunications conference about which we spoke on Tuesday--this is just for your information and to keep you advised on how we're progressing toward the conference.

If you have any questions either about the press release or the Pacific conference, please give me a call.

Sincerely,

Tom

Thomas M. Mustin

Enclosures

FOR IMMEDIATE RELEASE

FFICE OF TELECOMMUNICATIONS PC Y
EXECUTIVE OFFICE OF THE PRESIDENT
WASHINGTON, D.C. 20504

March 17, 1972

NEWS RELEASE

OTP RELEASES DOMESTIC SATELLITE STUDIES

The Office of Telecommunications Policy today released the results of three studies on domestic satellite communications. The studies, conducted for OTP by the Stanford Research Institute, Ross Telecommunications Engineering Corporation, and the Commerce Department's Office of Telecommunications, address technical and economic aspects of the several applications for domestic satellite systems now pending before the FCC, and the implications of these factors for the organization, operation, and regulation of the domestic satellite industry.

Walter Hinchman, OTP Assistant Director, noted in releasing the studies that their findings further support the Administration's view that multiple domestic satellite systems can be economically viable on a competitive basis and can be made technically compatible with one another and with existing and future terrestrial systems, with minimal regulatory controls.

Summary conclusions from the three OTP reports are attached. The complete texts of these reports may be examined at the OTP offices, and copies will be available from the National Technical Information Service, U.S. Department of Commerce near the end of April 1972. For those interested in obtaining further information or copies, the exact titles are:

"Economic Viability of the Proposed United States Communications Satellite Systems," Stanford Research Institute.

"A General Analysis of Domestic Satellite Orbit/Spectrum Utilization," Policy Support Division, Office of Telecommunications, U.S. Department of Commerce, Boulder, Colorado.

"Analysis of Earth Station Siting for the Proposed Domestic Satellite Systems," Ross Telecommunications Engineering Corporation.

OTP Studies* on Domestic Satellite Communications
Principal Conclus 1s

ECONOMIC

- o The data presented in the FCC applications for the several systems proposed show no clear indication of substantial economies of scale that would suggest a tendency to natural monopoly. Indicated unit costs are comparable for large and small systems of the same type and there are apparent economies of specialization for several of the proposed services which would offset any claimed economies of scale. Systems of substantially different types differ in function, performance, and probability of successful deployment and thus are not directly comparable on an economic basis.

- o The potential market for domestic satellite services in the near future, though substantial, will probably support several but not all of the proposed systems as presently envisioned. There is an apparent near-term market for 89-163 broadband satellite channels (transponders), whereas the total operational capacity of all proposed systems would be 336 transponders, with additional back-up capacity of 252 transponders.

- o The total market includes several sectors that are relatively insulated from one another (e.g., public message telephone traffic, broadcast and cable video interconnection, and various leased-line services), each of which could be served economically by a different operator.

- o More than one satellite operator may be expected to compete on a continuing basis for the leased line market, and to a more limited extent for the other market sectors.

- o Under a policy of open entry at least two, and probably three or more, separate systems would likely be established, having a combined capacity in excess of 100 channels (transponders) plus 50 or more back-up transponders. Each of these systems would likely incorporate an independently viable basic service offering (e.g., PMTS, video interconnection etc.) combined with competitive leased-line offerings.

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* "Economic Viability of the Proposed United States Communications Satellite Systems," Stanford Research Institute.

"A General Analysis of Domestic Satellite Orbit/Spectrum Utilization," Policy Support Division, Office of Telecommunications, U. S. Department of Commerce, Boulder, Colorado.

"Analysis of Earth Station Siting for the Proposed Domestic Satellite Systems," Ross Telecommunications Engineering Corporation.

- A policy of open entry can be expected to result in a viable competitive industry, with return on capital commensurate with risks. However, there is little solid evidence regarding the specific structure this industry would take, which will be affected by differences in technology, design concept and configuration, comparative market strategies, and consortia arrangements not readily apparent at this time.

TECHNICAL

- The average spacing of 3.7° required to accommodate all 23 of the initial U. S. and Canadian satellites in the relevant sector of the geostationary orbit (i.e., 53° - 138° W) is not inconsistent with the spacings proposed and analyzed in the applications.

- A general analysis indicates that 23 satellites with characteristics typical of those proposed could be accommodated, although minor adjustments in some system parameters might be necessary in the unlikely event that all systems were fully deployed.

- The ultimate capacity of the available geostationary orbit using (and reusing) 2000 MHz of spectrum vastly exceeds the indicated initial demand; thus, scarcity of this resource is not a compelling issue in policy determination.

- The siting of earth stations near large metropolitan areas in the manner proposed by the various applicants is feasible from an interference standpoint.

- Although the applicants did not coordinate specifically for off-path interference, this type of potential interference has been taken into account to some degree in the coordination for possible great-circle interference, since the terrestrial microwave facilities most likely to cause both types of interference are the same.

- For all cases of great-circle interference problems as represented by the applicants, there are viable techniques available for controlling the level of interference within acceptable limits.

- The installation of earth stations for several applicants in a certain area would not produce accumulative interference effects beyond those anticipated in the development of acceptable interference criteria by the CCIR.

- The installation of earth stations for several applicants in a certain area would not produce accumulative interference effects beyond those anticipated in the development of acceptable interference criteria by the CCIR.

April 3, 1972

MEMO

To: R. K. Salaman

From: D. N. Hatfield DNH

Subject: Telephone calls from Seb Lasher and Tom Mustin, OTP, March 28, 1972

I think it might be useful if I briefly summarized the subject telephone conversations.

1. Seb requested that we do some additional work on the DOMSAT issue. As you are aware, the FCC staff recommendations are for a modified open entry policy. OTP apparently feels that this would have many of the disadvantages of both open entry and monopoly but the advantages of neither. The staff recommendations would allow COMSAT to provide satellites to AT&T or have satellites of their own to compete in the remainder of the market--but not both. Seb reasons that COMSAT will choose the latter for numerous reasons. This will leave AT&T with three choices: (a) go to another supplier, (b) own and operate their own, or (c) enter into a joint ownership agreement with COMSAT. Seb notes that (a) would not be attractive and (b) would force them to be a second round entrant with considerably more requirements to show "public necessity." This leaves (c) which Seb feels is the loophole in FCC recommendations. He and Walt would like an economic analysis of this latter arrangement, particularly with regard to the very large earth stations that would be required. Seb's tentative position is that this is hardly different than the current (proposed) situation with separate AT&T and COMSAT systems. If it makes little economic difference then why require it? It has many disadvantages (redesign, revised proposals, delay, etc.). Any economic difference would be in terms of earth station economies of scale. This is the question we are to address.

2. Tom's call was in regard to the Pacific communications study. The agenda for the first meeting with the representatives from Alaska, Hawaii, and the Dept. of Interior (Pacific Trust Territories) isn't firm yet, but to allow us to get as much lead on the problem as possible,

4-3-72

Memo to RKS

Walt and Tom have identified several possible tasks for us. These include:

A. Identifying communication service requirements and highlighting areas of communication concern.

B. Identifying gaps and excessive supply (or plans) in current or planned facilities/services.

C. Surveying technical options (and relevant costs) which might serve the markets previously identified.

D. Providing a time phased schedule (PERT?) of communications support for the Pacific area over the next decade.

Nick is doing a background study on the Trust Territories for us and Sharon's work should also be useful. We also have the OT Hawaiian and Alaskan studies as background.