TECHNICAL CONSIDERATION OF FEEDER LINKS TO BROADCASTING SATELLITES

Prepared By: Telesat Canada
Communication
Systems Engineering

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PREPARED BY: Telesat Canada
Communication Systems Engineering Division
333 River Road
Ottawa, Ontario
K1L 8B9

DEPARTMENT OF SUPPLY AND SERVICES CONTRACT NO: OST82-00146

DOC SCIENTIFIC AUTHORITY: Dr. Marcel Bouchard
Communications Research Centre
Shirley's Bay
P.O. Box 11490, Station "H"
Ottawa, Ontario, Canada
K1A 8S2

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1.0 INTRODUCTION

In the past decade, broadcast undertakings in Canada have made use of Telesat Canada's facilities in the Fixed Satellite Service (FSS) for both network distribution and program collection. With the recent introduction of Cancom and Pay Television services, viewers in those remote regions where cable systems exist, have access to a program choice similar to that available in the heavily populated regions where a large infrastructure of VHF and UHF transmitters exists. Recently, technology trends have resulted in a marked reduction in the cost of receive only earth stations, to the extent that many individuals now own and operate such private receive stations in the FSS.

Nevertheless, the limited EIRP of FSS space stations results in earth stations of sufficient complexity that only a limited number of Canadians would be willing, or able, to install them. With the introduction of space stations in the Broadcast Satellite Service (BSS), characterized by high EIRP, the complexity and cost of the associated earth stations will be reduced, to the extent that universal accessibility to the service will be achievable.

Telesat has long maintained an interest in the BSS and has taken an active part in the preparation of Canadian proposals for the ITU's RARC '83, at which time a plan for the BSS in Region 2 will be adopted. In this report, we have drawn on Telesat's experience as the operator of Canada's FSS system and also on our work in the BSS RARC '83 studies, to consider some technical aspects of feeder-links to the BSS.

The organization of this report is somewhat different from the breakdown by task contained in the Statement of Work. In order to successfully treat some of the technical questions raised in the Statement of Work, it was necessary that all engineers working on the project be working to a consistent system model. Accordingly, a set of assumptions was agreed upon. These assumptions are outlined in Chapter 2 and deal, not only with the satellite and downlink earth segment characteristics, but also with the number of satellites and their coverage areas, channelization plans and performance requirements.

Feeder-link earth stations are considered in some detail in Chapter 3. The characteristics assumed for both fixed uplinks, located at major broadcast centres, and transportable uplinks, are discussed. Such practical areas as antenna pointing and power-handling capability, where Telesat's experience in the FSS is relevant, are included.

Chapter 4 is the key chapter of the report. Major concerns regarding the performance and reliability of the feeder-link, such as propagation, eclipses and equipment reliability, are treated. The results of our work in these areas, combined with the assumptions and characteristics outlined in Chapters 2 and 3, form the basis of link budget and reliability calculations. The results of these calculations indicate the degree to which the performance requirements may be met, given the system model.

Chapter 5 deals with the frequency sharing constraints due to the allocation of the 17.7 to 17.8 GHz portion of the feeder-link frequency band to the Fixed Service and FSS, also on a primary basis.

Finally, Chapter 6 presents a summary of the findings of our work and our conclusions. Suggestions of areas where further study seems warranted are also included.

2.0 SYSTEM MODEL ASSUMED

In order to assess feeder-link performance and reliability, a model for the entire broadcasting satellite system is required. This chapter outlines the assumptions made for the study. For the most part, values adopted at the CPM [1] have been used. In some cases, characteristics have been assumed that Telesat feels would be reasonable for a first generation Canadian BSS.

2.1 Number of Satellites and Orbital Positions

Two different satellite scenarios have been assumed for this study. These scenarios correspond to possible interim arrangements for satellites in the BSS in Canada.

The first model, consisting of two satellites located at 105°W and 135°W, respectively, is within the range of orbital allocation suggested by the Scientific Authority. In this model, each satellite has three beams. With reference to Figure 2.1.1, the spacecraft at 135°W provides the CAN1, CAN2 and CAN3 beams, whereas that at 105°W provides CAN4, CAN5 and CAN6 beams. The points defining the boundaries of each beam are given in the Canadian statement of BSS requirements which was recently submitted to the IFRB [2]. The locations of the satellites were selected such that they are both to the west of their respective illumination zones. This reduces the effect of solar eclipses by causing their occurrence to be delayed until after local midnight.

The second model contains three satellites located at 85°W, 105°W and 135°W. In this model, each satellite has two beams; the satellite at 135°W provides the CAN1 and CAN2 beams, while the satellites at 105°W and 85°W provide the CAN3, CAN4, and CAN5, CAN6 beams, respectively. Although this model calls for a spacecraft outside of the orbital

Figure 2.1.1: Boundaries of the downlink beams (CAN1, CAN2, CAN3, CAN4, CAN5 and CAN6) covering Canada

range suggested by the Scientific Authority, it was felt that a satellite at 85°W would considerably reduce the sensitivity to rain fade of the east coast provinces, while the solar eclipse would still be delayed until after local midnight within its coverage area.

2.2 Uplink Coverage

2.2.1 Introduction

Direct access to broadcasting satellites from outside the corresponding downlink service area in a multi-beam system, such as proposed for the Canadian system, provides a desirable flexibility for the broadcasting of national programmes. The Canadian system may require two types of channels: regional channels accessible only from within the corresponding downlink service area and national channels accessible from inside and/or outside the corresponding downlink service area [3]. If direct access to national channels is required from anywhere within the country, a country-wide uplink coverage area is needed.

National programming could also be distributed to regional centres by the use of techniques other than country-wide uplink coverage. For example, national channels could also be accessed using the fixed satellite or terrestrial microwave networks for the distribution of the national programs to regional centres, whence they would be uplinked to the broadcasting satellite system. However, indirect access to broadcasting satellites reduces flexibility. In addition, this type of distribution would be costly and may not result in effective utilization of the orbit and the frequency spectrum, [3].

It is to be noted that when the feeder-link service area is larger than the corresponding downlink service area, feeder-link isolation considerations may determine the minimum separation between satellites. This problem is beyond the scope of the present study. It is addressed in [4] and [5].

2.2.2 Spacecraft Receive Antenna

The spacecraft receive antenna may be implemented in a number of different ways, depending on requirements. These include, separate fixed aperture, separate pointable aperture, common aperture, separate feeds and common aperture shared feeds. Antenna gain for the Canadian BSS would depend on the type of coverage, with higher gain for spot beam than country-wide coverage. For strong technical reasons, a separate aperture for the uplink coverage pattern is recommended [6]. In this way, the uplink and downlink beam patterns can each be optimized over a single band, resulting in higher efficiencies and better beam shaping capability.

Nationwide coverage implies a relatively low G/T for the Canadian BSS. Two approaches have been suggested for this study. In the first approach, coverage similar to Anik D is assumed, whereby there exists relatively low gain over all Canada and only about 3 dB gain variation between beam centre and edge of coverage in the North. Alternatively, coverage similar to Anik C may be assumed. Such coverage is characterized by high gain over the southern portion of Canada (the probable location of fixed feeder-links) but a fast gain roll-off towards northern Canada, resulting in low gain for the sparsely populated area north of 60° latitude. Although uplink access to the BSS from the northern area is infrequent, it is desirable.

Telesat suggests that one possible means of providing northern coverage is to provide a steerable spot-beam. This could be achieved by a moveable receive (17 GHz) feed horn arrangement associated with the transmit (12 GHz) reflector. The large size of the 12 GHz reflector would provide a spot beam of high directivity. This, coupled with the moveable feed horns, would provide a scanning spot beam for northern uplink coverage, under control from the satellite TTAC earth station. The feeder-link from the North would probably employ a transportable earth station for broadcasting special events. The size of the transportable earth station antenna would be limited by the required simplicity of the system and it would probably be about 3m in diameter. In addition, the size of HPA would be limited by the available AC power. The higher directivity of the spot beam could easily compensate for these limitations of a transportable terminal. The feasibility of this scheme has been discussed with A. Raab of Antech Antenna Technologies Ltd. Mr. Raab feels the approach should work in principle, and that there should not be serious cross-polarization degradation if the beam is scanned for only a few beamwidths. Further study of the scheme is beyond the scope of this contract.

2.2.3 Coverage Area from Different Orbital Locations

The antenna coverage area depends on the longitudinal difference between the spacecraft orbital location and the centre of the coverage area. The larger the difference between the two, the smaller the antenna beamwidth required to cover the area. Table 2.2.1 shows the approximate required antenna beamwidth to cover Canada up to 70°, 60° and 55° north latitude. The last two latitudes indicate Anik C type of coverage.

An examination of the beam areas to be scanned by the proposed spot beam shows that the scanning angle for a beam with about 1° beamwidth (approximate beamwidth of the 1.5m x 1.14m transmitting antenna proposed in [6]) would be about six beamwidths. One method of avoiding serious cross-polarization discrimination (XPD) degradation would be to use two horns, one for scanning three beamwidths in the east and the other one to scan the rest of the northern strip.

2.2.4 BSS Satellites

From an economical point of view, the BSS satellites, in either the two or three satellite model, should be as similar as possible.

It is suggested that the uplink antenna system be optimized for the satellite at 135°W. The satellite at 135°W has the smallest uplink beamwidth and therefore the highest antenna gain. Using the same antenna system for the satellites at 105°W and 85°W indicates a slightly faster roll-off of the antenna gain above 50° - 55° north. However, larger elevation angles to these satellites from Eastern Canada, together with lower precipitation, would adequately compensate for the drop of the antenna gain in that region.

Satellite Position °W	Beam Area Covering Up To 70°N	Beam Area Covering Up To 60°N	Beam Area From 60°N - 70°N (Covered by Spot Beam)	Beam Area Covering Up To 55° N	Beam Area From 55° - 70° North (Covered By Spot Beam)
85°	1.8° x 8.5°	1.4° x 8.5°	0.6° x 8.5°	1.° x 8.5°	0.8° x 6.2°
105°	1.9° x 8.4°	1.4° x 8.4°	0.5° x 5.7°	1.1° x 8.4°	0.8° x 6.5°
135°	2.1° x 6.1°	1.4° x 6.1°	1.1° x 6.1°	0.7° x 4.6°	1° x 5.3°

Table 2.2.1: Beam areas for different types of coverage and for three satellite orbital locations. The Northern areas covered by the scanning spot beam are also shown in the Table.

2.2.5 Conclusion

The Canadian broadcast satellite system will likely require a direct access to the BSS satellites from anywhere within the country and, therefore, a nationwide uplink service area is needed.

In general, two types of coverage have been suggested here. In the first type, coverage similar to Anik D is assumed, whereby there exists relatively low gain over all Canada and less than 3 dB gain variation between beam centre and edge of coverage in the North. If the Anik D antenna were scaled down for 17 GHz applications, its G/T at the edge of coverage would be about -2 dB/K when T=1500K. Furthermore, the antenna may be shaped to give a higher G/T for eastern Canada where high rain rates are more likely.

Anik C type of coverage was suggested as an alternative. Such a coverage is characterized by high gain over the southern portion (up to 55° - 60° north) with a fast gain roll-off above this latitude. This type of coverage would increase the uplink fade margin. A G/T of about 0 dB/K would be obtained at the edge of the coverage area. Again, the antenna pattern may be shaped to give higher gain for Eastern Canada.

For coverage north of about 55° it is proposed to use a movable receive (17 GHz) feed horn together with the large transmit reflector to create a spot beam with a relatively high directivity. This would provide a scanning spot beam for northern uplink coverage under control of the satellite TTAC earth station. Since the uplink transmission from the North would be infrequent, the reliability of the overall system might not be affected significantly. However, the higher gain of the spot beam could compensate for the limitations of a transportable earth station, which would likely be used in the North.

The subject of a moveable feed should be studied in more detail to determine all mechanical and electrical aspects of this approach.

Finally, any locations in southern Canada with longitude east of about 58° are not visible to a satellite located west of 135°W. For these locations, a feeder-link could be provided to another BSS satellite (e.g. the one at 105°W), to a central earth station location and from there back to the satellite at 135°W. An alternative approach would be the use of the Fixed Satellite Service (FSS) for the purpose of double hopping.

2.3 Downlink Beam Arrangement

The downlink beam arrangements are as follows:

- in the two satellite models, the satellite at 135°W provides the CAN1 (BC), CAN2 (Alta. & Sask.) and CAN3 (Man.) beams while the satellite at 105°W provides the CAN4 (Ont.), CAN5 (Que.), and CAN6 (Maritime) beams;
- in the three satellite model, two beams are provided from each position as follows:

Satellite Position		Service Areas
135°W	-	CAN1, CAN2
105°W	-	CAN3, CAN4
85°W	-	CAN5, CAN6

2.4 Multiplexing/Polarization Arrangement

Considerations and assumptions concerning the RARC frequency plan and consequential multiplexing and polarization arrangements are discussed below.

2.4.1 RARC Frequency Plan

It is assumed that the RARC Frequency plan will provide 36 channels, each having 24 MHz bandwidth. The channel spacing would be 14.6775 MHz, with provision being made for lower and upper guardbands of 9 and 12 MHz, respectively, in an allocated bandwidth of 500 MHz.

The 14.6775 MHz channel spacing would result in relative protection ratios of -12 dB and -44.5 dB for the adjacent and alternate channels, respectively, based on Sec. 5.1.7.2 of the CPM Report. For a single entry co-channel protection ratio of 35 dB, the adjacent channel protection ratio would therefore be 23 dB while the alternate channel protection ratio would be -9.5 dB. Since there are two adjacent and alternate channels, the single entry protection ratios would be 3 dB higher, i.e. 26 and -6.5 dB, respectively.

2.4.2 Multiplexing/Polarization Arrangements

Two alternatives can be considered for multiplexing/ polarization arrangements, depending on the maximum number of channels that are required in each service area. These arrangements are constrained, since a Canada coverage feeder-link can accommodate only 36 channels.

The alternatives given below are based on the use of only a single polarization within each service area for an interim or initial DBS system. The use of both polarizations within each service area would provide greater initial capacities.

The first alternative is based on the use of a single polarization with the 36 channels divided, presumably equally, amongst the downlink beams. For example, the 18 channels on Polarization A in a 36 channel PLAN would provide a maximum of six channels per BSS service area for the two-satellite model and nine channels per BSS service area for the three-satellite model. In both cases, the 18 feeder-link channels would also be on a single polarization.

It is to be noted that these capacities would be doubled if both polarizations were used in each service area.

The second alternative is based on the use of dual polarization and division of the PLAN channels between the beams. In this case, the two satellite model would have a maximum capacity of nine channels in each service area (assuming equal capacity in each service area) with two of the beams using one polarization while the opposite polarization is used in the third beam. For the three-satellite model, this alternative would provide 18 channels in each BSS service area. This alternative would require the use of both polarizations for the feeder-links.

If dual rather than single polarization is used within each service area, the capacities for this alternative are the same as for dual polarization in alternative 1.

2.5 Satellite Characteristics

The assumed spacecraft characteristics for feeder-link reception and BSS transmission are identified below.

2.5.1 Feeder Link Receive Characteristics

The assumed satellite receive characteristics are as follows:

- Receiving System noise temperature (Ts)
  Ts=1500 Kelvins

- Figure of merit (G/T) at Edge of the Service Area (EOS) $G/T = -2.0\ dBK^{-1}$ at EOS

- Relative antenna gain at EOS with respect to boresight gain (G):

  $$G = -3.0\ dB$$

- Satellite receive antenna radiation pattern: The CPM reference pattern for a single feed transmitting antenna was also used for the receiving antenna. (See Figure 2.5.1).

2.5.2 Satellite Transponder Input/Output Characteristics

It is assumed that AGC is used in the satellite to maintain the transponder output power at saturation for a fade up to A_o dB. For fades greater than A_o dB, typical TWT input/output characteristics are assumed. A value of 10 dB has been assumed for A_o.

The output backoff, B_o, in dB for an input fade, A, in dB is taken as:

$$B_o = 0 \qquad ; \quad A \leqslant A_o$$
$$= \left(\frac{A-A_o}{5}\right)^2 \qquad ; \quad A_o < A \leqslant A_o + 10$$
$$= A - A_o - 6 \qquad ; \quad A > (A_o + 10)$$

Where A_o = Max AGC range (10 dB).

2.5.3 BSS Transmit Characteristics

The assumed satellite transmit characteristics are as follows:

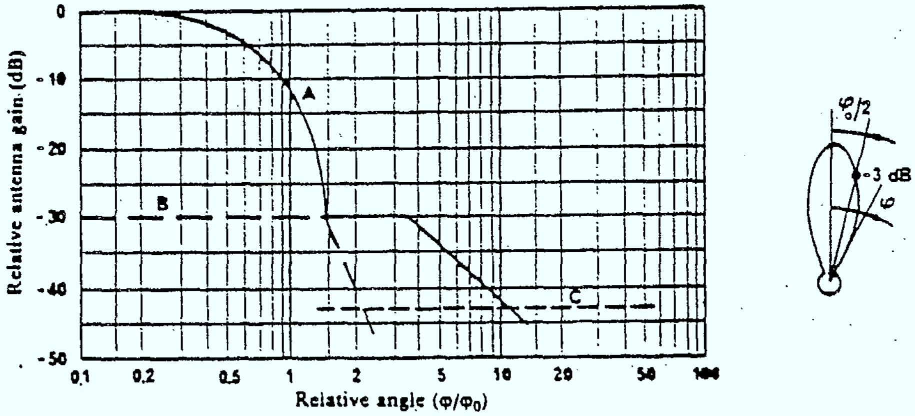


FIGURE 2.5.1 *Reference patterns for co-polar and cross-polar components for a single-feed satellite transmitting antenna producing a beam of circular or elliptical cross-section*

Curve A: Co-polar component (dB)

- $-12\,(\varphi/\varphi_0)^2$ for $0 \leq \varphi \leq 1.58\,\varphi_0$
- -30 for $1.58\,\varphi_0 < \varphi \leq 3.16\,\varphi_0$
- $-[17.5 + 25\log(\varphi/\varphi_0)]$ for $3.16\,\varphi_0 < \varphi$

After intersection with Curve C: as Curve C

B: Cross-polar component (dB)

- -30 for $0 \leq \varphi/\varphi_0 \leq 1.56$
- $-(40 - 40\log|(\varphi/\varphi_0) - 1|)$ for $1.56 < \varphi/\varphi_0$

After intersection with Curve C: as Curve C

C: minus the on-axis gain (dB)

- EIRP at the Edge of Service Area (EOS):

  $$EIRP = 54.7 + A_1$$

  where A_1 = rain attenuation exceeded 1% of the worst month.

- Relative antenna gain at EOS with respect to boresight gain (ΔG):

  $$G = -4.3 \text{ dB.}$$

- Satellite transmit antenna radiation pattern: The CPM reference pattern [1,(Sec 5.1.10.1)] was used (see Figure 2.5.1).

2.6 Receive Earth Station Characteristics

2.6.1 Receive Antenna Reference Patterns

Design of the earth station receiving antenna involves a trade off between antenna efficiency (gain) and suppression of side-lobe levels. Figure 2.6.1 shows the Canadian proposal on reference patterns for co-polar and crosspolar components for receiving antennas, as given in the CPM report. The pattern is currently under study and there are proposals for changes to the far out sidelobes. However, the reference patterns given in Figure 2.6.1 have been assumed for the present study.

2.6.2 Receive Earth Station Figure-of-Merit (G/T)

The calculation of figure-of-merit (G/T) for a receiving earth station can be done using the equation.

$$G/T = \frac{a\ b\ Gr}{a\ T_a + (1-a)\ T_a + (n-1)\ T_o}$$

Where:

a: the efficiency of the feed between the antenna feed structure and the input of the low noise receiver. For the design where the first stage amplifier is at the focal point of the reflector, as used in many low cost designs, the efficiency is very high and a= 0.975 (equivalent to 0.1 dB loss);

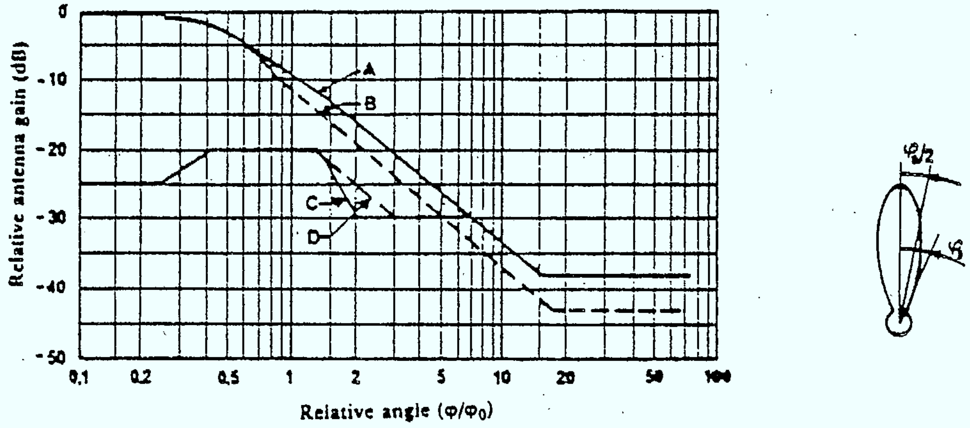


FIGURE 2.6.1 *Reference patterns for co-polar and cross-polar components for receiving antennas for individual reception in Region 2*

Antenna diameter : D = 1 m
Half-power beamwidth : φ_0 = 1.8°
Nominal on-axis gain : G_0 = 40.2 dB

Curves A : Co-polar component without side-lobe suppression (WARC-BS-77)
B : Co-polar component without side-lobe suppression (suggested)

0	for	$\varphi \leq 0.25\ \varphi_0$
$-12(\varphi/\varphi_0)^2$	for	$0.25\varphi_0 < \varphi \leq 0.94\ \varphi_0$
$-[11.3 + 25 \log\ (\varphi/\varphi_0)]$	for	$0.94\varphi_0 < \varphi \leq 18.88\varphi_0$
-43.2 dB (-3dBi)	for	$\varphi > 18.88\varphi_0$

C : Cross-polar component (WARC-BS-77)
D : Cross-polar component (suggested)

-25	for	$0 \leq \varphi \leq 0.25\varphi_0$
$-[30 + 40 \log\lvert(\varphi/\varphi_0) - 1\rvert]$	for	$0.25\varphi_0 < \varphi \leq 0.44\varphi_0$
-20	for	$0.44\varphi_0 < \varphi \leq 1.28\varphi_0$
$-[17.3 + 25 \log\lvert(\varphi/\varphi_0)\rvert]$	for	$1.28\varphi_0 < \varphi \leq 3.22\varphi_0$

- 30 until intersection with co-polar component curve; then as for co-polar component

Note 1. - The flat portion of the curves up to φ/φ_0 = 0.25 takes account of the pointing error of the antenna.

Note 2. - These patterns should determine the levels exceeded by 10% of the side-lobe peaks beyond the first antenna side-lobe.

b: The factor which takes into account the antenna mis-pointing and aging of the receiver system. As reported to CCIR, b might be as low as 0.590. (i.e. -2.3 dB) for earth station receivers in the 1 metre class. In the present study, antenna mispointing loss is assumed to be 1 dB, equivalent to a 0.5° pointing error of the antenna.

Gr: the receiver antenna gain = 40.1 dBi, (a diameter of 1m and an antenna efficiency of 60% are used).

T_a: the effective temperature of the antenna, the contribution due to the background. In clear-air conditions, Ta will be quite low (in the order of 30K depending on the elevation angle). However, during heavy rain conditions Ta will increase significantly. A value of 150K is frequently used. This includes antenna temperature degradation for a rain fade of up to 2 dB.

T_o: the reference noise temperature = 290K

n: the overall noise figure (expressed as a power ratio) of the receiving noise system. Canada is proposing the use of a 4 dB noise figure in the BSS plan.

Based on the values of these parameters, the G/T of the receiving earth terminal would be 10 dB (K^{-1}). In this study, this G/T value was used, as requested by the Scientific Authority. However, the assumption of a 4 dB noise figure in the mid-1980's is pessimistic even in today's technology (volume production).

Telesat strongly believes that a G/T = 12 dB/K will be available by 1986 in mass production. It is to be noted that a higher G/T for home terminals means a relaxation in the required satellite EIRP for a specified value of availability and, therefore, a considerable reduction of the space segment cost. That is, in the design of a BSS system, both satellite EIRP and home terminal G/T, should be considered in order to minimize the total cost of the system.

3.0 FEEDER-LINK EARTH STATIONS

This chapter considers the characteristics of the feeder-link earth stations. Both fixed earth stations, to be located at major broadcasting centres, and transportables are considered. Practical considerations such as power handling in combining networks, complexity introduced by site diversity and satellite tracking error are addressed.

3.1 Characteristics Assumed

In the present study, the feeder-link earth station antenna diameter is assumed to be 5m, with an antenna efficiency of 55%. This results in a maximum gain of 56.6 dB at 17.5 GHz. The suggested antenna reference patterns are given in Figure 3.1.

The co-polar reference radiation pattern is:

$46-20\log_{10}\phi$	dBi	for	$0.1° \leq \phi < 0.32°$
$51.3-53.44\phi^2$	dBi	for	$0.32° \leq \phi < 0.54°$
$29-25\log_{10}\phi$	dBi	for	$0.54° \leq \phi < 36°$
-10	dBi	for	$36° \leq \phi$

where ϕ is the off-axis angle in degrees.

The cross-polar reference radiation pattern is:

$G_{max}-30$	dBi	for	$0.6/D° \leq \phi$
$9-20\log_{10}\phi$	dBi	for	$0.6/D° \leq \phi < 8.7°$
-10	dBi	for	$8.7° \leq \phi$

where D is the diameter (m) of the antenna.

The power delivered to the input of the antenna is assumed to be 1000 watts. The transmitted EIRP is, therefore,

EIRP= 56.6+30= 86.6 dBW

while the effective EIRP used for C/N and C/I calculations is 86.1 dBW, taking into account the 0.5 dB pointing loss.

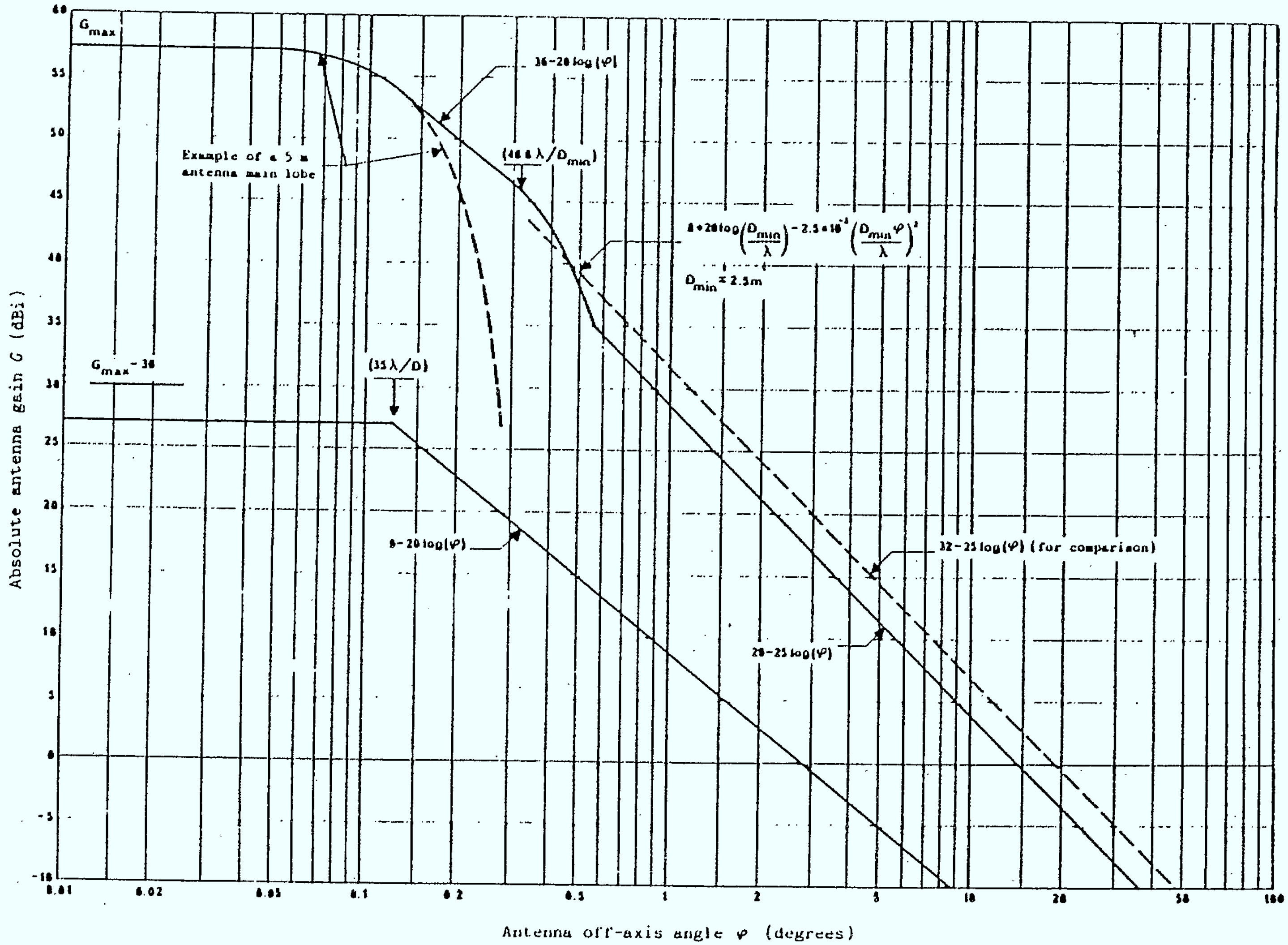


FIG. 3.1 - Suggested antenna reference patterns for planning of the feeder links

3.2 Major Broadcast Centres

The number and locations of the major broadcast centres in Canada will essentially be governed by the current major centres of program production. These locations constitute a natural choice for broadcasters because they have already invested in them considerable amounts of capital for production equipment. The cities of interest are as follows*.

Vancouver	Quebec City
Edmonton	Moncton
Calgary	Fredericton
Saskatoon	Charlottetown
Regina	Halifax
Winnipeg	Sydney
Windsor	St. John's
Toronto	Whitehorse
Ottawa	Yellowknife
Montreal	Frobisher Bay

The feeder-link frequency band is 17.3 to 17.8 GHz. At these frequencies, electromagnetic signals are subject to increased hydrometeoric fading. To achieve adequate protection against fading, a 5m antenna with 1000 watts at its input is recommended [1]. HPA power ratings in excess of 1000 watts will be required because of the combining network loss (about 3 dB) and provision for HPA output backoff. Considering that such equipment is readily available for Ku band at 14 GHz, no technological difficulties are foreseen in acquiring such equipment. However, with the feeder-link using a single antenna to access a satellite and limiting the transmission to one beam, a minimum of one TV carrier and a maximum of nine TV carriers could be uplinked from each location. As the number of TV carriers increases, the requirements on the

*Consultation with Canadian Broadcasting Corporation.

combining network may well challenge present technology. Although the theoretical power handling capability of the rectangular waveguides is in the order of 100 kilowatts [7], the power handling capability at discontinuities could be a small fraction of this. Careful attention would have to be given to the design of diplexers, loads, and waveguide switches to prevent arcing. Heat dissipation would also be a concern. Since water cooling is highly undesirable, air convection would be the cooling method. The smaller dimensions of the 17 GHz waveguide imply less surface area for heat dissipation. Adequate air circulation around the combining network would therefore be required, as would low-loss alloy material for the components. Thus, the number of channels that could be uplinked from one antenna would probably be limited by the power handling capability of the antenna feed network and the combining network, which must be able to handle as many kilowatts as there are TV carriers. A possible combining scheme for four channels is shown in Figure 3.2.1. Redundancy is used to achieve the necessary equipment reliability. The same approach could be extended to a larger number of channels.

To maintain a high service availability, it will be necessary to use site diversity (see Section 4.2.2) in certain areas having intense precipitation. This presents a number of special technical problems. To begin with, double illumination of the satellite should be avoided as this would overdrive the satellite TWT and lead to severe deterioration of the overall performance due to the different path delays of the two signals. The switching scheme from one uplink antenna to another should be such that reception remains roll-free. This is the most challenging problem encountered with site diversity. The investigation of site diversity and switching techniques for BSS is an area open for further study.

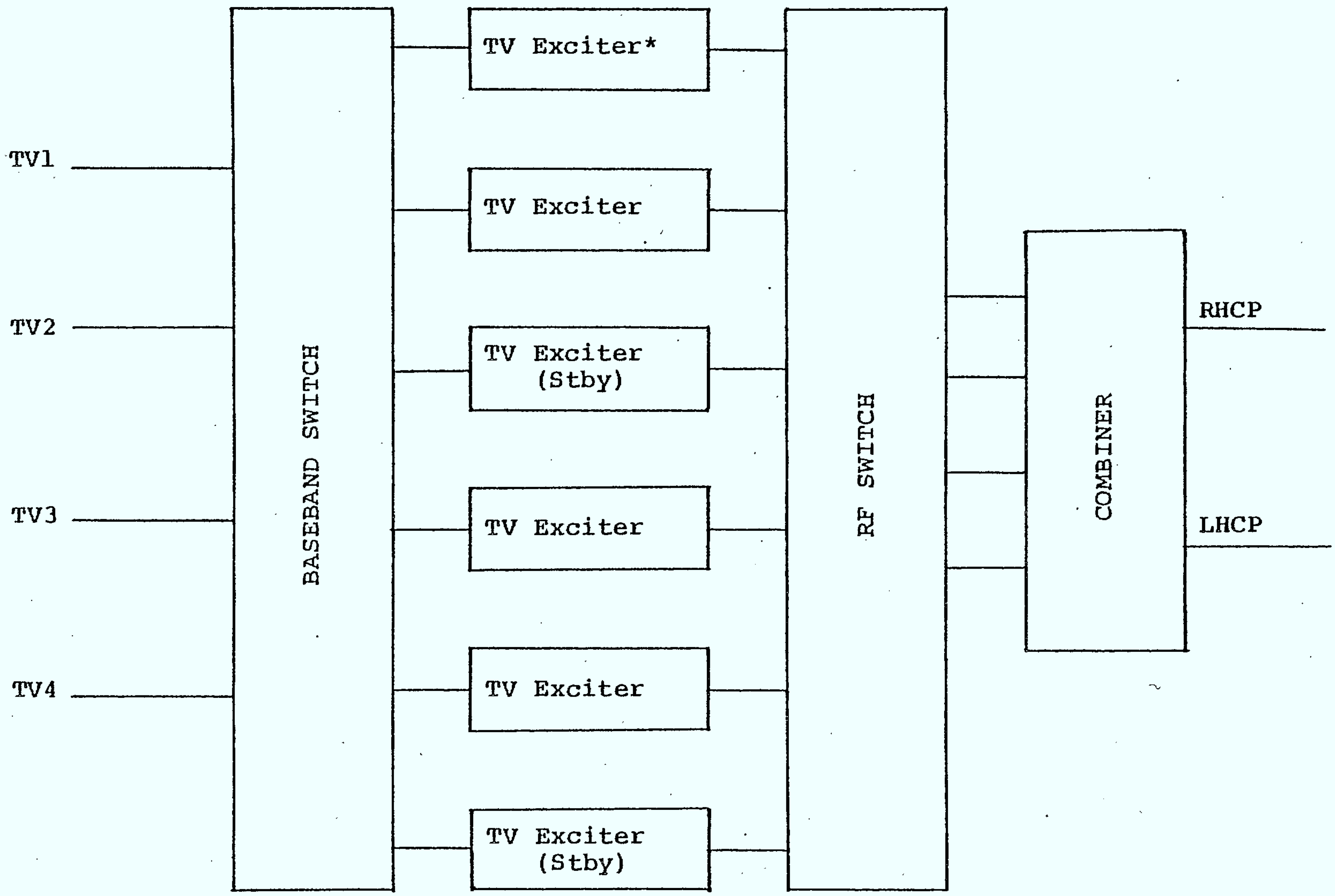


Figure 3.2.1 : Combining network with 1 for 2 redundancy

*TV Exciter has either a direct modulator or a modulator and an up-converter followed by the HPA.

3.3 Transportable Feeder-Links

Considering that transportable earth station feeder-links are permitted in the plan, some of their salient technical features will be discussed. As outlined in Chapter 4, it is evident that in order to achieve the BSS service availability objective, fairly stringent demands are imposed on the feeder-links.

However, for the transportable feeder-links, the availability objective will be somewhat less than that for the fixed feeder-links. In spite of this, an HPA power output of the order of 500 W is necessary to maintain the transmitting antenna size below about 3m. A transmitting antenna larger than 3m might require an auto-tracking system which would involve a substantial increase in complexity and an associated increase in capital expenditure. Another possibility is the use of elliptical aperture antennas on the transportable feeder-links which would be less sensitive to north-south movement of the satellites. This concept is discussed in Section 3.4. Even with the use of smaller antennas on transportables, the higher operating frequency of 17.5 GHz for the BSS feeder-links, as opposed to the present operating frequencies of Telesat's 6 GHz and 14 GHz transportables, would necessitate that the presently used camera type antenna mounts be improved. More precise antenna mounts cost between 30 and 40 thousand dollars compared to approximately five thousand for the camera type mounts.

Considering that transportable equipment is naturally subjected to additional vibrations in the process of moving from one site to another, special attention must be given to the system design to retain an appropriate level of equipment reliability. From Telesat's experience, it is felt that an appropriate level of reliability can be achieved by making the transportable fully redundant. This in itself will contribute a considerable portion of the cost of a transportable feeder-link.

The need for a high EIRP, to provide the availability through fading due to atmospheric conditions, and the need for redundancy, to provide equipment reliability, both add to the power supply requirements of transportable feeder-links. It is estimated that more than 10 kW of power would be required to supply such an installation. This power could be derived either from the local power utility, if it is available, or from a power generator.

It has been expressed by the CBC that transportable feeder-links would not be used for such purposes as news gathering since they do not offer the production flexibility of the main studios. Their use would likely be restricted to the coverage of special events, in which case a substantial time to set up the equipment could be allocated. In such a scenario, one could allocate a few hours to set up a transportable feeder-link. With the additional time, a system such as shown in Figure 3.3.1 could be adopted. Some of the simplicity generally strived for in the design of transportables could be sacrificed in order to acquire additional production flexibility.

The requirements associated with transportable feeder-links may well make their cost prohibitive for most applications. It is foreseen that transportable feeder-links would in fact consist of temporary feeder-link sites that would be set up for special events, lasting

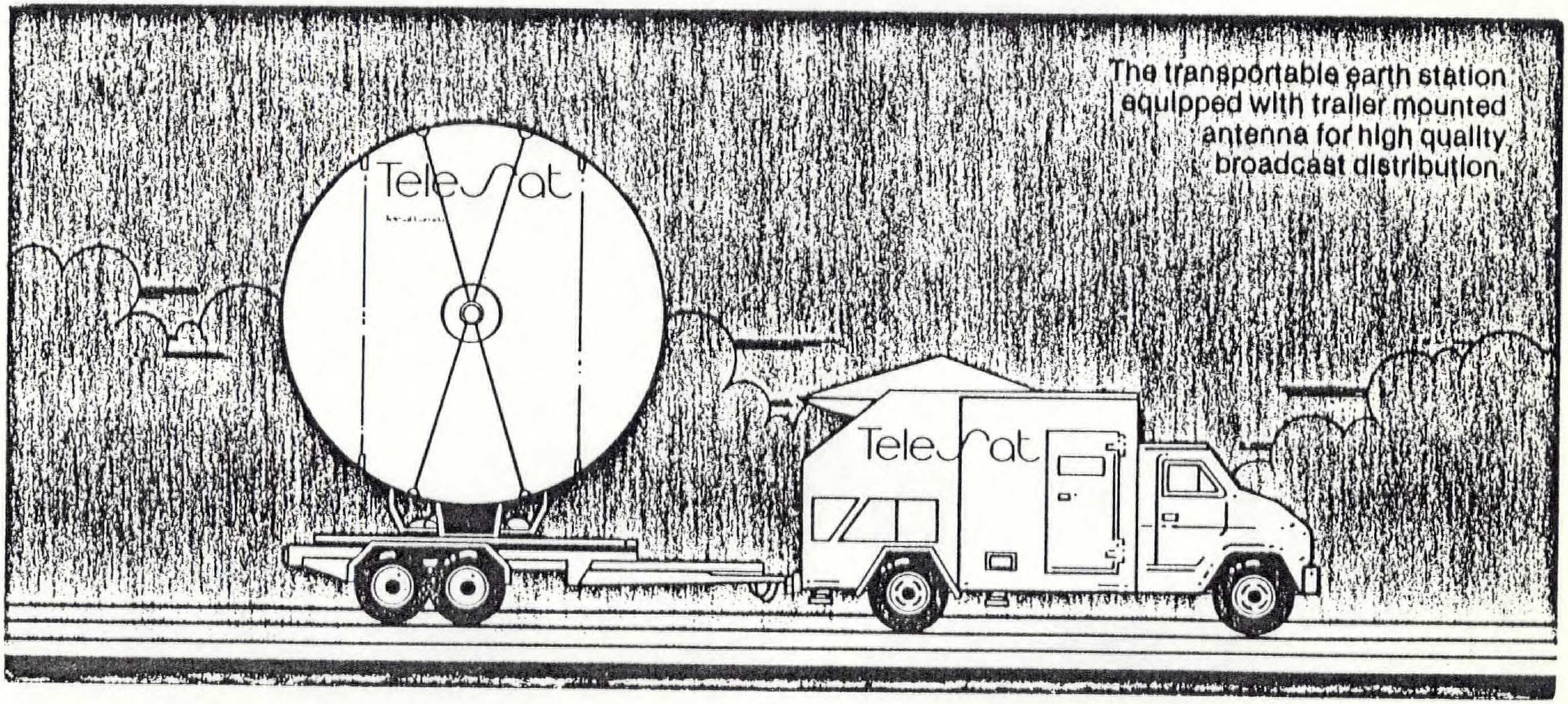


Figure 3.3.1: A typical transportable earth station.

perhaps a few days. For most instances where news gathering is involved, a double hop through the studio using the FSS would be more convenient.

3.4 Pointing Tolerance for Feeder-link Earth Station Antennas

The slight asymmetry in the Earth's gravitational field, together with the gravitational fields of the sun and moon, plus the solar radiation pressure, have perturbing effects on satellites which would otherwise remain stationary. However, the drift can be compensated for by orbit correction or station-keeping techniques.

The accuracy with which the satellite can be kept on station will depend not only on the accuracy to which the tracking, orbit-determination and orbit-control systems can be operated, but also on the design of the satellite (in particular, the solar-pressure perturbation and the mass and volume available for fuel) as well as on the satellite station longitude.

The present station-keeping techniques rely on a corrective thrust to overcome the drift, by the use of small propulsion jets on the satellite, powered by propellent stores on board. The extent to which correction is required depends upon the allowable displacement of the satellite.

CCIR Report 811-1 indicates that a geostationary satellite can be kept within $\pm 0.1°$ in the north-south and east-west directions, yielding a maximum resulting composite error as large as $\pm 0.14°$.

East-west and north-south station-keeping are independent operations, so they are usually specified as separate tolerances. The probability distribution versus time of the satellite within this tolerance band is fairly even, so it is necessary for the system designer to assume that the satellite will be near the limits of its deviation for a significant proportion of time.

Table 3.4.1 presents the loss of gain for different values of off-axis angle and antenna diameters of 2.5, 3, 4 and 5 meters at a frequency of 17.5 GHz. A parabolic taper on a pedestal is assumed for the aperture field distribution, with a practical edge taper of 11 dB.

TABLE 3.4.1

Antenna Diameter (m)	3 dB Beamwidth	Antenna Gain Loss (dB) for Off-Axis Angle					
		0.02°	0.04°	0.06°	0.08°	0.1°	0.14°
5	0.22°	0.1	0.4	0.9	1.6	2.5	5.2
4	0.27°	0.1	0.2	0.6	1.0	1.6	3.2
3	0.36°	0	0.1	0.3	0.6	0.9	1.8
2.5	0.44°	0	0.1	0.2	0.4	0.6	1.2

Table 3.4.1: Antenna pointing loss for different antenna diameters at 17.5 GHz (edge illumination 11 dB below the central region).

Note that the off-axis angle in the table is the one sided angle and the 3 dB beamwidth is double sided. Furthermore, these off-axis angles correspond to various station keeping strategies, e.g. 0.14° and 0.1° correspond respectively to ±0.1° and ±0.07° satellite drift in both the north-south and east-west directions.

With reference to Table 3.4.1, it is clear that the pointing tolerance of the feeder-link depends on the size of the antenna used in the plan. An off-axis angle of ±0.1° could be acceptable for a feeder-link with 3 m antenna size but it could be excessive for a 5 m antenna.

It should be noted that errors arising during the initial adjustment of the earth station must be added to the systematic errors introduced by the satellite station-keeping tolerance. This additional source of error stems from the stationing of the satellite at the time the earth station antenna pointing is set. This error can be reduced by co-ordinating with the satellite control centre in order to determine at what time the satellite is at its nominal station. Failure to observe this procedure could result in doubling the maximum off-axis angle, which could cause serious performance loss. However, experience has shown that a residual error of 0.5 dB over and above the systematic off-axis gain loss must be expected.

From the above discussion it is clear that the ultimate performance of a fixed mount earth station antenna is defined by the maximum off-axis gain for the limit off-axis angle. This is in turn defined by the satellite station-keeping performance. To this a 0.5 dB initial adjustment loss should be added. This optimum performance is the peak in the appropriate curve on Figure 3.4.1 and an antenna larger than the optimum size can only give degraded off-axis performance. If the design of the transmission system is such that it cannot handle the systematic variations in signal levels, the system designer may decide to choose a smaller antenna size (and therefore larger HPA) giving slightly less off-axis gain but reduced gain variation. In some cases a larger HPA may not be practical. Then, the system designer must choose an auto tracking system and accept the added cost and more importantly, maintenance of the moving mechanisms. With tracking, the antenna pointing can be continuously adjusted to minimize off-axis gain degradation due to satellite motion. In addition, the instability of the antenna due to thermal distortion, wind loading and foundation movements (particularly for roof mounted antennas) is corrected automatically by auto-tracking systems.

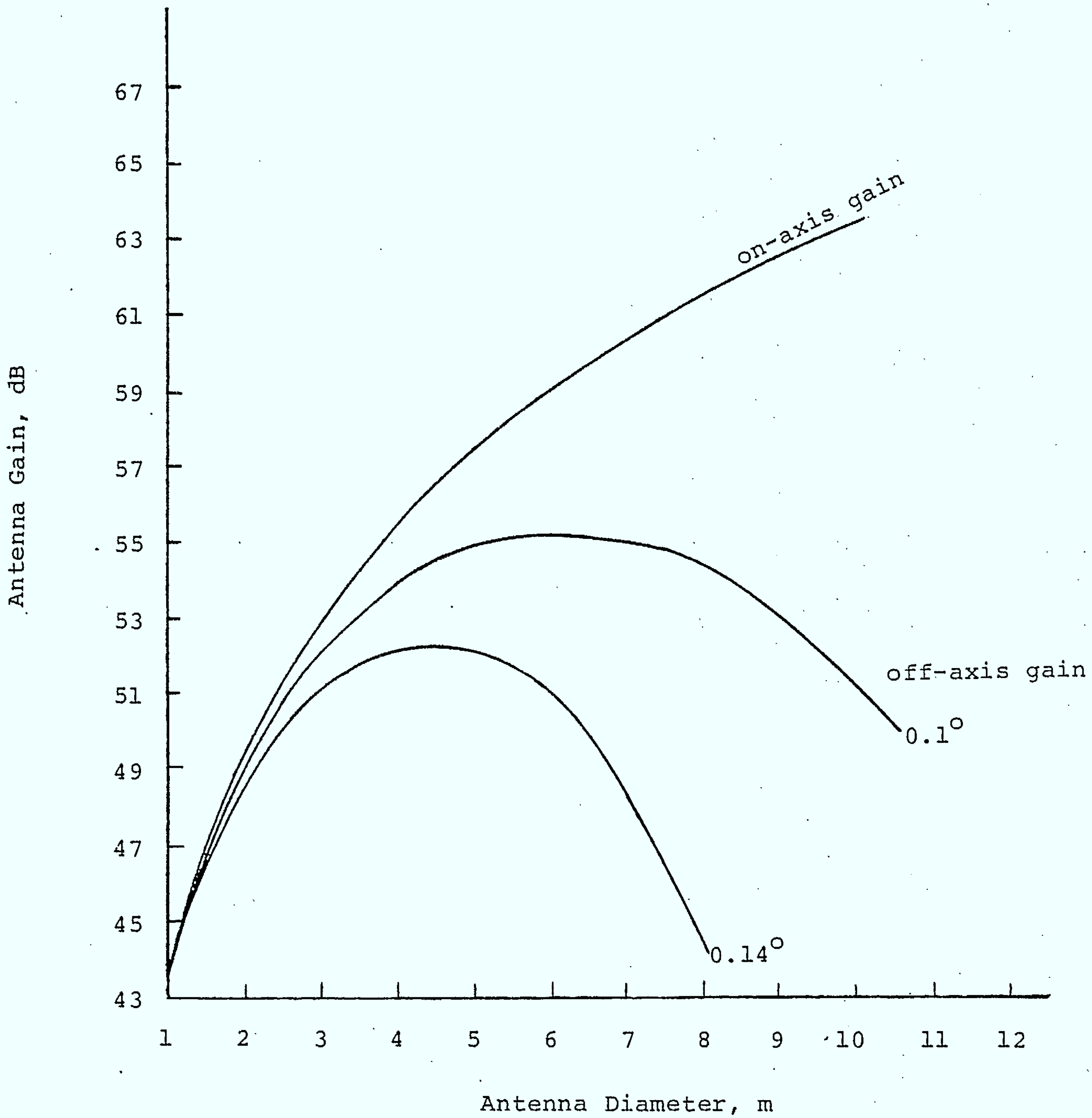


Figure 3.4.1 Variation of on-axis and off-axis gain with antenna diameter (frequency = 17.5 GHz)

The Telesat 8m antennas used in the 12/14 GHz FSS (manufactured by Andrew) employ a step-tracking system which maintains the received signal (12 GHz band) to within 0.3 dB of the maximum under normal weather conditions. The pointing accuracy of the receive main beam is 0.02° rms with respect to the true position of the satellite under normal weather conditions.

A transportable feeder-link earth station has been permitted in the plan. In keeping with the concept of simplicity, auto-tracking is usually not incorporated in a transportable terminal. An elliptical aperture antenna is proposed to be used at a transportable station in order to minimize the off-axis gain loss, as explained below.

Considering that the north-south deviation of a satellite is usually larger than the east-west deviation, an antenna may be designed to radiate an elliptical beam with its major axis running north to south. As a result of radiating an elliptical beam, this antenna may not need to track a satellite north to south if it is designed properly. The antenna radiating an elliptical beam with the major axis running north to south should have an elliptical aperture with the major axis running in the east to west (AZ) direction.

Figure 3.4.2 shows the gain reduction of an elliptical aperture antenna for different off-axis angles in azimuth and elevation, when the ratio of the major axis to the minor axis, K, varies. The aperture area is assumed to be the same as that of a circular aperture with diameter of 3m. If K=1, the aperture becomes circular. As K increases, the off-axis loss in elevation decreases, whereas the loss in azimuth puts a limit on the magnitude of K. K= 2 seems to be the optimum ratio for this aperture size. In elevation, the off-axis loss for 0.1° deviation is 0.4 dB. If the off-axis variation in azimuth angle due to the east-west

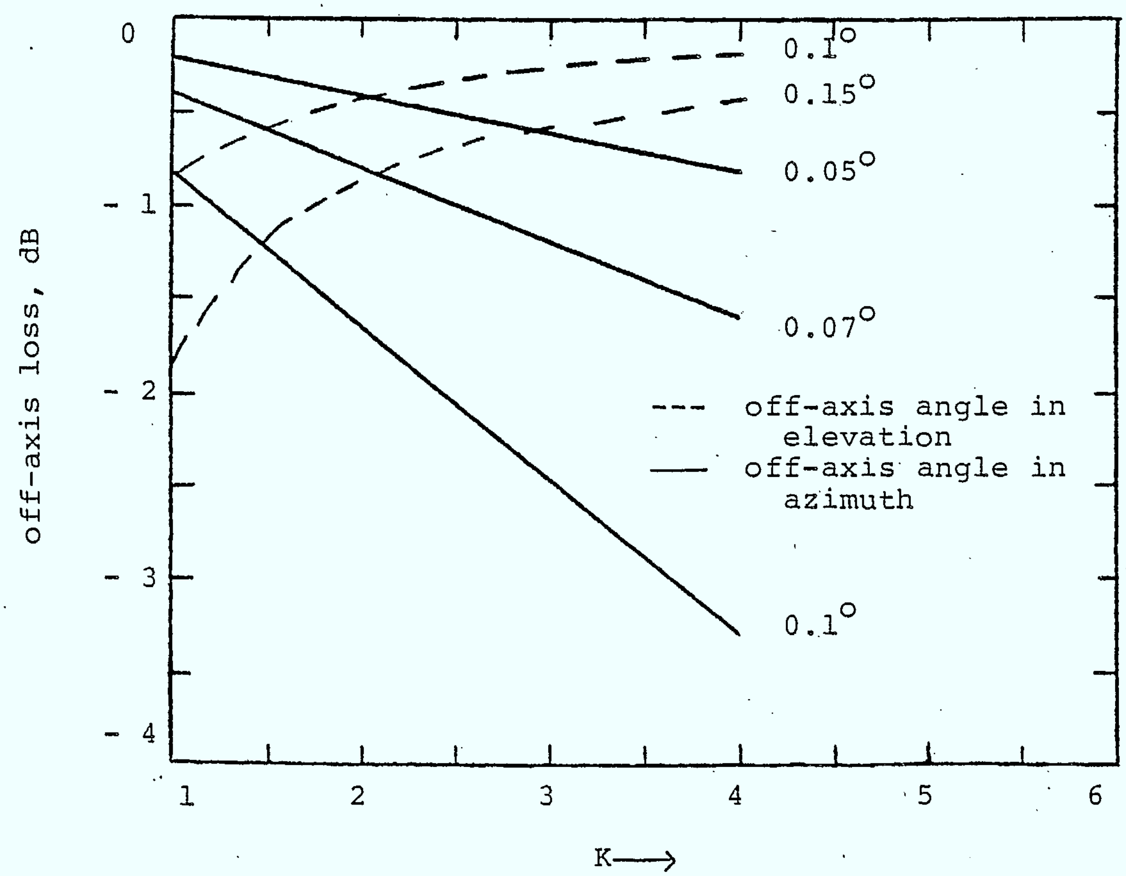


Figure 3.4.2 Off-axis loss of an elliplical operature antenna, equivalent to a circular aperature with 3 m in diameter, at 17.5 GHz as the ratio of the major axis to the minor axis K varies. The dashed lines are for off-axis angles in elevation and the solid lines are for off-axis angles in azimuth.

deviation of the satellite is limited to 0.05°, the antenna pointing loss in azimuth will also be 0.4 dB. That is, the antenna pointing loss of a transportable terminal with no auto-tracking could be limited to 0.5 dB. The advantage of an elliptical aperture becomes more evident when a larger deviation of the satellite, especially in the north-south direction, is allowed. For example, the antenna pointing loss would be limited to 0.8 dB if the north-south and the east-west deviations are 0.15° and 0.07°, respectively.

In addition, use of an elliptical aperture antenna might facilitate the mechanical design of a transportable antenna suitable for mounting on a truck chassis. The disadvantages associated with an elliptical aperture antenna are greater manufacturing complexity and higher cost.

3.4.1 Summary

Pointing tolerance of the feeder-link antenna depends on the antenna size and the range of the gain variation acceptable to the system. Since the size of the antenna is not fixed in the plan, expressing the pointing tolerance in terms of off-axis degrees is not realistic. Therefore, it is suggested that the pointing tolerance be based on dB degradation from the nominal point. It is certain that the choice of a 5 m antenna for feeder-link earth stations necessitates the employment of an auto-tracking system. Therefore, in view of the above discussions, it is suggested that a 0.5 dB limit on pointing tolerance be accepted for systems employing auto-tracking. For a transportable earth station, the 0.5 dB pointing error could also be achieved if an elliptical aperture antenna were employed.

4.0 PERFORMANCE

This chapter presents the performance calculations for feeder-links in a Canadian BSS which is consistent with the system model outlined in Chapter 2. First, the key issue of propagation is addressed, followed by a discussion of means of dealing with the rain fades. The effects of eclipses and equipment failures on service availability are discussed. Finally, the link budgets and reliability calculations are presented.

4.1 Propagation Effects

4.1.1 Introduction

The major propagation factors of concern in planning for the BSS in the frequency bands near 12.5 and 17.5 GHz are attenuation by rain and depolarization of signal, caused by rain and ice particles in the earth-space path.

When rainy weather is experienced along the link, the system performance will degrade in ways which may be reliably estimated. However, due to the randomness of the events occurring in the troposphere, only statistical predictions which factor into system design can be considered.

During the last decade, several models for estimation of cumulative attenuation statistics on earth-space paths have been developed. Each of these models appears to have advantages and disadvantages, depending on the specific application. These models are being updated and modified based on recent experimental results and analyses. The models provide either rain rate statistics or attenuation statistics [8]-[11]. Generally, these statistics can be related by use of the specific attenuation and effective path length relations. In the following study, a model recommended by the CPM [1], is used for prediction of rain attenuation and depolarization. The model is easy to apply without the need for a specialized computer program.

4.1.2 CPM Rain Attenuation Model

The CPM model is based on CCIR Method I which predicts rain attenuation exceeded for an average year, based on the rain rate at 0.01% of the year. An emperical correction was made to Method I to give a better fit to measured data sets from around the world.

The prediction of rain attenuation requires information on rainfall intensity, in mm/h, for 0.01% of the year at the ground locations of interest.

The CPM report provides median distribution estimates for broad geographical regions; fourteen climate regions are designated to classify regions covering the entire globe. Zone boundaries in Region 2 are shown in Figure 4.1.1. The corresponding rainfall intensities exceeded only for 0.01% of the time are given in Table 4.1.1.

ZONE	A	B	C	D	E	F	G	H	J	K	L	M	N	P
mm/h	8	12	15	19	22	28	30	32	35	42	60	63	95	145

Table 4.1.1 Rainfall intensity exceeded for 0.01% of the time for different rain climatic zones.

4.1.3 Results for Rain Attenuation and Depolarization

The CBC has reported that the current centres of broadcasting activity across Canada would likely be the origination centres for any future Canadian BSS. This would avoid new investment in program origination equipment and systems, since such equipment is already in place in these various cities. The cities of interest which currently produce significant quantities of TV programming are listed in Section 3.2.

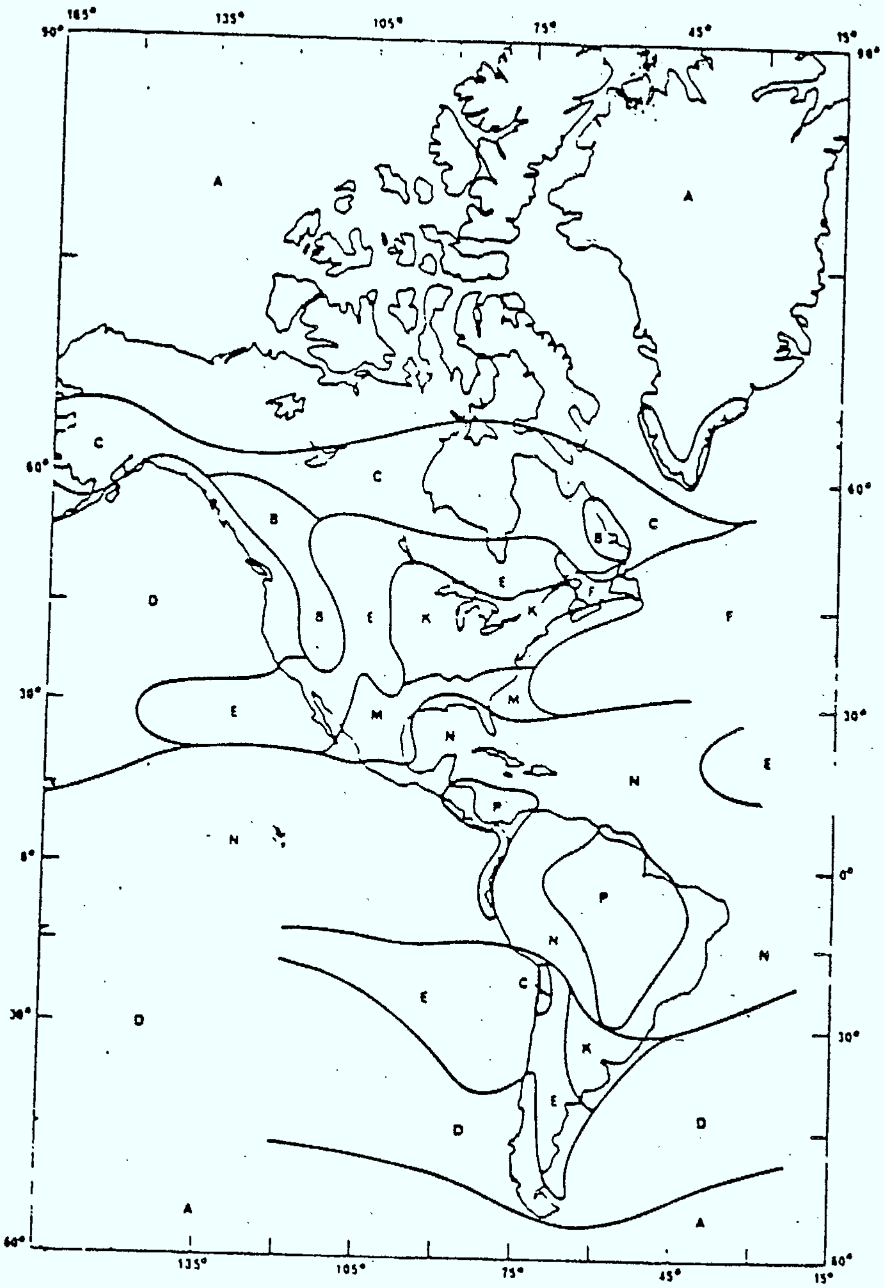


Figure 4.1.1: Rain climatic zones
(region 2).

Since the Canadian BSS would likely have six regional beams, at least one or two centres in each beam would be equipped with feeder-link facilities. These would likely coincide with the larger cities of the list.

Tables 4.1.2 - 4.1.49 give the rain attenuation and depolarization prediction as a function of % of the worst month (0.1% of the worst month is 43.2 minutes) for the cities listed in Section 3.2, at 17.5 GHz and for orbital locations 135°, 105° and 85°W. Cross Polarization discrimination (XPD) for cities with elevation angle less than 10° are not listed in the tables, since the prediction model is not valid for these elevation angles.

Figures 4.1.2 - 4.1.11 depict the rain attenuation prediction as a function of percentage of the worst month for different locations and elevation angles. The locations are representative of almost all possible feeder-link locations in different latitudes and rain climatic zones across Canada. The results are general and could be applied for any future orbital slots assigned to the Canadian BSS.

Tables 4.1.50 - 4.1.81 show the predicted downlink rain attenuation for minimum elevation angle in each rain climatic zone and in any of the six beams considered for downlink coverage, for both the two and three-satellite models.

4.1.4 Discussion

The CPM model for prediction of rain attenuation is simple and it does not need a specialized computer program. However, a model should also be accurate. To estimate its validity for planning the BSS in Region 2, the advisory committees of both the United States and Canada have compared the CPM predicted rain attenuation with measured rain attenuation data for a number of points across the

Table 4.1.2

CALGARY, RAIN ZONE E
HEIGHT ABOVE SEA LEVEL=1250. M
ELEVATION ANGLE= 25.57 DEG.
LATITUDE= 51.00 DEG. LONG.= 114.00 DEG.
SATELLITE LONG.= 85.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
10.29	15.93	.0100
7.27	19.40	.0250
5.59	22.03	.0500
4.64	23.88	.0750
4.05	25.23	.1000
2.63	29.55	.2500
1.96	32.50	.5000
1.55	34.83	.7500
1.31	36.48	1.0000

Table 4.1.3

CALGARY, RAIN ZONE E
HEIGHT ABOVE SEA LEVEL=1250. M
ELEVATION ANGLE= 30.99 DEG.
LATITUDE= 51.00 DEG. LONG.= 114.00 DEG.
SATELLITE LONG.= 105.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
8.87	18.30	.0100
6.27	21.77	.0250
4.82	24.40	.0500
4.00	26.25	.0750
3.50	27.60	.1000
2.27	31.92	.2500
1.69	34.87	.5000
1.34	37.20	.7500
1.13	38.85	1.0000

Table 4.1.4

CALGARY, RAIN ZONE E
HEIGHT ABOVE SEA LEVEL=1250. M
ELEVATION ANGLE= 28.34 DEG.
LATITUDE= 51.00 DEG. LONG.= 114.00 DEG.
SATELLITE LONG.= 135.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
9.50	17.15	.0100
6.71	20.63	.0250
5.16	23.26	.0500
4.29	25.10	.0750
3.74	26.46	.1000
2.43	30.77	.2500
1.81	33.73	.5000
1.43	36.06	.7500
1.21	37.71	1.0000

Table 4.1.5

CHARLOTTETOWN, ZONE F
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 32.65 DEG.
LATITUDE= 46.20 DEG. LONG.= 63.10 DEG.
SATELLITE LONG.= 85.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
19.55	10.71	.0100
13.81	14.19	.0250
10.62	16.82	.0500
8.82	18.66	.0750
7.70	20.02	.1000
5.00	24.33	.2500
3.72	27.29	.5000
2.95	29.62	.7500
2.50	31.27	1.0000

Table 4.1.6

CHARLOTTETOWN, ZONE F
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 23.02 DEG.
LATITUDE= 46.20 DEG. LONG.= 63.10 DEG.
SATELLITE LONG.= 105.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
24.66	6.85	.0100
17.42	10.32	.0250
13.39	12.95	.0500
11.13	14.80	.0750
9.72	16.15	.1000
6.31	20.47	.2500
4.69	23.42	.5000
3.72	25.75	.7500
3.15	27.40	1.0000

Table 4.1.7

CHARLOTTETOWN, ZONE F
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 3.75 DEG.
LATITUDE= 46.20 DEG. LONG.= 63.10 DEG.
SATELLITE LONG.= 135.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	% WM
60.89	.0100
43.01	.0250
33.06	.0500
27.48	.0750
23.99	.1000
15.58	.2500
11.59	.5000
9.18	.7500
7.78	1.0000

Table 4.1.8

EDMONTON, RAIN ZONE E
HEIGHT ABOVE SEA LEVEL=750.0 M
ELEVATION ANGLE= 23.47 DEG.
LATITUDE= 53.60 DEG. LONG.= 113.50 DEG.
SATELLITE LONG.= 85.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
12.60	13.62	.0100
8.90	17.09	.0250
6.84	19.72	.0500
5.69	21.56	.0750
4.96	22.92	.1000
3.22	27.24	.2500
2.40	30.19	.5000
1.90	32.52	.7500
1.61	34.17	1.0000

Table 4.1.9

EDMONTON, RAIN ZONE E
HEIGHT ABOVE SEA LEVEL=750.0 M
ELEVATION ANGLE= 28.30 DEG.
LATITUDE= 53.60 DEG. LONG.= 113.50 DEG.
SATELLITE LONG.= 105.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
10.95	15.73	.0100
7.73	19.21	.0250
5.94	21.83	.0500
4.94	23.68	.0750
4.31	25.04	.1000
2.80	29.35	.2500
2.08	32.31	.5000
1.65	34.63	.7500
1.40	36.29	1.0000

Table 4.1.10

EDMONTON, RAIN ZONE E
HEIGHT ABOVE SEA LEVEL=750.0 M
ELEVATION ANGLE= 25.69 DEG.
LATITUDE= 53.60 DEG. LONG.= 113.50 DEG.
SATELLITE LONG.= 135.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
11.77	14.60	.0100
8.31	18.08	.0250
6.39	20.71	.0500
5.31	22.55	.0750
4.64	23.91	.1000
3.01	28.22	.2500
2.24	31.18	.5000
1.77	33.51	.7500
1.50	35.16	1.0000

Table 4.1.11

FREDERICTON,NB,ZONE K
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 34.08 DEG.
LATITUDE= 46.00 DEG. LONG.= 66.70 DEG.
SATELLITE LONG.= 85.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
29.94	6.75	.0100
21.14	10.22	.0250
16.25	12.85	.0500
13.51	14.69	.0750
11.79	16.05	.1000
7.66	20.36	.2500
5.70	23.32	.5000
4.51	25.65	.7500
3.82	27.30	1.0000

Table 4.1.12

FREDERICTON,NB,ZONE K
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 25.18 DEG.
LATITUDE= 46.00 DEG. LONG.= 66.70 DEG.
SATELLITE LONG.= 105.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
36.58	3.21	.0100
25.83	6.68	.0250
19.86	9.31	.0500
16.50	11.15	.0750
14.41	12.51	.1000
9.36	16.82	.2500
6.96	19.78	.5000
5.51	22.11	.7500
4.67	23.76	1.0000

Table 4.1.13

FREDERICTON,NB,ZONE K
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 6.25 DEG.
LATITUDE= 46.00 DEG. LONG.= 66.70 DEG.
SATELLITE LONG.= 135.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	% WM
79.96	.0100
56.48	.0250
43.41	.0500
36.08	.0750
31.51	.1000
20.45	.2500
15.22	.5000
12.05	.7500
10.21	1.0000

Table 4.1.14

FROBISHER BAY, ZONE C
HEIGHT ABOVE SEA LEVEL=100.0 M
ELEVATION ANGLE= 22.40 DEG.
LATITUDE= 58.10 DEG. LONG.= 68.40 DEG.
SATELLITE LONG.= 85.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
9.53	16.27	.0100
6.73	19.75	.0250
5.17	22.37	.0500
4.30	24.22	.0750
3.75	25.58	.1000
2.44	29.89	.2500
1.81	32.85	.5000
1.44	35.18	.7500
1.22	36.83	1.0000

Table 4.1.15

FROBISHER BAY, ZONE C
HEIGHT ABOVE SEA LEVEL=100.0 M
ELEVATION ANGLE= 16.79 DEG.
LATITUDE= 58.10 DEG. LONG.= 68.40 DEG.
SATELLITE LONG.= 105.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
11.72	13.60	.0100
8.27	17.07	.0250
6.36	19.70	.0500
5.29	21.55	.0750
4.62	22.90	.1000
3.00	27.22	.2500
2.23	30.17	.5000
1.77	32.50	.7500
1.50	34.15	1.0000

Table 4.1.16

FROBISHER BAY, ZONE C
HEIGHT ABOVE SEA LEVEL=100.0 M
ELEVATION ANGLE= 3.45 DEG.
LATITUDE= 58.10 DEG. LONG.= 68.40 DEG.
SATELLITE LONG.= 135.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	% WM
27.73	.0100
19.58	.0250
15.05	.0500
12.51	.0750
10.93	.1000
7.09	.2500
5.28	.5000
4.18	.7500
3.54	1.0000

Table 4.1.17

HALIFAX, RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 34.27 DEG.
LATITUDE= 44.70 DEG. LONG.= 63.60 DEG.
SATELLITE LONG.= 85.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
30.53	6.57	.0100
21.57	10.06	.0250
16.58	12.69	.0500
13.78	14.54	.0750
12.03	15.89	.1000
7.81	20.21	.2500
5.81	23.16	.5000
4.60	25.49	.7500
3.90	27.14	1.0000

Table 4.1.18

HALIFAX, RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 24.31 DEG.
LATITUDE= 44.70 DEG. LONG.= 63.60 DEG.
SATELLITE LONG.= 105.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
38.25	2.64	.0100
27.02	6.11	.0250
20.77	8.74	.0500
17.26	10.59	.0750
15.07	11.94	.1000
9.78	16.26	.2500
7.28	19.21	.5000
5.77	21.54	.7500
4.89	23.19	1.0000

Table 4.1.19

HALIFAX, RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 4.45 DEG.
LATITUDE= 44.70 DEG. LONG.= 63.60 DEG.
SATELLITE LONG.= 135.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	% WM
91.62	.0100
64.71	.0250
49.75	.0500
41.35	.0750
36.10	.1000
23.44	.2500
17.44	.5000
13.81	.7500
11.70	1.0000

Table 4.1.20

MONTREAL, RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 36.40 DEG.
LATITUDE= 45.50 DEG. LONG.= 73.50 DEG.
SATELLITE LONG.= 85.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
28.95	7.58	.0100
20.45	11.05	.0250
15.72	13.68	.0500
13.07	15.52	.0750
11.41	16.88	.1000
7.41	21.19	.2500
5.51	24.15	.5000
4.36	26.48	.7500
3.70	28.13	1.0000

Table 4.1.21

MONTREAL, RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 29.12 DEG.
LATITUDE= 45.50 DEG. LONG.= 73.50 DEG.
SATELLITE LONG.= 105.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
33.50	4.70	.0100
23.66	8.17	.0250
18.19	10.80	.0500
15.12	12.64	.0750
13.20	14.00	.1000
8.57	18.32	.2500
6.37	21.27	.5000
5.05	23.60	.7500
4.28	25.25	1.0000

Table 4.1.22

MONTREAL, RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 11.02 DEG.
LATITUDE= 45.50 DEG. LONG.= 73.50 DEG.
SATELLITE LONG.= 135.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
61.31	-3.37	.0100
43.30	.11	.0250
33.29	2.74	.0500
27.67	4.58	.0750
24.16	5.94	.1000
15.68	10.25	.2500
11.67	13.21	.5000
9.24	15.54	.7500
7.83	17.19	1.0000

Table 4.1.23

OTTAWA, RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 37.23 DEG.
LATITUDE= 45.00 DEG. LONG.= 75.00 DEG.
SATELLITE LONG.= 85.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
28.80	7.82	.0100
20.34	11.29	.0250
15.64	13.92	.0500
13.00	15.77	.0750
11.35	17.12	.1000
7.37	21.44	.2500
5.48	24.39	.5000
4.34	26.72	.7500
3.68	28.37	1.0000

Table 4.1.24

OTTAWA, RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 30.27 DEG.
LATITUDE= 45.00 DEG. LONG.= 75.00 DEG.
SATELLITE LONG.= 105.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
32.94	5.06	.0100
23.26	8.54	.0250
17.88	11.16	.0500
14.86	13.01	.0750
12.98	14.37	.1000
8.43	18.68	.2500
6.27	21.64	.5000
4.96	23.97	.7500
4.21	25.62	1.0000

Table 4.1.25

OTTAWA, RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 12.22 DEG.
LATITUDE= 45.00 DEG. LONG.= 75.00 DEG.
SATELLITE LONG.= 135.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
58.27	-2.78	.0100
41.16	.69	.0250
31.64	3.32	.0500
26.29	5.17	.0750
22.96	6.52	.1000
14.90	10.84	.2500
11.09	13.79	.5000
8.78	16.12	.7500
7.44	17.77	1.0000

Table 4.1.26

REGINA, RAIN ZONE E
HEIGHT ABOVE SEA LEVEL=600.0 M
ELEVATION ANGLE= 29.41 DEG.
LATITUDE= 50.50 DEG. LONG.= 104.00 DEG.
SATELLITE LONG.= 85.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
12.40	14.67	.0100
8.76	18.14	.0250
6.73	20.77	.0500
5.60	22.62	.0750
4.89	23.97	.1000
3.17	28.29	.2500
2.36	31.24	.5000
1.87	33.57	.7500
1.58	35.23	1.0000

Table 4.1.27

REGINA, RAIN ZONE E
HEIGHT ABOVE SEA LEVEL=600.0 M
ELEVATION ANGLE= 32.15 DEG.
LATITUDE= 50.50 DEG. LONG.= 104.00 DEG.
SATELLITE LONG.= 105.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
11.64	15.80	.0100
8.22	19.27	.0250
6.32	21.90	.0500
5.25	23.75	.0750
4.59	25.10	.1000
2.98	29.42	.2500
2.21	32.37	.5000
1.75	34.70	.7500
1.49	36.36	1.0000

Table 4.1.28

REGINA, RAIN ZONE E
HEIGHT ABOVE SEA LEVEL=600.0 M
ELEVATION ANGLE= 25.19 DEG.
LATITUDE= 50.50 DEG. LONG.= 104.00 DEG.
SATELLITE LONG.= 135.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
13.88	12.89	.0100
9.80	16.36	.0250
7.53	18.99	.0500
6.26	20.84	.0750
5.47	22.19	.1000
3.55	26.51	.2500
2.64	29.46	.5000
2.09	31.79	.7500
1.77	33.44	1.0000

Table 4.1.29

ST. JOHN"S, ZONE F
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 27.00 DEG.
LATITUDE= 47.50 DEG. LONG.= 52.50 DEG.
SATELLITE LONG.= 85.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
21.67	8.71	.0100
15.30	12.18	.0250
11.76	14.81	.0500
9.70	16.66	.0750
8.54	18.01	.1000
5.54	22.33	.2500
4.12	25.23	.5000
3.27	27.61	.7500
2.77	29.26	1.0000

Table 4.1.30

ST. JOHN"S, ZONE F
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 15.94 DEG.
LATITUDE= 47.50 DEG. LONG.= 52.50 DEG.
SATELLITE LONG.= 105.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
30.61	3.93	.0100
21.62	7.40	.0250
16.62	10.03	.0500
13.81	11.88	.0750
12.06	13.23	.1000
7.83	17.55	.2500
5.82	20.50	.5000
4.61	22.83	.7500
3.91	24.48	1.0000

Table 4.1.31

SYDNEY,NS,RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 31.53 DEG.
LATITUDE= 46.20 DEG. LONG.= 60.20 DEG.
SATELLITE LONG.= 85.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
31.39	5.77	.0100
22.17	9.25	.0250
17.04	11.88	.0500
14.16	13.72	.0750
12.37	15.08	.1000
8.03	19.39	.2500
5.97	22.35	.5000
4.73	24.68	.7500
4.01	26.33	1.0000

Table 4.1.32

SYDNEY,NS,RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 21.33 DEG.
LATITUDE= 46.20 DEG. LONG.= 60.20 DEG.
SATELLITE LONG.= 105.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
40.68	1.64	.0100
28.73	5.12	.0250
22.08	7.74	.0500
18.36	9.59	.0750
16.03	10.95	.1000
10.40	15.26	.2500
7.74	18.22	.5000
6.13	20.54	.7500
5.20	22.20	1.0000

Table 4.1.33

SYDNEY,NS,RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 1.77 DEG.
LATITUDE= 46.20 DEG. LONG.= 60.20 DEG.
SATELLITE LONG.= 135.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	% WM
112.30	.0100
79.31	.0250
60.97	.0500
50.67	.0750
44.25	.1000
28.72	.2500
21.37	.5000
16.93	.7500
14.35	1.0000

Table 4.1.34

TORONTO, RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=150.0 M
ELEVATION ANGLE= 39.30 DEG.
LATITUDE= 43.70 DEG. LONG.= 79.40 DEG.
SATELLITE LONG.= 85.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
27.79	8.67	.0100
19.63	12.15	.0250
15.09	14.77	.0500
12.54	16.62	.0750
10.95	17.98	.1000
7.11	22.29	.2500
5.29	25.24	.5000
4.19	27.57	.7500
3.55	29.23	1.0000

Table 4.1.35

TORONTO, RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=150.0 M
ELEVATION ANGLE= 33.45 DEG.
LATITUDE= 43.70 DEG. LONG.= 79.40 DEG.
SATELLITE LONG.= 105.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
30.80	6.34	.0100
21.75	9.81	.0250
16.72	12.44	.0500
13.90	14.28	.0750
12.13	15.64	.1000
7.88	19.95	.2500
5.86	22.91	.5000
4.64	25.24	.7500
3.93	26.89	1.0000

Table 4.1.36

TORONTO, RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=150.0 M
ELEVATION ANGLE= 15.75 DEG.
LATITUDE= 43.70 DEG. LONG.= 79.40 DEG.
SATELLITE LONG.= 135.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
50.14	-1.01	.0100
35.41	2.46	.0250
27.22	5.09	.0500
22.63	6.93	.0750
19.76	8.29	.1000
12.83	12.60	.2500
9.54	15.56	.5000
7.56	17.89	.7500
6.41	19.54	1.0000

Table 4.1.37

VANCOUVER,RAIN ZONE D
HEIGHT ABOVE SEA LEVEL= .05 KM
ELEVATION ANGLE= 22.90 DEG.
LATITUDE= 49.20 DEG. LONG.= 123.20 DEG.
SATELLITE LONG.= 85.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
15.25	11.64	.0100
10.77	15.11	.0250
8.28	17.74	.0500
6.88	19.59	.0750
6.01	20.94	.1000
3.90	25.26	.2500
2.90	28.21	.5000
2.30	30.54	.7500
1.95	32.19	1.0000

Table 4.1.38

VANCOUVER,RAIN ZONE D
HEIGHT ABOVE SEA LEVEL= .05 KM
ELEVATION ANGLE= 30.93 DEG.
LATITUDE= 49.20 DEG. LONG.= 123.20 DEG.
SATELLITE LONG.= 105.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
12.43	14.91	.0100
8.78	18.39	.0250
6.75	21.01	.0500
5.61	22.86	.0750
4.90	24.22	.1000
3.18	28.53	.2500
2.37	31.49	.5000
1.87	33.82	.7500
1.59	35.47	1.0000

Table 4.1.39

VANCOUVER,RAIN ZONE D
HEIGHT ABOVE SEA LEVEL= .05 KM
ELEVATION ANGLE= 32.44 DEG.
LATITUDE= 49.20 DEG. LONG.= 123.20 DEG.
SATELLITE LONG.= 135.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
12.04	15.52	.0100
8.50	18.99	.0250
6.54	21.62	.0500
5.43	23.47	.0750
4.74	24.82	.1000
3.08	29.14	.2500
2.29	32.09	.5000
1.81	34.42	.7500
1.54	36.07	1.0000

Table 4.1.40

WHITEHORSE, ZONE D
HEIGHT ABOVE SEA LEVEL=350.0 M
ELEVATION ANGLE= 9.81 DEG.
LATITUDE= 60.65 DEG. LONG.= 135.00 DEG.
SATELLITE LONG.= 85.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	% WM
18.74	.0100
13.24	.0250
10.18	.0500
8.46	.0750
7.39	.1000
4.79	.2500
3.57	.5000
2.83	.7500
2.39	1.0000

Table 4.1.41

WHITEHORSE, ZONE D
HEIGHT ABOVE SEA LEVEL=350.0 M
ELEVATION ANGLE= 16.81 DEG.
LATITUDE= 60.65 DEG. LONG.= 135.00 DEG.
SATELLITE LONG.= 105.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
12.80	12.72	.0100
9.04	16.19	.0250
6.95	18.82	.0500
5.78	20.67	.0750
5.04	22.02	.1000
3.27	26.34	.2500
2.44	29.29	.5000
1.93	31.62	.7500
1.64	33.27	1.0000

Table 4.1.42

WHITEHORSE, ZONE D
HEIGHT ABOVE SEA LEVEL=350.0 M
ELEVATION ANGLE= 21.26 DEG.
LATITUDE= 60.65 DEG. LONG.= 135.00 DEG.
SATELLITE LONG.= 135.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
10.72	14.96	.0100
7.57	18.43	.0250
5.82	21.06	.0500
4.84	22.91	.0750
4.22	24.26	.1000
2.74	28.58	.2500
2.04	31.53	.5000
1.62	33.86	.7500
1.37	35.51	1.0000

Table 4.1.43

WINDSOR, RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=200.0 M
ELEVATION ANGLE= 41.16 DEG.
LATITUDE= 42.27 DEG. LONG.= 82.97 DEG.
SATELLITE LONG.= 85.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
27.35	9.31	.0100
19.32	12.78	.0250
14.85	15.41	.0500
12.34	17.25	.0750
10.78	18.61	.1000
7.00	22.93	.2500
5.20	25.88	.5000
4.12	28.21	.7500
3.49	29.86	1.0000

Table 4.1.44

WINDSOR, RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=200.0 M
ELEVATION ANGLE= 36.32 DEG.
LATITUDE= 42.27 DEG. LONG.= 82.97 DEG.
SATELLITE LONG.= 105.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
29.57	7.35	.0100
20.88	10.82	.0250
16.05	13.45	.0500
13.34	15.30	.0750
11.65	16.65	.1000
7.56	20.97	.2500
5.63	23.92	.5000
4.46	26.25	.7500
3.78	27.90	1.0000

Table 4.1.46

WINDSOR, RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=200.0 M
ELEVATION ANGLE= 18.87 DEG.
LATITUDE= 42.27 DEG. LONG.= 82.97 DEG.
SATELLITE LONG.= 135.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
45.27	.30	.0100
31.97	3.77	.0250
24.58	6.40	.0500
20.43	8.25	.0750
17.84	9.60	.1000
11.58	13.92	.2500
8.61	16.87	.5000
6.82	19.20	.7500
5.78	20.86	1.0000

Table 4.1.47

WINNIPEG, RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=350.0 M
ELEVATION ANGLE= 31.63 DEG.
LATITUDE= 49.90 DEG. LONG.= 97.20 DEG.
SATELLITE LONG.= 85.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
26.66	7.43	.0100
18.83	10.90	.0250
14.47	13.53	.0500
12.03	15.37	.0750
10.50	16.73	.1000
6.82	21.04	.2500
5.07	24.00	.5000
4.02	26.33	.7500
3.41	27.98	1.0000

Table 4.1.48

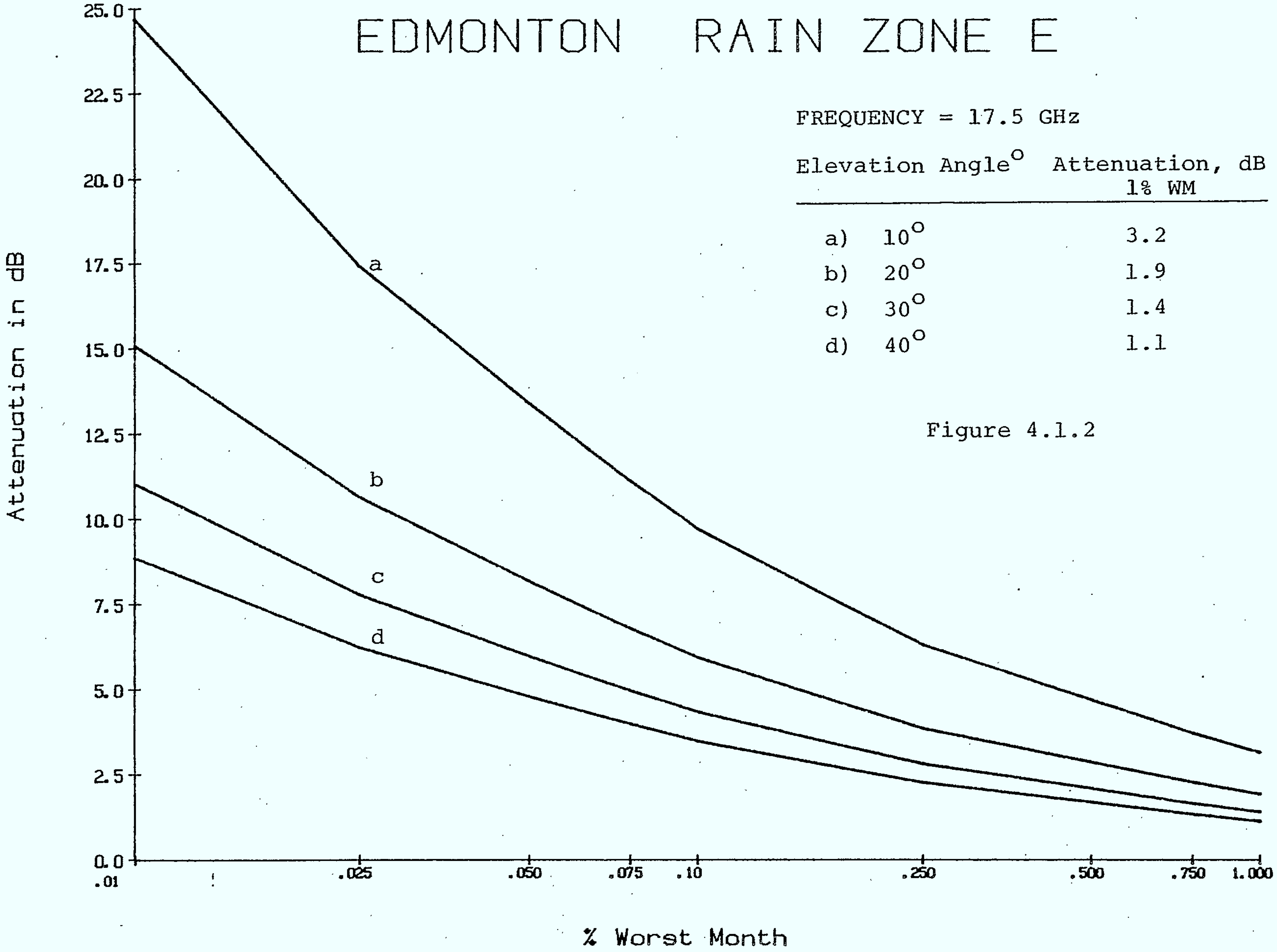
WINNIPEG, RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=350.0 M
ELEVATION ANGLE= 32.32 DEG.
LATITUDE= 49.90 DEG. LONG.= 97.20 DEG.
SATELLITE LONG.= 105.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
26.26	7.71	.0100
18.55	11.18	.0250
14.26	13.81	.0500
11.85	15.66	.0750
10.35	17.01	.1000
6.72	21.33	.2500
5.00	24.28	.5000
3.96	26.61	.7500
3.35	28.26	1.0000

Table 4.1.49

WINNIPEG, RAIN ZONE K
HEIGHT ABOVE SEA LEVEL=350.0 M
ELEVATION ANGLE= 22.58 DEG.
LATITUDE= 49.90 DEG. LONG.= 97.20 DEG.
SATELLITE LONG.= 135.00 DEG. FREQUENCY= 17.50 GHZ

ATTEN.,DB	XPD,DB	% WM
33.77	3.65	.0100
23.85	7.13	.0250
18.33	9.76	.0500
15.24	11.60	.0750
13.30	12.96	.1000
8.64	17.27	.2500
6.43	20.23	.5000
5.09	22.56	.7500
4.31	24.21	1.0000



EDMONTON RAIN ZONE E
FREQUENCY = 17.5 GHz
Elevation Angle° Attenuation, dB 1% WM
a) 10° 3.2
b) 20° 1.9
c) 30° 1.4
d) 40° 1.1
a
b
c
d
Attenuation in dB
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
.01
.025
.050
.075
.10
.250
.500
.750
1.000
% Worst Month

Figure 4.1.2

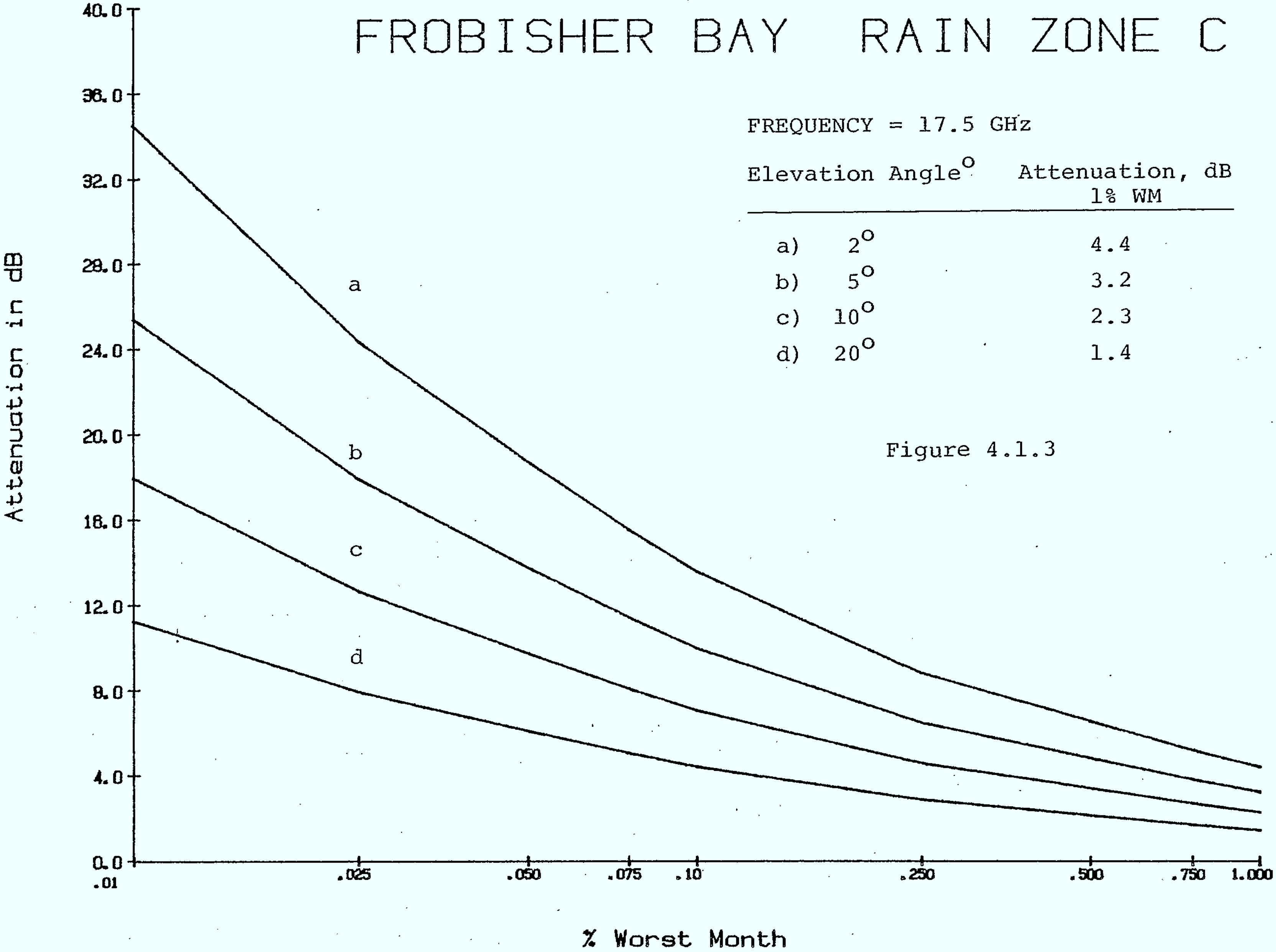

FROBISHER BAY RAIN ZONE C
FREQUENCY = 17.5 GHz
Elevation Angle° | Attenuation, dB 1% WM
a) 2° 4.4
b) 5° 3.2
c) 10° 2.3
d) 20° 1.4
Attenuation in dB
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0
.01
.025
.050
.075
.10
.250
.500
.750
1.000
% Worst Month
a
b
c
d

Figure 4.1.3

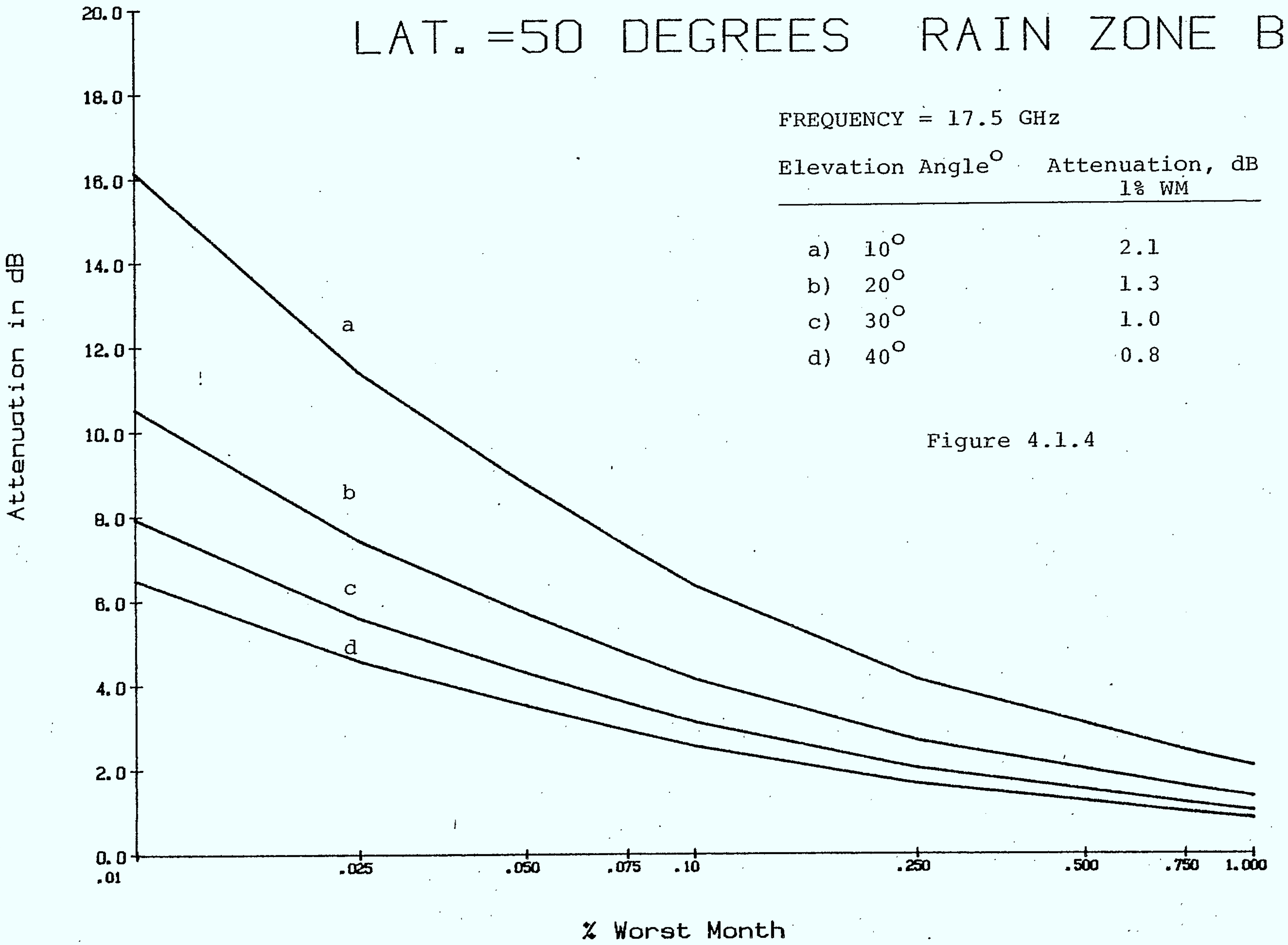

LAT. =50 DEGREES RAIN ZONE B
FREQUENCY = 17.5 GHz
Elevation Angle° Attenuation, dB 1% WM
a) 10° 2.1
b) 20° 1.3
c) 30° 1.0
d) 40° 0.8
a
b
c
d
Attenuation in dB
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
.01
.025
.050
.075
.10
.250
.500
.750
1.000
% Worst Month

Figure 4.1.4

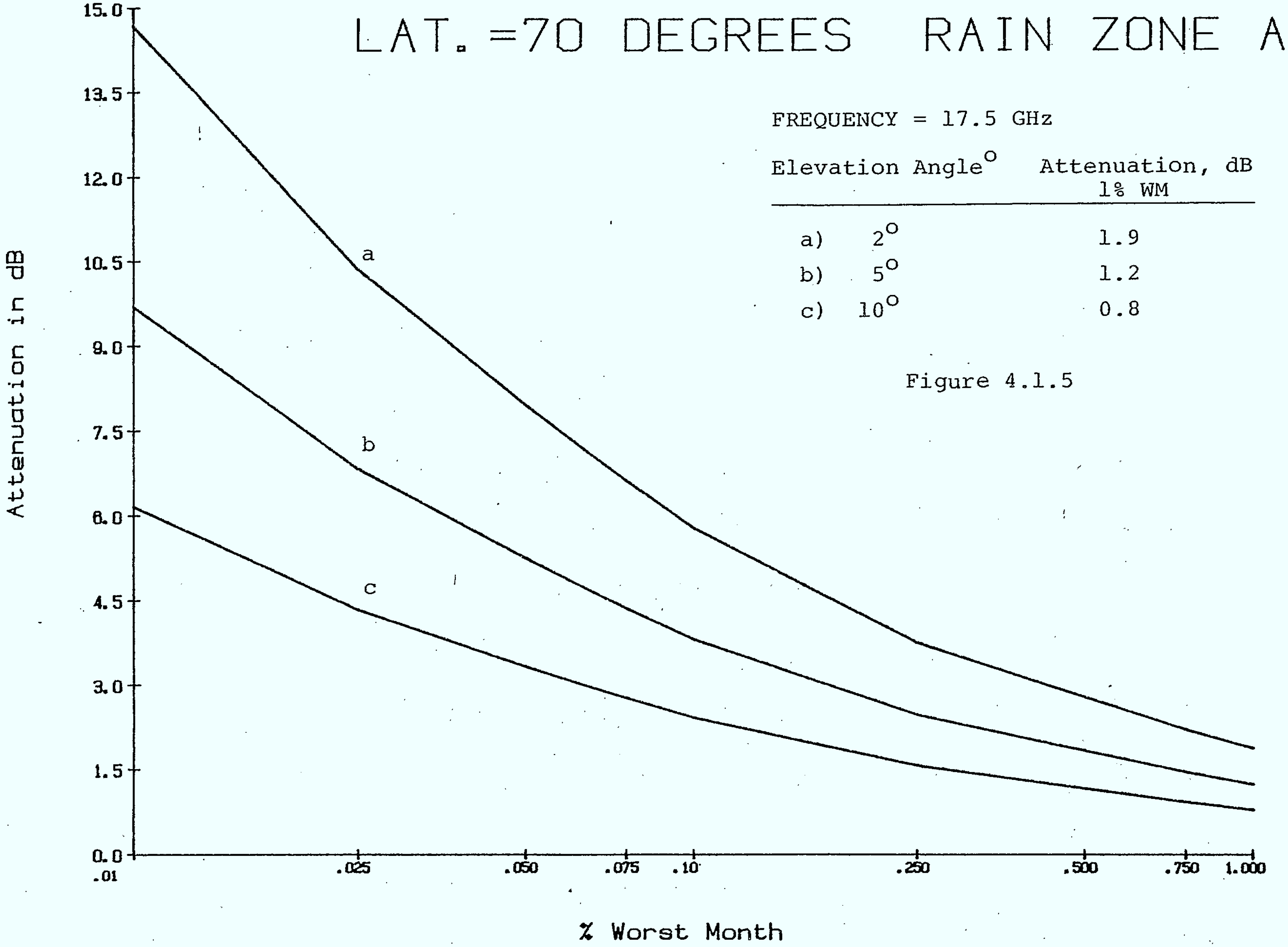

LAT. =70 DEGREES   RAIN ZONE A
FREQUENCY = 17.5 GHz
Elevation Angle° Attenuation, dB 1% WM
a) 2° 1.9
b) 5° 1.2
c) 10° 0.8
Attenuation in dB
15.0
13.5
12.0
10.5
9.0
7.5
6.0
4.5
3.0
1.5
0.0
.01
.025
.050
.075
.10
.250
.500
.750
1.000
% Worst Month
a
b
c

Figure 4.1.5

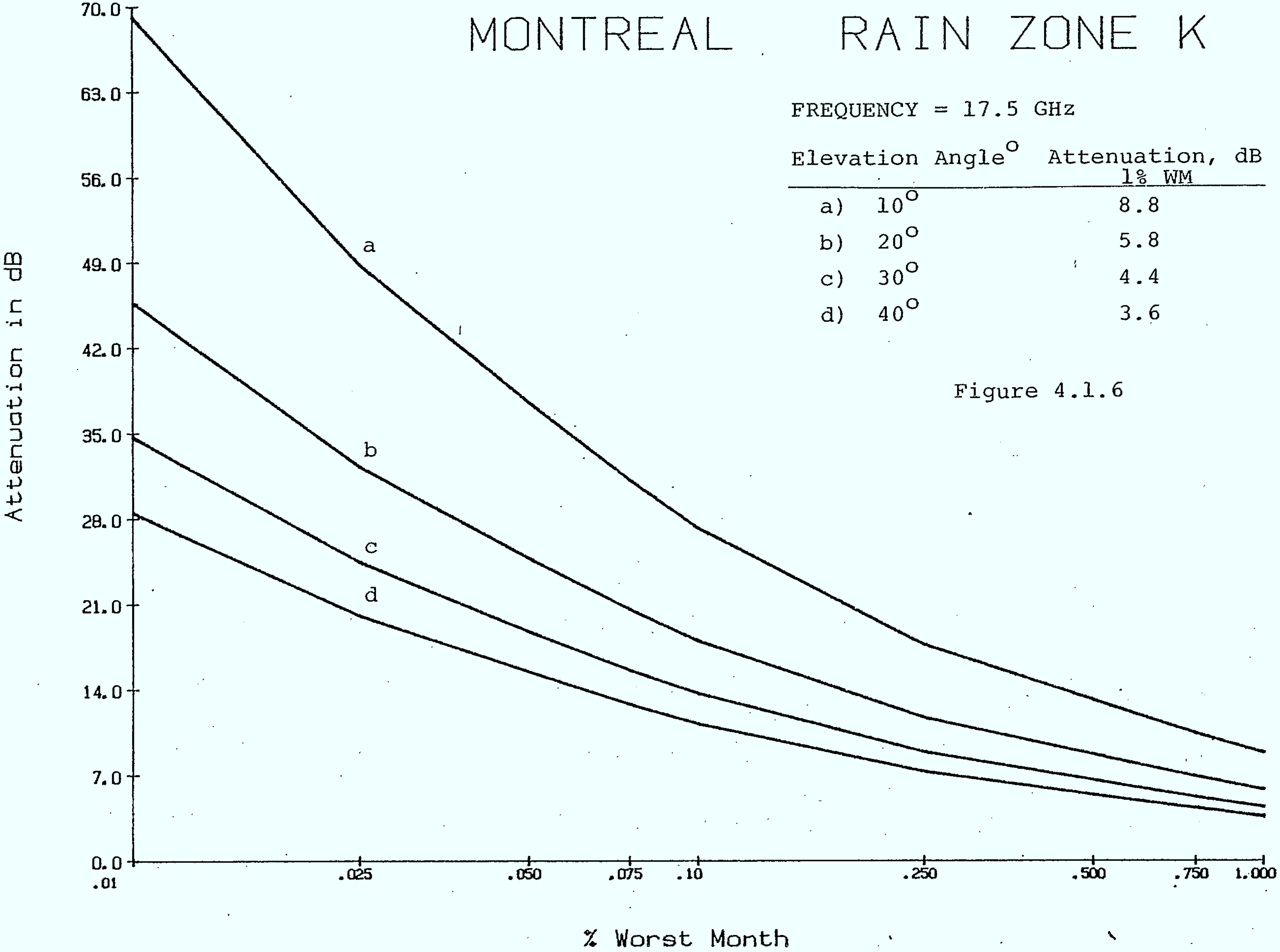

MONTREAL RAIN ZONE K
FREQUENCY = 17.5 GHz
Elevation Angle° Attenuation, dB 1% WM
a) 10° 8.8
b) 20° 5.8
c) 30° 4.4
d) 40° 3.6
a
b
c
d
Attenuation in dB
70.0
63.0
56.0
49.0
42.0
35.0
28.0
21.0
14.0
7.0
0.0
.01
.025
.050
.075
.10
.250
.500
.750
1.000
% Worst Month

Figure 4.1.6

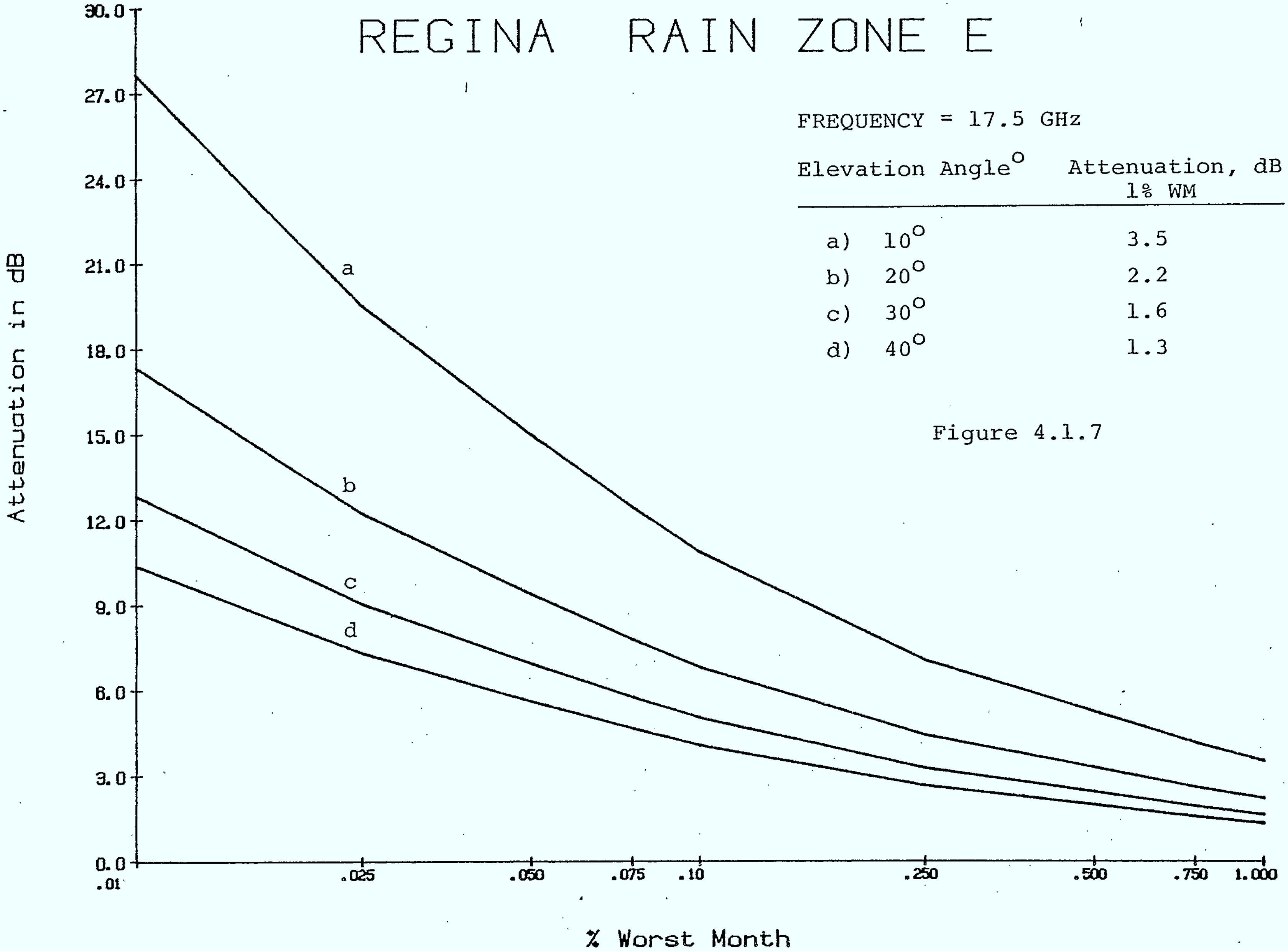

REGINA RAIN ZONE E
FREQUENCY = 17.5 GHz
Elevation Angle°
Attenuation, dB 1% WM
a) 10° 3.5
b) 20° 2.2
c) 30° 1.6
d) 40° 1.3
Attenuation in dB
30.0
27.0
24.0
21.0
18.0
15.0
12.0
9.0
6.0
3.0
0.0
.01
.025
.050
.075
.10
.250
.500
.750
1.000
% Worst Month
a
b
c
d

Figure 4.1.7

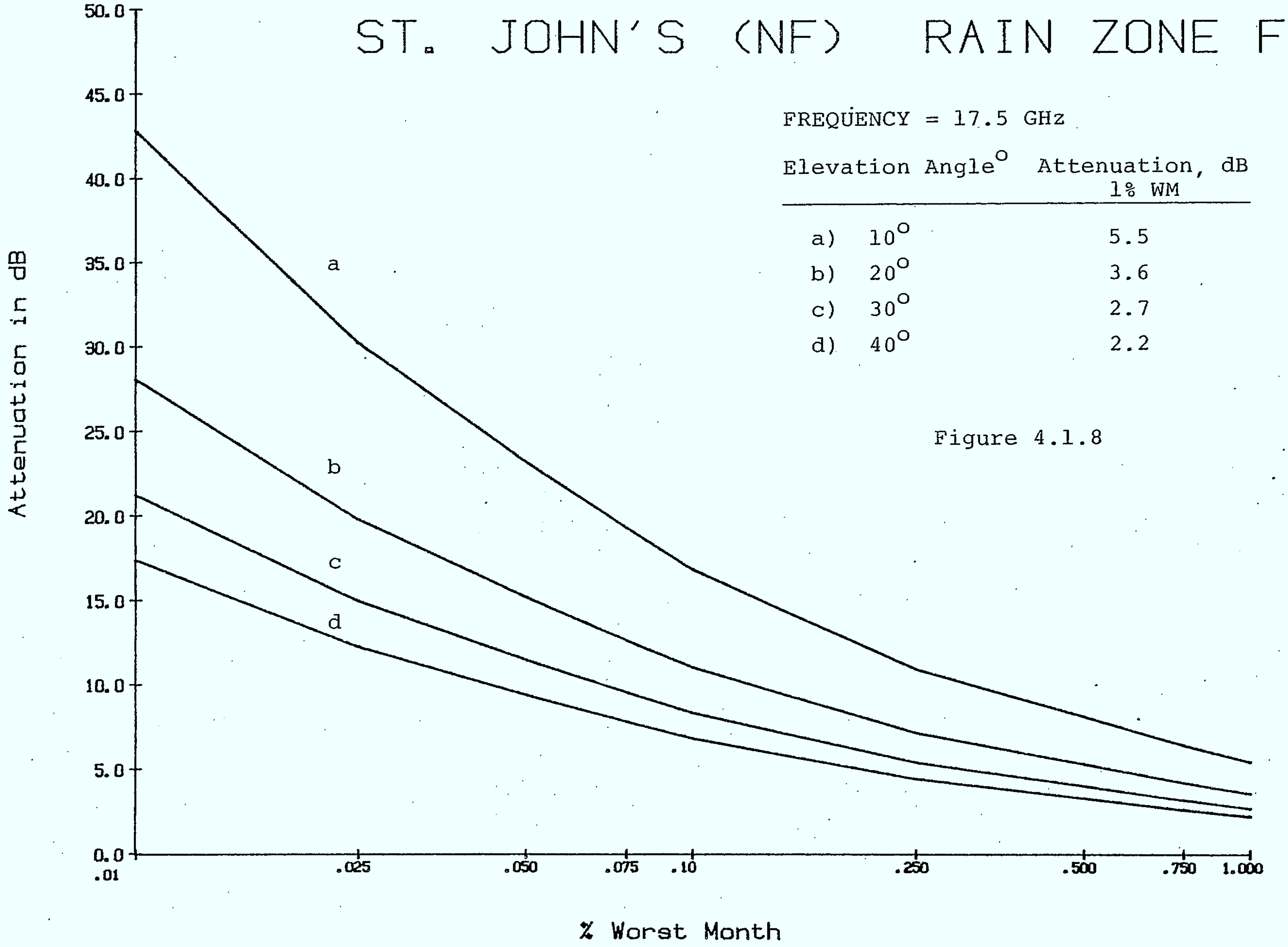

ST. JOHN'S (NF) RAIN ZONE F
FREQUENCY = 17.5 GHz
Elevation Angle° Attenuation, dB 1% WM
a) 10° 5.5
b) 20° 3.6
c) 30° 2.7
d) 40° 2.2
a
b
c
d
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Attenuation in dB
.01
.025
.050
.075
.10
.250
.500
.750
1.000
% Worst Month

Figure 4.1.8

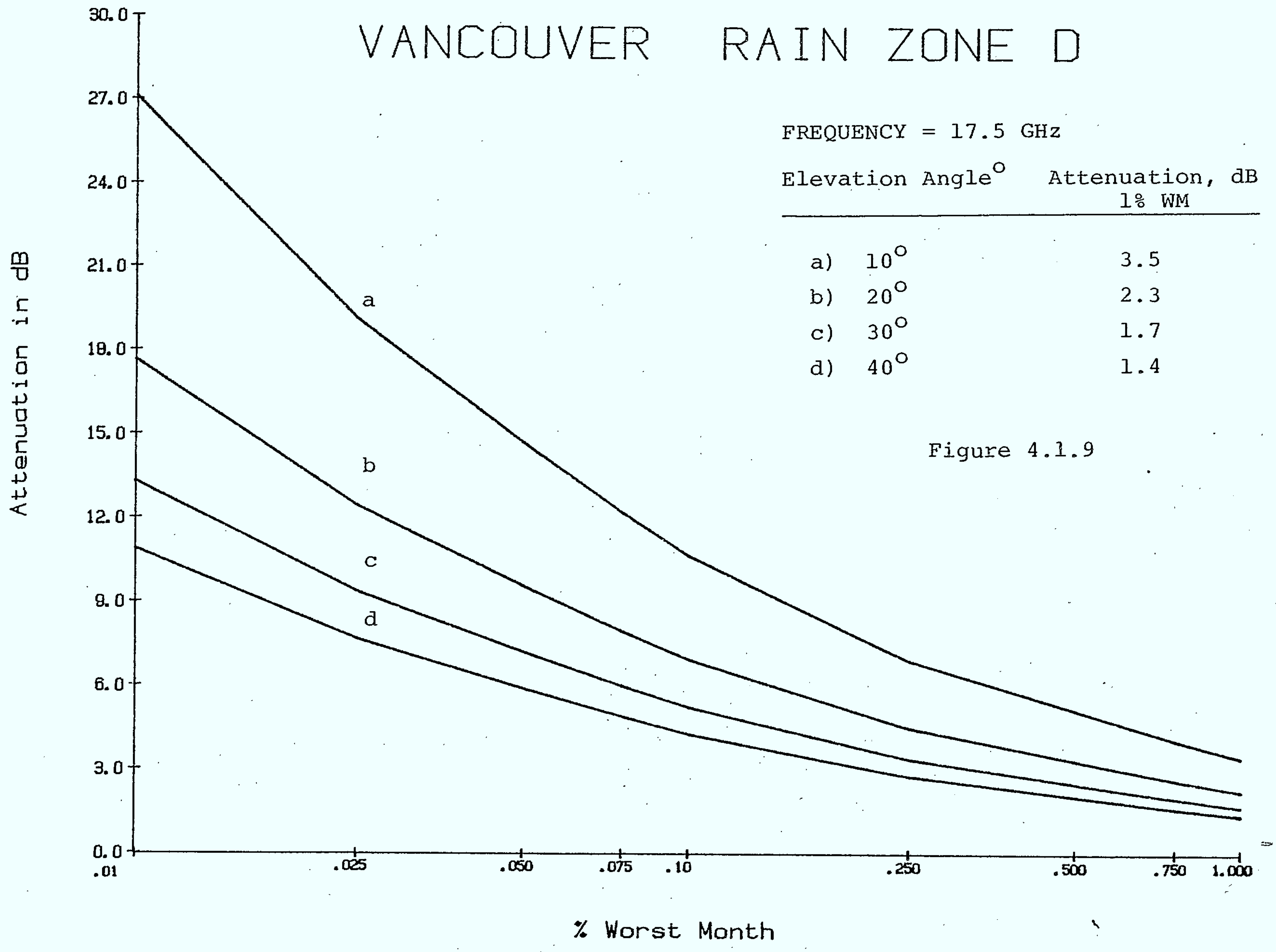

VANCOUVER RAIN ZONE D
FREQUENCY = 17.5 GHz
Elevation Angle° Attenuation, dB 1% WM
a) 10° 3.5
b) 20° 2.3
c) 30° 1.7
d) 40° 1.4
a
b
c
d
Attenuation in dB
30.0
27.0
24.0
21.0
18.0
15.0
12.0
9.0
6.0
3.0
0.0
.01
.025
.050
.075
.10
.250
.500
.750
1.000
% Worst Month

Figure 4.1.9

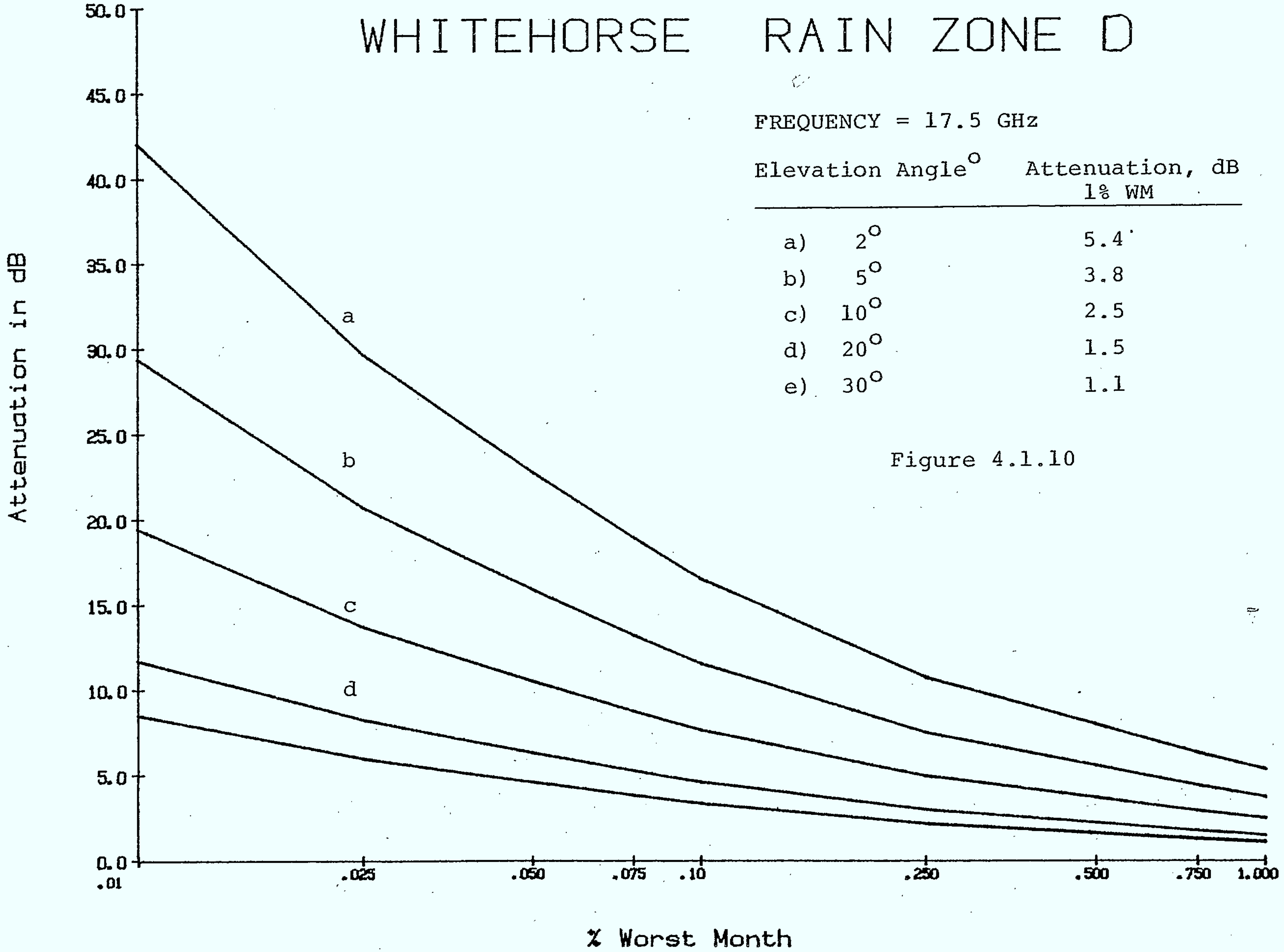

WHITEHORSE RAIN ZONE D
FREQUENCY = 17.5 GHz
Elevation Angle° Attenuation, dB 1% WM
a) 2° 5.4
b) 5° 3.8
c) 10° 2.5
d) 20° 1.5
e) 30° 1.1
Attenuation in dB
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
.01
.025
.050
.075
.10
.250
.500
.750
1.000
a
b
c
d
% Worst Month

Figure 4.1.10

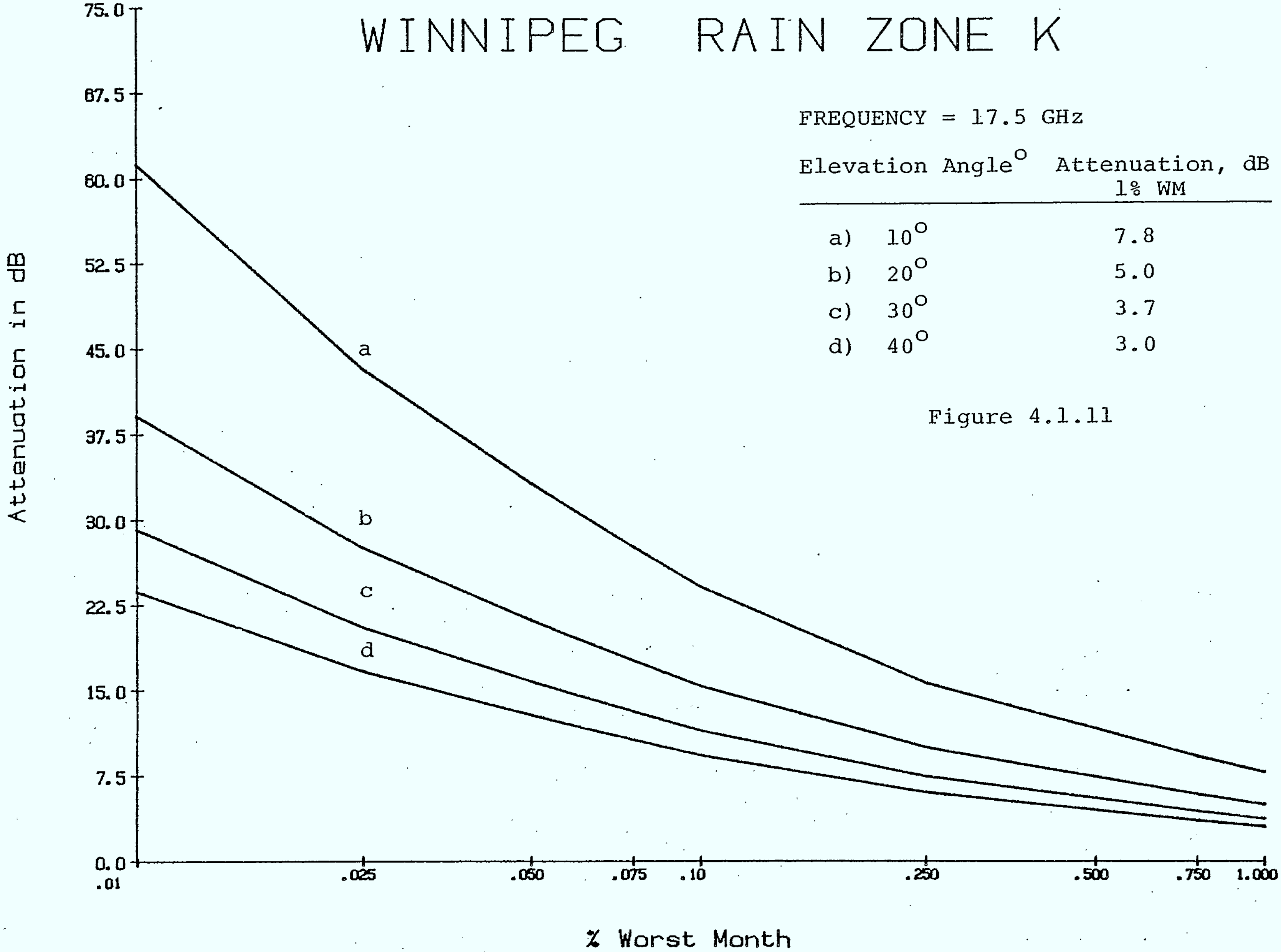

WINNIPEG RAIN ZONE K
FREQUENCY = 17.5 GHz
Elevation Angle° Attenuation, dB 1% WM
a) 10° 7.8
b) 20° 5.0
c) 30° 3.7
d) 40° 3.0
Attenuation in dB
75.0
67.5
60.0
52.5
45.0
37.5
30.0
22.5
15.0
7.5
0.0
.01
.025
.050
.075
.10
.250
.500
.750
1.000
% Worst Month
a
b
c
d

Figure 4.1.11

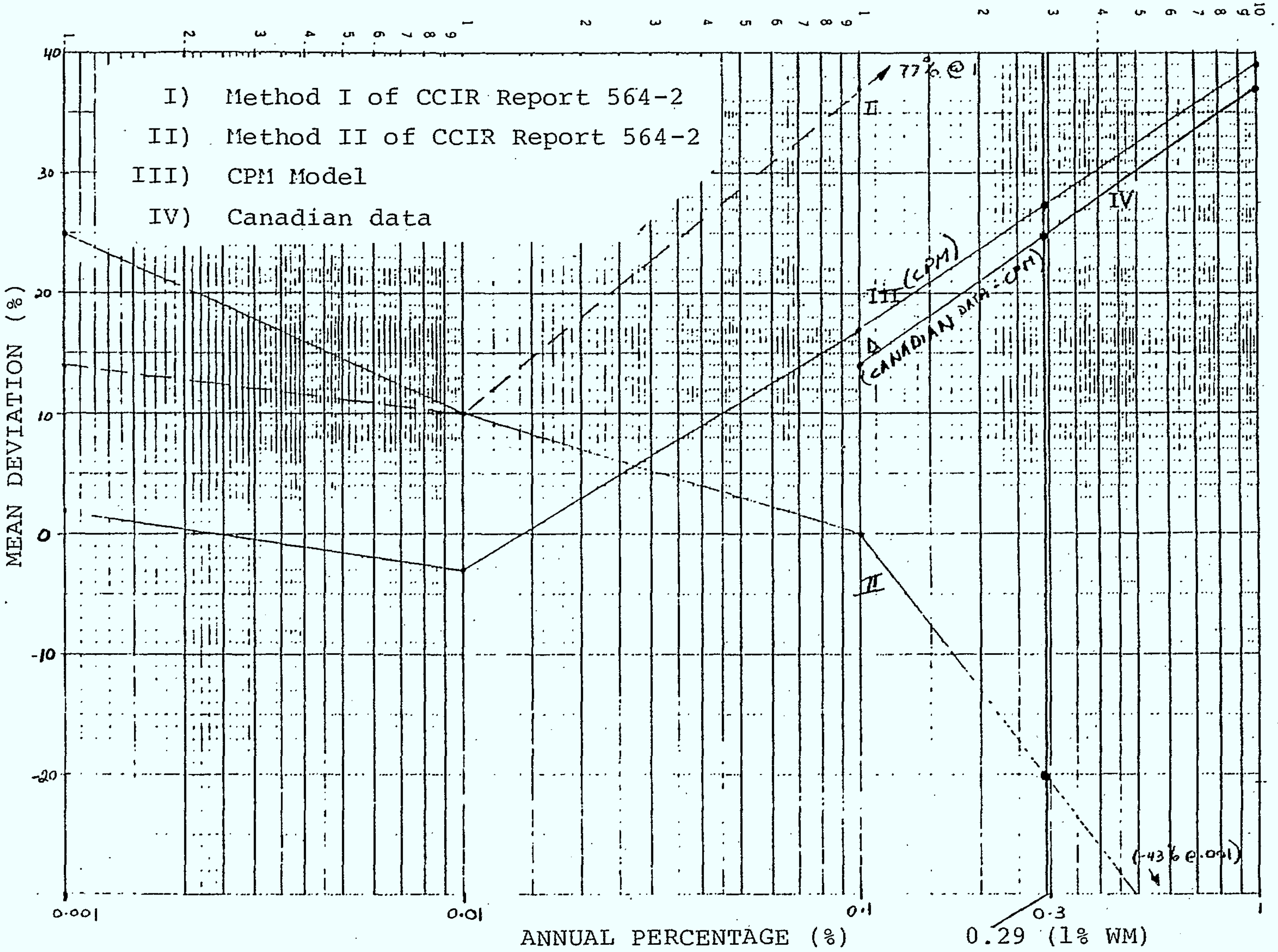


Figure 4.1.12 Comparision of mean deviation for different models from measured data across the world.

TABLE 4.1.50

BEAM CAN1,RAIN ZONE A
MINIMUM ELEVATION ANGLE IN CAN1
HEIGHT ABOVE SEA LEVEL=750.0 M
ELEVATION ANGLE= 10.76 DEG.
LATITUDE= 70.00 DEG. LONG.= 120.00 DEG.
SATELLITE LONG.= 135.00 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
1.37	30.62	.0100
.97	33.64	.0250
.74	35.92	.0500
.62	37.53	.0750
.54	38.71	.1000
.35	42.46	.2500
.26	45.03	.5000
.21	47.05	.7500
.17	48.49	1.0000

TABLE 4.1.51

BEAM CAN1, ZONE B
HEIGHT ABOVE SEA LEVEL=100.0 M
ELEVATION ANGLE= 25.8 DEG.
MINIMUM ELEVATION ANGLE IN CAN1 AND ZONE B
LATITUDE= 55.00 DEG. LONG.= 120.00 DEG.
SATELLITE LONG.= 135.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
3.5	23.9	.010
2.5	26.9	.025
1.9	29.2	.050
1.6	30.8	.075
1.4	32.0	.100
.9	35.7	.250
.7	38.3	.500
.5	40.3	.750
.5	41.8	1.000

TABLE 4.1.52

BEAM CAN1, ZONE D
HEIGHT ABOVE SEA LEVEL=350.0 M
ELEVATION ANGLE= 20.9 DEG.
MINIMUM ELEVATION ANGLE IN CAN1 AND ZONE D
LATITUDE= 61.00 DEG. LONG.= 135.00 DEG.
SATELLITE LONG.= 135.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
5.4	19.5	.010
3.8	22.6	.025
2.9	24.8	.050
2.4	26.4	.075
2.1	27.6	.100
1.4	31.4	.250
1.0	33.9	.500
.8	36.0	.750
.7	37.4	1.000

TABLE 4.1.53

BEAM CAN2,RAIN ZONE A
MINIMUM ELEVATION ANGLE IN CAN2
HEIGHT ABOVE SEA LEVEL=100.0 M
ELEVATION ANGLE= 10.20 DEG.
LATITUDE= 70.00 DEG. LONG.= 115.00 DEG.
SATELLITE LONG.= 135.00 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
2.55	25.20	.0100
1.80	28.22	.0250
1.38	30.50	.0500
1.15	32.11	.0750
1.00	33.29	.1000
.65	37.04	.2500
.48	39.61	.5000
.38	41.64	.7500
.33	43.07	1.0000

TABLE 4.1.54

BEAM CAN2, ZONE E
HEIGHT ABOVE SEA LEVEL=150.0 M
ELEVATION ANGLE= 23.8 DEG.
MINIMUM ELEVATION ANGLE IN CAN2 AND ZONE E
LATITUDE= 53.00 DEG. LONG.= 106.00 DEG.
SATELLITE LONG.= 135.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
8.0	16.5	.010
5.7	19.5	.025
4.4	21.8	.050
3.6	23.4	.075
3.2	24.6	.100
2.1	28.3	.250
1.5	30.9	.500
1.2	32.9	.750
1.0	34.4	1.000

TABLE 4.1.55

BEAM CAN3,RAIN ZONE A
HEIGHT ABOVE SEA LEVEL=350.0 M
MINIMUM ELEVATION ANGLE IN CAN3
ELEVATION ANGLE= 11.16 DEG.
LATITUDE= 70.00 DEG. LONG.= 95.00 DEG.
SATELLITE LONG.= 105.00 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
2.01	27.33	.0100
1.42	30.35	.0250
1.09	32.64	.0500
.90	34.24	.0750
.79	35.42	.1000
.51	39.17	.2500
.38	41.74	.5000
.30	43.77	.7500
.26	45.20	1.0000

TABLE 4.1.56

BEAM CAN3, ZONE C
HEIGHT ABOVE SEA LEVEL=750.0 M
ELEVATION ANGLE= 21.9 DEG.
MINIMUM ELEVATION ANGLE IN CAN3 AND ZONE C
LATITUDE= 60.00 DEG. LONG.= 101.00 DEG.
SATELLITE LONG.= 105.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
3.3	23.9	.010
2.4	26.9	.025
1.8	29.2	.050
1.5	30.8	.075
1.3	32.0	.100
.9	35.7	.250
.6	38.3	.500
.5	40.3	.750
.4	41.7	1.000

TABLE 4.1.57

BEAM CAN3, ZONE E
HEIGHT ABOVE SEA LEVEL=750.0 M
ELEVATION ANGLE= 32.6 DEG.
MINIMUM ELEVATION ANGLE IN CAN3 AND ZONE E
LATITUDE= 50.00 DEG. LONG.= 101.50 DEG.
SATELLITE LONG.= 105.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
5.7	20.9	.010
4.0	24.0	.025
3.1	26.3	.050
2.6	27.9	.075
2.2	29.0	.100
1.4	32.8	.250
1.1	35.4	.500
.9	37.4	.750
.7	38.8	1.000

TABLE 4.1.58

BEAM CAN3, ZONE K
HEIGHT ABOVE SEA LEVEL=350.0 M
ELEVATION ANGLE= 32.5 DEG.
MINIMUM ELEVATION ANGLE IN CAN3 AND ZONE K
LATITUDE= 50.00 DEG. LONG.= 100.00 DEG.
SATELLITE LONG.= 105.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
14.2	13.0	.010
10.0	16.0	.025
7.7	18.3	.050
6.4	19.9	.075
5.6	21.1	.100
3.6	24.8	.250
2.7	27.4	.500
2.1	29.4	.750
1.8	30.8	1.000

TABLE 4.1.59

BEAM CAN3,RAIN ZONE A
HEIGHT ABOVE SEA LEVEL=350.0 M
MINIMUM ELEVATION ANGLE IN CAN3
ELEVATION ANGLE= 6.56 DEG.
LATITUDE= 70.00 DEG. LONG.= 95.00 DEG.
SATELLITE LONG.= 135.00 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	% WM
2.99	.0100
2.11	.0250
1.62	.0500
1.35	.0750
1.18	.1000
.76	.2500
.57	.5000
.45	.7500
.38	1.0000

TABLE 4.1.60

BEAM CAN3, ZONE C
HEIGHT ABOVE SEA LEVEL=750.0 M
ELEVATION ANGLE= 16.1 DEG.
MINIMUM ELEVATION ANGLE IN CAN3 AND ZONE C
LATITUDE= 60.00 DEG. LONG.= 101.00 DEG.
SATELLITE LONG.= 135.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
4.2	21.2	.010
3.0	24.2	.025
2.3	26.5	.050
1.9	28.1	.075
1.7	29.3	.100
1.1	33.0	.250
.8	35.6	.500
.6	37.6	.750
.5	39.1	1.000

TABLE 4.1.61

BEAM CAN3, ZONE E
HEIGHT ABOVE SEA LEVEL=350.0 M
ELEVATION ANGLE= 20.9 DEG.
MINIMUM ELEVATION ANGLE IN CAN3 AND ZONE E
LATITUDE= 53.20 DEG. LONG.= 99.00 DEG.
SATELLITE LONG.= 135.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
8.3	15.9	.010
5.8	18.9	.025
4.5	21.2	.050
3.7	22.8	.075
3.3	24.0	.100
2.1	27.7	.250
1.6	30.3	.500
1.2	32.3	.750
1.1	33.8	1.000

TABLE 4.1.62

BEAM CAN3, ZONE K
HEIGHT ABOVE SEA LEVEL=350.0 M
ELEVATION ANGLE= 22.1 DEG.
MINIMUM ELEVATION ANGLE IN CAN3 AND ZONE K
LATITUDE= 49.00 DEG. LONG.= 95.00 DEG.
SATELLITE LONG.= 135.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
19.0	8.8	.010
13.4	11.8	.025
10.3	14.1	.050
8.6	15.7	.075
7.5	16.9	.100
4.9	20.6	.250
3.6	23.2	.500
2.9	25.2	.750
2.4	26.7	1.000

TABLE 4.1.63

BEAM CAN4,RAIN ZONE A
HEIGHT ABOVE SEA LEVEL=150.0 M
MINIMUM ELEVATION ANGLE IN CAN4
ELEVATION ANGLE= 9.49 DEG.
LATITUDE= 70.00 DEG. LONG.= 80.00 DEG.
SATELLITE LONG.= 105.00 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	% WM
2.61	.0100
1.84	.0250
1.41	.0500
1.18	.0750
1.03	.1000
.67	.2500
.50	.5000
.39	.7500
.33	1.0000

TABLE 4.1.64

BEAM CAN4, ZONE E
HEIGHT ABOVE SEA LEVEL=350.0 M
ELEVATION ANGLE= 30.0 DEG.
MINIMUM ELEVATION ANGLE IN CAN4 AND ZONE E
LATITUDE= 48.40 DEG. LONG.= 81.40 DEG.
SATELLITE LONG.= 105.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
7.2	18.4	.010
5.1	21.4	.025
3.9	23.7	.050
3.2	25.3	.075
2.8	26.5	.100
1.8	30.3	.250
1.4	32.8	.500
1.1	34.9	.750
.9	36.3	1.000

TABLE 4.1.65

BEAM CAN4, ZONE K
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 29.5 DEG.
MINIMUM ELEVATION ANGLE IN CAN4 AND ZONE K
LATITUDE= 45.60 DEG. LONG.= 74.40 DEG.
SATELLITE LONG.= 105.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
18.0	10.3	.010
12.7	13.3	.025
9.8	15.6	.050
8.1	17.2	.075
7.1	18.4	.100
4.6	22.2	.250
3.4	24.7	.500
2.7	26.8	.750
2.3	28.2	1.000

TABLE 4.1.66

BEAM CANS,RAIN ZONE A
HEIGHT ABOVE SEA LEVEL=200.0 M
MINIMUM ELEVATION ANGLE IN CANS
ELEVATION ANGLE= 10.44 DEG.
LATITUDE= 70.00 DEG. LONG.= 67.00 DEG.
SATELLITE LONG.= 85.00 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
2.35	25.91	.0100
1.66	28.93	.0250
1.28	31.21	.0500
1.06	32.82	.0750
.93	33.99	.1000
.60	37.75	.2500
.45	40.32	.5000
.35	42.34	.7500
.30	43.78	1.0000

TABLE 4.1.67

BEAM CANS, ZONE B
HEIGHT ABOVE SEA LEVEL=350.0 M
ELEVATION ANGLE= 25.1 DEG.
MINIMUM ELEVATION ANGLE IN CANS AND ZONE B
LATITUDE= 52.00 DEG. LONG.= 57.00 DEG.
SATELLITE LONG.= 85.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
3.6	23.6	.010
2.5	26.6	.025
2.0	28.9	.050
1.6	30.5	.075
1.4	31.7	.100
.9	35.5	.250
.7	38.0	.500
.5	40.1	.750
.5	41.5	1.000

TABLE 4.1.68

BEAM CANS, ZONE E
HEIGHT ABOVE SEA LEVEL=350.0 M
ELEVATION ANGLE= 30.7 DEG.
MINIMUM ELEVATION ANGLE IN CANS AND ZONE E
LATITUDE= 50.00 DEG. LONG.= 69.00 DEG.
SATELLITE LONG.= 85.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
6.8	19.0	.010
4.8	22.0	.025
3.7	24.3	.050
3.1	25.9	.075
2.7	27.1	.100
1.7	30.9	.250
1.3	33.4	.500
1.0	35.5	.750
.9	36.9	1.000

TABLE 4.1.69

BEAM CANS, ZONE K
HEIGHT ABOVE SEA LEVEL=350.0 M
ELEVATION ANGLE= 32.1 DEG.
MINIMUM ELEVATION ANGLE IN CANS AND ZONE K
LATITUDE= 48.50 DEG. LONG.= 68.50 DEG.
SATELLITE LONG.= 85.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
14.8	12.5	.010
10.5	15.5	.025
8.0	17.8	.050
6.7	19.4	.075
5.8	20.6	.100
3.8	24.3	.250
2.8	26.9	.500
2.2	28.9	.750
1.9	30.4	1.000

TABLE 4.1.70

BEAM CANS,RAIN ZONE A
HEIGHT ABOVE SEA LEVEL=200.0 M
MINIMUM ELEVATION ANGLE IN CAN4
ELEVATION ANGLE= 7.02 DEG.
LATITUDE= 70.00 DEG. LONG.= 67.00 DEG.
SATELLITE LONG.= 105.00 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	% WM
3.14	.0100
2.22	.0250
1.70	.0500
1.42	.0750
1.24	.1000
.80	.2500
.60	.5000
.47	.7500
.40	1.0000

TABLE 4.1.71

BEAM CANS, ZONE B
HEIGHT ABOVE SEA LEVEL=350.0 M
ELEVATION ANGLE= 16.0 DEG.
MINIMUM ELEVATION ANGLE IN CANS AND ZONE B
LATITUDE= 52.00 DEG. LONG.= 57.00 DEG.
SATELLITE LONG.= 105.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
4.9	19.8	.010
3.5	22.9	.025
2.7	25.2	.050
2.2	26.8	.075
1.9	27.9	.100
1.3	31.7	.250
.9	34.3	.500
.7	36.3	.750
.6	37.7	1.000

TABLE 4.1.72

BEAM CANS, ZONE E
HEIGHT ABOVE SEA LEVEL=350.0 M
ELEVATION ANGLE= 23.4 DEG.
MINIMUM ELEVATION ANGLE IN CANS AND ZONE E
LATITUDE= 50.00 DEG. LONG.= 69.00 DEG.
SATELLITE LONG.= 105.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
8.2	16.2	.010
5.8	19.2	.025
4.5	21.5	.050
3.7	23.1	.075
3.2	24.3	.100
2.1	28.1	.250
1.6	30.6	.500
1.2	32.7	.750
1.1	34.1	1.000

TABLE 4.1.73

BEAM CANS, ZONE K
HEIGHT ABOVE SEA LEVEL=350.0 M
ELEVATION ANGLE= 24.3 DEG.
MINIMUM ELEVATION ANGLE IN CANS AND ZONE K
LATITUDE= 48.40 DEG. LONG.= 68.50 DEG.
SATELLITE LONG.= 105.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
18.0	9.6	.010
12.7	12.6	.025
9.8	14.9	.050
8.1	16.5	.075
7.1	17.6	.100
4.6	21.4	.250
3.4	24.0	.500
2.7	26.0	.750
2.3	27.4	1.000

TABLE 4.1.74

BEAM CAN6, ZONE B
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 23.3 DEG.
MINIMUM ELEVATION ANGLE IN CAN6 AND ZONE B
LATITUDE= 53.50 DEG. LONG.= 55.70 DEG.
SATELLITE LONG.= 85.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
4.0	22.4	.010
2.8	25.5	.025
2.2	27.7	.050
1.8	29.3	.075
1.6	30.5	.100
1.0	34.3	.250
.8	36.8	.500
.6	38.9	.750
.5	40.3	1.000

TABLE 4.1.75

BEAM CAN6, ZONE C
HEIGHT ABOVE SEA LEVEL=200.0 M
ELEVATION ANGLE= 19.7 DEG.
MINIMUM ELEVATION ANGLE IN CAN6 AND ZONE C
LATITUDE= 60.00 DEG. LONG.= 64.00 DEG.
SATELLITE LONG.= 85.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
4.7	20.6	.010
3.3	23.6	.025
2.6	25.9	.050
2.1	27.5	.075
1.9	28.7	.100
1.2	32.4	.250
.9	35.0	.500
.7	37.0	.750
.6	38.5	1.000

TABLE 4.1.76

BEAM CAN6, ZONE F
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 26.8 DEG.
MINIMUM ELEVATION ANGLE IN CAN6 AND ZONE F
LATITUDE= 47.50 DEG. LONG.= 52.00 DEG.
SATELLITE LONG.= 85.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
11.4	13.9	.010
8.1	16.9	.025
6.2	19.2	.050
5.2	20.8	.075
4.5	21.9	.100
2.9	25.7	.250
2.2	28.3	.500
1.7	30.3	.750
1.5	31.7	1.000

TABLE 4.1.77

BEAM CAN6, ZONE K
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 31.6 DEG.
MINIMUM ELEVATION ANGLE IN CAN6 AND ZONE K
LATITUDE= 46.00 DEG. LONG.= 60.00 DEG.
SATELLITE LONG.= 85.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
17.1	11.2	.010
12.1	14.2	.025
9.3	16.5	.050
7.7	18.1	.075
6.7	19.3	.100
4.4	23.0	.250
3.3	25.6	.500
2.6	27.6	.750
2.2	29.1	1.000

Table 4.1.78

BEAM CAN6, ZONE B
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 14.4 DEG.
MINIMUM ELEVATION ANGLE IN CAN6 AND ZONE B
LATITUDE= 53.50 DEG. LONG.= 55.70 DEG.
SATELLITE LONG.= 105.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
5.6	18.7	.010
3.9	21.7	.025
3.0	24.0	.050
2.5	25.6	.075
2.2	26.8	.100
1.4	30.5	.250
1.1	33.1	.500
.8	35.1	.750
.7	36.6	1.000

Table 4.1.79

BEAM CAN6, ZONE C
HEIGHT ABOVE SEA LEVEL=200.0 M
ELEVATION ANGLE= 13.7 DEG.
MINIMUM ELEVATION ANGLE IN CAN6 AND ZONE C
LATITUDE= 60.00 DEG. LONG.= 64.00 DEG.
SATELLITE LONG.= 105.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
6.1	17.8	.010
4.3	20.8	.025
3.3	23.1	.050
2.8	24.7	.075
2.4	25.9	.100
1.6	29.7	.250
1.2	32.2	.500
.9	34.2	.750
.8	35.7	1.000

Table 4.1.80

BEAM CAN6, ZONE F
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 15.6 DEG.
MINIMUM ELEVATION ANGLE IN CAN6 AND ZONE F
LATITUDE= 47.50 DEG. LONG.= 52.00 DEG.
SATELLITE LONG.= 105.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
16.2	9.5	.010
11.5	12.5	.025
8.8	14.8	.050
7.3	16.4	.075
6.4	17.6	.100
4.2	21.3	.250
3.1	23.9	.500
2.4	25.9	.750
2.1	27.4	1.000

Table 4.1.81

BEAM CAN6, ZONE K
HEIGHT ABOVE SEA LEVEL=50.00 M
ELEVATION ANGLE= 21.3 DEG.
MINIMUM ELEVATION ANGLE IN CAN6 AND ZONE K
LATITUDE= 46.00 DEG. LONG.= 60.00 DEG.
SATELLITE LONG.= 105.0 DEG. FREQUENCY= 12.50 GHZ

ATTEN.,DB	XPD,DB	% WM
22.2	7.4	.010
15.7	10.4	.025
12.0	12.7	.050
10.0	14.3	.075
8.7	15.4	.100
5.7	19.2	.250
4.2	21.8	.500
3.3	23.8	.750
2.8	25.2	1.000

world. For measured data in the U.S., it was found that the CPM model overpredicts the attenuation with a mean deviation of 38%.

In Canada, J. Schlesak of CRC has compared mean deviations for different models from measured data at 81 locations across the world, using Methods I, II of CCIR Report 564-2 and the CPM model. See Figure 4.1.12. It is seen that the CPM model is the closest to the measured data in the range from 0.001% to 0.05% of the time, since it is optimized to fit the data best at 0.01%. For percentages of the time greater than 0.05%, the CPM model overpredicts the attenuation and at 0.29% (1% of the worst month), for example, the predicted results should be reduced by about 28%. For Canadian data the reduction factor is 25% [12].

It is to be noted that at high percentages of the time the rain attenuation is in the range of 0-2 dB in temperate climates. Therefore, a difference of 0.5 dB to 1 dB between measured and predicted results leads to deviations of 50-100%.

As was pointed out above, the CPM model is based on the prediction of rain attenuation at 0.01% of the time. Therefore, the CPM rain statistics at 0.01% of the time were checked against the long term rainfall statistics in Canada [13]. The places used for comparison were those cities suggested by the CBC as the possible future feeder-link locations. The examination showed that, in general, the climatic zones suggested by the CPM overestimate the rainfall statistics at 0.01% of the time. Table 4.1.82 shows cities with the most deviation of rainfall statistics from the long term measured rainfall statistics and it suggests the rain climatic zones that these cities should be in.

City	CPM		MEASURED	
	Rain Rate 0.01%mm/h	Rain Zone	Rain Rate 0.01%mm/h	Rain Zone Suggested
Vancouver	19	D	12.5	B
Calgary	22	E	17	D
Winnipeg	42	K	33	H
Fredericton	42	K	27	F
Sydney, N.S.	42	K	27	F

Table 4.1.82 Comparison between the CPM suggested and the measured long term rainfall for certain cities across Canada.

Finally, the attenuation predicted by the CPM model peaks at about 40° latitude for a given rain zone, as shown in Figures 3-4 and 3-5 of the CPM report. This is counter-intuitive, since the strong dependence of attenuation on elevation angle and climatic zone should preclude a consistent peak attenuation at one latitude.

4.1.5 Concluding Remarks

The rain attenuations for different locations across Canada have been predicted using the CPM model which is, in turn, based on CCIR Method I. This method calculates rain attenuation exceeded for an average year based on the rain rate at 0.01% of the year. The net result of the CPM rain attenuation model is an overprediction of about 28% in rain attenuation for 1% of the worst month. This overprediction should be considered in the feeder-link design, unless the CPM model is corrected at this range.

When there is an excessive uplink rain attenuation, the whole coverage area might suffer, whereas a downlink fade would affect only a limited number of viewers. Hence, the percentage of time that an acceptable level of uplink rain fade might be exceeded should be as small as possible to minimize the service outage.

As seen in the tables, the predicted rain attenuation for feeder-links located in rain climatic zone K, such as Montreal, could be as much as 24 dB for 0.1% of the worst month (43 minutes) when the antenna is pointed to the 135°W orbital slot. It is clear that 43 minutes total service blackout is not acceptable for a national programme and a smaller outage time should be sought. This indicates that service must continue when even a greater rain attenuation occurs. Even if the use of power control were permitted in the BSS plan, the magnitude of the required uplink power compensation might not be practical. Thus, another means, such as site diversity should be employed to overcome excessive rain attenuation in certain rain climatic zones.

4.2 Uplink Fade Compensation Techniques

This section studies techniques which could be used to reduce the effect of rain attenuation on feeder-links, since it is desirable to operate the satellite transponder at or near the saturation point during all but a small percentage of the time. Several approaches are available, such as, Automatic Gain Control (AGC) on board the spacecraft, site diversity, and uplink power control. Power control is not discussed in the following, because the CPM agreed that it should not be generally used, since it causes an increase in the interference level to other cross-polarized feeder-links operating in clear sky conditions. However, in special cases where the elevation angle is greater than about 60°, power control up to 5 dB could be used. Under these conditions, it would degrade carrier to interference ratios to other satellites by less than 0.5 dB.

4.2.1 Automatic Gain Control on Board the Satellite

The use of Automatic Gain Control (AGC) on board the spacecraft helps to keep the TWTA near saturation and thus minimizes the reduction of the downlink carrier due to feeder-link fades. The effect of AGC on total C/N_T is shown in Figure 4.2.1 in cases where it rains at the feeder-link site only and in the worst case where rain is correlated at the feeder-link and downlink station [14]. The figure shows that in the absence of AGC, the total C/N decreases rapidly with increases in rain attenuation. However, AGC on board the satellite effectively compensates the uplink fade.

The effect of AGC on cross-polar C/I_u for different cases has been studied thoroughly [14]. The results indicate that while AGC on board the satellite keeps the transponder at saturation, it does not increase C/I_u. The AGC operates on individual channels and increases the transponder gain of the wanted signal and of any portion of an interfering signal which falls within the filter bandwidth of the wanted channel. Therefore, during rain at the feeder-link station(s), the use of AGC permits the operation of the transponder close to saturation but the ratio of the wanted carrier to the portion of the interfering adjacent cross-polarized carrier which falls into the filter bandwidth of the wanted channel remains constant.

However, while the satellite using AGC radiates on the downlink a constant level of the wanted signal which has been attenuated on the feeder-link, it radiates on the downlink a higher level of the interfering cross-polar signal on the adjacent channel. This interfering signal would not have been attenuated when there is no rain on the interfering feeder-link. AGC may therefore cause an increase in downlink interference to stations receiving this re-radiation as co-channel interference.

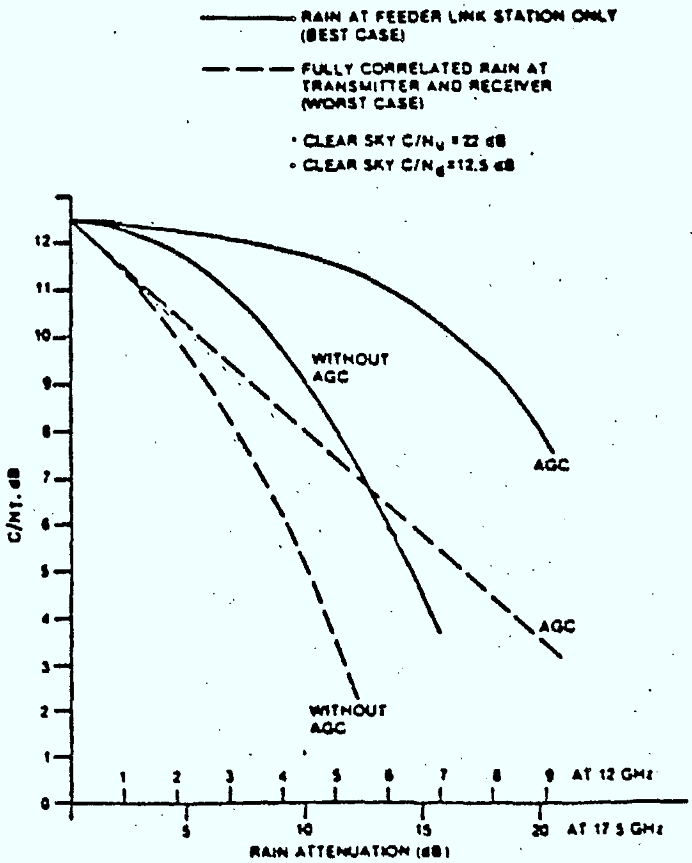


Figure 4.2.1 - The effect of rain attenuation on C/N_T in the presence of Automatic Gain Control (AGC).

The use of AGC may also increase the interference into receivers of the network to which the feeder-link transmitting on the adjacent cross-polarized channel belongs. This is caused by re-radiation of the adjacent cross-polarized channel by the satellite using AGC. This re-radiation is a time shifted, cross-polarized version of the downlink signal desired by the network using the adjacent cross-polarized channel. This problem could be of significance only for co-located satellites serving common or adjacent service areas.

Since the required protection ratio for adjacent cross-polar channels is 15 to 20 dB lower than that for co-polar co-frequency channels, there is some margin allowable for increased interference from adjacent cross-polar channels due to AGC. However, because of the possible lower protection margins achievable between cross-polar feeder-links to co-located satellites, because of the possible mispointing of feeder-link transmitting antennas, and because of the possible presence of multiple interferers, the CPM concluded that the dynamic range of AGC in the satellite transponder should be limited to 10-15 dB to guard against the problem of re-radiation on the downlink. This limit in AGC range should not affect Canadian systems, since the maximum uplink rain attenuation in Canada for 1% of the worst month should not exceed the AGC limit. Moreover, satellites with cross-polarized channels and at least 0.3° separation need not be subject to the limit of AGC range.

4.2.2 Site Diversity

To maintain a required level of reliability (minimum outage time) in the presence of rain, it has been proposed to employ site diversity or large scale spatial antenna separations, thereby avoiding high attenuation due to rain on a single path. The approach is based on the fact that rain cells and, in particular, the intense rain cells that cause the most severe fading are rather limited in spatial extent. Furthermore, these rain cells do not occur immediately adjacent to one another. Thus, one may expect that the probability of simultaneous fading on the two paths from spatially separated earth terminals would be less than that associated with either individual path.

At any given site location and period of high rainfall, a cluster of rain cells in an array constituting a storm region may have a particular orientation with respect to the weather fronts passing over the region. The shape and orientation of the storm will have an effect on the diversity system providing two (or more) alternative paths through the region.

A set of S-band radar data from Ottawa during 1970 [15] was analyzed statistically to determine cell size distributions and joint probabilities of occurrence as a function of two path separation distances. The results showed that 80% of the cells had a size greater than 2 km, 50% exceeded about 6 km, and about 20% exceeded 14 km extent, for an attenuation level criterion of 3 dB. The cell separation statistics were distances of about 15, 30, and 45 km for the 80%, 50%, and 20% occurrence exceeded, respectively. Recent measurements from Goodland, Kansas [11] have yielded cell diameters of about 2.5 km with cell separations of 5 to 6 km for all cells and 10 to 12 km for significant cells. Storm sizes of 30 to 60 km in length and 10 to 20 km in width are typically observed. Nominal agreement with the Ottawa observations was therefore obtained.

Given two (or more) propagation paths, diversity gain is defined [16] as the difference in dB between the rain attenuation on a single path and that obtained jointly with diversity paths at a specified exceeded percentage of time.

The diversity gain is therefore a function of the specified percentage of time that the single path attenuation (or fade depth) is exceeded.

Figure 4.2.2 compares the performance of the diversity sites to the performance of a single site, with and without AGC, in the case where it rains at the feeder-link station only [1]. It is seen that site diversity gives a greater total C/N availability when compared to single sites, with or without AGC. The relative joint probability, defined as the ratio of the probability of attenuation being exceeded at a single site to the probability of the same attenuation being exceeded simultaneously at the two sites, is shown in Figure 4.2.3 as a function of attenuation and distance between diversity sites. A log-normal distribution of rain cells has been assumed [15]. It is noted that for a given distance between diversity sites, the relative joint probability decreases rapidly with attenuation, and remains almost constant for attenuation greater than 10 dB.

Site diversity also improves the cross-polar C/I_u performance during rain. It has been shown that [14] in the absence of site diversity, the cross-polar C/I_u decreases rapidly with increasing availability when it rains at the wanted site only or when it rains simultaneously at the wanted and interfering sites, Figures 4.2.4 - 4.2.6. This is not representative of a worst case analysis but of a typical case of interference at sites likely to suffer large attenuation and depolarization. The attenuation conditions are similar to those for a 15° elevation angle in rain climatic zone K or for a 60° elevation angle in rain climatic zone N. However, for any given attenuation, the XPD at 60° elevation angle is higher than the XPD at 15° elevation angle. Under these conditions, the figures indicate that site diversity may be the only mechanism available to achieve high cross-polar C/I_u availability when it rains at the wanted site only or when it rains at

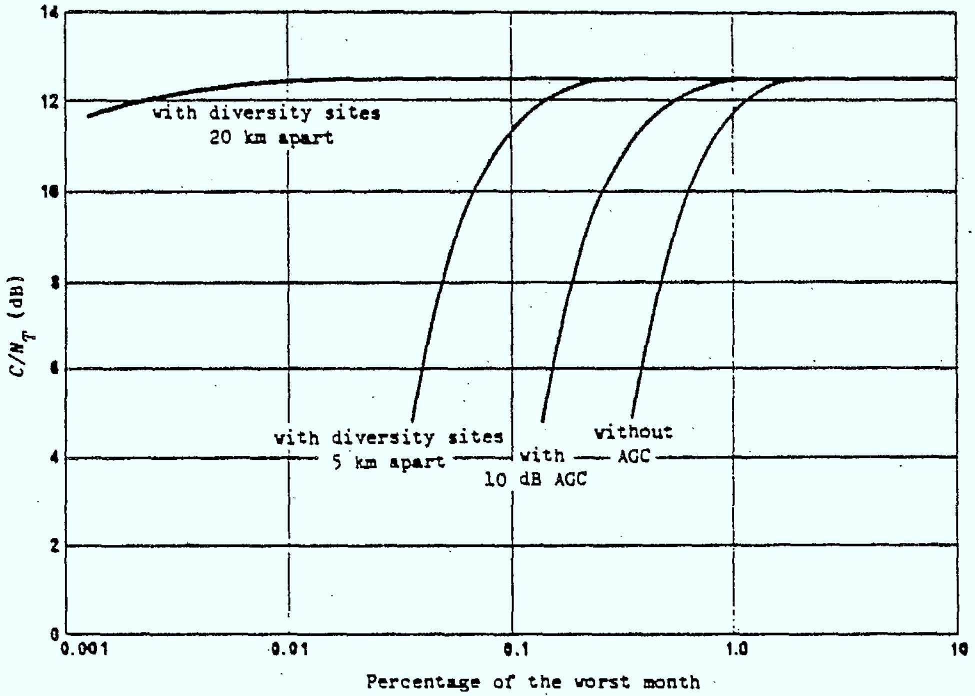
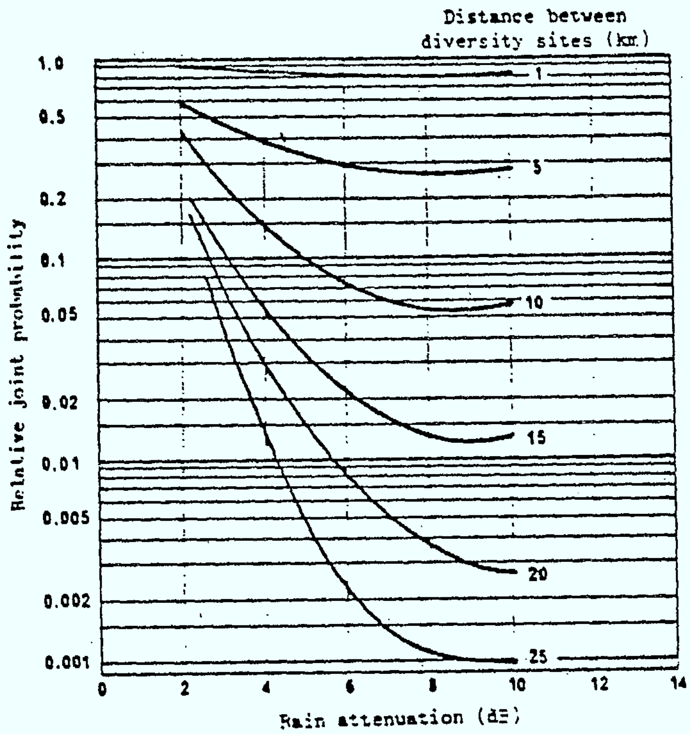


Figure 4.2.2 - The effect of site diversity on C/N_T in rain climatic zone E with a 10° elevation angle and a latitude of 40° or in rain climatic zone M with a 40° elevation angle, and a latitude of 40°.

- 17.5 GHz feeder-links
- 10 dB AGC
- Rain at feeder-link station only
- C/N_d= 12.5 dB (clear sky)

- Rain climatic zone E with 10° elevation

- Rain climatic zone M with 40° elevation
- C/N_u= 22.5 dB



<u>Figure 4.2.3</u> Relative joint probability of site diversity as a function of rain attenuation and distance between diversity sites.

- 13 GHz
- 25° elevation angle

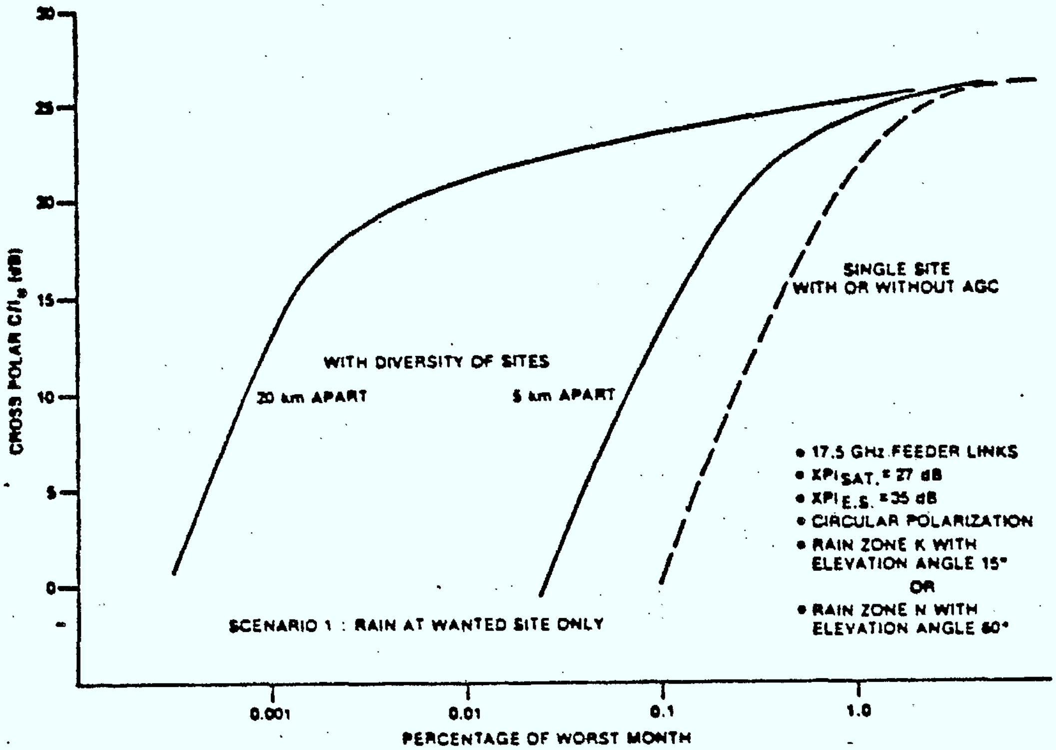


Figure 4.2.4 - The effect of site diversity on the availability of cross-polar C/I_u of 17.5 GHz feeder links when it rains at the wanted site(s) only. The example shown corresponds approximately to sites with an elevation angle of 15° in rain climatic zone K or to sites with an elevation angle of 60° in rain climatic zone N.

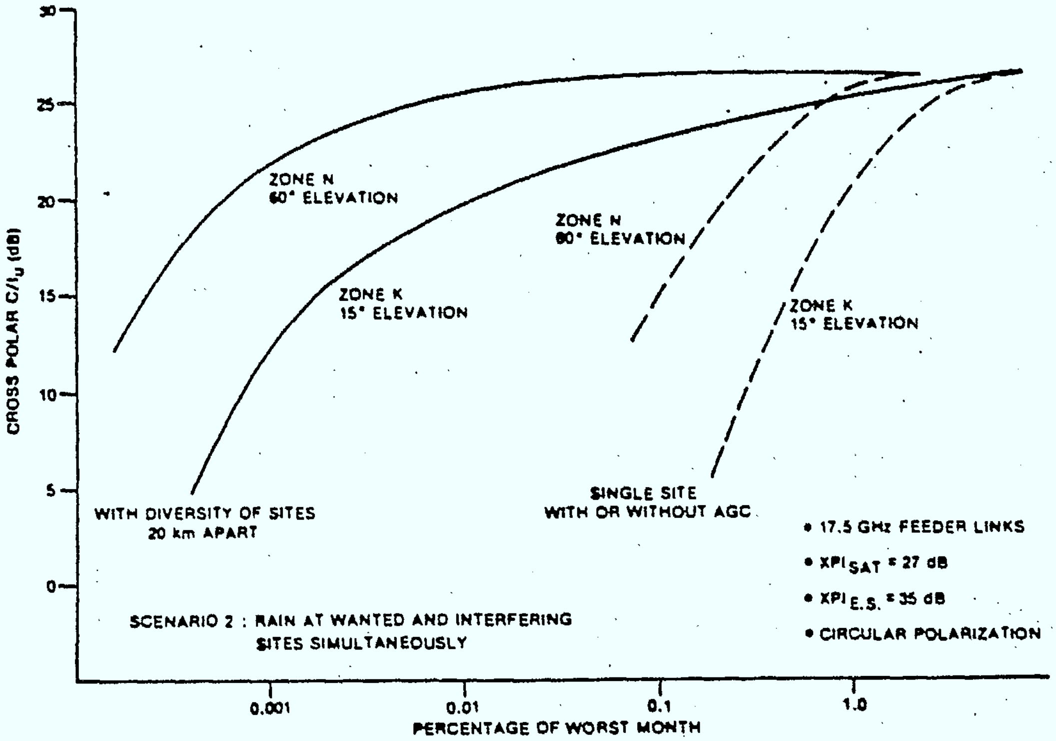


Figure 4.2.5 - The effect of site diversity on the availability of cross-polar C/I_u of 17.5 GHz feeder links when it rains at the wanted and interfering sites simultaneously. The example shown corresponds approximately to sites with an elevation angle of 15° in rain climatic zone K or sites with an elevation angle of 60° in rain climatic zone N.

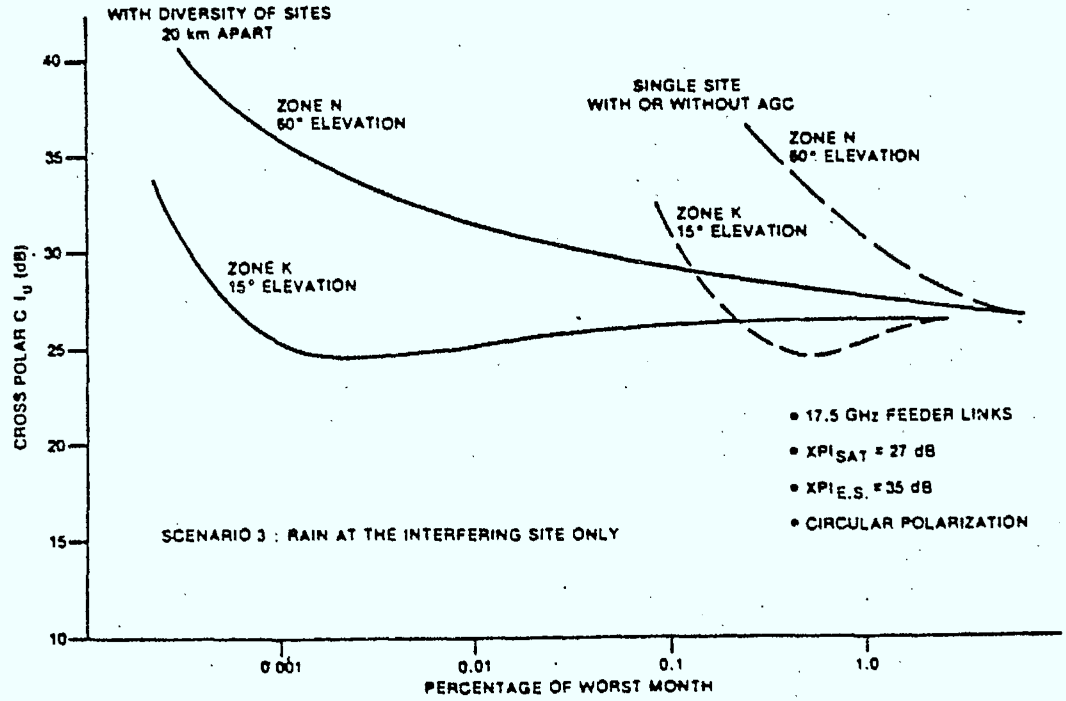


Figure 4.2.6 - The effect of site diversity on the availability of cross-polar C/I_u of 17.5 GHz feeder links when it rains at the interfering site(s) only. The example shown corresponds approximately to sites with an elevation angle of 15° in rain climatic zone K or to sites with an elevation angle of 60° in rain climatic zone N.

the wanted and at the interfering site simultaneously. Figure 4.2.6 shows that the onset of the improvement of the cross-polar C/I_u possible for a single interfering site is simply retarded by the use of site diversity at the interfering sites.

The use of site diversity is also the only rain compensation mechanism capable of increasing the availability of C/N_u of cross-polarized feeder-links to co-located satellites, particularly where the combination of rain climatic zone and elevation angle indicates high rain attenuation.

Site-diversity can be made cost effective by the provision of a secondary site which could be equipped with a smaller earth station antenna (or EIRP) than the primary site station. In evaluating the system performance required for these "unbalanced" diversity stations, the joint exceedance statistics used for balanced diversity stations do not provide the required information, because the permissible rain attenuation to be allocated to each of the two stations is different. In this case, reliable statistics are required on the conditional probability of rain attenuation, $Pr(L_2|L_1)$, [17]. This is the probability that the attenuation at Site 2 exceeds L_2 under the condition that the attenuation at Site 1 exceeds L_1. When statistics of this kind are not available because of insufficient attenuation measurements, use may be made of the conditional probability of rain rate, $Pr(R_2|R_1)$, which may be converted into the attenuation statistics in terms of the effective path length of rain and the attenuation co-efficient corresponding to each rain rate. In order to obtain reliable estimates of the earth station performance, in the form of the conditional probability, more data based on long term propagation tests are crucial.

A dual polarized site-diversity system could carry twice as much traffic as a single-polarized link and its path diversity operation would resist both rain fading and depolarization [18]. Figure 4.2.7 compares a plot of predicted isolation diversity gain versus single-site isolation with data measured at Virginia Polytechnic Institute and State University (VPI & SU) in a dual-polarized site-diversity experiment employing the SIRIO spacecraft 11.6 GHz right-hand circularly polarized down-link. The path elevation angle was 10.6°, the site separation was 7.3 km, and the data displayed were collected in July through November, 1980. The curve indicated by M's represents measured data and shows the isolation diversity gain as a function of the average of the isolations measured at the two sites for the same percentage of time. It includes the residual effects of the antennas. For isolation values above about 15 dB the measured values of isolation diversity gain are close to those predicted using Hodge's model [16] for attenuation diversity gain and represented by H's. The deviation below 15 dB arises because Hodge's model was developed for paths with elevation angles near 35° and does not fit the measured values of attenuation diversity gain at high attenuations. The curve indicated by P's, which was predicted using a curve fit to the measured attenuation diversity gain values, agrees well with the measured isolation diversity gain. The departure of the Hodge prediction and the VPI & SU prediction at around 15 dB isolation may indicate an elevation angle dependence associated with a longer slant path length through rain and ice.

4.2.3 Summary

Although the CPM agreed that the broadcast satellite plan should not be based on the use of site diversity, site diversity can maintain carrier to noise and carrier to interference ratios at near nominal values during rain. It

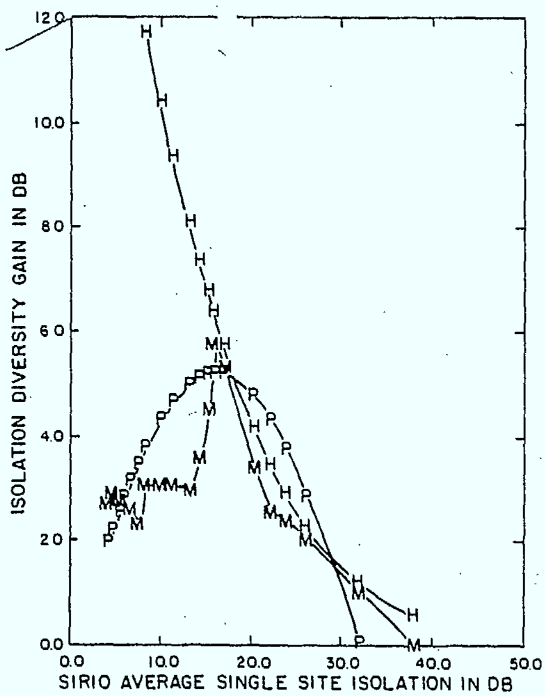


Figure 4.2.7 - Isolation diversity gain versus single-site isolation for an 11.6 GHz right-hand circularly polarized down-link with a 7.3 km site separation and a 10.6° elevation angle. The M's are measured values for the period July-November 1980; the H values were predicted using Hodge's model for attenuation diversity gain and the P values were predicted using a curve fit to the measured attenuation diversity gain.

is a technique that could improve the interference problems accompanying co-located satellites serving common areas on adjacent cross-polarized or alternate co-polarized channels. Furthermore, such a secondary earth station would be most useful during periods of maintenance and repair to the primary earth station. Another advantage of a site-diversity system is the possible use of smaller earth station antennas, since a site diversity system requires a smaller link margin than a single feeder-link. However, the cost and operational complexity of diversity stations must be compared to that of the use of sufficient link margin at a single feeder-link station. The drawbacks of a sufficiently large margin are [19].

- those stations located in areas of little rain or low rain attenuation will have to install and use transmitters of higher power (and, therefore, higher capital and operating cost) than they would ever require otherwise, solely to match the equally high EIRP's being transmitted by other stations to co-located or nearby satellites;
- even stations in regions of occasional high rain attenuation will have to use transmitters of high power when this high power capability will be required for only a small percentage of time;
- sharing with space-to-earth links of the fixed-satellite service, and with terrestrial services (i.e. in the band 17.7 - 17.8 GHz), will be made more difficult, requiring more coordination and greater separation between feeder-link stations and receiving FSS earth stations in the first case, and between feeder-link stations and terrestrial stations in the second;
- operating with higher signal levels at the wideband satellite receiver input may in certain cases increase passive intermodulation. This situation would occur for large percentages of the time (i.e. under clear-sky conditions).

Site diversity is undesirable for transportable stations, since it is not practical from the standpoint of cost and operational complexity. The system operators would probably accept the lower availability and lower C/I ratio at the desired satellite that the use of a non-diversity transportable station might cause, given their relatively infrequent use.

AGC on board the satellite effectively reduces the impact of rain attenuation on total C/N, although it may cause an increase in down-link interference to other systems receiving this re-radiation as co-polarized interference. The AGC dynamic range must take into account ground station EIRP variations, propagation loss variation, satellite antenna gain changes and the variation of the transponder input section characteristics with time and temperature. The dynamic range of AGC of co-located satellites is suggested by the CPM to be about 10-15 dB. Further study should be carried out to determine whether a real need exists to so limit AGC range.

AGC would result in a more complex device than the conventional driver amplifier. The reliability of the AGC would typically be in the range of 1500 to 2000 FITS (Failure In Tera Seconds) compared to 500 FITS for a fixed gain system in the Ku band. However, the AGC circuit could be designed in such a way that the RF signal would by-pass the AGC circuit if there were a failure in the AGC circuit.

4.3 Availability Considerations

4.3.1 The Impact of Earth and Moon Solar Eclipses

Terrestrial and lunar eclipses have had a minimal impact on the fixed satellite services. These services, which operate with a considerably lower EIRP than is proposed for the BSS, can operate without interruption through eclipses by having recourse to an alternate energy source, such as batteries, for the duration of an eclipse. However, for BSS systems, providing uninterrupted service for the duration of an eclipse would require an excessively heavy battery payload. As this is not a physically and economically viable solution, it is foreseen that the BSS service will have to operate at reduced capacity during eclipses.

Considering that operation at a reduced capacity would occur, a portion of the satellite's transmission payload could consist of pre-emptible services. It is thus apparent that the accurate prediction of terrestrial and lunar eclipses would be of great value in assessing the availability of the BSS service.

For a satellite in geostationary orbit, one earth solar eclipse occurs each day during the periods of approximately February 27th to April 12th and September 1st to October 15th. Near the center of these periods, the eclipses last about seventy minutes centred around midnight at the satellite longitude. By placing the satellite to the west of the illumination zone, the earth eclipse will occur after midnight local time [20]. Thus, the BSS service could be foreseen to go off-air sometime after midnight. However, with many broadcasters not broadcasting much later than midnight, limited battery packs could perhaps provide alternate power to maintain operation of a few channels during eclipses.

On the other hand, moon solar eclipses are not as regularly behaved. Positioning the satellite to the west of the illumination area is not suitable to reduce their effect. Table 4.3.1, illustrates the forecasted moon solar eclipses for a satellite located at 104°W. Similar eclipses would be expected for the proposed BSS orbital locations. From Table 4.3.1, it is clear that some services would have

TABLE 4.3.1

ECLIPSE OF THE SUN BY THE MOON AT 104°W LONGITUDE

DATE YR:DAY	START TIME HR:MN:SC (GMT)	END TIME HR:MN:SC (GMT)	DURATION MN:SC	MAXIMUM SHADOWING (%)
82:201	09:51:31	10:25:53	34:22	58.7
83:014	06:20:53	06:36:52	15:59	4.3
83:191	08:03:20	08:28:42	25:22	33.0
84:003	06:14:03	06:46:03	32:00	71.2
84.152	02:56:32	03:36:05	39:33	50.2
84:181	05:48:28	06:14:57	26:29	37.3
84:357	07:51:25	08:17:50	26:25	31.6
85:140	04:38:20	05:10:43	32:23	44.2
86:070	01:47:10	02:10:29	23:19	1.6
86:276	18:49:54	19:18:18	28:23	10.6
86:306	06:30:05	07:00:00	29:55	73.8
87:117	12:55:32	14:31:49	01:36:18	83.7
87:236	23:55:35	01:11:45	01:16:10	29.9
87:266	05:48:14	06:07:32	19:18	8.4
87:295	09:29:38	09:57:42	28:04	16.1
88:225	23:49:10	01:24:39	01:35:29	51.0
88:284	10:40:39	11:34:56	54:17	58.6
89:037	06:48:44	07:17:59	29:15	60.5
90:351	06:14:57	06:29:18	14:21	3.3
91:163	08:04:37	08:34:47	30:09	89.2
91:192	10:08:55	10:33:23	24:28	12.4
91:340	06:00:18	06:32:13	31:55	67.6
92:004	10:59:24	11:44:51	45:27	29.2
92:182	22:26:05	22:55:06	29:01	3.6
93:170	13:40:35	15:18:33	01:37:58	84.4
93:318	04:10:21	04:43:41	33:20	78.3
94:131	03:09:17	03:52:13	42:56	77.3
94:336	16:15:50	16:33:05	17:15	1.1
95:120	03:12:02	03:50:51	38:49	38.6
95:326	20:29:51	20:59:10	29:19	5.4

to be dropped during moon eclipse periods and furthermore, the pre-emption of service could occur during prime viewing time. Lunar eclipses further complicate the problems associated with providing alternate power because they can occur on days when earth solar eclipses also occur. On those days, there could be insufficient time between the two eclipses to allow for complete recharging of the batteries. In fact, in such instances, all transmission would certainly have to be halted.

Special considerations have to be accorded to temperature variations on-board the satellite. From Table 4.3.1 it can be seen that for this particular orbital location, on the 10th of March 1986, a moon and an earth solar eclipse will occur at times very close to one another. Such events effectively yield one eclipse of considerable duration. Considering that transmission would be halted, the on-board electronics would be operating at a quiescent level, thus generating a minimal amount of heat. Figure 4.3.1, illustrates the temperature change of the solar arrays on-board the Japanese satellite Yuri [21] while it was subjected to two eclipses.

To assure the ability of a satellite to withstand such events, a portion of the stored electrical energy should be dedicated to allow for minimal heating of the satellite. This further reduces the possibility that the satellite could carry a diminished communications payload through an eclipse.

The best policy appears to be that of first predicting with good accuracy the lunar eclipses that are due to occur at the proposed BSS orbital location. This can easily be done, albeit with a substantial computational effort. Having done this, users of the BSS could be advised long in advance of a scheduled service outage, as is presently the case with FSS users regarding sun transit outages at earth

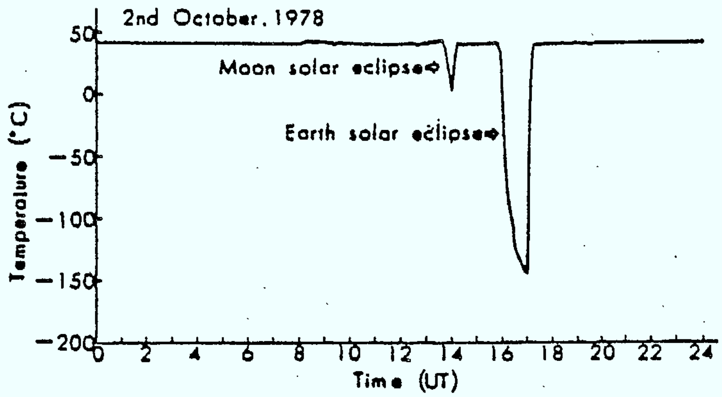


Figure 4.3.1 Temperature change of the solar battery of "Yuri".

stations. Considering that for an average year, the total duration of moon solar eclipses is expected to be less than two hours, there is not sufficient cause for great concern.

4.3.2 Equipment Reliability and Sparing Philosophy

The utilization of well-known FM technology will likely prevail in the implementation of feeder-links operating at 17 GHz. This equipment would be similiar in nature to the equipment presently used by Telesat for the transmission of television signals over the FSS. Also, considering that the feeder-links will constitute a very limited number of important sites, these would likely be manned. By providing redundancy of the RF equipment, along with an appropriate complement of spare modules, it has been Telesat's experience that with trained personnel on location, a reliability of better than 99.99% could be achieved with the feeder-link equipment.

With regard to the space segment, a simple consideration of the large number of potential users of the BSS service, leads one to the conclusion that appropriate measures must be taken to protect such a service against possible catastrophic failures. A substantial degree of protection can be achieved by providing one spare satellite [22]-[24].

In the first system model, which has two satellites, respectively located at 105°W and 135°W, one spare satellite could be co-located or interstitially located halfway between these two orbital locations. Since the two operational satellites employ different beam patterns, the spare would have to be reconfigurable or, as was discussed in Section 2.2.4, a compromise pattern assumed. In reference [24], a scheme was proposed whereby the two operational satellites and the spare are identical and reconfigurable. This leads to a substantial saving in the cost of each satellite, since only one design has to be tested. This scheme further provides the additional flexibility that, as more satellites are added to the BSS system, it can easily be reconfigured to accommodate the greater number of satellites.

In the second model, which employs three satellites, respectively at 85°W, 105°W and 135°W, a co-located spare at 105°W could protect the system. This would provide immediate protection for the satellite at 105°W along with providing equal relocation time for the spare to reach the two extreme satellite positions. However, considering the number of users of the BSS, a possible outage of a few weeks in a large portion of the country, due to the failure of one satellite, may not be acceptable.

Another possibility would be a co-located spare for each active broadcasting satellite. This, however, requires a very substantial outlay of capital. From a reliability point of view, it is clear that launching two satellites in a short time is not the most effective scheme, since their reliability curves would decrease simultaneously at the same rate. Their combined reliability would not be substantially better than what would be expected for one satellite. However, if the colocated spare satellites where launched between one and three years after the initial set of satellites, the lifetime of the system would be extended, while the reliability of the space segment would be kept above 90%, when using medium risk designs.

Thus, a practical scenario could involve one initial spare satellite for both the two and three satellite BSS models, with the provision for co-located spares to be launched approximately two years after initiation of the BSS system.

4.4 Link Budget

4.4.1 Noise

The overall carrier-to-noise ratio under clear sky conditions consists typically of a small contribution from the feeder-link and a dominant contribution from the downlink. The contribution of the uplink noise should be less than 10% of the total system noise, corresponding to an uplink carrier-to-noise ratio 10 dB higher than downlink C/N. Here, it is shown that this objective is achievable under the assumed link parameters.

4.4.1.1 Noise Link Budget

The assumed link parameters have been given in the previous sections. They are summarized in Table 4.4.1 for convenience. The table also shows the clear weather uplink, downlink, and overall C/N for 10° elevation angle. It is seen that uplink C/N is about 15 dB greater than the downlink C/N and it degrades downlink C/N by only about 0.1 dB. However, when a transportable terminal is used, the limitations associated with it may cause an increase in the contribution of the uplink noise to the total system noise, even under clear sky conditions. The contribution could be well above the 10% level as was suggested by the CPM.

4.4.2 Interference

The approach taken for the evaluation of interference degradation has been, firstly, to determine the nominal clear weather overall satellite link carrier-to-interference ratio (C/I) performance for the model assumed and, secondly, to determine the C/I degradations caused by fading on the feeder-links while there is no downlink fading. The rationale for this approach is that clear weather interference is determined solely by the system model and

Uplink	Values
Earth station antenna size	5m
Input Power to the antenna feed	1000 watts
Satellite G/T -2 dB/K	
Noise Bandwidth	24 MHz
Antenna pointing loss	0.5 dB
Atmospheric absorption loss (10° elevation)	0.6 dB
Pathloss (10° elevation)	209.5 dB
Uplink Clear Weather C/N	28.8 dB

Downlink	Values
Home terminal G/T	10 dB/K
Satellite EIRP (EOS)*	56.1 dBW
Atmospheric absorption loss (10° elevation)	0.4 dB
Pathloss (10° elevation)	206.5 dB
Downlink Clear Weather C/N	14 dB
OVERALL CLEAR WEATHER C/N	13.9 dB

*Including the compensation for rain fade (1.5 dB).

TABLE 4.4.1: Overall Clear Sky C/N Link Budget

parameters (in particular the antenna radiation patterns) while, the degradation of the clear weather C/I is essentially determined by propagation factors (i.e., attenuation and depolarization), with only a weak dependence on system characteristics.

4.4.2.1 Uplink Clear Weather C/I

The uplink clear weather C/I ratios would be -0.5 dB and 24.6 dB for a single co-polarized or cross-polarized interfering carrier, respectively. These are based on the following assumptions:

- The feeder-link earth stations are located at the edge of the feeder-link service area, where the relative satellite receive antenna co-polar gain is -3 dB and the cross-pol discrimination is thus 27 dB;
- The feeder-link earth stations have the same boresight EIRP (86.6 dBW) but the wanted station has 0.5 dB pointing loss, while the interfering station has none;
- The interfering feeder-link earth station antenna has a cross-pol discrimination of 29.5 dB;
- Path loss differentials are negligible.

4.4.2.2 Downlink Clear Weather C/I

The downlink clear weather C/I ratios at a receiving BSS earth station are critically dependent on the location of the station relative to the boresight axes of the wanted and interfering satellite transmit beams. Large variations of 6 to 8 dB, or more, would occur.

Typical downlink clear weather C/I ratios have therefore been determined for use in calculating the overall satellite link clear weather C/I ratios and feeder-link fade degradations. In addition, "worst" and "best" case C/I ratios are given below for illustrative purposes, but are not used for subsequent availability/reliability calculations.

The assumptions pertinent to the typical, worst and best cases are as follows:

- <u>General Assumptions</u>

- path loss differentials are negligible, and
- the satellite transmit beams are on the same spacecraft and have the same boresight EIRP's.

- <u>Typical Case</u>

The typical case is based on the assumption of 0 dB EIRP differential between the wanted and interfering carriers and applies to situations where:

- the wanted and interfering carriers are transmitted in the same beam and the receiving BSS earth station is on the -3 dB relative gain contour of the satellite transmit beam
- the receiving BSS earth station is on the -3 dB relative gain contour of both the wanted and interfering satellite transmit beams serving contiguous service areas.

The consequence of the foregoing is that the cross-pol discriminations of the satellite transmit antenna and the earth station receive antenna would be 27.0 dB and 24.0 dB, respectively. The latter value is about midway between the best and worst values of 25 dB and 23.1 dB, respectively.

- <u>Worst Case</u>

The worst case occurs when the receiving BSS earth station is at the edge of the service area. Then, the wanted satellite EIRP is down 4.3 dB, while the interference EIRP is only slightly reduced (0.3 dB assumed) due to beam overlap.

The cross-pol discriminations of the satellite transmit antenna and the earth station receive antenna for the above conditions would be 29.7 dB and 23.1 dB respectively. The latter value is consequential to the assumed 1 dB pointing loss for receiving BSS earth stations.

- Best Case

This case is the inverse of the worst case and assumes the receiving BSS earth staion is near the boresight of the wanted transmit beam (0.3 dB relative gain assumed) while the interfering transmit beam EIRP reduction is 4.3 dB relative to boresight.

The cross-pol discriminations of the satellite transmit antenna and the earth station receive antenna would be 25.7 dB and 25 dB, respectively.

The downlink clear weather C/I ratios for a single co-polarized or cross-polarized interfering carrier for the above three cases are given in Table 4.4.2.

Interfering Carrier Polarization	Downlink Clear Weather C/I (dB)		
	Worst	Typical	Best
Co-polarized	-4.0	0.0	4.0
Cross-polarized	18.24	22.24	26.32

Table 4.4.2: Downlink Clear Weather C/I Ratios

4.4.2.3 Satellite Link Clear Weather C/I

The overall satellite link clear weather C/I ratios are given in Table 4.4.3 for the conditions described in the foregoing sections. The worst and best values are shown only for comparison purposes with the typical values which are used later.

Interfering Carrier Polarization	Overall Satellite Link Clear Weather C/I (dB)		
	Worst (4.3 dB)	Typical (3 dB)	Best (0 dB)
Co-polarized	-5.6	-3.26	-1.8
Cross-polarized	17.3	20.24	22.4

4.4.3: Overall Satellite Clear Weather C/I Ratios

4.5 Reliability Studies

4.5.1 Noise

When rainy weather is experienced along the link, the system performance will degrade in ways which may jeopardize the service continuity. The degradation of the overall clear weather carrier-to-noise ratio due to the rain attenuation is studied in this section.

The overall C/N is related to the feeder-link C/N and the downlink C/N by a relationship which must include the transfer characteristic of the satellite transponder, in addition to the statistics of rain attenuation on the feeder-link and the downlink. Assuming that the statistics of the feeder-link and the downlink attenuations are known, this will involve a convolution integral in terms of the probability density functions of the uplink and the downlink fades. For simplicity, however, the following study assumes a clear weather condition on the downlink, as suggested by the Scientific Authority. The great majority of downlink earth stations will be geographically separated from the feeder-link locations. Therefore, the assumption of the clear weather condition on the downlink is not unrealistic since the probability of simultaneous raining in both the feeder-link and downlink service areas is very small.

It is also assumed that AGC is employed on board the satellite with a dynamic range of 10 dB. The input-output characteristic of the satellite transponder is as given in Section 2.5.2.

4.5.1.1 <u>Results and Discussion</u>

Tables 4.5.1 - 4.5.17 demonstrate the overall carrier-to-noise ratio under downlink clear weather conditions for the feeder-links located in cities representative of the important rain climatic zones across Canada.

An examination of the tables reveals that under clear weather conditions on the downlink, certain locations could provide a very high availability of service. For example, uplinking from Vancouver or Edmonton to satellites at 135°W or 105°W would degrade the overall clear weather C/N by less than 2 dB. An availability of better than 99.99% of the worst month could be achieved under clear weather downlink conditions.

The availability would be reduced sharply if the feeder-link earth terminals were located in the rain climatic zone K. For example, uplinking from Toronto or Montreal to the satellite at 135°W would give an availability of about

EDMONTON, RAIN ZONE E

CLEAR WEATHER TOTAL C/N = 14.5 DB

SATELLITE LONGITUDE = 105.0 DEG.   ELEVATION ANGLE = 28.3 DEG.

%WM	UP-LINK FADE, DB*	TOTAL C/N, DB**	C/N DEGRADATION, DB
.010	10.95	13.15	1.31
.025	7.73	13.86	.60
.050	5.94	14.10	.37
.075	4.94	14.19	.27
.100	4.31	14.25	.22
.250	2.80	14.35	.12
.500	2.08	14.38	.08
.750	1.65	14.40	.06
1.000	1.40	14.41	.05

* CLEAR WEATHER FOR DOWN-LINK IS ASSUMED.

** THE ANIK C TYPE OF TWT CHARACTERISTICS ASSUMED WITH THE DYNAMIC RANGE OF AGC EQUAL TO 10.0 DB

TABLE 4.5.1 EFFECT OF UP-LINK ON OVERALL C/N WHEN THE FEEDER-LINK IS IN EDMONTON.

EDMONTON, RAIN ZONE E

CLEAR WEATHER TOTAL C/N = 14.4 DB

SATELLITE LONGITUDE = 135.0 DEG.   ELEVATION ANGLE = 25.7 DEG.

%WM	UP-LINK FADE, DB*	TOTAL C/N, DB**	C/N DEGRADATION, DB
.010	11.77	12.78	1.62
.025	8.31	13.70	.70
.050	6.39	13.98	.42
.075	5.31	14.09	.30
.100	4.64	14.15	.24
.250	3.01	14.27	.13
.500	2.24	14.31	.09
.750	1.77	14.33	.07
1.000	1.50	14.34	.05

* CLEAR WEATHER FOR DOWN-LINK IS ASSUME.

** THE ANIK C TYPE OF TWT CHARACTERISTICS ASSUMED WITH THE DYNAMIC RANGE OF AGC EQUAL TO 10 DB.

TABLE 4.5.2 EFFECT OF UP-LINK FADES ON OVERALL C/N WHEN THE FEEDER-LINK IS IN EDMONTON.

HALIFAX, RAIN ZONE K

CLEAR WEATHER TOTAL C/N = 14.6 DB

SATELLITE LONGITUDE = 85.0 DEG.   ELEVATION ANGLE = 34.3 DEG.

%WM	UP-LINK FADE, DB*	TOTAL C/N, DB	C/N DEGRADATION, DB
.010	30.53	-3.28	17.88
.025	21.57	5.69	8.91
.050	16.58	10.12	4.48
.075	13.78	12.00	2.60
.100	12.03	12.89	1.72
.250	7.81	13.99	.61
.500	5.81	14.25	.35
.750	4.60	14.37	.24
1.000	3.90	14.42	.19

* CLEAR WEATHER FOR DOWN-LINK ASSUMED.

TABLE 4.5.3 EFFECT OF UP-LINK FADES ON OVERALL C/N
WHEN THE FEEDER-LINK IS IN HALIFAX.
THE AGC DYNAMIC RANGE = 10 DB.

HALIFAX, RAIN ZONE K

CLEAR WEATHER TOTAL C/N = 14.4 DB

SATELLITE LONGITUDE = 105.0 DEG. ELEVATION ANGLE = 24.3 DEG.

%WM	UP-LINK FADE, DB*	TOTAL C/N, DB	C/N DEGRADATION, DB
.010	38.25	-11.26	25.61
.025	27.02	-.02	14.38
.050	20.77	6.23	8.13
.075	17.26	9.33	5.02
.100	15.07	10.94	3.42
.250	9.78	13.36	.99
.500	7.28	13.82	.53
.750	5.77	14.01	.35
1.000	4.89	14.09	.26

* CLEAR WEATHER FOR DOWN-LINK IS ASSUMED.

TABLE 4.5.4 EFFECT OF UP-LINK FADES ON OVERALL C/N WHEN THE FEEDER-LINK IS IN HALIFAX. THE AGC DYNAMIC RANGE = 10 DB.

MONTREAL, RAIN ZONE K

CLEAR WEATHER TOTAL C/N = 14.7 DB

SATELLITE LONGITUDE = 85.0 DEG.   ELEVATION ANGLE = 36.4 DEG.

%WM	UP-LINK FADE, DB*	TOTAL C/N, DB**	C/N DEGRADATION, DB
.010	28.95	-1.65	16.30
.025	20.45	6.86	7.80
.050	15.72	10.80	3.85
.075	13.07	12.44	2.21
.100	11.41	13.19	1.47
.250	7.41	14.10	.55
.500	5.51	14.33	.32
.750	4.36	14.43	.22
1.000	3.70	14.48	.17

* CLEAR WEATHER FOR DOWN-LINK IS ASSUMED.

** THE ANIK C TYPE OF TWT CHARACTERISTICS ASSUMED WITH THE DYNAMIC RANGE OF AGC EQUAL TO 10.0 DB.

TABLE 4.5.5 EFFECT OF UPLINK FADES ON OVERALL C/N WHEN THE FEEDER-LINK IS IN MONTREAL.

MONTREAL, RAIN ZONE K

CLEAR WEATHER TOTAL C/N = 14.5 DB.

SATELLITE LONGITUDE = 104.0 DEG.   ELEVATION ANGLE = 29.1 DEG.

%WM	UP-LINK FADE, DB*	TOTAL C/N, DB**	C/N DEGRADATION, DB
.010	33.50	-6.37	20.85
.025	23.66	3.47	11.01
.050	18.19	8.71	5.77
.075	15.12	11.04	3.44
.100	13.20	12.20	2.29
.250	8.57	13.74	.74
.500	6.37	14.07	.41
.750	5.05	14.21	.28
1.000	4.28	14.27	.21

* CLEAR WEATHER FOR DOWN-LINK IS ASSUMED.

** THE ANIK C TYPE OF TWT CHARACTERISTICS ASSUMED WITH THE DYNAMIC RANGE OF AGC EQUAL TO 10.0 DB.

TABLE 4.5.6 EFFECT OF UPLINK FADES ON OVERALL C/N WHEN THE FEEDER-LINK IS IN MONTREAL.

MONTREAL, RAIN ZONE K

CLEAR WEATHER TOTAL C/N = 13.9 DB

SATELLITE LONGITUDE = 135.0 DEG. ELEVATION ANGLE = 11.0 DEG.

%WM	UP-LINK FADE,DB*	TOTAL C/N,DB**	C/N DEGRADATION, DB
.010	61.31	-34.88	48.73
.025	43.30	-16.87	30.72
.050	33.29	-6.85	20.71
.075	27.67	-1.23	15.09
.100	24.16	2.28	11.58
.250	15.68	9.97	3.89
.500	11.67	12.25	1.61
.750	9.24	12.96	.89
1.000	7.83	13.22	.63

* CLEAR FOR DOWN-LINK IS ASSUMED.

** THE ANIK C TYPE OF TWT CHARACTERISTICS ASSUMED WITH THE DYNAMIC RANGE OF AGC EQUAL TO 10.0 DB.

TABLE 4.5.7 EFFECT OF UPLINK FADES ON OVERALL C/N WHEN THE FEEDER IS IN MONTREAL.

ST.JOHN'S, RAIN ZONE F

CLEAR WEATHER TOTAL C/N = 14.4 DB

SATELLITE LONGITUDE = 85.0 DEG.   ELEVATION ANGLE = 27.0 DEG.

%WM	UP-LINK FADE, DB*	TOTAL C/N, DB	C/N DEGRADATION, DB
.010	21.67	5.41	9.02
.025	15.30	10.86	3.57
.050	11.76	12.82	1.61
.075	9.78	13.44	.99
.100	8.54	13.69	.74
.250	5.54	14.10	.32
.500	4.12	14.23	.20
.750	3.27	14.28	.14
1.000	2.77	14.31	.11

* CLEAR WEATHER FOR DOWN-LINK IS ASSUMED.

TABLE 4.5.8 EFFECT OF UP-LINK FADES ON OVERALL C/N WHEN THE FEEDER-LINK IS IN ST.JOHN'S. THE AGC DYNAMIC RANGE = 10 DB.

ST.JOHN'S, RAIN ZONE F

CLEAR WEATHER TOTAL C/N =14.1 DB

SATELLITE LONGITUDE = 105.0 DEG.   ELEVATION ANGLE = 14.1 DEG.

%WM	UP-LINK FADE, DB*	TOTAL C/N, DB	C/N DEGRADATION, DB
.010	30.61	-3.91	18.00
.025	21.62	5.08	9.01
.050	16.62	9.54	4.55
.075	13.81	11.43	2.65
.100	12.06	12.33	1.75
.250	7.83	13.46	.62
.500	5.82	13.73	.36
.750	4.61	13.84	.24
1.000	3.91	13.90	.19

* CLEAR WEATHER IS ASSUMED.

TABLE 4.5.9 EFFECT OF UP-LINK FADES ON OVERALL C/N.
WHEN THE FEEDER-LINK IS IN ST. JOHN'S.
THE AGC DYNAMIC RANGE IS 10 DB.

TORONTO, RAIN ZONE K

CLEAR WEATHER TOTAL C/N = 14.7 DB

SATELLITE LONGITUDE = 85.0 DEG. ELEVATION ANGLE= 39.3 DEG.

%WM	UP-LINK FADE, DB*	TOTAL C/N, DB	C/N DEGRADATION, DB
.010	27.79	-.42	15.13
.025	19.63	7.71	7.01
.050	15.09	11.03	3.41
.075	12.54	12.77	1.95
.100	10.95	13.41	1.30
.250	7.11	14.21	.51
.500	5.29	14.41	.30
.750	4.19	14.51	.21
1.000	3.55	14.55	.16

* CLEAR WEATHER FOR DOWN-LINK ASSUMED.

TABLE 4.5.10 EFFECT OF UPLINK FADES ON OVERALL C/N WHEN THE FEEDER LINK IS IN TORONTO. THE AGC DYNAMIC RANGE IS 10 DB.

TORONTO, RAIN ZONE K

CLEAR WEATHER TOTAL C/N = 14.6 DB

SATELLITE LONGITUDE = 105.0 DEG. ELEVATION ANGLE = 33.5 DEG.

%WM	UP-LINK FADE, DB*	TOTAL C/N, DB	C/N DEGRADATION, DB
.010	30.80	-3.56	18.15
.025	21.75	5.49	9.10
.050	16.72	10.01	4.59
.075	13.90	11.91	2.67
.100	12.13	12.82	1.76
.250	7.88	13.97	.62
.500	5.86	14.23	.36
.750	4.64	14.34	.24
1.000	3.93	14.40	.19

* CLEAR WEATHER FOR DOWN-LINK IS ASSUMED.

TABLE 4.5.11 EFFECT OF UPLINK FADES ON OVERALL C/N WHEN THE FEEDER-LINK IS IN TORONTO. THE DYNAMIC RANGE OF AGC IS 10 DB.

TORONTO, RAIN ZONE K

CLEAR WEATHER TOTAL C/N = 14.1 DB

SATELLITE LONGITUDE = 135.0 DEG.　　　ELEVATION ANGLE = 15.8 DEG.

%WM	UP-LINK FADE, DB*	TOTAL C/N, DB	C/N DEGRADATION,DB
.010	50.14	-23.45	37.53
.025	35.41	-8.72	22.80
.050	27.22	-.53	14.61
.075	22.63	4.06	10.01
.100	19.76	6.91	7.17
.250	12.83	11.96	2.11
.500	9.54	13.13	.95
.750	7.56	13.50	.58
1.000	6.41	13.65	.42

* CLEAR WEATHER FOR DOWN-LINK ASSUMED.

TABLE 4.5.12 EFFECT OF UPLINK FADES ON OVERALL C/N WHEN THE FEEDER-LINK IS IN TORONTO. THE DYNAMIC RANGE OF AGC IS 10 DB.

VANCOUVER,RAIN ZONE D

CLEAR WEATHER TOTAL C/N = 14.5 DB.

SATELLITE LONGITUDE = 105.0 DEG.   ELEVATION ANGLE = 30.9 DEG.

%WM	UP-LINK FADE,DB*	TOTAL C/N, DB**	C/N DEGRADATION, DB
.010	12.43	12.63	1.90
.025	8.78	13.75	.78
.050	6.75	14.07	.46
.075	5.61	14.20	.33
.100	4.90	14.26	.26
.250	3.18	14.39	.14
.500	2.37	14.43	.09
.750	1.87	14.46	.07
1.000	1.59	14.47	.06

* CLEAR WEATHER FOR DOWN-LINK IS ASSUMED.

** THE ANIK C TYPE OF TWT CHARACTERISTICS ASSUMED WITH THE DYNAMIC RANGE OF AGC EQUAL TO 10.0 DB.

TABLE 4.5.13 EFFECT OF UPLINK FADES ON OVERALL C/N WHEN THE FEEDER LINK IS IN VANCOUVER.

VANCOUVER, RAIN ZONE D

CLEAR WEATHER TOTAL C/N = 14.6 DB

SATELLITE LONGITUDE = 135.0 DEG.   ELEVATION ANGLE = 32.4 DEG.

%WM	UP-LINK FADE, DB*	TOTAL C/N, DB**	C/N DEGRADATION, DB
.010	12.04	12.84	1.72
.025	8.50	13.84	.73
.050	6.54	14.13	.43
.075	5.43	14.25	.31
.100	4.74	14.31	.25
.250	3.08	14.43	.13
.500	2.29	14.47	.09
.750	1.81	14.50	.07
1.000	1.54	14.51	.05

* CLEAR WEATHER FOR DOWN-LINK IS ASSUMED.

** THE ANIK C TYPE OF TWT CHARACTERISTICS ASSUMED WITH THE DYNAMIC RANGE OF AGC EQUAL TO 10.0 DB.

TABLE 4.5.14 EFFECT OF UPLINK FADES ON OVERALL C/N WHEN THE FEEDER-LINK IS IN VANCOUVER.

WINNIPEG, RAIN ZONE K
CLEAR WEATHER TOTAL C/N= 14.5 DB
SATELLITE LONGITUDE = 85.0 DEG.   ELEVATION ANGLE= 31.6 DEG.

%WM	UP LINK FADE, DB*	TOTAL C/N, DB*	C/N DEGRADATION, DB
.010	26.66	.54	14.01
.025	18.83	8.23	6.31
.050	14.47	11.52	3.02
.075	12.03	12.82	1.72
.100	10.50	13.38	1.17
.250	6.82	14.07	.47
.500	5.07	14.26	.28
.750	4.02	14.35	.19
1.000	3.41	14.39	.15

* CLEAR WEATHER FOR DOWN-LINK IS ASSUMED.

** ANIK C TYPE OF TWT CHARACTERISTICS ASSUMED WITH THE DYNAMIC RANGE OF AGC EQUAL TO 10 DB.

TABLE 4.5.15: EFFECT OF UPLINK FADES ON OVERALL, C/N WHEN THE FEEDER LINK IS IN WINNIPEG.

WINNIPEG, RAIN ZONE K

CLEAR WEATHER TOTAL C/N = 14.6 DB.

SATELLITE LONGITUDE = 105.0 DEG.   ELEVATION ANGLE = 32.3 DEG.

%WM	UP-LINK FADE,DB*	TOTAL C/N,DB**	C/N DEGRADATION, DB.
.010	26.26	.95	13.61
.025	18.55	8.49	6.07
.050	14.26	11.67	2.89
.075	11.85	12.92	1.64
.100	10.35	13.44	1.12
.250	6.72	14.10	.46
.500	5.00	14.29	.27
.750	3.96	14.37	.19
1.000	3.35	14.41	.15

* CLEAR WEATHER DOWN-LINK IS ASSUMED.

** ANIK C TYPE OF TWT CHARACTERISTICS ASSUMED WITH THE DYNAMIC RANGE OF AGC EQUAL TO 10 DB.

TABLE 4.5.16 EFFECT OF UPLINK FADES ON OVERALL C/N WHEN THE FEEDER-LINK IS IN WINNIPEG.

WINNIPEG, RAIN ZONE K

CLEAR WEATHER TOTAL C/N = 14.3 DB

SATELLITE LONGITUDE = 135.0 DEG. ELEVATION ANGLE = 22.6 DEG.

%WM	UP-LINK FADE, DB*	TOTAL C/N, DB**	C/N DEGRADATION, DB
.010	33.77	-6.83	21.13
.025	23.85	3.09	11.22
.050	18.33	8.40	5.90
.075	15.24	10.77	3.53
.100	13.30	11.96	2.35
.250	8.64	13.55	.76
.500	6.43	13.88	.42
.750	5.09	14.02	.28
1.000	4.31	14.09	.22

* CLEAR WEATHER FOR DOWN-LINK IS ASSUMED.

** ANIK C TYPE OF TWT CHARACTERISTICS ASSUMED WITH DYNAMIC RANGE OF AGC EQUAL TO 10.0 DB.

TABLE 4.5.17 EFFECT OF UPLINK FADES ON OVERALL C/N WHEN THE FEEDER LINK IS IN WINNIPEG.

99.75% of the worst month, under clear weather downlink conditions. An overall C/N of 6.5 dB (corresponding to picture grade of 1.5, as suggested by CBC) is the assumed threshold value.

On the other hand, if there were a clear weather condition in the feeder-link path and rain on the downlink, the availability (for C/N 6.5 dB) would be about 99.9% of the worst month in downlink service areas located in the K zones, except for those in Atlantic provinces pointed to 105°W. Here, the availability would be reduced to 99.75% of the worst month. The availability for downlink service areas in other rain climatic zones, is in general, better than 99.9% of the worst month.

The worst case occurs when it is raining in both the feederlink and downlink service areas. If we assume that the uplink and downlink fades are independent events, the total outage time would be the sum of the uplink outage and downlink outage times. That is, if the feeder-link and downlink service areas are both in region K, the availability would be 99.65% of the worst month.

The above results have been obtained using an AGC dynamic range equal to 10 dB. Tables 4.5.18 and 4.5.19 show the effect of the uplink fade on overall C/N when the dynamic ranges of AGC are 15 and 20 dB, respectively. The feeder-link is assumed to be in Toronto. It is interesting to note that the availability of the service does not improve significantly with an increase in the dynamic range of AGC, since for a small percentage of the worst month, the uplink fade is so great that the service remains uplink limited. Therefore, another technique, such as site diversity, should be employed to reduce the effect of uplink fade when the feeder-link is in rain climate zone K (such as Toronto or Montreal) and the elevation angle is relatively low.

TORONTO, RAIN ZONE K

CLEAR WEATHER TOTAL C/N = 14.1 DB

SATELLITE LONGITUDE 135.0 DEG. ELEVATION ANGLE = 15.8 DEG.

%WM	UP-LINK FADE, DB*	TOTAL C/N, DB**	C/N DEGRADATION, DB
.010	50.14	-21.88	35.95
.025	35.41	-7.15	21.23
.050	27.22	1.04	13.04
.075	22.63	5.49	8.59
.100	19.76	7.98	6.10
.250	12.83	12.17	1.91
.500	9.54	13.13	.95
.750	7.56	13.50	.58
1.000	6.41	13.65	.42

* CLEAR WEATHER FOR DOWN-LINK IS ASSUMED.

** THE ANIK C TYPE OF TWT CHARACTERISTICS ASSUMED WITH THE DYNAMIC RANGE OF AGC EQUAL TO 15.0 DB.

TABLE 4.5.18 EFFECT OF UP-LINK FADES ON OVERALL C/N WHEN THE FEEDER-LINK IS IN TORONTO AND THE AGC DYNAMIC RANGE IS INCREASED TO 15 DB.

TORONTO, RAIN ZONE K

CLEAR WEATHER TOTAL C/N = 14.1 DB

SATELLITE LONGITUDE = 135.0 DEG.   ELEVATION ANGLE = 15.8 DEG.

%WM	UP-LINK FADE, DB*	TOTAL C/N, DB**	C/N DEGRADATION, DB
.010	50.14	-21.23	35.31
.025	35.41	-6.51	20.58
.050	27.22	1.62	12.46
.075	22.63	5.88	8.20
.100	19.76	8.23	5.85
.250	12.83	12.17	1.91
.500	9.54	13.13	.95
.750	7.56	13.50	.58
1.000	6.41	13.65	.42

* CLEAR WEATHER FOR DOWN-LINK IS ASSUMED.

** THE ANIK C TYPE OF TWT CHARACTERISTICS ASSUMED WITH THE DYNAMIC RANGE OF AGC EQUAL TO 20.0 DB.

TABLE 4.5.19 EFFECT OF UP-LINK FADES ON OVERALL C/N WHEN THE FEEDER-LINK IN IN TORONTO AND THE AGC DYNAMIC RANGE IS INCREASED TO 20 DB.

TORONTO, RAIN ZONE K

CLEAR WEATHER TOTAL C/N = 16.0 DB

SATELLITE LONGITUDE = 135.0 DEG. ELEVATION ANGLE = 15.8 DEG.

%WM	UP-LINK FADE, DB*	TOTAL C/N, DB**	C/N DEGRADATION, DB
.010	50.14	-22.67	38.67
.025	35.41	-7.95	23.95
.050	27.22	.25	15.76
.075	22.63	4.84	11.16
.100	19.76	7.69	8.31
.250	12.83	13.14	2.86
.500	9.54	14.60	1.40
.750	7.56	15.13	.87
1.000	6.41	15.36	.64

* CLEAR WEATHER FOR DOWN-LINK ASSUMED.

** THE ANIK C TYPE OF TWT CHARACTERISTICS ASSUMED WITH THE DYNAMIC RANGE OF AGC EQUAL TO 10.0 DB.

TABLE 4.5.20 EFFECT OF UP-LINK FADES ON OVERALL C/N WHEN THE FEEDER-LINK IS IN TORONTO AND THE HOME TERMINAL, G/T IS IMPROVED TO 12 DB/K.

Finally, as mentioned in Section 2.6.2, Telesat believes that home terminals with G/T values in excess of 10 dB/K will be readily available by 1986. This belief is based on an investigation of the present state of the art of LNA's at 12 GHz and, to some extent, antenna development for receive-only terminals. A reasonable projection of development trends indicates that a practical G/T would be about 12 dB/K for the terminals to be available in high volume production in the near future. This is based on an antenna diameter of 1 m, with about 70% aperture efficiency, and an LNA noise figure of 3 dB.

The improved G/T for the home terminals could affect the system performance in two ways: a) If all other link parameters, including the satellite EIRP, were kept constant, then the clear weather signal-to-noise ratio (S/N) would increase by about 2 dB and, therefore, a better service quality would be available; and b) Alternatively, if the increase in G/T were offset with a decrease in the satellite EIRP, in order to reduce the spacecraft cost (the logical direction to follow), then the clear weather S/N would stay constant. However, the receiver would be more sensitive to other noise contributions such as noise temperature enhancement due to rain.

Table 4.5.20 demonstrates an example for the overall carrier-to-noise ratio under the clear weather downlink condition, when the home terminal G/T is improved to 12 dB/K, but the satellite EIRP is unchanged. The feeder-link is assumed to be in Toronto. A comparison between Tables 4.5.12 and 4.5.17 shows that the overall C/N for 99% of the worst month is improved by about 1.7 dB.

4.5.1.2 Degradation of Overall C/N Due to Snow

Wet snow may cause several times larger attenuation per unit propagation path than does rain at the same precipitation rate. However, the height where snow precipitates is much lower than that of rain, so that effective attenuation paths become shorter. Consequently, snow usually causes much smaller attenuation on a slanted path. The effects of snow lying on the receiving antenna can, however, be severe.

Measurements of the effects of snowfall on receiving antennas were carried out in Japan at 12 GHz [25]. Figure 4.5.1 shows the insertion loss of snow in terms of the moisture content of the snow deposit. The insertion loss is severely dependent on the amount of moisture content in the snow. The insertion loss is increased as new dry snow deposits on an antenna and becomes wet when it is exposed to sunlight. The snow deposits will be generally more on the lower half surface of a parabolic antenna. This may degrade the antenna directivity due to disturbance of the phase uniformity at the aperture of the antenna. Figure 4.5.2 shows the experimental results of the effect of snow deposited [25]. The snow deposit causes a beam tilt upwards at first and then degrades the shape of the beam as the thickness of the snow deposit increases.

The combined effect of the insertion loss and the aperture phase distortion could easily be about 2 dB. This is the average rain attenuation on the downlink exceeded for 1% of the worst month across most of Canada. Considering that in Canada snow could be sitting on the home receiving terminals for as long as six months, its effects should be considered for BSS studies.

Installation of a radome on the receiving antenna can be a countermeasure to reduce the effect of snow on the antenna's performance. However, the employment of a radome would increase the cost of the home receiving terminals. In addition, the transmission losses in water layers formed on the radome during heavy rainfall are reported to be significant [26].

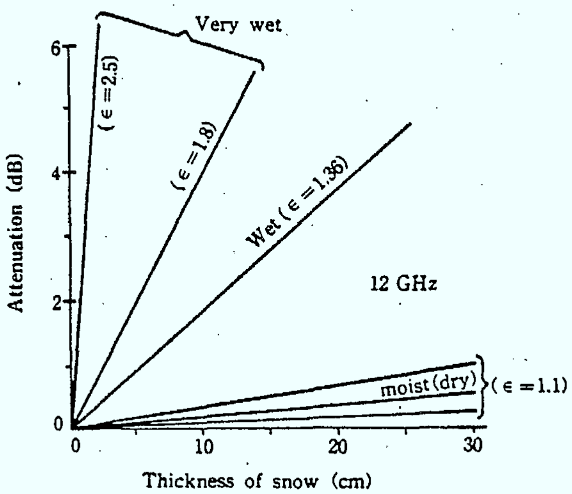


Figure 4.5.1 Insertion loss in terms of thickness of snow.

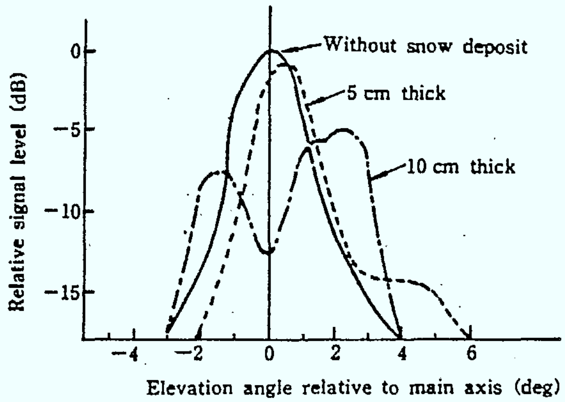


Figure 4.5.2 Variation of directivity due to snow deposit on lower half surface of parabolic antenna.

4.5.1.3 Conclusion

A key objective of a transmission system is to provide an excellent picture under normal conditions and an acceptable picture under all but the heaviest rain conditions. The worst case link performance, excluding eclipses, should be considered at the edge-of-coverage for the region in Canada suffering the heaviest rain.

Assuming an AGC with 10 dB dynamic range and a satellite transponder having transfer characteristics the same as that of the Anik C TWT, the overall C/N was calculated for different cities across Canada under clear weather downlink conditions. It was noted that the feeder-link earth terminals located in any rain climatic zones other than K can provide an availability better than 99.98% of the worst month. Placing a feeder-link earth terminal in rain climatic zone K would reduce the availability. The outage time could still be reasonable if a viewer would accept a picture with a grade of 1.5. The effect of a higher dynamic range for AGC was also studied. It was concluded that, for locations in rain climatic zone K and elevation angles less than about 20°, a higher AGC dynamic range cannot reduce the outage time since the system becomes uplink limited. In this case, the use of site diversity was suggested.

4.5.2 Interference

The degradation of the overall satellite link clear weather C/I ratio, due to rain attenuation and depolarization of the uplink and downlink wanted carriers and interfering carriers, is a random variable. The determination of the percentage of time a specified degradation is exceeded, is not a trivial problem.

A simplified approach has been used which provides a first order estimate of the severity of the feeder-link fading problem. The fundamental assumption is that clear weather propagation conditions exist on the downlinks for both the wanted and interfering carriers and that the sole cause of downlink C/I degradation is the satellite transponder output power backoff due to fading beyond the AGC level on the associated feeder-link.

The assumption of downlink clear weather propagation conditions accurately models the conditions that would prevail over a large percentage of a BSS service area, since the probability of simultaneous up and downlink fading will typically be very small. In addition, for independent up and downlink fades, the model allows an estimation of total outage statistics for a specified threshold by the simple process of adding the percentages of time the up and downlinks are each below threshold. The major failing of the model occurs for correlated up and downlink fading which would be the case for receiving BSS earth stations in the vicinity of the feeder-link stations.

Feeder-link fade degradations are examined below for two cases of intra-system interference. The first studies link C/I degradations where the wanted and interfering feeder-link earth stations are co-located, and includes the case of a common transmit antenna. The second case accounts for feeder link earth stations that are not co-located. In both cases the wanted and interfering carriers are received at the same satellite and re-transmitted in the same or adjacent downlink beams.

The degradations in the typical overall satellite link clear weather C/I ratios due to feeder-link fading are given in Tables 4.5.21 to 4.5.24 for Toronto, Vancouver, Winnipeg and Halifax, respectively, for feeder-link earth stations transmitting to BSS satellites at 135°W, 105°W or 85°W as appropriate. The results are discussed further below.

Table 4.5.21: Degradation in Overall Satellite Link Clear Weather C/I Due to Fading on Feeder Links

TORONTO --- 135°W

	Uplink		Link C/N Degrad. (Note 1)	Co-Pol Interference Degradation (dB) (Note 2)		X-Pol Interference Degradation (dB) (Note 3)	
% WM	ATT (dB)	XPD (dB)	(dB)	Same Site	Diff. Sites	Same Site	Diff. Sites
1.00	6.41	19.54	0.38	0.0	4.44	3.64	3.51
.75	7.56	17.89	0.52	0.0	5.42	4.66	4.37
.50	9.54	15.56	0.85	0.0	7.18	6.32	5.97
.25	12.83	12.60	1.95	0.0	10.27	8.75	8.90
.10	19.76	8.29	6.90	0.0	17.08	12.68	15.62
.075	22.63	6.93	9.74	0.0	19.95	13.98	18.48
.050	27.22	5.06	14.33	0.0	24.54	15.79	23.07
.025	35.41	2.46	22.52	0.0	32.73	18.33	31.26
.010	50.14	-1.01	37.25	0.0	47.46	21.77	45.99

Notes:
1. Clear Weather Link C/N= 13.9 dB
2. Clear Weather Link C/I= -3.26 dB
3. Clear Weather Link C/I= 20.24 dB

TORONTO --- 105°W

	Uplink		Link C/N Degrad. (Note 1)	Co-Pol Interference Degradation (dB) (Note 2)		X-Pol Interference Degradation (dB) (Note 3)	
% WM	ATT (dB)	XPD (dB)	(dB)	Same Site	Diff. Sites	Same Site	Diff. Sites
1.0	3.93	26.89	0.17	0.0	2.50	0.94	1.88
.75	4.64	25.24	0.22	0.0	3.03	1.32	2.32
.50	5.86	22.91	0.32	0.0	3.99	2.06	3.12
.25	7.88	19.95	0.56	0.0	5.70	3.42	4.62
.10	12.13	15.64	1.63	0.0	9.60	6.26	8.25
.075	13.90	14.28	2.51	0.0	11.30	7.34	9.91
.050	16.72	12.44	4.38	0.0	14.07	8.89	12.62
.025	21.75	9.81	8.86	0.0	19.07	11.26	17.60
.010	30.80	6.34	17.91	0.0	28.12	14.55	26.65

Notes:
1. Clear Weather Link C/N= 13.9 dB
2. Clear Weather Link C/I= -3.26 dB
3. Clear Weather Link C/I= 20.24 dB

Table 4.5.22 Degradation in Overall Satellite Link Clear Weather C/I Due to Fading on Feeder Links

VANCOUVER --- 135°W

	Uplink		Link C/N Degrad. (Note 1)	Co-Pol Interference Degradation (dB) (Note 2)		X-Pol Interference Degradation (dB) (Note 3)	
% WM	ATT (dB)	XPD (dB)	(dB)	Same Site	Diff. Sites	Same Site	Diff. Sites
1.00	1.54	36.07	0.05	0.0	0.88	0.13	0.63
.75	1.81	34.42	0.06	0.0	1.05	0.18	0.76
.50	2.29	32.09	0.08	0.0	1.36	0.31	0.99
.25	3.08	29.14	0.12	0.0	1.89	0.59	1.40
.10	4.74	24.82	0.23	0.0	3.11	1.43	2.38
.075	5.43	23.47	0.28	0.0	3.65	1.85	2.83
.050	6.54	21.62	0.39	0.0	4.55	2.59	3.61
.025	8.50	18.99	0.66	0.0	6.24	3.97	5.11
.010	12.04	15.52	1.59	0.0	9.51	6.35	8.17

Notes: 1. Clear Weather Link C/N= 13.9 dB
2. Clear Weather Link C/I= -3.26 dB
3. Clear Weather Link C/I= 20.24 dB

VANCOUVER --- 105°W

	Uplink		Link C/N Degrad. (Note 1)	Co-Pol Interference Degradation (dB) (Note 2)		X-Pol Interference Degradation (dB) (Note 3)	
% WM	ATT (dB)	XPD (dB)	(dB)	Same Site	Diff. Sites	Same Site	Diff. Sites
1.00	1.59	35.47	0.05	0.0	0.91	0.14	0.66
.75	1.87	33.82	0.06	0.0	1.09	0.21	0.79
.50	2.37	31.49	0.08	0.0	1.41	0.35	1.03
.25	3.18	28.53	0.12	0.0	1.96	0.67	1.46
.10	4.90	24.22	0.24	0.0	3.23	1.61	2.48
.075	5.61	22.86	0.30	0.0	3.79	2.07	2.95
.050	6.75	21.01	0.42	0.0	4.73	2.87	3.76
.025	8.78	18.39	0.71	0.0	6.49	4.34	5.34
.010	12.43	14.91	1.76	0.0	9.88	6.83	8.53

Notes: 1. Clear Weather Link C/N= 13.9 dB
2. Clear Weather Link C/I= -3.26 dB
3. Clear Weather Link C/I= 20.24 dB

Table 4.5.22 Degradation in Overall Satellite Link Clear Weather
(cont'd) C/I Due to Fading on Feeder Links

VANCOUVER --- 85°W

	Uplink		Link C/N Degrad. (Note 1)	Co-Pol Interference Degradation (dB (Note 2)		X-Pol Interference Degradation (dB) (Note 3)	
% WM	ATT (dB)	XPD (dB)	(dB)	Same Site	Diff. Sites	Same Site	Diff. Sites
1.00	1.95	32.19	0.07	0.0	1.14	0.30	0.82
.75	2.30	30.54	0.08	0.0	1.36	0.43	1.00
.50	2.90	28.21	0.11	0.0	1.77	0.71	1.30
.25	3.90	25.26	0.17	0.0	2.48	1.31	1.87
.10	6.01	20.94	0.34	0.0	4.11	2.91	3.23
.075	6.88	19.59	0.43	0.0	4.84	3.62	3.86
.050	8.28	17.74	0.62	0.0	6.05	4.76	4.93
.025	10.77	15.11	1.14	0.0	8.31	6.67	7.02
.010	15.25	11.64	3.34	0.0	12.62	9.60	11.20

Notes: 1. Clear Weather Link C/N= 13.9 dB
2. Clear Weather Link C/I= -3.26 dB
3. Clear Weather Link C/I= 20.24 dB

Table 4.5.23 Degradation in Overall Satellite Link Clear Weather C/I Due to Fading on Feeder Links

WINNIPEG --- 135°W

	Uplink		Link C/N Degrad. (Note 1)	Co-Pol Interference Degradation (dB) (Note 2)		X-Pol Interference Degradation (dB) (Note 3)	
% WM	ATT (dB)	XPD (dB)	(dB)	Same Site	Diff. Sites	Same Site	Diff. Sites
1.00	4.31	24.21	0.19	0.0	2.78	1.61	2.11
.75	5.09	22.56	0.25	0.0	3.38	2.19	2.61
.50	6.43	20.23	0.38	0.0	4.46	3.27	3.53
.25	8.64	17.27	0.68	0.0	6.37	5.08	5.22
.10	13.30	12.96	2.18	0.0	10.72	8.44	9.34
.075	15.24	11.60	3.34	0.0	12.61	9.63	11.19
.050	18.33	9.76	5.66	0.0	15.66	11.30	14.20
.025	23.85	7.13	10.96	0.0	21.17	13.79	19.70
.010	33.77	3.65	20.88	0.0	31.09	17.16	29.62

Notes: 1. Clear Weather Link C/N= 13.9 dB
2. Clear Weather Link C/I= -3.26 dB
3. Clear Weather Link C/I= 20.24 dB

WINNIPEG --- 105°W

	Uplink		Link C/N Degrad. (Note 1)	Co-Pol Interference Degradation (dB) (Note 2)		X-Pol Interference Degradation (dB) (Note 3)	
% WM	ATT (dB)	XPD (dB)	(dB)	Same Site	Diff. Sites	Same Site	Diff. Sites
1.00	3.35	28.26	0.13	0.0	2.08	0.71	1.55
.75	3.96	26.61	0.17	0.0	2.52	1.00	1.90
.50	5.00	24.28	0.25	0.0	3.31	1.59	2.55
.25	6.72	21.33	0.41	0.0	4.70	2.72	3.74
.10	10.35	17.01	1.03	0.0	7.92	5.26	6.66
.075	11.85	15.66	1.52	0.0	9.33	6.25	7.99
.050	14.26	13.81	2.72	0.0	11.66	7.72	10.25
.025	18.55	11.18	5.84	0.0	15.88	10.01	14.42
.010	26.26	7.71	13.37	0.0	23.58	13.23	22.11

Notes: 1. Clear Weather Link C/N= 13.9 dB
2. Clear Weather Link C/I= -3.26 dB
3. Clear Weather Link C/I= 20.24 dB

Table 4.5.24 Degradation in Overall Satellite Link Clear Weather C/I Due to Fading on Feeder Links

HALIFAX --- 105°W

	Uplink		Link C/N Degrad. (Note 1)	Co-Pol Interference Degradation (dB) (Note 2)		X-Pol Interference Degradation (dB) (Note 3)	
% WM	ATT (dB)	XPD (dB)	(dB)	Same Site	Diff. Sites	Same Site	Diff. Sites
1.00	4.89	23.19	0.24	0.0	3.22	1.95	2.48
.75	5.77	21.54	0.31	0.0	3.92	2.62	3.06
.50	7.28	19.21	0.48	0.0	5.18	3.84	4.16
.25	9.78	16.26	0.90	0.0	7.40	5.80	6.17
.10	15.07	11.94	3.22	0.0	12.45	9.33	11.02
.075	17.26	10.59	4.80	0.0	14.60	10.54	13.15
.050	20.77	8.74	7.88	0.0	18.09	12.26	16.62
.025	27.02	6.11	14.13	0.0	24.34	14.77	22.87
.010	38.25	2.64	25.36	0.0	35.57	18.16	34.10

Notes: 1. Clear Weather Link C/N= 13.9 dB
2. Clear Weather Link C/I= -3.26 dB
3. Clear Weather Link C/I= 20.24 dB

HALIFAX --- 85°W

	Uplink		Link C/N Degrad. (Note 1)	Co-Pol Interference Degradation (dB) (Note 2)		X-Pol Interference Degradation (dB) (Note 3)	
% WM	ATT (dB)	XPD (dB)	(dB)	Same Site	Diff. Sites	Same Site	Diff. Sites
1.00	3.90	27.14	0.17	0.0	2.48	0.89	1.87
.75	4.60	25.49	0.22	0.0	3.00	1.25	2.29
.50	5.81	23.16	0.32	0.0	3.95	1.96	3.09
.25	7.81	20.21	0.55	0.0	5.64	3.28	4.56
.10	12.03	15.89	1.59	0.0	9.50	6.07	8.16
.075	13.78	14.54	2.44	0.0	11.19	7.13	9.79
.050	16.58	12.69	4.28	0.0	13.93	8.67	12.49
.025	21.57	10.06	8.68	0.0	18.89	11.03	17.42
.010	30.53	6.59	17.64	0.0	27.85	14.30	26.38

Notes: 1. Clear Weather Link C/N= 13.9 dB
2. Clear Weather Link C/I= -3.26 dB
3. Clear Weather Link C/I= 20.24 dB

4.5.2.1 Co-located Feeder-Link Earth Stations

When the wanted and interfering carriers are transmitted from the same earth station antenna or co-located antennas, the uplink attenuation of each is assumed equal, as is the satellite output power backoff resulting from the fade. There is consequently no degradation in the downlink C/I and the sole cause of uplink C/I degradation is rain depolarization, the effects of which depend on whether the carriers are co-polarized or cross-polarized.

In the case of co-polarized wanted and interfering carriers, it can be shown that rain depolarization interference effects are negligible, with the result that there is essentially no degradation in the overall satellite link clear weather C/I ratio.

For cross-polarized wanted and interfering carriers, the degradation effects of up-link rain depolarization are not negligible as shown in Tables 4.5.21 - 4.5.24. More importantly, the tables show that the link C/I degrades substantially faster than the link C/N.

4.5.2.2 Non-co-located Feeder Link Earth Stations

When the wanted and interfering carriers are transmitted from feeder-link earth stations which are separated by distances large enough to ensure independence of the uplink fade distributions, degradation of the satellite link clear weather C/I ratio is dependent on both the fading of the wanted carrier and the fading and depolarization of the interfering carrier.

For co-polarized carriers, degradations due to depolarization are negligible, as previously mentioned, and the worst case C/I degradation will occur when the interfering carrier is unfaded while the wanted carrier is attenuated by rain on the uplink and by the satellite output power backoff on the downlink. The degradations shown in Tables 4.5.21 - 4.5.24 indicate that the satellite link C/I will degrade almost dB for dB with an uplink fade.

In the case of cross-polarized carriers, two situations must be considered. The first is rain attenuation and depolarization of the interfering cross-polarized carrier where the former increases the C/I but the latter degrades C/I. It can be shown that, for the assumed typical values of transmit and receive antenna cross-polarization discriminations used in this study, the net effect is generally an improvement in link C/I. In some exceptional cases, a negligible degradation would occur.

The second situation is that discussed for co-polarized carriers, i.e. fading of the wanted carrier when the interfering carrier is unfaded. The calculated degradations given in Tables 4.5.21 - 4.5.24 are similar to, but slightly smaller than those for co-polarized carriers.

4.5.2.3 <u>Discussion of Interference Reliability Consideration</u>

The results given in Tables 4.5.21 to 4.5.24 reveal the following:

a) Feeder-link fading results in overall satellite link C/I degradations (in dB) which are substantially greater than the satellite link C/N degradations. The critical question is; which degradation determines the availability of the service?

   A subjective impairment grade of 1.5 has been taken as the outage threshold for availability purposes. For thermal noise, the corresponding C/N has been taken as 6.5 dB. Hence, for a clear weather link C/N of 13.9 dB, the link C/N degradation availability threshold is 7.4 dB.

For interference, the availability threshold is not as well defined and, moreover, it depends on the frequency separation between the wanted and interfering carriers. In the case of co-channel carriers, Figure 5-1 of the CPM Report [1] indicates that a C/I of 2-5 dB results in an impairment grade of 1.5. This result suggests that a link C/I degradation of about 25 dB could be taken as the availability threshold for a clear weather co-channel C/I of 30 dB. However, the recent results from the DOC/CRC TV Interference Measurement Program [27] indicate that a C/I of 10-15 dB may be required for an impairment grade of 1.5. As a consequence, the C/I degradation threshold would be reduced to 15-20 dB.

In the case of adjacent channel interference (ie, for frequency separations of 13-15 MHz) no information was previously available, to allow definition of availability thresholds, and the recent DOC/CRC measurement results are timely. These results indicate that the adjacent channel C/I for an impairment grade of 1.5 ranges from about 0 dB to 3-4 dB for 15 and 13 MHz spacing, respectively. Since the adjacent channels are usually cross-polarized, a clear weather link C/I of 20-24 dB has been assumed in this study. Hence, the adjacent channel C/I degradation threshold would be in the 16-20 dB range.

In the case of alternate channel interference (ie, for frequency separations of 26-30 MHz), there is at the present time, no information available relating C/I to impairment grade.

b) On the basis of the considerations in part a) above, it would appear that C/N degradations will primarily determine the availability for the model and assumptions considered in this study. However, this conclusion is not general, since it is anticipated that it would not be true in worst-case situations, or if the underlying assumptions were modified (ie, if the AGC range was increased to 15 or 20 dB).

c) It is to be noted that the C/I degradations shown in Tables 4.5.21 to 4.5.24 are due to feeder-link fading and for depolarization and that the use of AGC has virtually no effect on these degradations. That is, the sole effect of AGC is to reduce the C/N degradations and if a large AGC range is used (eg. 15-20 dB), then C/I degradations will determine availability.

5.0 SHARING CONSTRAINTS

The 17.7 - 18.1 GHz frequency band is allocated on an equal primary basis to the Fixed, Mobile and Fixed-Satellite (Earth-to-Space and Space-to-Earth) services. The Fixed Satellite Service (Earth-to-Space) allocation is restricted (by RR. No. 869) to use for feeder-links for the Broadcasting-Satellite Service.

The Feeder-Link Plan (FL Plan) to be developed by the '83 RARC will complement the 12 GHz BSS Plan and it seems almost certain that the FL Plan will include feeder-links in the 17.7 - 18.1 GHz band, as well as the associated technical and administrative regulatory provisions governing sharing between the feeder-links and the other services sharing the bands.

Sharing constraints arise from the need to limit to acceptable levels the interference that feeder-link earth stations cause to terrestrial and earth stations in the Fixed and Fixed-Satellite (Space-to-Earth) services, respectively. These sharing constraints include both technical and operational constraints affecting the design and operation of feeder-link earth stations, and would apply equally to fixed and transportable feeder-link earth stations.

The nature, extent and ramifications of these sharing constraints are examined below. The assumptions and supporting rationale regarding the FL Plan to be adopted by the '83 RARC are given first, in order to define the context for the subsequent sections which examine the specific sharing constraints for protection of the Fixed and Fixed-Satellite services.

5.1 Assumptions and Rationale

The provisions of the 83 RARC FL plan can only be speculated on at this time and a number of assumptions have therefore been made concerning the plan. These assumptions are described below. The supporting rationale and, where appropriate, a discussion of relevant consequential ramifications are also provided.

Assumption A:
The FL plan will contain frequency assignments in the band above 17.7 GHz relating to specified fixed points, within a feeder-link service area. Feeder-link earth stations must be located at these points to be a) in conformity with the FL plan and b) operated without coordination with the other radio services sharing the band.

Rationale:
This assumption reflects the current Canadian position concerning the question of frequency allotments versus frequency assignments in the band above 17.7 GHz. The FL plan therefore would establish the right to locate a feeder-link earth station at the specified location without any coordination whatsoever, as long as the technical characteristics are in conformity with the FL plan.

The consequence of this right is that receiving terrestrial or earth stations could not claim protection from interference from a feeder-link earth station which is implemented in accordance with the FL plan. Protection would however be afforded against increased interference that might be caused due to modifications to the FL plan.

Assumption B:
The locations of specified fixed points in the FL plan can be readily changed and such changes do not constitute a modification to the FL plan for which the agreement of other Administrations is required.

Rationale:

While fixed locations for feeder-link earth stations are assumed in the FL plan, it is also assumed that the FL plan is based on an interference analysis which provides for the feeder-link earth station being located at any point in the feeder-link service area. Simple changes in the longitude and/or latitude of the specified location in the FL plan will therefore not affect other feeder-links in the FL plan and the agreement of other Administrations in accordance with the formal FL plan modification procedure will not be required.

If the FL plan does not contain explicit provisions along the lines of this assumption, then any change in the location of the specified fixed points, whether for a permanent or transportable earth station, would legally constitute a modification of the PLAN requiring the agreement of affected Administrations.

Assumption C:

The administrative provisions of the FL plan specify that coordination of a feeder-link earth station viz-a-viz terrestrial stations is necessary only if the new (or revised) coordination area of the feeder-link earth station includes (or increases) the affected area in the territory of another Administration.

Rationale:

This is a necessary consequence of the shared primary allocation above 17.7 GHz.

Assumption D:

The administrative provisions of the FL plan specify that coordination of a feeder-link earth station viz-a-viz any receiving earth station in the Fixed-Satellite service is necessary only if the new (or revised) coordination area of the feeder-link earth station encompasses such a receiving earth station (or increases the interference levels).

Rationale:
This is a necessary consequence of the shared primary allocation above 17.7 GHz.

Assumption E:
In the cases of interference to the feeder-link receiving space station due to transmitting terrestrial and space stations in the Fixed and Fixed-Satellite Services, respectively, the acceptable interference levels are defined on the basis of operating conditions with fixed feeder-link earth stations and not transportable earth stations.

Rationale:
This assumption is speculative and defines the conditions for the operation of transportable feeder-link earth stations.

5.2 Fixed Satellite Service

The considerations relevant to the evaluation of the sharing constraints involving the fixed satellite service are somewhat different for permanent feeder-link earth stations (PES's) and transportable feeder-link earth stations (TES's) and they are therefore considered separately.

5.2.1 Permanent Feeder-Link Earth Stations

The sharing constraints affecting PES's will be determined by a number of factors such as:

- whether or not the technical characteristics are in conformity with the FL plan;
- whether or not the location is in conformity with the FL plan;
- the state of development of Canadian and/or US domestic FSS systems and
- the state of development of international FSS systems.

It is to be noted that there will be no technical or operational constraints whatsoever affecting a PES which has technical characteristics and a location in conformity with the FL plan. The only conceivable exception to this right would be the adoption by DOC of a domestic policy granting priority to existing or planned Canadian FSS earth stations.

It is only in cases where PES's, not in conformity with the FL plan, are to be implemented that sharing may impose constraints. Any change in technical characteristics which causes or is capable of causing increased interference, or a change in location, will result in a requirement for formal coordination (in accordance with the administrative procedures in the FL plan) with any existing or planned FSS earth stations which may be affected. This coordination is unlikely to be required in this decade, since there are no operational or planned FSS systems but it is obvious that such coordination could become onerous when FSS systems are implemented. In some situations, significant technical or operational constraints could result from the need to protect FSS earth stations.

The reduction of interference to an acceptable level in a particular case could result in constraints on PES location and/or transmit power and/or antenna size/radiation pattern unless other alternatives were available, (e.g. site shielding). Restrictions on PES location would be proportional to the number of FSS earth stations, in view of the large coordination distances.

The coordination distances required for a PES are considered in Section 7.5.2.1.1 of the CPM Report [1]. The cited Mode (1) coordination distances are probably pessimistic, since neither the reference bandwidth, B, of 1 MHz nor the fade margin, M_s, of 5 dB is likely to be typical of 18 GHz FSS system designs. The CPM Mode (2) (i.e. rain scatter) coordination distance of 360 km would, on the other hand, not change for different values of B and M_s and the avoidance of main beam intersections, would be a critical necessity.

It is highly probable that site diversity will be used for 18 GHz FSS downlinks and the advantages to be realized in terms of decreased coordination distances, have not yet been studied. Substantially smaller coordination distances can be anticipated and further investigation is warranted.

5.2.2 Transportable Feeder-Link Earth Stations

Given the assumptions regarding the FL plan, the operation of TES's in the band above 17.7 GHz will not be in accordance with the FL plan. While it is assumed that TES's can be operated without coordination with other feeder-link assignments, it is evident that they would need still to be coordinated with other affected radio services sharing the band.

The comments in Section 5.2.1, concerning coordination of PES's not in conformity with the FL plan, are therefore equally applicable to TES's. The feasibility of TES operation will thus be critically dependent on the state of development of domestic and international FSS systems and, in the long term, it is likely that TES operations would be significantly constrained or possibly even precluded above 17.7 GHz due to sharing with the FSS (and FS). However, operation of TES's until that time would be feasible to the extent that the restrictions on TES location were acceptable.

5.3 Fixed and Mobile Services

Sharing constraints and considerations for permanent and transportable feeder-link earth stations are discussed seperately below.

5.3.1 Permanent Feeder-Link Earth Stations (PES's)

The discussion in Section 5.2.1 concerning FSS sharing is equally applicable to sharing with the Fixed and Mobile services when account is taken of the following differences:

- the number of terrestrial fixed stations will be significantly greater than the number of FSS earth stations if the band is used extensively. Therefore, coordination will be more difficult and time consuming;
- coordination distance requirements for terrestrial stations should be appreciably smaller, since the lower antenna gain and higher system noise temperature would reduce interference susceptibility;
- the consequential advantages of route diversity would be similar to those for FSS earth station site diversity;
- the implementation of mobile services in the band above 17.7 GHz could drastically affect the feasibility of sharing since areas rather than points would need to be protected.

As in the case of sharing with FSS earth stations, the fundamental constraints on PES's will be the restrictions on a position, relative to terrestrial stations. Few, if any, other operational or technical constraints would need to be considered.

5.3.2 Transportable Feeder Link Earth Stations

The operation of transportable feeder-link earth stations in the band above 17.7 GHz will be feasible only as long as the band is very lightly used by the terrestrial services. The restrictions, as to useable locations will be directly proportional to the number of terrestrial stations in operation. While the use of very low sidelobe TES antennas would substantially reduce the required separation distances, the net benefit in terms of reduced siting restrictions may be negligible if the terrestrial systems use route diversity, as seems necessary, or if the band is extensively used and the station density is large.

The fundamental problem, as in all the other cases above, is the operational constraint on locations at which a TES may be used. The only real solution to this problem is the unacceptable one of placing the FSS, FS and MS on a secondary basis to TES's in the band above 17.7 GHz.

5.4 Summary

Sharing in the band above 17.7 GHz will result in constraints on feeder-link earth stations that will become increasingly real as time progresses and the other radio services develop and expand. However, the implementation and operation of permanent feeder-link earth stations in conformity with the FL plan would be fully protected by the FL plan and not subject to any constraints.

There would initially be few, if any, constraints affecting transportable feeder-link earth stations but their future use would be critically dependent on rate of development and expansion of the other radio services sharing the band. In view of the fact that such operations could ultimately be unacceptably constrained, it would appear prudent to ensure that BSS channels requiring the use of TES's be assigned feeder-link frequencies below 17.7 GHz.

6.0 SUMMARY AND SUGGESTIONS FOR FURTHER WORK

6.1 Summary

In this report, a model has been proposed which would be reasonable for a first generation Canadian BSS. Two variants have been included, one containing two satellites with three downlink beams each, and the other containing three satellites with two downlink beams each. Nationwide feeder-link coverage to all satellites has been assumed, except where precluded by elevation angle. The frequency plan would provide a total of 36 channels of 24 MHz bandwidth. Two multiplexing arrangements have been proposed, one employing single polarization and the other frequency reuse through dual polarization. In general, characteristics assumed for the receive earth stations were as outlined in the CPM. It was, however, noted that technology trends indicate that the assumed G/T value of 10 dB/K is pessimistic.

The feeder-link earth stations were assumed to be located at major television production centres, as indicated by the CBC. These permanent feeder-link earth stations were assumed to have 5m antennas and transmit powers of 1000 watts at the antenna flange. Transportable earth stations with antenna diameters of about 3m and transmit powers of 500 watts were also considered, although it was concluded that their use would be limited to coverage of special events. As such, they would play a relatively minor role in a Canadian BSS. Feeder-link antenna pointing tolerance was considered in some detail. It was suggested that auto-tracking would be necessary for the permanent earth stations and that a 0.5 dB limit would be appropriate.

A major portion of the report analyzed the performance to be expected in a Canadian BSS. Due to the uplink and downlink frequency bands that will be used in the BSS, attenuation and depolarization due to precipitation are a major factor influencing performance. Using the CPM model, predictions of the statistics of these effects were generated for the proposed permanent feeder-link locations. It was concluded that to be a successful service offering, the BSS must employ some means to compensate for the precipitation effects. Accordingly, on-board AGC and site diversity improvements were considered. It was concluded that AGC effectively reduces the impact of uplink rain attenuation on downlink noise , although a possible increase in downlink interference and a more complicated spacecraft are its drawbacks. Site diversity can maintain both C/N and C/I values at near nominal values during rain events. However, cost and operational complexity are serious concerns.

The impact of eclipses and equipment sparing philosophy on system availability was discussed. Due to the likely lack of full battery backup during eclipses, outages are inevitable. Since these outages are predictable, the BSS system design and operational procedure can be tailored to minimize their impact. A high degree of equipment redundancy is indicated to meet the availability requirements.

Clear air C/N and C/I link budgets were presented, consistent with the system model. Then, the more complicated topic of performance reliability, as influenced by the statistical nature of propagation, was addressed. Tables of typical performance statistics were produced. It was concluded that, although high availability will be achieved (for the BSS system assumed) under most conditions, services having uplinks in rain zone K will be subject to outages often enough to cause concern. In this case, site diversity would significantly improve the situation. Interference is a more serious concern than thermal noise, since C/I tends to degrade faster than C/N.

The portion of the feeder-link band above 17.7 GHz is shared with the Fixed Service and Fixed Satellite Service. A set of assumptions concerning the likely nature of the feeder-link plan to be adopted at RARC '83 was outlined. The mechanisms and impact of sharing, consistent with these assumptions, was then presented.

6.2 Suggestions For Further Work

In the body of the report, several suggestions were made of areas where further investigation, beyond the scope of this study, appears warranted. These areas are listed below, together with the section of the report in which they were discussed:

- Steerable satellite receive spotbeam for northern coverage (Section 2.2.2)
- Power-handling and cooling problems in feeder-link earth station combining networks (Section 3.2)
- The feasibility of elliptical aperture antennas for transportable terminals
- Rain climate zone boundaries as outlined in the CPM (Section 4.1.4)
- Dependence of attenuation on latitude in the CPM model (Section 4.1.4)
- Diversity improvement obtained when the diversity stations are not identical (Section 4.2.2)
- Investigation of the maximum AGC limit for Canadian propagation conditions (Section 4.2.3)
- Satellite temperature variations during eclipses (Section 4.3.1)
- Effects of snow on BSS receive earth stations (Section 4.5)
- Effect on coordination distance when interfered with system employs diversity (Section 5.1)

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