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Orbit Frequency Utilization Simulation	DOCUMENT # 0710-50-TR-101	ISSUE # 1
SIMULATION AND ANALYSIS OF TYPICAL INTERFERENCE PROBLEMS		

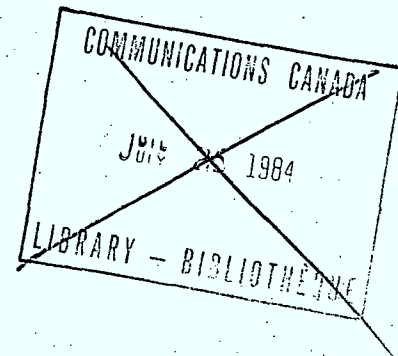
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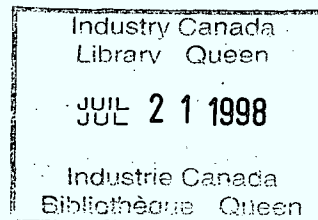
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PREFACE

This report documents analytical services using the Orbit Frequency Utilization Simulation performed by SED Systems Ltd., under Supply and Services Contract OST5-0004 with the Department of Communications.

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1.0 INTRODUCTION

This report documents the results of a series of simulation runs made using the Orbit Frequency Utilization Simulation, (References 1 to 4), to gain confidence in the predictive accuracy of the simulation before it is implemented for routine use in analytical studies.

Ideally, it would be desirable to compare the simulation results with actual measurements. However, this was not possible for two reasons:

- . present systems margins are such that interference is not a serious problem.
- . measurement of interference on existing systems is costly and difficult.

As a result, a carefully designed set of problems were drawn up to exercise the simulation models and algorithms. These problems are typical of those the simulation was designed to analyse. In most cases the behavior of these systems could be checked independently using "hand calculations", measured data, system designs on which the source data for the problem was obtained, or the results of independent studies.

This report describes each simulation task, the parameters characterizing the systems involved, the results of the simulation runs, and the suitability and limitations of the simulation for that task.

2.0 SUMMARY

The simulation has been used to analyse the following problems:

- . Flux grids of ANIK and CTS satellites.
- . Homogenous system of satellites with overlapping coverage zones.
- . Homogenous system of satellites with non-overlapping coverage zones.
- . 4-6 GHz communications link for a satellite system similar to the ANIK system.
- . 12-15 GHz communications link for a multi-beam SHF satellite system. Various propagation phenomena were considered in this analysis.
- . Precipitation Scatter interference calculations from 4 to 18 GHz for several interference configurations.
- . Interference between two direct broadcasting-satellite systems using the 12/14 GHz bands.
- . Interference between a direct broadcasting-satellite system and a fixed-satellite system including both heavy-route and thin-route carriers.

The results of these simulation runs are presented herein and indicate that the simulation is suitable for the analysis of problems of this type.

3.0 FLUX GRID CALCULATIONS.

3.1 · Introduction

The Orbit Frequency Utilization Simulation has been used to calculate the flux density, at the earth's surface, due to a single geosynchronous satellite. Two cases have been analysed as part of this task. The first consisted of a satellite located over central Canada with parameters similar to an ANIK satellite. The second case consisted of a satellite located over western Canada with parameters similar to the CTS satellite. In each case, the only propagation loss considered was clear weather tropospheric absorption. A detailed description of all of the parameters of each system together with the results of the simulation runs are presented in the remainder of this chapter.

3.2 4 GHz ANIK Flux Grid

3.2.1 Description of Satellite Model Parameters

The satellite location and antenna beam orientation used in the simulation runs is illustrated in Figure 1. The transmitting antenna beam has been approximated by a beam of elliptical cross section. The parameters used in the simulation runs are described below:

. Satellite location : longitude = 105° W
 latitude = 0° N

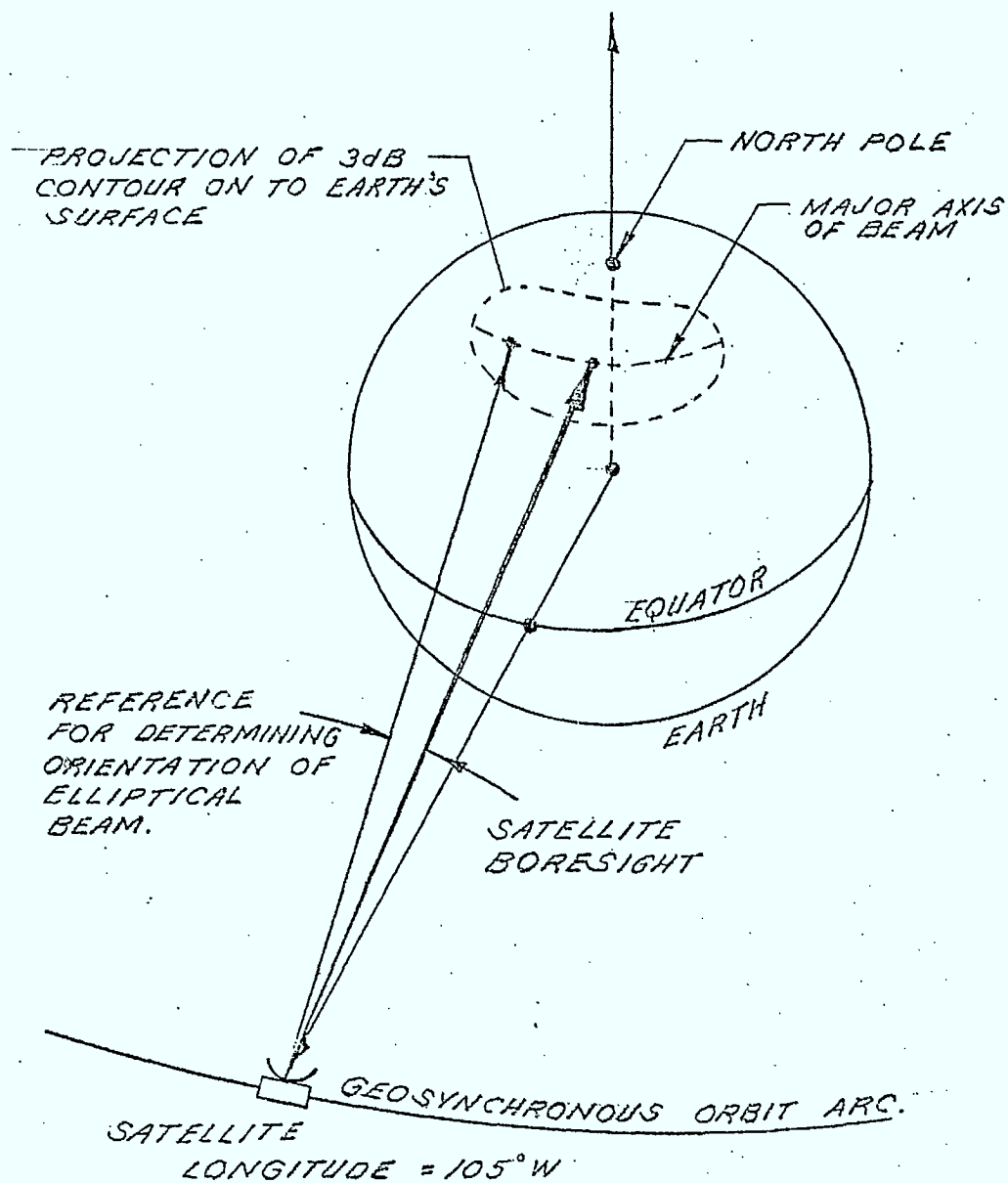


FIG: 1

ANIK-TYPE SATELLITE CONFIGURATION
FOR FLUX GRID CALCULATIONS

- Transmitting antenna parameters

- . Boresight target: longitude = 97.0° W
latitude = 56.0° N
- . Reference vector target
location on major axis
of beam : longitude = 105.0° W
latitude = 57.0° N
- . Polarization : Vertical
- . On-axis gain = 28.40 dB
- . Major-axis 3-dB beamwidth = 8°
- . Minor-axis 3-dB beamwidth = 4°

- Carrier Parameters

- . Type : FM/TV
- . Frequency = 4.0 GHz
- . Peak-to-peak frequency deviation = 16.0 MHz
- . Output power = 5.64 watts (determined from
the condition that the E.I.R.P. = 36 dBW).
- . RF bandwidth = 40 MHz

In addition to these parameters, simulation-provided default values were used where required.

3.2.2 Results of the Simulation Runs

The flux density at 80 sites on the earth's surface was calculated for this satellite, over a 40 MHz band centered at 4 GHz. The 'SITE' calculation was used to perform these calculations. It was found that for this carrier, 50 step spectral resolution was sufficient to accurately determine the integrated flux density across the 40 MHz simulation bandwidth. For all of the simulation runs, the C.C.I.R. satellite antenna model was used. The results of these calculations are listed in Table 1.

TABLE 1 FLUX AT EARTH'S SURFACE OVER 40 MHz
BANDWIDTH

LATITUDE (N) (degrees)	LONGITUDE (W of G) (degrees)	CTS. (12 GHz) (DBW/M ²)	ANIK (4 GHz) DBW/M ²
90	90	NV *	NV
85	90	NV	NV
80	90	-115.41	-129.16
75	90	-110.86	-128.12
70	90	-108.65	-127.71
65	90	-107.00	-127.37
60	90	-105.92	-127.10
55	90	-105.61	-126.97
50	90	-106.36	-127.09
45	90	-108.47	-127.58
40	90	-112.31	-128.59
35	90	-118.19	-130.28
30	90	-124.71	-132.79
25	90	-124.64	-136.26
20	90	-124.59	-140.79
15	90	-124.54	-146.37
10	90	-124.31	-146.33
5	90	-124.16	-146.32
0	90	-124.61	-146.31
-5	90	-125.61	-146.32
-10	90	-126.52	-146.34
-20	90	-128.11	-146.10
-30	90	-129.43	-146.05
-40	90	-130.52	-146.94
-50	90	-131.43	-147.82
-60	90	-132.17	-148.53
-70	90	-132.87	-149.12
-80	90	-136.07	-150.44
-90	90	NV	NV

* NV = Not Visible

TABLE 1 (Continued)

LATITUDE	LONGITUDE	CTS	ANIK
0	0	NV	NV
0	+180	-130.18	-147.70
0	+270	NV	NV
-40	180	-132.54	-148.31
-50	0	NV	NV
50	10	NV	NV
50	20	NV	NV
50	30	NV	-133.48
50	40	-128.86	-131.82
50	50	-125.95	-130.74
50	60	-125.44	-129.64
50	70	-118.11	-128.57
50	80	-111.25	-127.67
50	90	-106.35	-127.09
50	100	-105.01	-126.91
50	110	-108.38	-127.21
50	120	-116.92	-127.96
50	+130	-124.99	-129.10
50	+140	-125.06	-130.49
50	+150	-125.16	-131.98
50	+160	-125.13	-133.42
50	+170	-125.22	-134.74
50	+180	-125.49	-136.56
50	+190	-126.81	NV
60	60	-113.47	-128.42
60	70	-110.08	-127.84
60	80	-107.28	-127.38
60	90	-105.91	-127.10
60	100	-106.77	-127.05
60	110	-110.39	-127.27
60	120	-116.96	-127.74
60	130	-125.25	-128.43
70	60	-109.23	-128.29
70	70	-108.19	-127.99

TABLE 1 (Continued)

LATITUDE	LONGITUDE	CTS	ANIK
70	80	-107.96	-127.79
70	90	-108.65	-127.70
70	100	-110.48	-127.73
70	110	-113.61	-127.87
70	120	-118.03	-128.13
70	130	-123.65	-128.48
70	140	-125.71	-128.92
55	110	-109.08	-127.13
55	70	-113.29	-128.05
55	100	-105.49	-126.87
55	80	-108.59	-127.39
45	100	-105.69	-127.32
45	80	-115.49	-128.35
45	120	-118.11	-128.57
65	150	-125.58	-129.67
35	85	-123.47	-130.77
35	120	-124.64	-131.50

3.3 12 GHz CTS Flux Grid

3.3.1 Description of Satellite Model Parameters

The CTS satellite antenna beam has been approximated by a beam of circular cross section. The parameters used in the simulation runs to describe the satellite location, beam orientation and RF carrier properties are listed below:

- Satellite location : Longitude = 116.0° W
Latitude = 0.0° N
- Transmitting Antenna Parameters
 - . Boresight target : Longitude = 97.0° W
Latitude = 56.0° N
 - . Polarization : Horizontal
 - . On-axis gain = 36.3 dB
- Carrier Parameters
 - . Type : FM/TV
 - . Frequency = 12.0 GHz
 - . Peak-to-peak frequency deviation = 16.0 MHz
 - . Output power = 147.0 watts
(chosen so that the E.I.R.P. = 58 dBW)
 - . RF bandwidth = 40.0 MHz

In addition to these parameters, the simulation default values were used for other, non-critical parameters.

3.3.2 Results of Simulation Runs

The flux density at the earth's surface was calculated by the simulation, at each of the 80 sites used in the previous flux grid. In this case, however, the calculations were performed over a 40 MHz band centered at 12 GHz. Again,

50 step spectral resolution was used for the 'SITE' calculations. For these simulation runs, the C.C.I.R. antenna model was used. The results of these calculations are summarized in Table 1.

3.4 Evaluation of Simulation Results

The results of these simulation runs indicate that the geometric routines function correctly, even for sites at the north and south poles and at other sites not visible to the satellite. The visibility test for earth-space paths correctly stops SITE calculations from proceeding with flux calculations at points that are not visible to the satellite.

The antenna pointing algorithms for both circular and elliptical beams also function correctly. It was found that for both cases run, the flux increased slightly when moving south towards the equator (longitude = 90° W). This misleading behavior results from use of the C.C.I.R. spacecraft antenna model because a region of constant gain exists for off-axis angles near the first sidelobe (see Figure 3.2/3 of Volume 1). Since the antenna gain is constant and the distance to the satellite is decreasing the flux increases slightly. The same effect would occur if the RICE antenna model had been used since it also contains a region of constant gain near the first sidelobe.

The propagation model for tropospheric attenuation, the only propagation model used in these runs, was only important for very low elevation angles. These were only encountered at a few northern sites. As expected, the predicted attenuation was higher at 12 GHz than at 4 GHz although for most mid-Canada sites the attenuation never exceeded a few tenths of a decibel.

The other simulation models did not affect the results of these simulation runs. It should be noted also that any of the spectrum models could have been used for the flux grid calculation. The FM/TV spectrum was chosen since it requires the minimum computation time of all of the spectrum models in the simulation.

The results of these simulation runs indicate that when C.C.I.R. antenna patterns are used in flux density calculations, the flux densities should be interpreted as an upper bound on the received flux.

4.0 HOMOGENOUS SYSTEM OF SATELLITES WITH OVERLAPPING COVERAGE ZONES

4.1 Introduction

The simulation has been used to calculate the interference-to-carrier ratio at a mid-Canada earth station resulting from a set of uniformly spaced geosynchronous satellites each of which has its transmitting antenna directed at the earth station. The situation is illustrated in Figure 2. The calculations for this task have been performed at 4 GHz. As a result, the satellite beams were modelled such that the on-axis gain was comparable to an ANIK satellite. For the simulation runs, fifteen identical satellites were considered at inter-satellite spacings of 1°, 3° and 5 degrees. Several earth station antenna diameters were used in the calculations.

The results of these simulation runs, together with those of a simple model described in Reference 5, are presented in the remainder of this chapter.

4.2 Satellite and Earth Station Parameters

The satellites have been numbered sequentially from 1 to 15 for identification purposes. The locations of all of the satellites for inter-satellite spacings of 1, 3 and 5 degrees are given in Table 2. In all cases, satellite #8 was located at the same longitude. The parameters used in the simulation to describe each of the satellites follow:

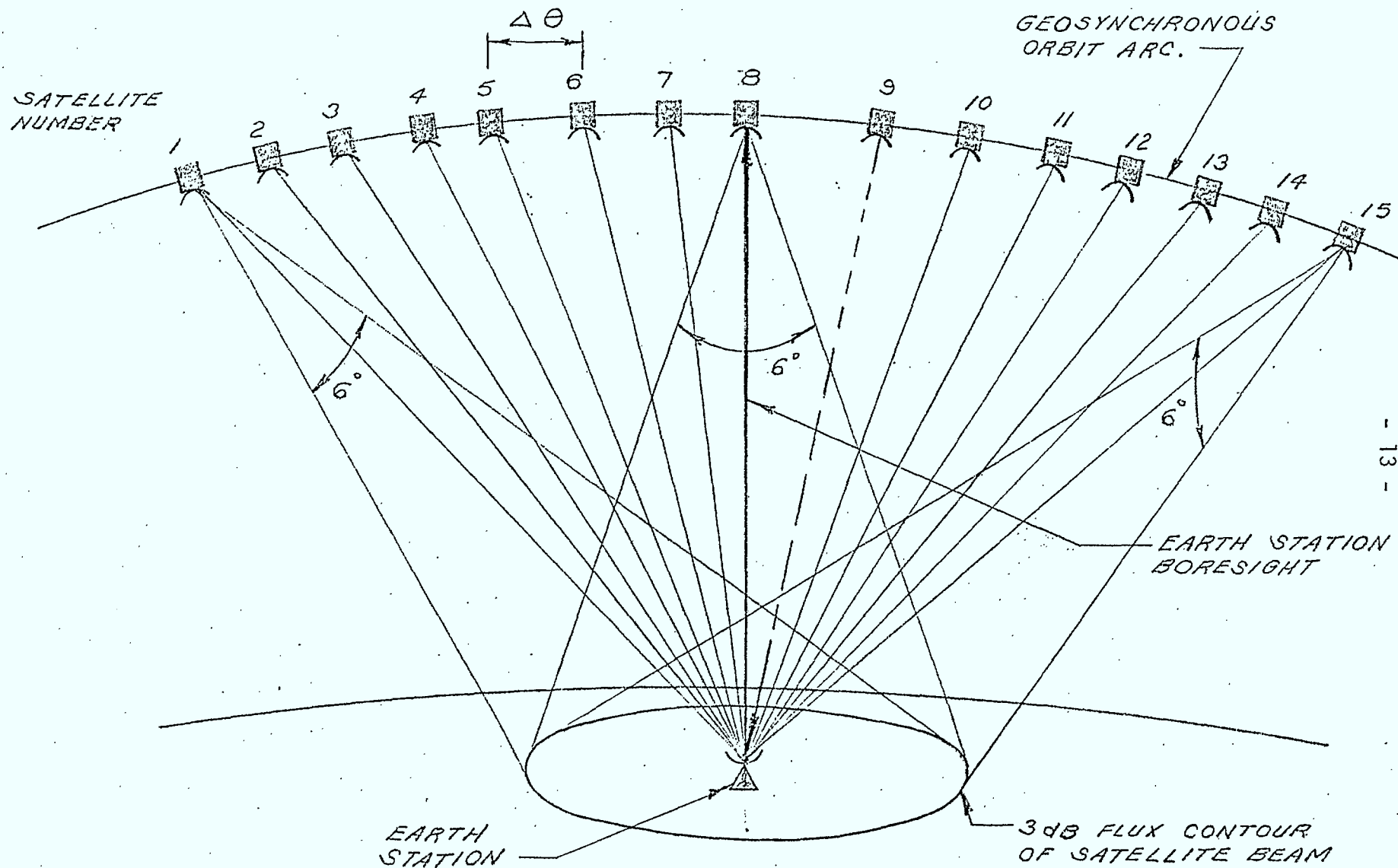


FIG. 2 HOMOGENOUS SYSTEM OF SATELLITES WITH OVERLAPPING COVERAGE ZONES

TABLE 2. Satellite Locations for various inter-satellite spacings

Satellite Number	Longitude W of G (degrees)		
	1 degree spacing	3 degree spacing	5 degree spacing
1	98	84	70
2	99	87	75
3	100	90	80
4	101	93	85
5	102	96	90
6	103	99	95
7	104	102	100
8	105	105	105
9	106	108	110
10	107	111	115
11	108	114	120
12	109	117	125
13	110	120	130
14	111	123	135
15	112	126	140

- Transmitting Antenna Parameters

- . Boresight target : Longitude = 100° W
Latitude = 52° N
- . 3-dB beamwidth = 6.0 degrees
- . Polarization : Vertical

- Carrier Parameters

- . Type : FM/TV
- . Frequency = 4.0 GHz
- . Peak-to-peak frequency deviation = 16.0 MHz
- . Output power = 1.0 watt

The receiving site was located at the satellite's boresight target position.

The receiving antenna diameters used in the calculations were:

- . 98 ft. (29.87 m) - comparable to a TELESAT heavy route antenna.
- . 32.8 ft. (10.0 m) - comparable to the TV earth station antennae used by TELESAT.
- . 12 ft. (3.66 m) - comparable to the thin route transportable antennae used by TELESAT.

The receiving antennae were vertically polarized and aligned with the transmitting beam on satellite #8.

4.3. Results of Simulation Runs

The simulation was used to calculate the power received from each of the fifteen satellites over a 40 MHz band centered at 4 GHz for the three receiving antenna diameters and satellite spacings. Only tropospheric losses were included.

The C.C.I.R. antenna models were used for both the satellites and earth station antennae. For the 98 ft. receiving antenna, the C.C.I.R. antenna model for $D/\lambda > 175$ was used. For the 32 ft. receiving antenna, the C.C.I.R. antenna model for $100 < D/\lambda < 175$ was used, while the C.C.I.R. antenna model for $D/\lambda < 100$ was used for the 12 ft. diameter antenna. The results of these simulation runs are summarized in Table 3.

If the RF carrier on satellite #8 is designated the "wanted" carrier, and the remaining fourteen satellites are considered as interferors, then it is possible to calculate the carrier-to-interference ratio (C/I) for each spacing/diameter combination. These ratios, given in Table 3, are also plotted in Figure 3.

4.4 Evaluation of Simulation Results

The results of the simulation can be compared with those of a simple model for the homogenous system developed in Reference 5. The basic assumptions of the model are:

- . the C.C.I.R. sidelobe equation, $32-35 \log \theta$, applies for the earth station beam
- . the satellites are equally spaced at separations of $\Delta\theta$.
- . the distance from the earth station to any of the interfering satellites is the same as to the wanted satellite.
- . an infinite number of interfering satellites are present and can be "seen" by the earth station.

Satellite Number	One Degree Spacing			3 Degree Spacing			5 Degree Spacing		
	RX Diameter			RX Diameter			RX Diameter		
	12'	32'	98'	12'	32'	98'	12'	32'	98'
1	155.3	158.4	158.4	167.3	170.4	170.4	172.9	176.0	176.0
2	153.6	156.7	156.7	165.6	168.7	168.7	171.2	174.3	174.3
3	151.6	154.8	154.8	163.6	166.7	166.7	169.2	172.3	172.3
4	149.2	152.4	152.4	161.2	164.3	164.3	166.7	169.8	169.8
5	146.1	149.2	149.2	158.0	161.1	161.2	153.6	166.7	166.7
6	142.2	144.8	144.8	153.6	156.7	156.7	159.2	162.3	162.3
7	136.4	137.3	137.3	146.1	149.2	149.2	151.7	154.7	154.7
8	127.3	118.6	109.1	127.3	118.6	109.1	127.3	118.6	109.1
9	136.4	137.3	137.3	146.1	149.3	149.2	151.7	154.7	154.7
10	142.2	144.8	144.8	153.6	156.7	156.7	159.2	162.3	162.3
11	146.1	149.2	149.2	158.0	161.2	161.2	163.6	166.7	166.7
12	149.2	152.3	152.3	161.1	164.3	164.3	166.8	169.9	169.9
13	151.6	154.8	154.8	163.6	166.7	166.7	169.2	172.3	172.3
14	153.6	156.7	156.7	165.6	168.7	168.7	171.2	174.3	174.3
15	155.3	158.4	158.4	167.3	170.4	170.4	172.9	176.0	176.0
Sum of Interference Power (-dBW)	131.7	133.1	133.1	141.9	145.0	145.0	147.5	147.9	147.9
$\left(\frac{C}{I}\right)$ (dB)	4.4	14.5	24.1	14.6	26.5	36.0	20.2	29.3	38.8

TABLE 3 SUMMARY OF RECEIVED POWER FOR EACH SATELLITE

(NOTE: Table entries for each satellite are -dBW)

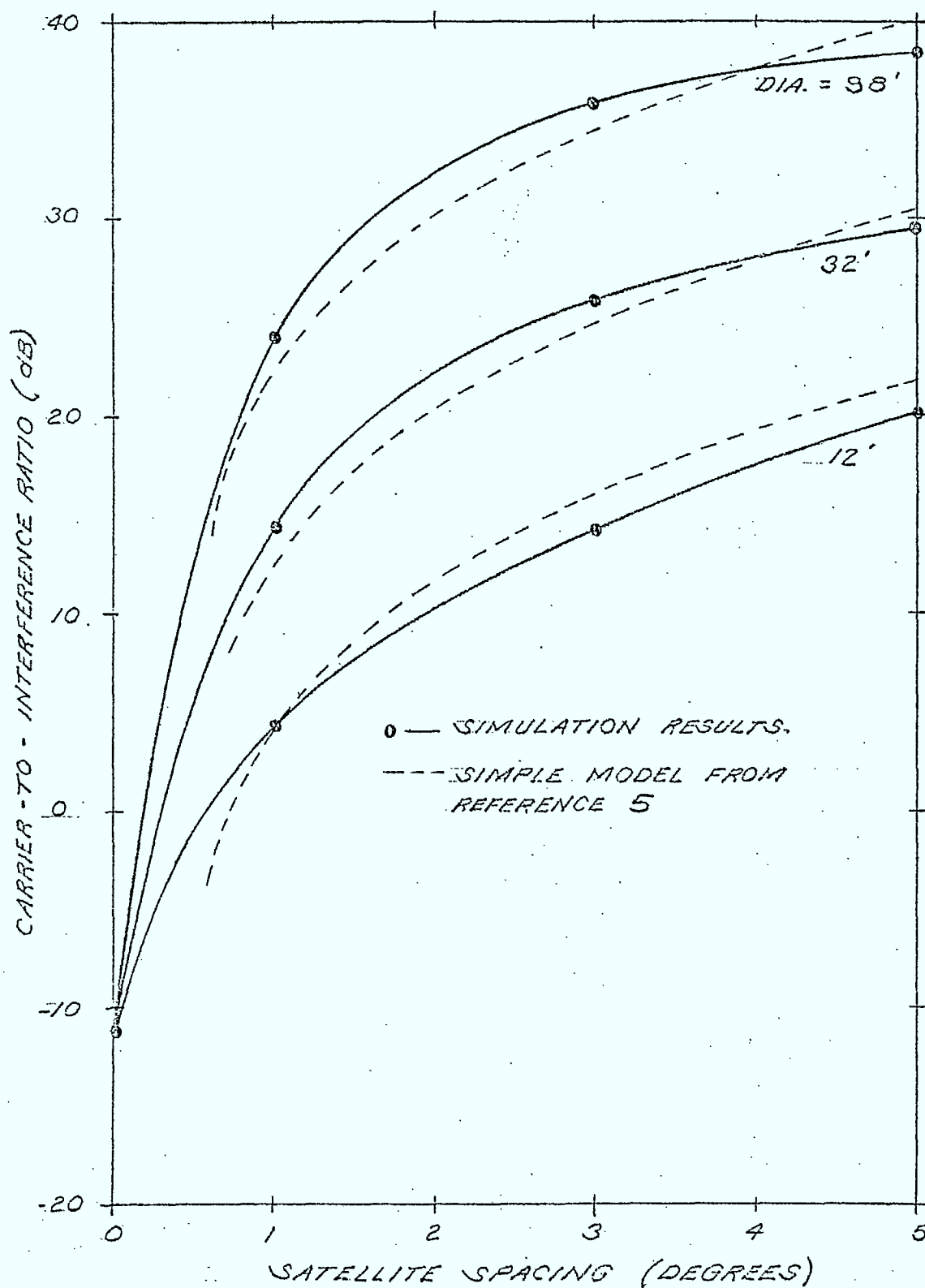


FIG. 3 C/I FOR 4Ghz HOMOGENOUS SYSTEM FOR SEVERAL RECEIVING EARTH STATION ANTENNA DIAMETERS.

From these assumptions it can be shown that the wanted carrier power is proportional to $\eta/(\pi D/\lambda)^2 G_{SAT}$ where D is the receiving antenna diameter, η is the aperture efficiency, (0.5), and G_{SAT} is the on-axis gain of the satellite antennae. The interference power is proportional to

$$I \propto 2 \sum_{i=1}^{\infty} G_{SAT} \frac{1585}{(i \Delta\theta)^{2.5}}$$

$$= \frac{G_{SAT} 3170}{(\Delta\theta)^{2.5}} \left\{ \sum_{i=1}^{\infty} i^{-2.5} \right\}$$

The summation term is equal to 1.34, resulting in

$$\left(\frac{C}{I} \right) = \frac{(\Delta\theta)^{2.5} \left(\frac{D}{\lambda} \right)^2}{860}$$

This equation has been plotted in Figure 3 for comparison with the simulation results. It can be seen that the trends predicted by the simulation and the simple model are similar. The differences can be explained as follows:

- . The simulation results include the effects of only fifteen satellites, not an infinite number.

- . the antenna pattern used in Reference 1 does not contain the breakpoint, beyond which the gain is at most - 10 dB, and hence unlike the simulation, for large satellite spacings it predicts C/I ratios that are too high.
- . For small receiving antennae, the simulation uses a different sidelobe equation than that used in Reference 1. (i.e., the C.C.I.R. pattern for $D/\lambda < 100$).
- . For small satellite spacings the simple model predicts C/I ratios that are much too low. This occurs since a sidelobe equation is used to describe the main beam gain. This problem does not occur in the simulation results.

It should be noted that use of the C.C.I.R. antenna model in the simulation calculations results in the same interference power for the 98 and 32 ft. diameter antennae for each satellite spacing, since the receiving antenna uses the same sidelobe equation. The change in the C/I ratio for these two antennae diameters, results from a change in the on-axis gain of the receiving antenna.

As a result of these simulation runs, the models used in the simulation can be evaluated for their suitability for this and other analyses of this type:

- . Geometric routines - adequate.
- . Antenna Model - subject to the limitations of the C.C.I.R. models as being representative of real antennae, upper bounds on the interference power can be determined. The model should not be used in a sensitivity analysis as misleading trends may be obtained (i.e. as noted above for changing antenna diameters).

- . Spectrum models - any of the RF spectrum models are adequate for this type of analysis since the shape of the spectrum does not affect the results. The FM/TV spectrum was used since it requires the least computer time at the resolution used.
- . High Power amplifier - adequate for this type of analysis.
- . Other simulation models - although they are used in the calculations, the propagation and antenna depolarization models do not affect the results of this analysis by more than a fraction of a decibel. At higher frequencies the tropospheric attenuation model will become a more important parameter in an analysis of this type.
- . Program outputs - sufficient output generated. No need for spectrum plots.

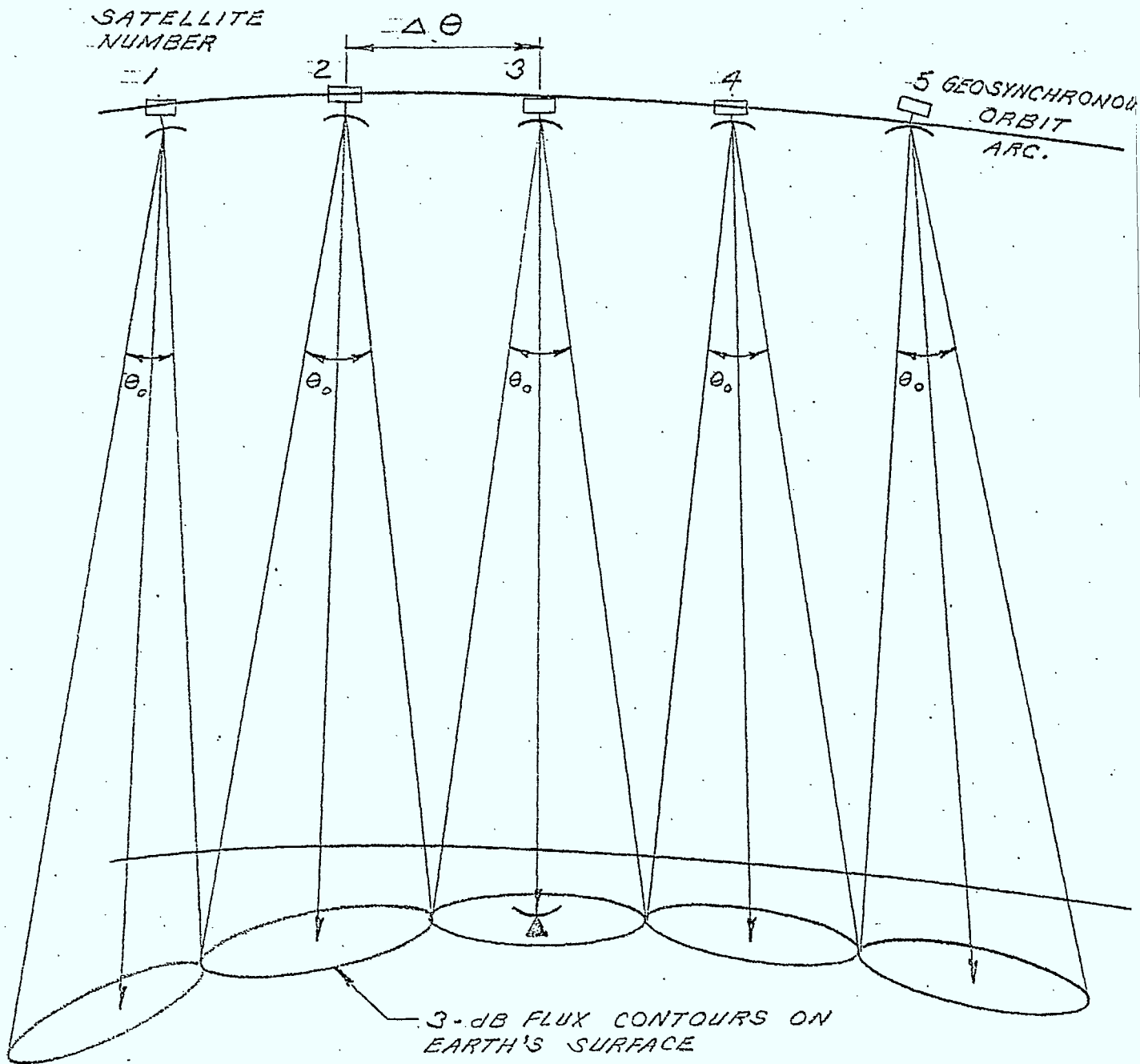
5.0 HOMOGENOUS SYSTEM OF SATELLITES WITH NON-OVERLAPPING COVERAGE ZONES

5.1 Introduction

The simulation has been used to calculate the carrier-to-interference ratio at a mid-Canada earth station resulting from a set of five identical, uniformly spaced geosynchronous satellites, each of which has its beam directed to an adjacent coverage zone. The situation is illustrated in Figure 4. The earth station has its antenna directed at the center satellite. The calculations were performed at 12 GHz for several satellite spacing and for several satellite antenna polarization plans. A simple model, developed for comparison against the simulation results, is also presented in this chapter.

5.2 Satellite and Earth Station Parameters

The satellites have been numbered sequentially from 1 to 5, with satellite #3 being the source of the wanted signal. Five satellites were chosen for this analysis task since five antenna beams of 1.5 degree beamwidth can fit across Canada in a manner similar to the multi-beam satellite system proposed in Reference 6. The satellite locations and boresight target locations used in the simulation runs are listed in Table 4. It should be noted that the satellite containing the wanted-carrier (Satellite #3) is located due south of the receiving earth station for the three inter-satellite spacings. The zero degree spacing results in a configuration equivalent to a single multi-beam satellite.



$\Delta\theta$ = SATELLITE SPACING

θ_0 = 3-dB BEAMWIDTH OF SATELLITE BEAM.

FIG. 4 HOMOGENOUS SYSTEM OF SATELLITES WITH NON-OVERLAPPING COVERAGE ZONES.

Satellite #	Boresight Target		Satellite Longitude (W of G)		
	Latitude (Degrees)	Longitude, (W of G) (Degrees)	Satellite Spacing (Degrees)		
			0	5	10
1	55.0	125.0	93.0	103.0	113.0
2	55.0	108.0	93.0	98.0	103.0
3	55.0	93.0	93.0	93.0	93.0
4	55.0	78.0	93.0	88.0	83.0
5	55.0	61.0	93.0	83.0	73.0

TABLE 4 : Boresight Pointing and Satellite Locations

The following parameters were used in the simulation runs to describe each satellite:

- Transmitting Antenna Parameters
 - . 3-dB beamwidth = 1.5 degrees. (Results in an on-axis gain of 40 dB)
 - . Linear polarization
 - . Main-beam depolarization ratio = -30 dB
 - . Near-sidelobe depolarization ratio = -15 dB
 - . Backlobe depolarization ratio = 0 dB
 - (Note: these are the simulation default values)
- Carrier Parameters:
 - . Type : FM/TV
 - . Frequency = 12 GHz
 - . Peak-to-peak frequency deviation = 16.0 MHz
 - . Output power = 1.0 watt

The receiving site was located at the boresight target of satellite #3 (longitude = 93° W, latitude = 55° N). The receiving antenna was 2 meters in diameter, (at 12 GHz, on-axis gain = 45.3 dB) and pointed to satellite #3. Its polarizer was aligned with the satellite antenna polarizer for maximum received power. The depolarization ratios of the receiving antenna were assumed to be the same as those of the satellite antennae.

5.3 Results of the Simulation Runs

The simulation was used to calculate the power received from each of the five satellites over a 40 MHz band centered at 12 GHz for three inter-satellite spacings and two polarization plans. For the first polarization plan all of the satellite antennae had the same polarization while for the second plan, the satellites adjacent to satellite #3 had the opposite polarization. The received power from each satellite for the various spacing/polarization

combinations is listed in Table 5. The sum of the interference power received from satellites 1, 2, 4 and 5, together with the carrier-to-interference ratios are listed in Table 5. The C/I ratios are also plotted in Figure 5, as a function of inter-satellite spacing.

5.4 Evaluation of Simulation Results

The results of these simulation results can be compared against a very simple model presented in Reference 7. The model is based on following assumptions:

- . interference from all but the two closest satellites is negligible. (This is only valid for the co-polarized satellite antenna plan).
- . the C.C.I.R. antenna pattern, $32-25 \log \theta$, applies to both the satellite and earth station sidelobes.

From these assumptions it can be shown that the carrier-to-interference ratio is given by

$$\left(\frac{C}{I}\right)_{\text{copolar}} = \frac{G_{\theta E} G_{\theta S}}{2 \left(\frac{1585}{(\Delta\theta)^{2.5}} \right) \left(\frac{1585}{\theta_o^{2.5}} \right)}$$

Satellite Number	Zero Degree Spacing				5 Degree Spacing				10 Degree Spacing			
	Pol	Power	Pol	Power	Pol	Power	Pol	Power	Pol	Power	Pol	Power
1	H	-140.9	H	-140.9	V	-179.1	V	-179.1	V	-186.6	V	-186.6
2	H	-130.9	V	-150.1	V	-161.8	H	-167.8	V	-169.3	H	-173.4
3	H	-120.7	H	-120.6	V	-120.6	V	-120.6	V	-120.6	V	-120.6
4	H	-130.9	V	-150.1	V	-161.8	H	-167.8	V	-169.3	H	-173.4
5	H	-140.9	H	-140.9	V	-179.1	V	-179.1	V	-186.6	V	-186.6
Total Interference (dBW)	-127.8		-137.4		-158.7		-168.5		-166.3		-170.1	
C/I (dB)	7.2		16.8		38.1		43.8		45.6		49.5	

TABLE 5 Received Power for Various Spacing/Polarization Combinations (NOTE: All powers in dBW)

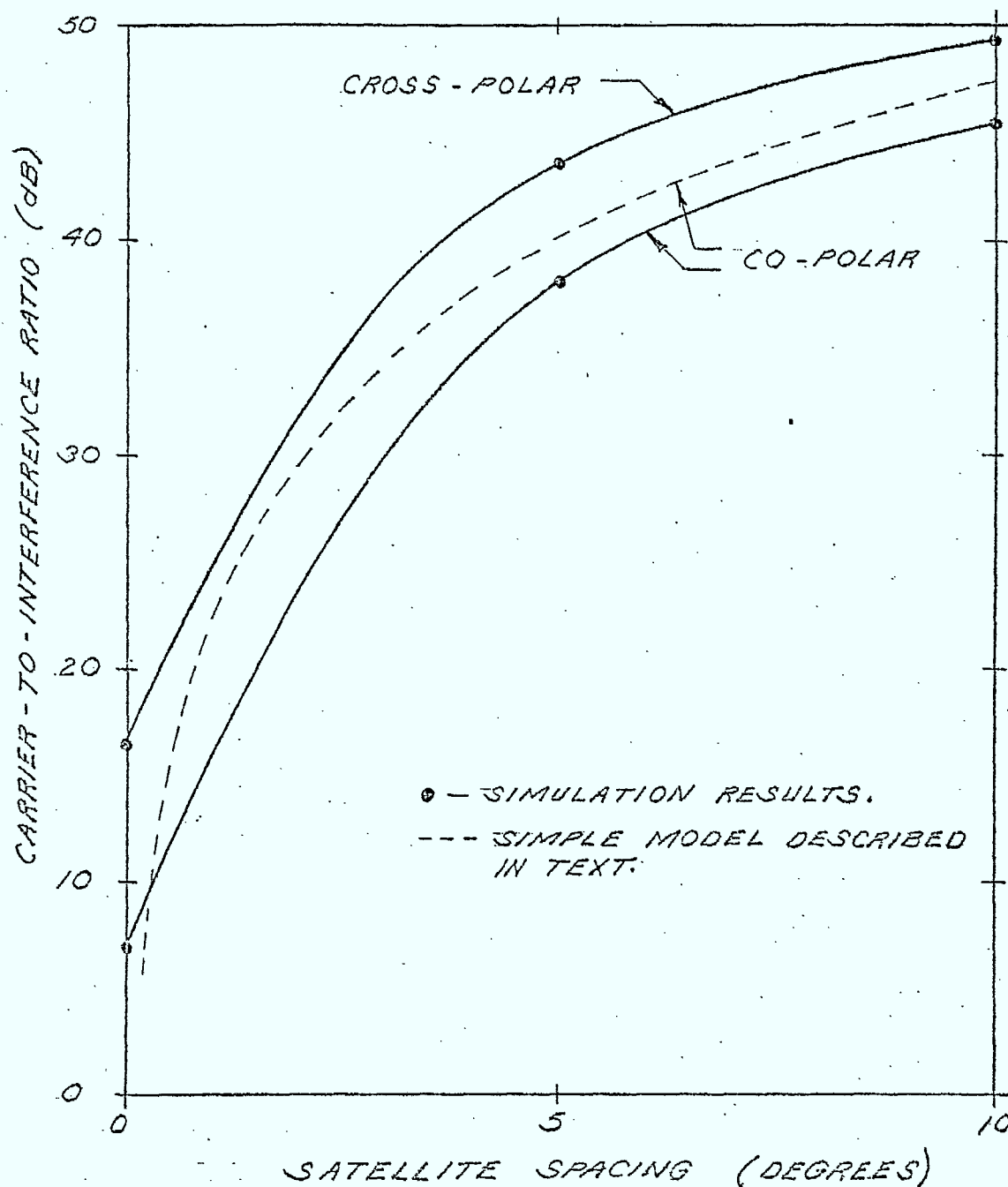


FIG. 5 $\left(\frac{C}{I}\right)$ FOR 12 GHz HOMOGENOUS SYSTEM
FOR CO AND CROSS-POLARIZATION PLANS

where G_{OE} is the on-axis gain of the receiving antenna

G_{OS} is the on-axis gain of the satellite antennae

$\Delta\theta$ is the inter-satellite spacing (degrees)

θ_0 is the 3-dB beamwidth of the satellite antennae.

Substituting the appropriate values for the gains and beamwidth gives:

$$\left(\frac{C}{I}\right)_{\text{copolar}} = 187.6 (\Delta\theta)^{2.5}$$

This equation has been plotted in Figure 5 for comparison with the copolar curve derived from the simulation runs.

It can be seen that for separation angles greater than 5° , the simple model predicts C/I ratios several decibels too high since it neglects the other interferors. For small separation angles the simple model breaks down since the sidelobe equation used in its derivation does not apply. This problem is not encountered in the simulation results however.

The improvement in the C/I ratio predicted by the simulation for cross-polarized adjacent satellites cannot be directly compared to published results since comparable calculations and models could not be found in the literature. However, in comparison with the results for copolarized satellites, the trends predicted by the simulation are realistic. For example, at all satellite spacings, the C/I ratios are higher for the cross-polarized arrangement. Due to the decrease in polarization discrimination achievable in the antenna

sidelobes, the advantage decreases with increasing satellite separation angle. For the zero degree spacing arrangement, the increase in C/I ratio that results from alternating the polarization of adjacent beams is approximately 9.6 dB, even though the mainbeam depolarization ratio of both the receiving and transmitting antennae is -30 dB.

The polarization mismatch angle between the incident electric field and the receiver polarizer is significant in determining the polarization mismatch factors for the outermost beams.

As a result of these simulation runs, the models used in the simulation can be evaluated for their suitability for this and other analyses of this type:

- . Geometric routines - adequate
- . Antenna Model - the C.C.I.R. principle polarization gain model did not produce any misleading results over the angular range used in this particular simulation run. As usual, caution should be used in interpreting the results.
- . Antenna depolarization model - the model produces correct trends. Although the program defaults were employed, similar trends would be expected for other antenna depolarization ratios. The polarization mismatch factor algorithm is adequate for this type of analysis.
- . Spectrum models - any of the RF spectrum models could have been used for this type of analysis.

- . High power amplifier model - adequate.
- . Propagation models - only the tropospheric absorption model was used by the simulation. Over the range of elevation angles and the frequency at which the calculations were performed, the model is adequate.
- . Program outputs - the detailed interference report package should be used to obtain detailed geometric parameters. No plots are required.

6.0 4-6 GHZ LINK CALCULATIONS

6.1 Introduction

In this chapter, the performance of communications links utilizing a geosynchronous satellite with parameters similar to the ANIK satellites are studied. Two links are considered in this analysis. The first is a west to east heavy-route FDM/FM telephony link and the second is a northern television link. In each case, the simulation has been used to determine the signal-to-noise ratios at the output of the link receiver for comparison against hand calculations.

The interference environment for these runs consisted of two ANIK-type satellites, one on each side of the satellite used for the link analysis. The situation is illustrated in Figure 6. The interference was assumed to be co-channel heavy route and television carriers.

6.2 Description of Parameters used in Simulation Runs

6.2.1 Heavy-Route Link

For this case a multi-channel telephone communications link between Lake Cowichan, B.C. and Allan Park, Ontario is analysed. The following parameters have been used in the simulation runs and hand calculations:

Lake Cowichan

- location: latitude = 49.76° N
 longitude = 124.06° N

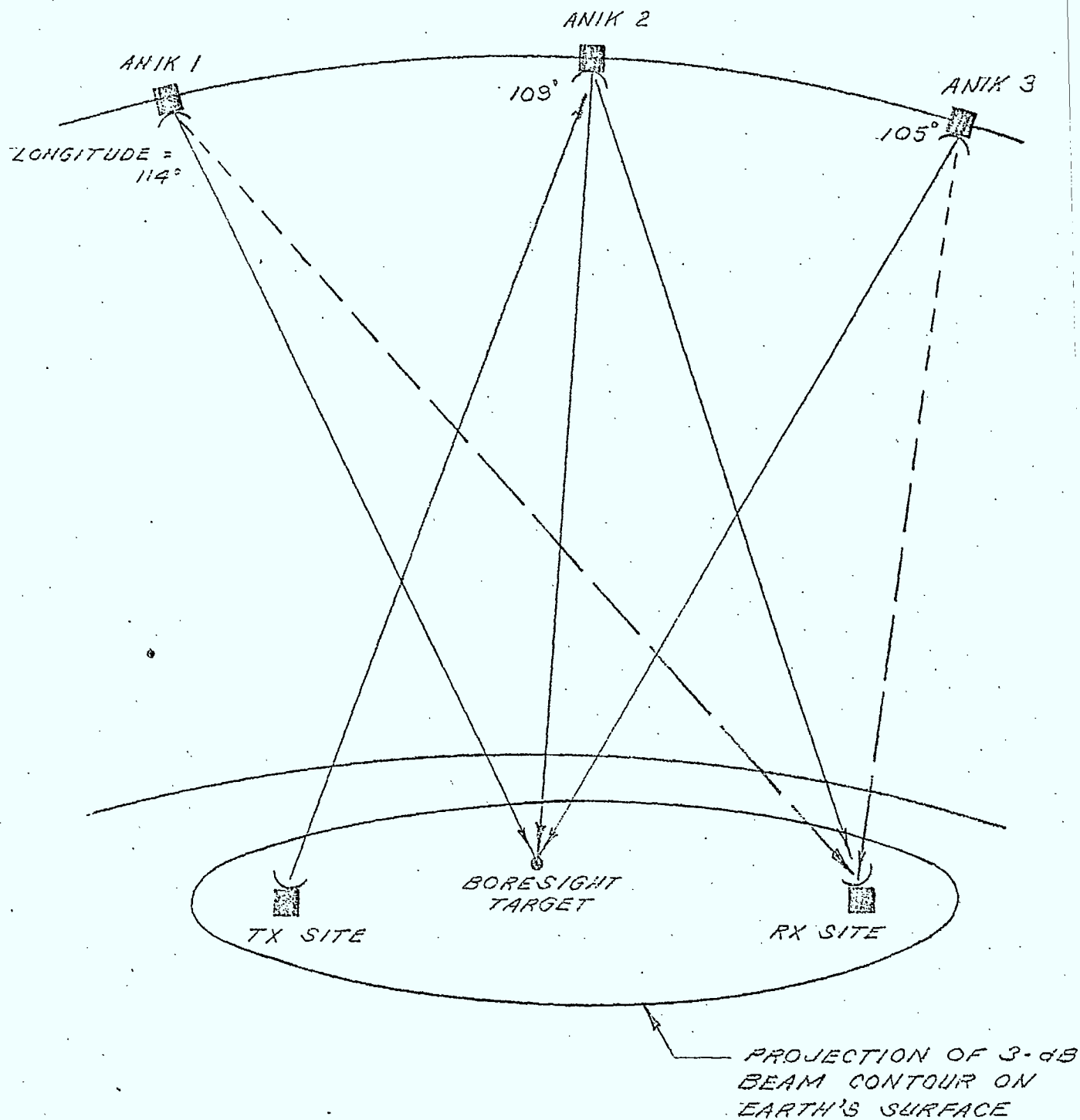


FIG. 6 4/6 GHz LINK CONFIGURATION

- TX Antenna Parameters

- . points at ANIK 2 with polarizer aligned with RX beam on ANIK 2
- . Diameter = 98 ft. (on axis gain = 63 dB at 6 GHz)
- . Vertical Polarization

- Carrier Parameters

- . Type: FDM/FM telephony
- . Carrier frequency = 6.0 GHz
- . 960 voice channels
- . lower baseband frequency = 0.06 MHz
- . upper baseband frequency = 4.028 MHz
- . RMS modulation index = 1.09
- . C.C.I.R. pre-emphasis used
- . RF bandwidth = 40.0 MHz
- . output power = 107 watts
(Note: gives up-link E.I.R.P. of 83 dBW)
- . nominal D/C ratio = -50 dB (default)

Allan Park

- location: latitude = 44.11° N
longitude = 80.0° W

- TX Antenna Parameters

- . Boresight target: longitude = 97.0° W
latitude = 56.0° N

- . Reference target on major axis of beam
 longitude = 105.0° W
 latitude = 56.0° N

- . Vertical polarization
- . On-axis gain = 28.49 dB
- . Major-axis 3dB beamwidth = 8.0°
- . Minor-axis 3dB beamwidth = 4.0°

- TX Carrier Parameters

- . carrier frequency = 4.0 GHz
- . output power = 3.56 watts
 (Note: gives E.I.R.P. = 34 dBW)
- . nominal (D/C) ratio = -28.0 dB

- RX Antenna Parameters

- . same beam pointing parameters as TX beam
- . Vertical polarization
- . On-axis = 28.49 dB
- . Major-axis beamwidth = 8.0°
- . Minor-axis beamwidth = 4.0°
 (Note: these last three values are based on
 the assumption that the RX beam is the same
 shape as the TX beam, even though the uplink
 and downlink frequencies are different).

- LNA Noise temperature = 3249.0° K
 (Derived from G/T = -7.0 dB and assuming an antenna
 noise temperature = 290° K)

6.2.2 Northern TV Link

The FM television link was set up between Allan Park and Inuvik, N.W.T., via ANIK 2. The following parameters have been used in the simulation runs:

ANIK 2

- all parameters same as those used in the heavy-route analysis, with the exception of the D/C ratio. For the N-S TV link, a value of -31 dB was used.

ALLAN PARK

- same location, antenna parameters as for heavy-route analysis.
- Carrier parameters
 - . Type: FM/TV, Canada/US System M, 525-line
 - . carrier frequency = 6.0 GHz
 - . peak-to-peak frequency deviation = 27.6 MHz
(chosen such that Carson Rule bandwidth = 36 MHz)
 - . output power = 107 watts

INUVIK

- location: latitude = 68° 21' 44" N
longitude = 133° 41' 45" W
- RX Antenna Parameters
 - . Vertical polarization. Points to ANIK 2 and is aligned with TX beam on ANIK 2.
 - . Diameter = 27 ft.
(gives on-axis gain = 48.5 dB at 4 Hz)

- LNA Noise Temperature = 100° K
(ie. $G/T = 28$ dB)

- RF Noise Bandwidth = 36 MHz

6.2.3 Description of Interfering Satellites

For both the heavy route FDM/FM link, and the FM/TV link, the interference arises only from the two satellites denoted ANIK 1 and ANIK 3. No uplink interference is present in either analysis. The parameters of the interfering satellites used in the analysis follow:

ANIK 1

- location: longitude = 114° W

- TX Antenna Parameters

 - . same as those of ANIK 2

- Carrier Parameters

 - . carrier frequency = 4.0 GHz

 - . Type: FM/TV

 - . peak-to-peak frequency deviation = 27.6 MHz

 - . output power = 3.56 watts

ANIK 3

- location: longitude = 104° W

- TX Antenna Parameters

- . same as those of ANIK 2

- Carrier Parameters

- . carrier frequency = 4.0 GHz
- . Type: FDM/FM
- . 960 voice channels
- . lower baseband frequency = 0.06 MHz
- . upper baseband frequency = 4.028 MHz
- . rms modulation index = 1.09
- . output power = 3.56 watts

6.3 Results of Simulation Runs

6.3.1 Heavy-Route Link

The performance of the FDM/FM link connecting Lake Cowichan, B.C. to Allan Park, Ontario has been evaluated using the simulation. For the calculation, C.C.I.R. antenna models were used. (Note: the choice of the sidelobe model is only of interest on the downlink interference calculation). The only propagation phenomenon included in the calculation was tropospheric absorption. To evaluate the RF spectra across the 36 MHz bandwidth, 500 step spectral resolution was used. For the FDM carriers, the rms modulation index was sufficiently low that the Fast Fourier Transform analysis was used by the simulation in evaluating the RF spectra (Note: the simulation used a 1024 point FFT). Some of the

reports generated by the simulation are shown in Figure 7. From these reports it can be seen that thermal noise and distortion are the most important effects in determining the performance of this communications link, as the downlink interference contributes only 2% of the total unwanted signal. It should be noted that the highest baseband channel is not affected as seriously by the interference as is the channel located at 3.168 MHz in the FDM baseband. In this case, there is approximately 40% more interference-induced noise in the worst channel than in the highest channel.

6.3.2 Northern TV Link

The quality of the received TV signal transmitted from Allan Park to Inuvik has been evaluated using the simulation. For this simulation run, the C.C.I.R. antenna patterns were used. Only clear weather tropospheric attenuation was included in the calculations. The results of this simulation run are shown in Figure 8. As with the FDM/FM link, thermal noise is the limiting factor in determining the performance of the system. From the LINK SUMMARY table in Figure 8, it can be seen that interference makes up only 7% of the total noise budget for the link.

It should be noted that the demodulated interference noise spectrum is approximately proportional to the square of the baseband frequency since the noise weighting/de-emphasis improvement factor differs by only .2 dB from that for thermal noise.

not directly applicable to OFUS Issue #2.

(Uplink)

HCP NUMBER 1 SUMMARY

ANTENNA PARAMETERS		TX BEAM	RX BEAM
POLARIZATION TYPE :	=	VERTICAL	VERTICAL
APERTURE EFFICIENCY	=	0.540	0.540
MAJOR-AXIS BEAMWIDTH (DEG)	=	0.1087	8.0000
MINOR-AXIS BEAMWIDTH (DEG)	=	0.1087	4.0000
ON-AXIS GAIN (DB)	=	62.798	28.490
BORESIGHT ELEVATION (DEG)	=	31.188	
BORESIGHT AZIMUTH (DEG)	=	160.658	
OFF-AXIS ANGLE (DEG)	=	0.0	2.719
PRINCIPAL POL GAIN (DB)	=	62.798	26.922

ATMOSPHERIC/GEOMETRIC FACTORS

SITE SEPARATION DISTANCE	=	38522.30 KM
FREE SPACE LOSS	=	-199.725 DB
TROPOSPHERIC ABSORPTION LOSS	=	-0.073 DB
TOTAL ATMOSPHERIC LOSS	=	-0.073 DB

CARRIER POWER SUMMARY

POWER INTO TX ANTENNA	=	20.294 DBW
E.I.R.P.	=	83.092 DBW
FLUX DENSITY AT RX SITE	=	-79.683 DBW/M**2
POWER AT RX ANTENNA TERMINALS	=	-89.784 DBW
POWER AT LNA	=	-89.784 DBW

RF NOISE SUMMARY

ANTENNA NOISE TEMPERATURE (DEGREES K)	=	290.000
LNA NOISE TEMPERATURE (DEGREES K)	=	3249.000
TOTAL THERMAL-TO-CARRIER RATIO AT LNA OUTPUT	=	-27.765 DB
TOTAL DISTORTION-TO-CARRIER RATIO AT LNA OUTPUT	=	-50.000 DB
TOTAL UNWANTED POWER-TO-CARRIER POWER RATIO	=	-27.739 DB

Fig. 7 Heavy Route FDM/FM Link Analysis

(Downlink)

HOP NUMBER 2 SUMMARY

ANTENNA PARAMETERS	TX BEAM	RX BEAM
POLARIZATION TYPE :	= VERTICAL	VERTICAL
APERTURE EFFICIENCY	= 0.540	0.540
MAJOR-AXIS BEAMWIDTH (DEG)	= 8.0000	0.1630
MINOR-AXIS BEAMWIDTH (DEG)	= 4.0000	0.1630
ON-AXIS GAIN (DB)	= 28.490	59.276
BORESIGHT ELEVATION (DEG)	=	31.507
BORESIGHT AZIMUTH (DEG)	=	218.533
OFF-AXIS ANGLE (DEG)	= 2.493	0.0
PRINCIPAL POL GAIN (DB)	= 26.640	59.276

ATMOSPHERIC/GEOMETRIC FACTORS

SITE SEPARATION DISTANCE	= 38494.40 KM
FREE SPACE LOSS	= -196.197 DB
TROPOSPHERIC ABSORPTION LOSS	= -0.065 DB
TOTAL ATMOSPHERIC LOSS	= -0.065 DB

CARRIER POWER SUMMARY

POWER INTO TX ANTENNA	= 5.514 DBW
E.I.R.P.	= 34.004 DBW
FLUX DENSITY AT RX SITE	= -130.605 DBW/M**2
POWER AT RX ANTENNA TERMINALS	= -104.830 DBW
POWER AT LNA	= -104.830 DBW

RF NOISE SUMMARY

ANTENNA NOISE TEMPERATURE (DEGREES K)	= 12.539
LNA NOISE TEMPERATURE (DEGREES K)	= 100.000
TOTAL THERMAL-TO-CARRIER RATIO AT LNA OUTPUT	= -24.720 DB
TOTAL DISTORTION-TO-CARRIER RATIO AT LNA OUTPUT	= -27.973 DB
NUMBER OF CONTRIBUTING INTERFERERS	= 2
TOTAL INTERFERENCE-TO-CARRIER RATIO AT LNA OUTPUT	= -41.337 DB
TOTAL UNWANTED POWER-TO-CARRIER POWER RATIO	= -22.974 DB

DEMODULATION CALCULATION SUMMARY

THRESHOLD LEVEL	= -6.343 DB : CARRIER ABOVE DEMODULATOR THRESHOLD
TOTAL NOISE ACROSS BASEBAND	= -23.461 DBW

(USE OF OFUS ISSUE #2 WILL RESULT IN ALTERED VALUES)

LINK SUMMARY

USE OF OFUS ISSUE #2

WILL RESULT IN ALTERED
VALUES.

TELEPHONY BASEBAND SIGNAL QUALITY SUMMARY

SIGNAL PROCESSING APPLIED AFTER DEMODULATOR :
CCIR DEEMPHASIS
CCIR NOISE WEIGHTING

	NOISE BEFORE PROCESSING (DB MW)	NOISE AFTER PROCESSING (DB MW)	IMPROVEMENT FACTOR (DB)
INTERFERENCE	-39.63	-42.05	-2.42
THERMAL	-25.25	-28.72	-3.47
DISTORTION	-28.50	-31.97	-3.47
TOTAL	-23.46	-26.90	-3.44

NOISE EQUIVALENT SIGNAL POWER PER VOICE CHANNEL = -16.246 DBMW

NOISE EQUIVALENT SIGNAL POWER ACROSS BASEBAND = 14.826 DBMW

ITEM	UNITS	WORST CHANNEL	HIGHEST CHANNEL
BASEBAND FREQUENCY	MHZ	3.1680	4.0280
INTERFERENCE NOISE POWER	DB PW	16.76	15.30
THERMAL NOISE POWER	DB PW	31.94	31.95
DISTORTION NOISE POWER	DB PW	28.68	28.70
TOTAL NOISE POWER	DB PW	33.71	33.70
TEST-TONE SNR	DB	56.29	56.30

END OF LINK ANALYSIS

(uplink)

HCP NUMBER 1 SUMMARY

ANTENNA PARAMETERS	TX BEAM	RX BEAM
POLARIZATION TYPE :	VERTICAL	VERTICAL
APERTURE EFFICIENCY	0.540	0.540
MAJOR-AXIS BEAMWIDTH (DEG)	0.1087	8.0000
MINOR-AXIS BEAMWIDTH (DEG)	0.1087	4.0000
ON-AXIS GAIN (DB)	62.798	28.490
BORESIGHT ELEVATION (DEG)	31.507	
BORESIGHT AZIMUTH (DEG)	218.533	
OFF-AXIS ANGLE (DEG)	0.0	2.493
PRINCIPAL POL GAIN (DB)	62.798	26.640

ATMOSPHERIC/GEOMETRIC FACTORS

SITE SEPARATION DISTANCE	= 38494.40 KM
FREE SPACE LOSS	= -199.719 DB
TROPOSPHERIC ABSORPTION LOSS	= -0.072 DB
TOTAL ATMOSPHERIC LOSS	= -0.072 DB

CARRIER POWER SUMMARY

POWER INTO TX ANTENNA	= 20.294 DBW
E.I.R.P.	= 83.092 DBW
FLUX DENSITY AT RX SITE	= -79.676 DBW/M**2
POWER AT RX ANTENNA TERMINALS	= -90.059 DBW
POWER AT LNA	= -90.059 DBW

RF NOISE SUMMARY

ANTENNA NOISE TEMPERATURE (DEGREES K)	= 290.000
LNA NOISE TEMPERATURE (DEGREES K)	= 3249.000
TOTAL THERMAL-TC-CARRIER RATIO AT LNA OUTPUT	= -27.491 DB
TOTAL DISTORTION-TC-CARRIER RATIO AT LNA OUTPUT	= -50.000 DB
TOTAL UNWANTED POWER-TC-CARRIER POWER RATIO	= -27.466 DB

Fig. 8 N-S ANIK Link Analysis

(downlink)

HCP NUMBER 2 SUMMARY

ANTENNA PARAMETERS	TX BEAM	RX BEAM
POLARIZATION TYPE :	= VERTICAL	VERTICAL
APERTURE EFFICIENCY	= 0.540	0.540
MAJOR-AXIS BEAMWIDTH (DEG)	= 8.0000	0.5917
MINOR-AXIS BEAMWIDTH (DEG)	= 4.0000	0.5917
ON-AXIS GAIN (DB)	= 28.490	48.080
BORESIGHT ELEVATION (DEG)	=	11.053
BORESIGHT AZIMUTH (DEG)	=	153.677
OFF-AXIS ANGLE (DEG)	= 2.555	0.0
PRINCIPAL PEL GAIN (DB)	= 27.069	48.080

ATMOSPHERIC/GEOMETRIC FACTORS

SITE SEPARATION DISTANCE	= 40486.09 KM
FREE SPACE LOSS	= -196.635 DB
TROPOSPHERIC ABSORPTION LOSS	= -0.181 DB
TOTAL ATMOSPHERIC LOSS	= -0.181 DB

CARRIER POWER SUMMARY

POWER INTO TX ANTENNA	= 5.514 DBW
E.I.R.P.	= 34.004 DBW
FLUX DENSITY AT RX SITE	= -130.732 DBW/M**2
POWER AT RX ANTENNA TERMINALS	= -116.154 DBW
POWER AT LNA	= -116.154 DBW

RF NOISE SUMMARY

ANTENNA NOISE TEMPERATURE (DEGREES K)	= 28.286
LNA NOISE TEMPERATURE (DEGREES K)	= 100.000
TOTAL THERMAL-TO-CARRIER RATIO AT LNA OUTPUT	= -15.518 DB
TOTAL DISTORTION-TO-CARRIER RATIO AT LNA OUTPUT	= -30.946 DB
NUMBER OF CONTRIBUTING INTERFERERS	= 2
TOTAL INTERFERENCE-TO-CARRIER RATIO AT LNA OUTPUT	= -29.598 DB
TOTAL UNWANTED POWER-TO-CARRIER POWER RATIO	= -15.233 DB

DEMODULATION CALCULATION SUMMARY

THRESHOLD LEVEL =	-9.396 DB : CARRIER ABOVE DEMODULATOR THRESHOLD
TOTAL NOISE ACROSS BASEBAND =	-45.591 DB VOLTS**2

Fig. 8 (continued)

LINK SUMMARY

USE OF OFUS ISSUE # 2

TELEVISION BASEBAND SIGNAL QUALITY SUMMARY

WILL RESULT IN ADDED
VALUES.

SIGNAL PROCESSING APPLIED AFTER DEMODULATOR :
CCIR DEEMPHASIS
CCIR NOISE WEIGHTING

	NOISE BEFORE PROCESSING (DB VOLTS**2)	NOISE AFTER PROCESSING (CB VOLTS**2)	IMPROVEMENT FACTOR (DB)
INTERFERENCE	-57.35	-69.93	-12.58
THERMAL	-46.01	-58.76	-12.75
DISTORTION	-61.44	-74.19	-12.75
TOTAL	-45.59	-58.33	-12.74

PEAK PICTURE SIGNAL-TC-RMS NOISE RATIO = 55.40 DB

PEAK VIDEO SIGNAL-TO-RMS NOISE RATIO = 58.33 DB

END OF LINK ANALYSIS

6.4 Evaluation of Simulation Results

The results of these simulation runs can be compared against hand calculations. It has been shown in Reference 6, that for the highest channel in a telephone multiplex, the test-tone signal-to-noise ratio at the output of an FM demodulator is given by:

$$\left(\frac{S}{N}\right)_{TT} = \left(\frac{C}{N}\right) \left(\frac{B}{f_{ch}}\right) \left(\frac{31.6}{n}\right) \beta^2 P_w$$

where

- $\left(\frac{C}{N}\right)$ = carrier-to-thermal noise ratio into the demodulator
- B = receiver noise bandwidth
- f_{ch} = voice channel bandwidth (3.1 kHz)
- n = number of voice channels
- β = rms modulation index
- P_w = noise-weighting/pre-emphasis improvement factor (6.5 dB for the highest channel, for psophometric weighting and C.C.I.R. pre-emphasis)

For television basebands, the peak-signal-to-rms thermal noise ratio (ie. sync tip included) is given by Reference 6,

$$\left(\frac{S}{N}\right) = 3 \left(\frac{C}{N}\right) \left(\frac{B}{f_m}\right) \left(\frac{\Delta f_{pp}}{f_m}\right)^2 P_w$$

where

f_m = highest baseband frequency

Δf_{pp} = peak-to-peak frequency deviation

P_w = pre-emphasis/noise weighting improvements factor (12.8 dB for Canada/US System M).

The carrier-to-thermal noise ratio at the input to the demodulator consists of contributions from the uplink and the downlink, ie:

$$\left(\frac{C}{N}\right)_{TOT} = \frac{1}{\frac{1}{\left(\frac{C}{N}\right)_{up}} + \frac{1}{\left(\frac{C}{N}\right)_{down}}}$$

The carrier-to-noise ratio on a hop can be determined from:

$$\left(\frac{C}{N}\right) = \frac{P_T G_T G_R \lambda^2 l}{(4\pi r)^2 k T B}$$

where

P_T = carrier power into TX antenna

G_T = gain of transmitting antenna

G_R = gain of receiving antenna

λ = wavelength

l = atmospheric attenuation factor (assumed zero)

r = separation distance of receiver and transmitter

k = Boltzmanns constant
(1.38×10^{-17} watts/MHz - °K)

T = sum of LNA and antenna noise
temperatures

B = receiver noise bandwidth.

These expressions have been evaluated using the values listed in the previous sections. The results of these "hand" calculations have been compared with the simulation results in Table 6. It can be seen that the simulation results are in excellent agreement with the values calculated from the preceding expressions.

The interference-to-carrier ratio calculated by the simulation can be compared with that predicted by a very simple hand calculation. Assuming an earth station receiving antenna sidelobe pattern given by $32-25 \log \theta$, and two equal power interferors at 5 degrees from the boresight, the C/I ratios for the two receiving sites can be estimated, ie.:

$$\begin{aligned} \left(\frac{C}{I} \right)_{dB} &= G_o - (32 - 25 \log_{10}(5^\circ)) - 3 \\ &= \begin{cases} 41.75 \text{ dB}, & \text{heavy-route} \\ 30.55 \text{ dB}, & \text{Northern TV} \end{cases} \end{aligned}$$

These values are within one decibel of those predicted by the simulation (ie. 41.3 dB for the heavy route telephony link, and 29.6 dB for the TV link). It is of interest to note that in going from a 98 ft. diameter to a 32 ft. diameter receiving antenna, the change in the C/I ratio results from the change in carrier power, not interference power, as pointed out in Chapter 4.

TABLE 6: Comparison of Hand Calculations and Simulation Results

Thermal Noise Analysis Only

E-W Heavy Route Link

	<u>Hand Calculation</u>	<u>Simulation</u>
up-link C/N	27.84	27.765
down-link C/N	27.69	27.696
Total C/N	24.75	24.720
Test-Tone S/N in highest channel	64.12	64.56

N-S FM/TV Link

	<u>Hand Calculation</u>	<u>Simulation</u>
up-link C/N	27.72	27.491
down-link C/N	15.92	15.803
Total C/N	15.64	15.518
S/N	58.89	58.76

(NOTE: All values in decibels)

As a result of these simulation runs, the models used in the simulation can be evaluated for their suitability for this type of analysis:

- . geometric models - suitable.
- . antenna models - suitable. Caution required in interpreting the results.
- . FDM/FM spectrum model. For low modulation indices, the FFT analysis is used, while for rms modulation indices greater than 1.5, a different spectrum model is used. At the breakpoint, the two spectra are not identical and hence inaccurate trends may result for sensitivity analyses in which the modulation index crosses the breakpoint value.
- . FM/TV spectrum model: this model is only approximate and thus the results must be used with caution.
- . the antenna noise temperature model is suitable.
- . the FM demodulator model is suitable for thermal noise and interference. The assumption is made however that RF intermodulation distortion can be treated in the same way as thermal noise by the FM demodulator. This assumption may not always be valid.
- . the noise weighting/de-emphasis improvement factors are suitable. For FM/TV analyses, the simulation results are superior to those of many simpler analyses in that arbitrary noise spectral distributions across the baseband can be considered.

7.0 12-15 GHZ LINK CALCULATIONS

7.1 Introduction

In this chapter, the performance of a hypothetical 12-15 GHz satellite communications system is evaluated using the simulation. The system to be analysed is the multi-beam, dual polarization satellite system proposed in Reference 6. The subsequent analysis has been limited to two communications links. One is a heavy route digital transmission from Toronto to Vancouver, and the second is an educational television broadcast from Toronto to Churchill, Manitoba. (These links use beam Plan C, Frequency Plan N3 of Reference 6). The effects of rain and cloud are considered in these simulation runs.

The interference environment for each communications link consists of a number of co-channel carriers on the other satellite beams, and may be either co or cross-polarized, as illustrated in Figures 9 and 10. No uplink interference is considered in these analyses.

7.2 Description of Parameters Used in the Simulation Runs

7.2.1 E-W Digital Link

In this case the performance of a high bit-rate digital signal from Toronto to Vancouver is analysed using the simulation. The interference arises from carriers on satellite Beams #1 and #3. For this analysis, the satellite antenna beams have been approximated as either circular or elliptical patterns. A list of parameters used in the simulation runs follow:

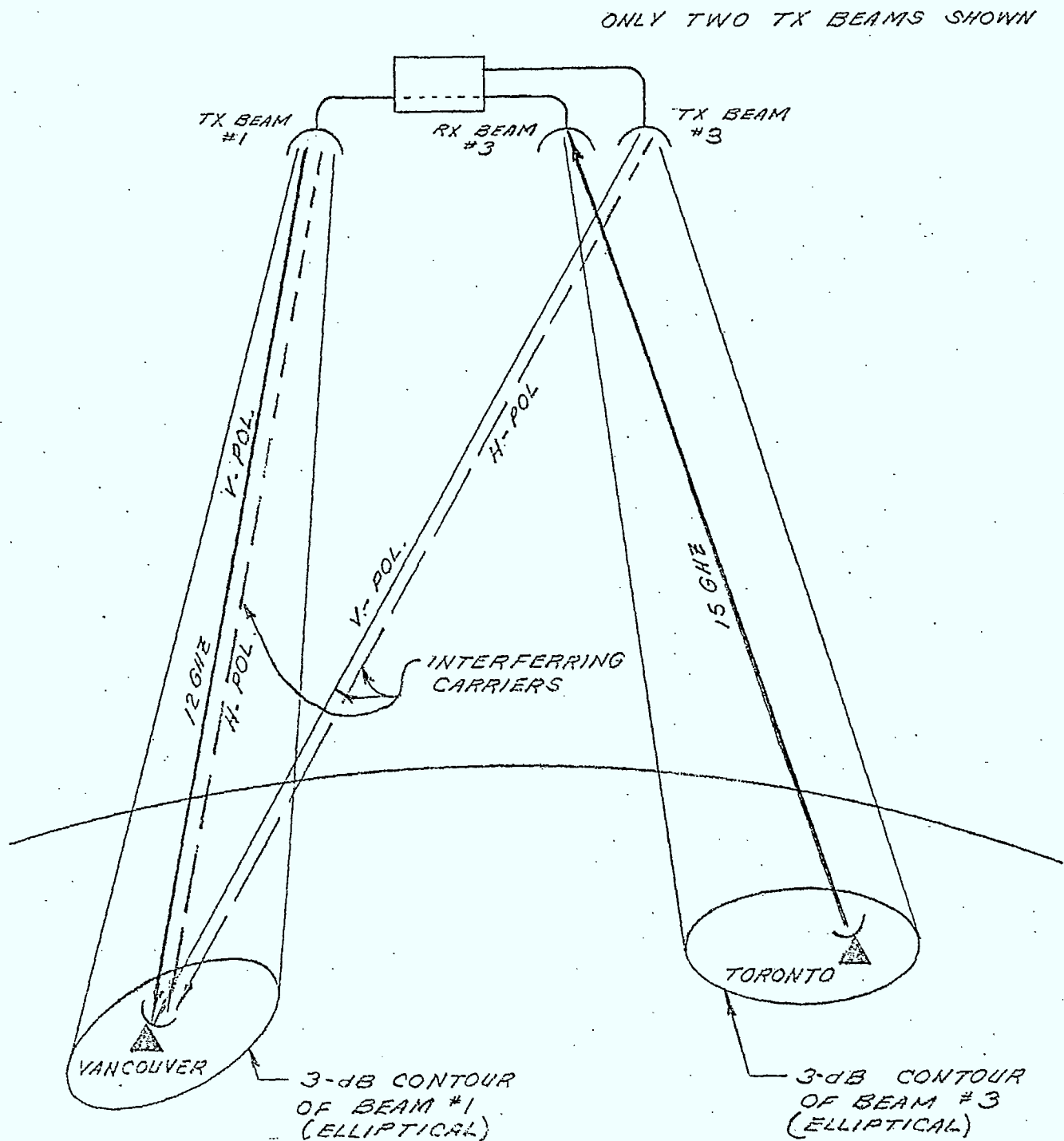


FIG. 9 12/15 GHz HEAVY-ROUTE DIGITAL LINK

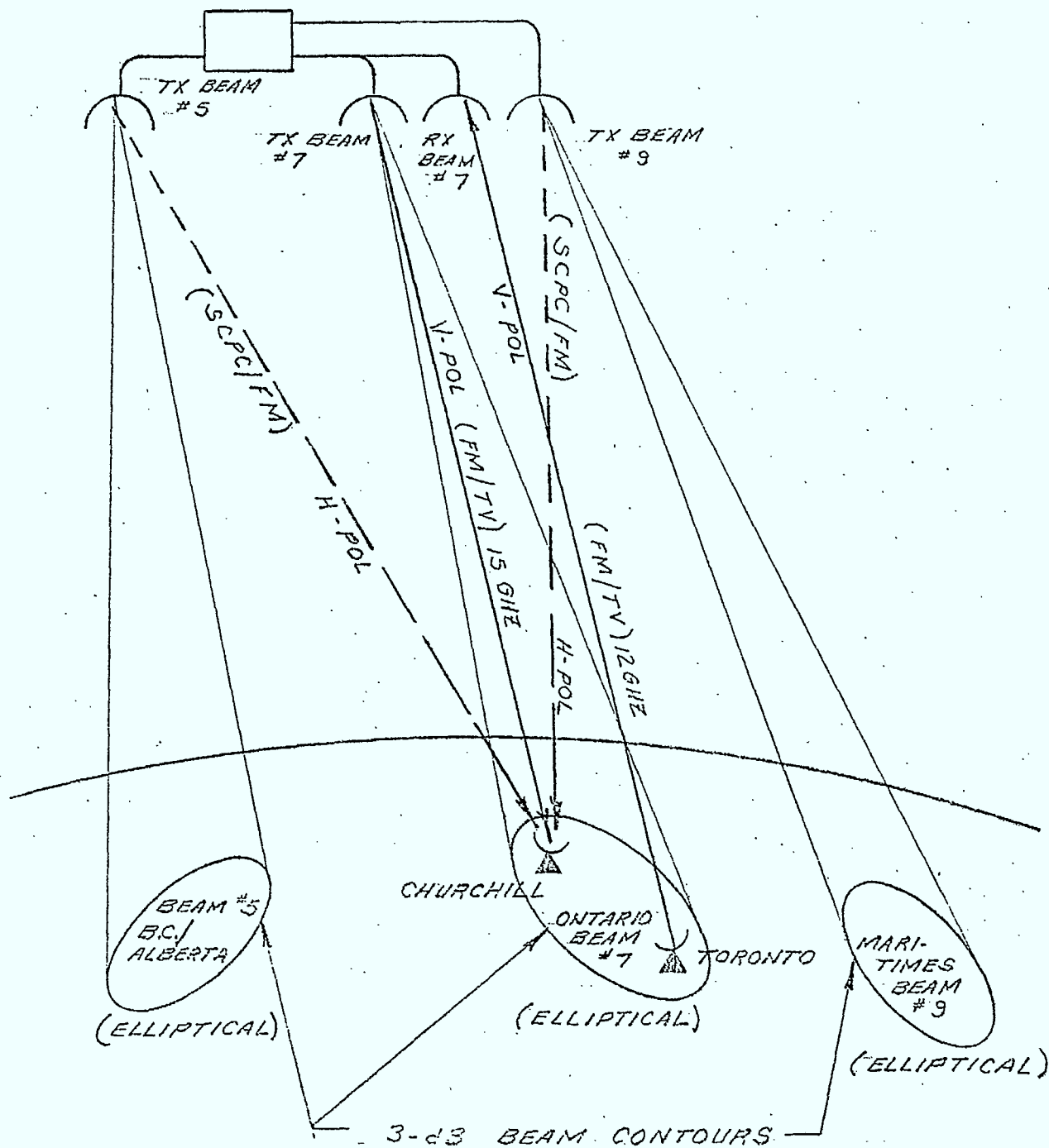


FIG. 10 12/15 GHz ETV LINK

Toronto

- Location: latitude = 43.70°N
longitude = 79.24° W
Rain Zone #2

- TX Antenna Parameters

- . vertical polarization (antenna is pointed at the satellite and polarizer aligned with RX Beam #3).
- . diameter = 59 ft.
(gives on-axis gain = 66 dB at 15 GHz)
- . depolarization ratios: mainbeam: -27 dB
near sidelobes: -10 dB
backlobes: -3 dB

- Transmitted Carrier Parameters

- . carrier frequency = 15 GHz
- . RF bandwidth = 62.5 MHz
- . Type: 4-phase CPSK
- . Bit Rate = 104.17 Mbits/sec
- . no IF Filtering
- . carrier output power = 292 watts

Vancouver

- Location: latitude = 49.27° N
longitude = 123.06° W
Rain Zone #3

- RX Antenna Parameters

- . vertical polarization (points at satellite and has polarizer aligned with TX beam #1)
 - . diameter = 59 ft.
(gives on-axis gain = 64.4 dB at 12 GHz)
 - . depolarization ratios same as Toronto TX beam.
- LNA Noise temperature = 200°K
- Receiver noise bandwidth = 62.5 MHz

Satellite Parameters

- Location: longitude = 105° W

- TX Antenna #1 Parameters (BC/ALBERTA beam)

- . Boresight target: latitude = 52° N
longitude = 118° W
- . Reference target: latitude = 54° N
longitude = 112.0° W
- . on-axis gain = 39.2 dB
- . major-axis beamwidth = 1.7 degrees
- . minor-axis beamwidth = 0.7 degrees
- . depolarization ratios: same as Toronto TX beam
- . Polarization #1: vertical

- TX Carrier Parameters:

- . carrier frequency = 12 GHz
- . 4-phase CPSK

- . bit-rate = 104.17 Mbits/sec.
- . RF bandwidth = 62.5 MHz
- . no IF filtering
- . output power = 1.1 watt
(saturated TWT)

. Polarization #2: horizontal

- same carrier parameters as polarization #1.

- TX Antenna #3 Parameters (Ontario beam)

- . Boresight Target: latitude = 45° N
longitude = 77° W
- . Reference target: latitude = 44° N
longitude = 83° W
- . Same antenna parameters as TX Beam #1
- . Same frequency plan and carrier parameters as Beam #1.

- RX Antenna #3 Parameters

- . Same boresight pointing as TX Beam #3.
- . Vertical polarization
- . Same antenna parameters as TX Beam #3.

- LNA Noise Temperature = 832.0° K.
- Receiver Noise Bandwidth = 62.5 MHz

7.2.2 Northern ETV Link

In this case, the performance of an educational TV broadcast link from Toronto to Churchill is to be evaluated using the simulation. Interference arises from the co-channel operation of transponders on Beams #5 and #9. (Note, these beams are horizontally polarized, while the link antenna is vertically polarized). These channels carry many demand access single-channel-per-carrier (SCPC/FM) carriers on pre-assigned frequencies. Each carrier is frequency modulated. Since the simulation does not have a suitable spectrum model for a channel consisting of many very narrow SCPC/FM carriers, one of the existing spectrum models was used to approximate the interference spectrum of the SCPC satellite channel, as described in this section.

Toronto TX Site Parameters

- location and antenna parameters - same as for heavy route digital case.
- transmitted carrier parameters
 - . Type: FM/TV
 - . Carrier frequency: 15007.8125 MHz
 - . Peak-to-peak frequency deviation: 7.225 MHz
(ie. obtained from Carson Rule bandwidth)
 - . RF bandwidth: 16 MHz
 - . Output power: 10.0 watts

Chruchill RX Site Parameters

- location: latitude = 56.0° N
 longitude = 90.0° W
 Rain Zone #2

- RX Antenna Parameters

- . vertical polarization (aligned with satellite TX Beam #7).
 - . Diameter = 17 ft.
(gives on-axis gain = 53.6 dB at 12 GHz)
 - . same depolarization ratios as Toronto TX beam
- LNA Noise temperature = 800° K.
 - Receiver Noise Bandwidth = 15.625 MHz.

Satellite Parameters

- location: longitude = 105° W

- TX Beam #5

- . Boresight target: latitude = 55° N
 longitude = 120° W
- . Reference target: latitude = 57° N
 longitude = 110° W
- . Horizontal Polarization
- . On-axis gain = 35.2 dB
- . Major-axis beamwidth = 2.0°
- . Minor-axis beamwidth = 1.5°
- . Same depolarization ratios as previous satellite beams.

- Carrier Parameters

- . Type: SCPC/FM, demand access
- . Center frequency of channel = 12015.625 MHz.
- . Channel bandwidth = 31.25 MHz
- . TWT saturated power per transponder = 4 watts.
(in SCPC/FM mode, output back off is 4.0 dB
resulting in a channel power of 1.32 watts).

The spectrum of this transponder can be approximated as a band of white noise occupying the channel, with total power of 1.32 watts. As the simulation does not contain such a model, the digital PSK spectrum model was used to approximate the spectrum. Since the spectrum is only evaluated over the "simulation" bandwidth (in the case 15.63 MHz) a very high bit rate 2-phase CPSK spectrum can be used to approximate the spectrum across this band.

To determine the bit rate and output power of the 2-Ø CPSK carrier approximating the spectrum that gives 1.32 watts across the 31.25 MHz band, the following analysis is presented. If R is the bit rate, B is the simulation bandwidth, P_{dig} is the equivalent power of the digital carrier, and P_i is the in-band power, then for a 2-phase CPSK carrier with no filtering, it can be shown that:

$$\begin{aligned}
 P_i &= P_{dig} \int_{-B/2}^{B/2} \frac{1}{R} \left[\frac{\sin\left(\frac{\pi f}{R}\right)}{\left(\frac{\pi f}{R}\right)} \right]^2 df \\
 &= P_{dig} \frac{2}{\pi} \int_0^{\pi B/2R} \left(\frac{\sin u}{u} \right)^2 du
 \end{aligned}$$

If at the channel edges, the CPSK spectrum has only decreased by 10% from its mid-band level, then the bit-rate can be determined from the channel bandwidth, ie:

$$R = 2.78 B$$

Substituting this value into the integral gives:

$$P_{\text{dig}} = 2.876 P_i$$

For use in the simulation, the spectrum at the output of the multi-carrier SCPC transponder is described as follows:

- . Type: 2- ϕ CPSK
- . Bit rate = 86.88 Mbits/sec.
- . Output power = 3.796 watts

TX Antenna #7

- . Boresight target: latitude = 49° N
longitude = 85° W
- . Reference target: latitude = 47.0° N
longitude = 80.0° W
- . Vertical Polarization
- . On-axis gain = 35.97 dB
- . Major-axis beamwidth = 2.5 degrees
- . Minor-axis beamwidth = 1.0 degrees
- . same depolarization ratios as the other satellite antennae

- Transmitted Carrier Parameters

- . Type: FM/TV
- . Carrier Frequency = 12007.8125 MHz
- . Peak-to-peak frequency deviation = 7.227 MHz
- . RF bandwidth = 16 MHz
- . Output power = 2.7 watts

TX Antenna #9

- . Boresight target: latitude = 48° N
 longitude = 60° W
- . Circular cross-section
- . Horizontal polarization
- . On-axis gain = 36.4 dB
(ie. beamwidth = 2.3°)
- . All other parameters are same as Beam #5.

RX Antenna #7

- LNA Noise temperature = 832° K.
- Receiver Noise bandwidth = 15.625 MHz

7.3 Results of Simulation Runs

The signal quality of the heavy route digital carrier transmitted from Toronto to Vancouver has been calculated for a variety of uplink and down link propagation conditions using the simulation. For these calculations, the C.C.I.R. antenna models were used. All of the calculations were performed using 200 step spectral resolution across the receiver bandwidth. The results of these calculations are shown in Table 7.

It is interesting to note that for severe uplink attenuation the final carrier-to-noise ratio is below threshold since the simulation models an IF-type satellite repeater as a linear amplifier. Also, the overall carrier-to-thermal noise ratio is very dependent on the down link propagation attenuation since the receiving earth station's noise temperature increases in proportion to the down link carrier attenuation for rain and cloud.

The signal quality of an ETV transmission from Toronto to Churchill was also analysed using the simulation for the same set of propagation conditions. C.C.I.R. antenna models were also used. The results of the simulation runs are shown in Table 8. In this case the interference is relatively unimportant compared to thermal noise, unlike the heavy route digital link in which interference is a major part of the link noise budget. In each case however, the interference-to-thermal noise ratio is largest for clear weather conditions. This results because the downlink wanted carrier and the interference occur at the same elevation angle, ie., along the receiving earth station antenna boresight.

SIMULATION RUN	UPLINK		DOWNLINK			TOTAL	LOG OF SYMBOL ERROR PROBABILITY
	PROPAGATION PHENOMENA	$\left(\frac{C}{N}\right)$	PROPAGATION PHENOMENA	CARRIER TO THERMAL NOISE RATIO	$\left(\frac{C}{I}\right)$	$\left(\frac{C}{N}\right)$	
1	clear weather	41.51	clear weather	23.52	17.88	16.82	negligible
2	clear weather	41.51	rain exceeded for 0.01% of time	16.18	17.72	13.86	-7.07
3	rain exceeded for 0.01% of time	32.04	clear weather	13.46	7.83	6.77	below threshold
4	rain exceeded for 1% of time	39.89	rain exceeded for 1% of time	19.45	16.02	14.38	negligible
5	rain exceeded for 1% of time	39.89	cloud exceed for 1% of time	20.76	16.06	14.78	negligible
6	cloud exceeded for 1% of time	41.18	rain exceeded for 1% of time	20.90	17.47	15.83	
7	cloud exceeded for 1% of time	41.18	cloud exceeded for 1% of time	22.21	17.51	16.22	

(NOTE: All values in decibels)

TABLE 7 - RESULTS OF HEAVY-ROUTE DIGITAL LINK CALCULATIONS

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VALUES.

SIMULATION RUN	UPLINK PROPAGATION ATTENUATION (dB)	DOWNLINK PROPAGATION ATTENUATION (dB)	RX EARTH STATION ANTENNA TEMPERATURE (°K)	RATIO OF CARRIER POWER INTO LNA-TO-CLEAR WEATHER POWER (dB)	PERCENT OF TOTAL RECEIVED INTERFERENCE POWER		
					BEAM # 3		BEAM #1
					V	H	H
1	-0.15	-0.12	14.8	0	72.03	7.35	20.62
2	-0.15	-4.83	192.4	-4.72	69.46	7.14	23.40
3	-10.20	-0.12	14.8	-10.05	72.03	7.35	20.62
4	-1.97	-1.12	85.6	-2.83	71.47	7.30	21.23
5	-1.97	-0.37	51.2	-2.08	72.03	7.35	20.62
6	-0.53	-1.12	85.6	-1.38	71.47	7.30	21.23
7	-0.53	-0.37	51.2	-0.63	72.03	7.35	20.62

TABLE 7 - (continued)

SIMULATION RUN	UPLINK		DOWNLINK			TOTAL	
	PROPAGATION PHENOMENA	$\left(\frac{C}{N}\right)$	PROPAGATION PHENOMENA	CARRIER TO THERMAL NOISE RATIO	$\left(\frac{C}{I}\right)$	$\left(\frac{C}{N}\right)$	$\left(\frac{S}{N}\right)$ CCIR
1	clear weather	28.05	clear weather	15.32	34.90	15.05	40.20
2	clear weather	28.05	rain exceeded for 0.01% of time	7.66	34.84	7.616	32.77
3	rain exceeded for 0.01% of time	18.01	clear weather	5.03	24.84	4.99	below threshold
4	rain exceeded for 1% of time	26.23	rain exceeded for 1% of time	11.83	33.06	11.64	36.80
5	rain exceeded for 1% of time	26.23	cloud exceeded for 1% of time	12.98	33.07	12.74	37.89
6	cloud exceeded for 1% of time	27.68	rain exceeded for 1% of time	13.28	34.51	13.09	38.25
7	cloud exceeded for 1% of time	27.68	cloud exceeded for 1% of time	14.43	34.52	14.19	39.34

(NOTE: All values in decibels)

TABLE 8 - RESULTS OF ETV LINK CALCULATIONS

SIMULATION RUN	UPLINK PROPAGATION ATTENUATION (dB)	DOWNLINK PROPAGATION ATTENUATION (dB)	RX EARTH STATION ANTENNA TEMPERATURE (°K)	RECEIVED DOWNLINK CARRIER POWER-TO-CLEAR WEATHER RECEIVED POWER (dB)	PERCENT OF TOTAL INTERFERENCE	
					Beam #9 H	Beam #5 H
1	-0.15	-0.14	18.1	0	81.17	18.83
2	-0.15	-6.83	221.7	-6.69	80.83	19.17
3	-10.21	-0.14	18.1	-10.06	81.17	18.83
4	-1.98	-1.40	97.2	-3.09	81.11	18.89
5	-1.98	-0.46	56.0	-2.14	81.17	18.83
6	-0.53	-1.40	97.2	-1.64	81.11	18.89
7	-0.53	-0.46	56.0	-0.69	81.17	18.83

TABLE 8 (continued)

7.4 Evaluation of Simulation Results

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The results of these simulation runs are consistent with the link performance calculations carried out in Reference 6, with the exception of the error probabilities predicted by the simulation. These values differ from those predicted in Reference 6 since the simulation model uses the actual carrier-to-noise ratio while the calculations of Reference 6 are based on a carrier-to-noise ratio 4 dB lower to allow for non-ideal demodulation equipment.

The SHF satellite communications system described in Reference 6 was designed with the assumption that uplink power control would be used. The simulation results indicate that rain attenuation on the uplink can drive the signal below threshold when uplink power control is not used. This results because the carrier power on the down link is decreased due to the satellite input backoff while the interference is not, making the system much more susceptible to interference. This effect is present in the simulation results. Although the simulation can model variable gain uplink transmitters, this model was not used in the simulation runs so that the effects of severe uplink attenuation could be illustrated.

The simulation results also indicate that the overall system performance for small percentages of time is determined by individual propagation phenomena expected to occur for that percentage of time, and not by the combinations of higher probability independent effects on the up and down links. If uplink power control is used, the simulation results indicate that the propagation margins required for successful operation of the communications links studied is determined by the downlink rain

attenuation.

As a result of these simulation runs, the models used in the simulation can be evaluated for their suitability for this and similar analyses:

- . geometric models - suitable
- . antenna models - suitable as long as the actual antenna patterns can be approximated by the circular or elliptical patterns used in the simulation.
- . spectrum models - suitable, with the exception of a model for the multi-carrier SCPC spectrum.
- . antenna noise temperature model - suitable, since the effects of antenna elevation angle and propagation phenomena are considered.
- . high power amplifier model - suitable for TWT amplifiers operating in the linear region. For systems operating at or near saturation, where the input/output power curve is no longer linear, the overall effects of uplink rain and cloud attenuation may not be modeled accurately since the HPA model used in the simulation assumes linear operation.
- . demodulator model - the digital error probability model used in the simulation predicts error probabilities lower than most real equipment is capable of achieving. For operation at high carrier-to-noise ratios, the calculated error probabilities may be lower than the best equipment is capable of achieving since the simulation model

NOT RELEVANT TO
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neglects all equipment nonlinearities and non-ideal equipment effects. As a result the current error probability models should be used with caution, keeping in mind the assumptions which form the basis of the models.

8.0 PRECIPITATION SCATTER INTERFERENCE CALCULATIONS

8.1 Introduction

In this chapter, the results of simulation runs using the precipitation scatter interference model are discussed. Three series of simulation runs were analysed. In the first series, the simulation was used to analyse the interference due to a configuration of transmitters identical to that used in the Virginia Precipitation Scatter Experiment (Reference 8). The results of these calculations, performed at 4 GHz, are compared with measurements obtained in the Virginia Experiment. The next series of simulation runs were made at 6, 12 and 18 GHz for a transmitter/receiver configuration similar to that described in Reference 9. In this Reference, measurements obtained by COMSAT are presented. These measurements have been compared with the results of the simulation.

The final simulation runs involved the analysis of a communications link operating in the presence of precipitation scatter interference. Various separation distances between the receiver and the interfering transmitter were considered.

8.2 Simulation of Virginia Scatter Experiment

8.2.1 Introduction

The Virginia Precipitation Scatter Experiment (Reference 8) has provided data for distribution functions of transmission loss (i.e. ratio of received-to-transmitted power) for four propagation paths. Two transmitting sites, each with two antennae operating at

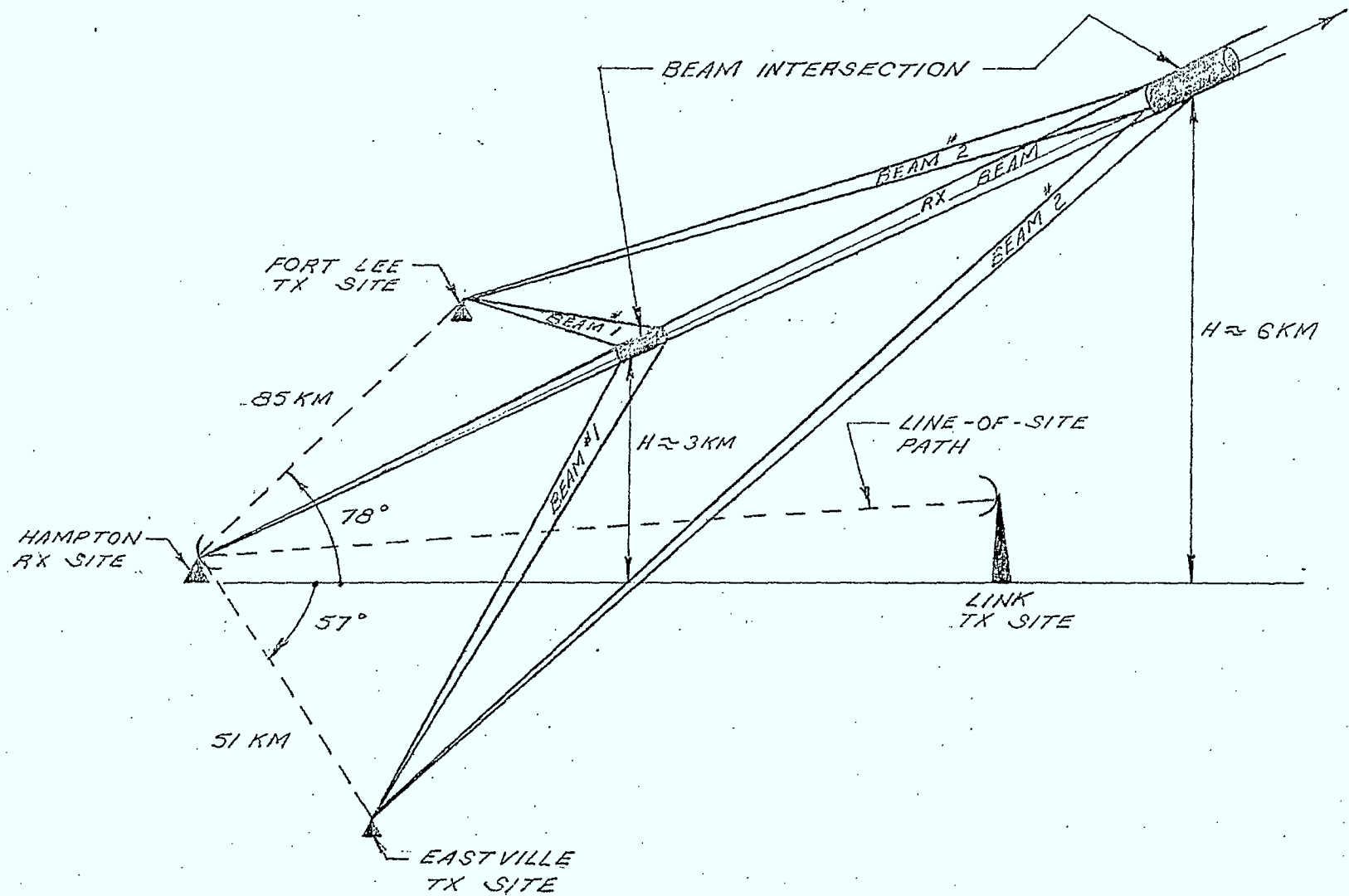


FIG. 11 : VIRGINIA SCATTER EXPERIMENT RX/TX CONFIGURATION

3.672 GHz with parameters similar to terrestrial microwave station antennae were used. The receiving site used an antenna with parameters typical of a satellite earth station. The antennae were oriented such that the transmitter and receiver mainbeams intersected at heights of 3 and 6 km, as illustrated in Figure 11.

The parameters used to describe the transmitters and receiver used in the simulation runs are listed in this section. The simulation runs were performed for a range of percentage of time to obtain the transmission loss distribution function for each path. Since the precipitation scatter model is only used by the simulation for "LINK" calculations, it was necessary to set up a hypothetical "link" transmitter to provide a communications link for the simulation to analyse. Since the only simulation results of interest in this report are the ratio of received-to-transmitted power for each interferor, the hypothetical communications link performance is not discussed in this report.

8.2.2 Description of TX/RX Parameters used in Simulation Runs

In this section a detailed list of the parameters used in the simulation runs is presented. It should be noted that the receiving antenna at Hampton pointed towards the north, away from the geosynchronous orbit arc. As a result, a hypothetical communications link was set up between an earth based transmitter and the receive site, resulting in unrealistic communications link performance.

All of the transmitted carriers were assumed to be FM/TV carriers occupying an RF bandwidth of 36 MHz.

HAMPTON, VIRGINIA: RX SITE PARAMETERS

- Location: Latitude = 37.09° N
Longitude = 76.43° W
Rain Zone #1
 - Receiving Antenna Parameters
 - . Boresight azimuth = 331.1° E of N
elevation = 13.5°
 - . Diameter = 9.2 m
 - . On-axis gain = 48.0 dB
 - . 3-dB beamwidth = 0.68°
 - . Polarization type: RHC
- NOTE: Since scatter model is independent of RX and TX polarization the choice of antenna polarization is arbitrary.

EASTVILLE, VIRGINIA: TX SITE PARAMETERS

- Location: Latitude = 37.33383° N
Longitude = 75.94647° W
- TX Antenna #1
 - . Boresight azimuth = 252.1° E of N
elevation = 3.6°
 - . diameter = 3.0 m
 - . on-axis gain = 38.8 dB
 - . 3-dB beamwidth = 2.0°
 - . polarization: RHC

- TX Carrier parameters
 - . Frequency = 3.672 GHz
 - . Type: FM/TV
 - . Peak-to-peak frequency deviation = 16 MHz
 - . RF bandwidth = 40 MHz
 - . Output power = 1.0 watt
- TX Antenna #2
 - . Boresight azimuth = 265.2° E of N
elevation = 6.2°
 - . All other parameters same as beam #2

FORT LEE, VIRGINIA: TX SITE PARAMETERS

- Location: latitude = 37.24553° N
longitude = 77.37134° W
- TX Beam #1
 - . Boresight azimuth = 94.0° E of N
elevation = 2.1°
 - . All other parameters same as Eastville
TX beam #1
- TX Beam #2
 - . Boresight azimuth = 84.6° E of N
elevation = 4.4°
 - . All other parameters same as Eastville TX
beam #1

8.2.3 Results of Simulation Runs

The simulation was run for this configuration of transmitters for a range of p , where p is the percentage of time for which the rainfall rate at the receiving site will be exceeded. The results of these calculations are plotted in Figure 12. Also shown on the figure are the measurements reported in Reference 8 for the 3 km and 6 km scatter heights.

From this figure it can be seen that the results of the simulation are in excellent agreement with the 3 km measurements except near the 1% range. The measurements of transmission loss corresponding to the 6 km scatter height are lower than the simulation values by as much as 10 dB for percentages of the time greater than 0.01%. For values less than 0.01% of the time, the difference is not as large. As pointed out in Reference 8, the C.C.I.R. rainfall rate distribution function for Rain Climate #1 is an average over large geographical regions over which rainfall rates, and hence distribution functions related to rainfall rates may vary significantly. It should be noted that the C.C.I.R. precipitation scatter model predicts the same trends as the simulation in this case, also over-estimating the amount of interference from the 6 km scatter height. The poor agreement between predicted and measured transmission loss for the 6 km scatter height may indicate that the rainfall rate for rain cells at high altitudes may not be the same as surface rainfall rates, as assumed in the simulation model.

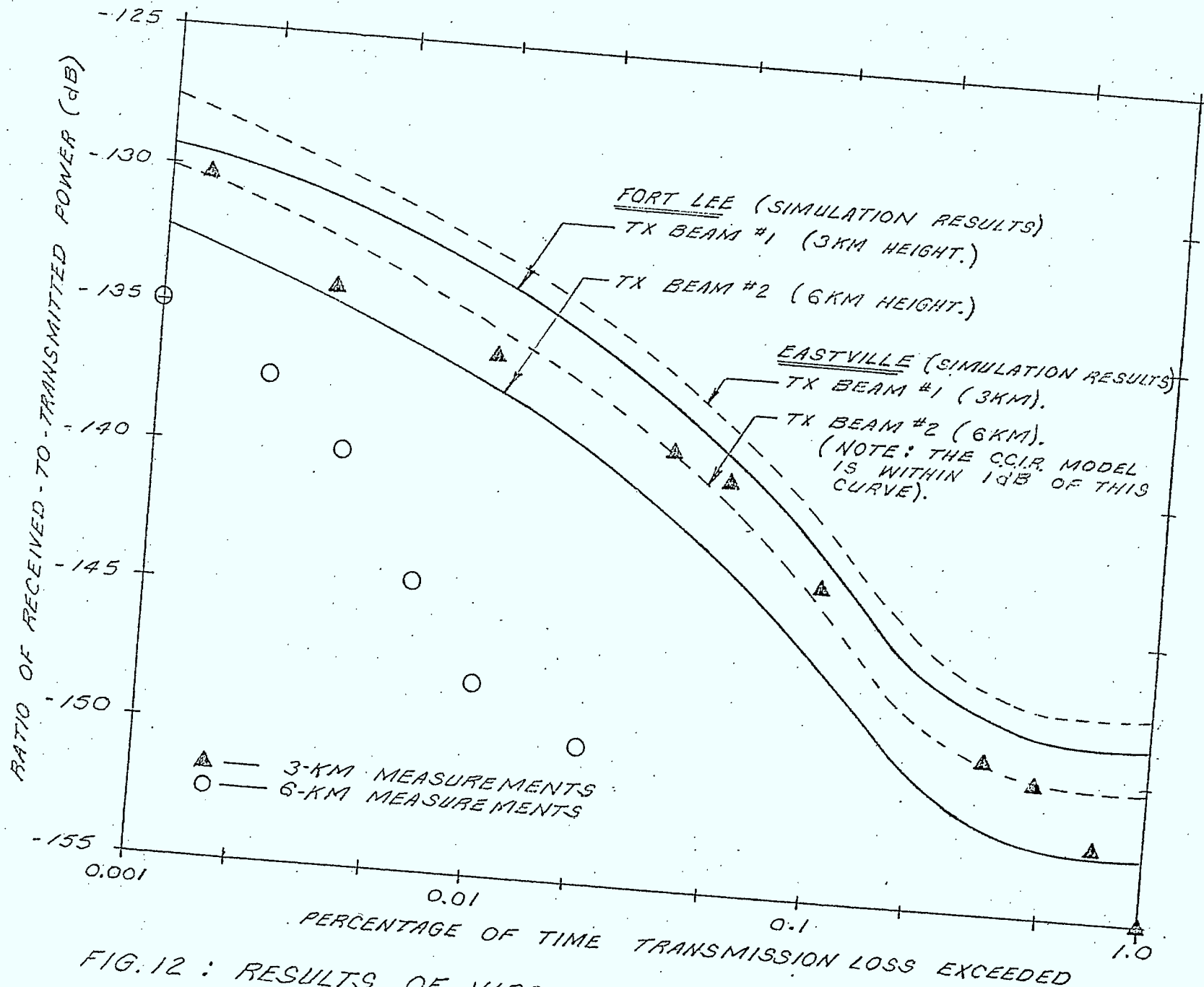


FIG.12 : RESULTS OF VIRGINIA SCATTER EXPERIMENT
 SIMULATION RUNS.

8.3 Precipitation Scatter Calculations at 6, 12 and 18 GHz

8.3.1 Introduction

The transmitter/receiver configurations used by COMSAT to perform precipitation scatter interference measurements at 6, 12 and 18 GHz illustrated in Figure 13 were analyzed using the simulation. The sites were situated in the Eastern U.S.A. with the antennae oriented for direct mainbeam intersections. The simulation results were compared with the COMSAT measurements and the predictions of the C.C.I.R. model. The simulation runs were performed for a range of percentage of time to obtain the distribution function of transmission loss for the three frequency ranges.

Values for the receiving antenna parameters were not given in Reference 9. The values used in the simulation runs were chosen to be representative of a receiving earth station in the fixed satellite service. The differences between the values used in the simulation runs and the values chosen by COMSAT for their measurements may affect the validity of direct comparisons of the two path loss distribution functions.

8.3.2 Description of Parameters used in Simulation Runs

In this section, a detailed description of the parameters used in the simulation runs is provided. Since the precipitation scatter model is only used in "LINK" analyses, it was necessary to define a hypothetical link transmitter so that a communications link could be set up for the simulation to analyze. As with the previous

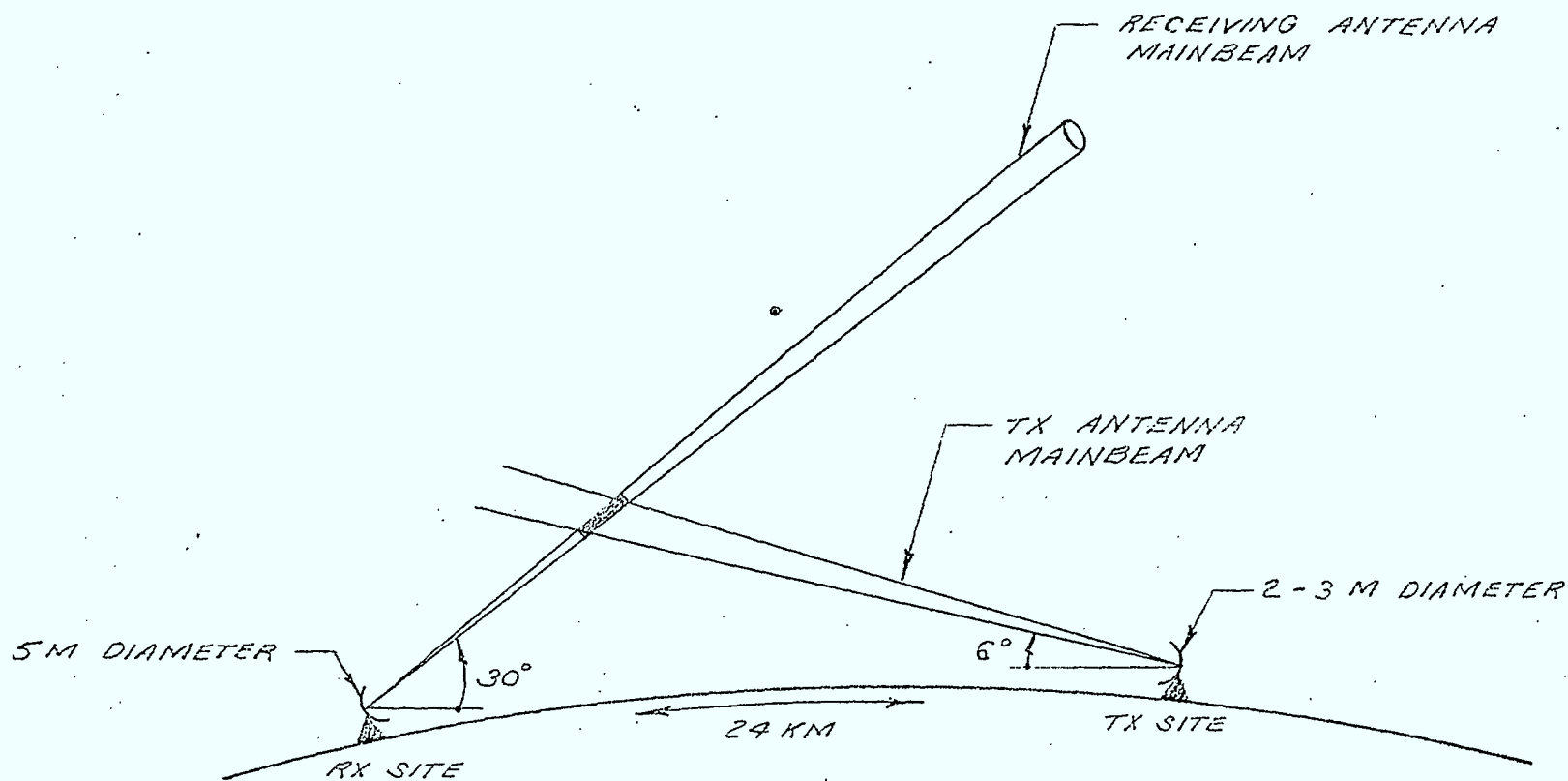


FIG. 13 : PRECIPITATION SCATTER INTERFERENCE CONFIGURATION
AT 6, 12 AND 18 GHE

precipitation scatter calculations, the actual parameters of the link transmitter are of no importance in this analysis as only the ratio of received-to-transmitted power for the interferor is of interest.

Receiving Site Parameters

- Location: Latitude = 35.0° N
Longitude = 74.0° W
Rain Zone #2
- RX Antenna Parameters
 - . Boresight Azimuth = 180.0° E of N
Elevation = 30.0°
 - . Diameter = 5.0 m
(NOTE: gives on-axis gain = 47.3 dB at 6 GHz
= 53.3 dB at 12 GHz
= 56.8 dB at 18 GHz)
 - . Polarization: Right Hand Circular
- Receiver bandwidth = 36.0 MHz

Transmitting Site Parameters

- Location: Latitude = 34.78399° N
Longitude = 74.0° W
(i.e. 24 km south of RX site)
- TX Antenna Parameters
 - . Boresight Azimuth = 0.0°
Elevation = 6.0°
 - . Polarization: Right Hand Circular
 - . On-axis gain = 39 dB for 6 GHz
49 dB for 12 GHz
52 dB for 18 GHz

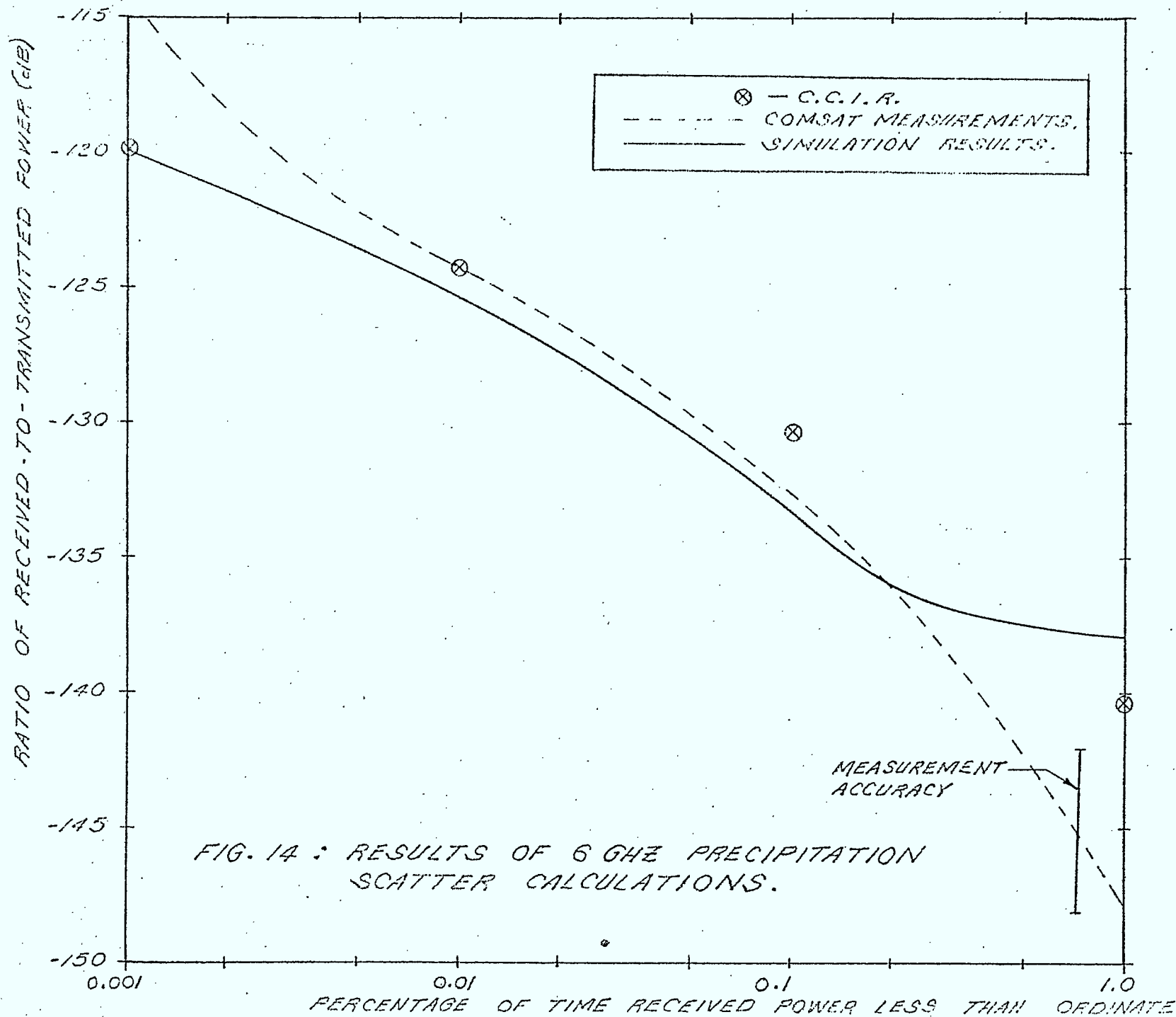
- TX Carrier Parameters

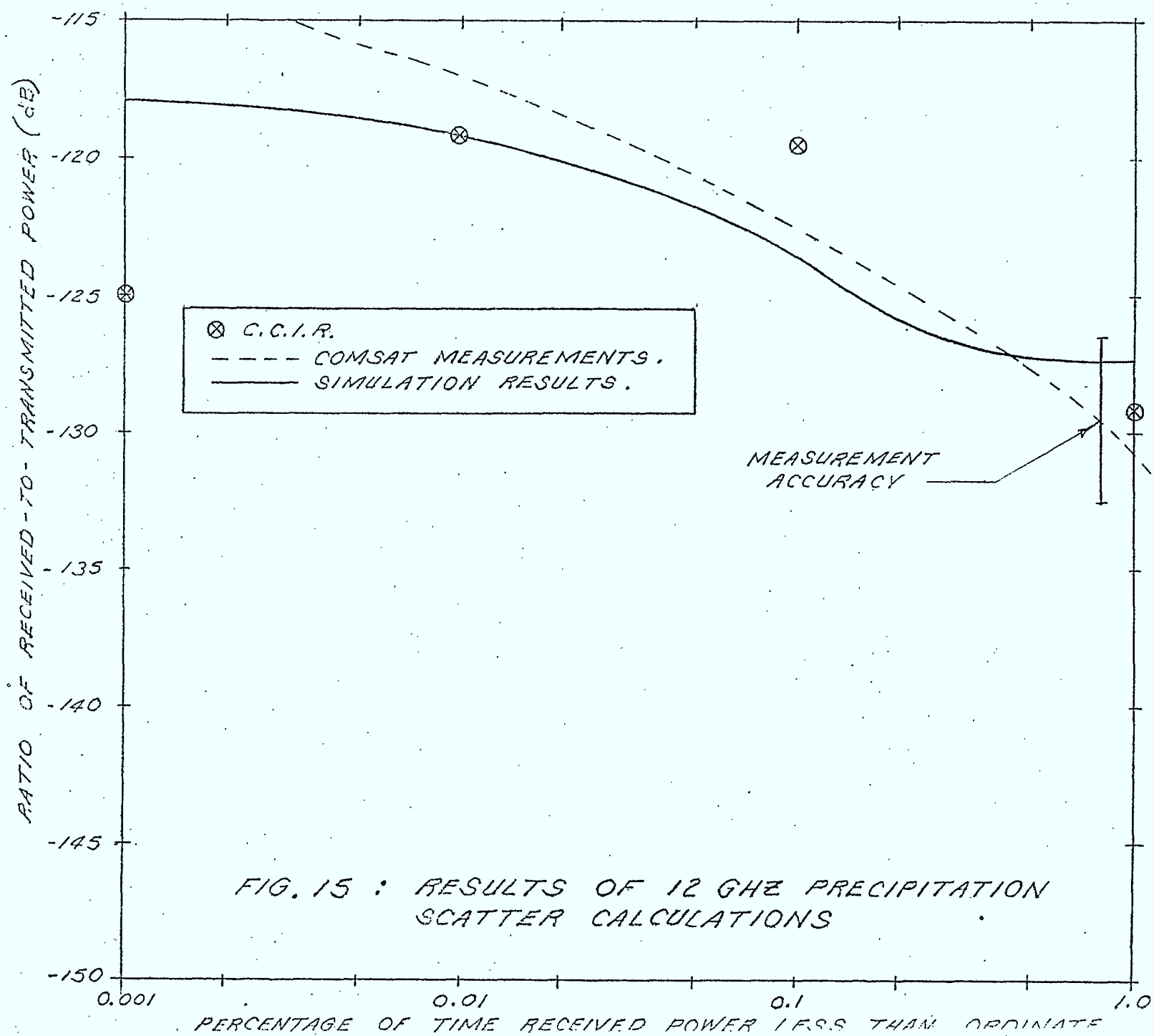
- . Type: FM/TV
- . Peak-to-peak frequency deviation = 16 MHz
- . RF bandwidth = 40 MHz
- . Output power = 1 watt

8.3.3 Results of Simulation Runs

The simulation was run for this receiver/transmitter configuration for frequencies of 6, 12 and 18 GHz to obtain the transmission loss distribution function for each frequency. The results of these calculations are shown in Figures 14, 15 and 16, together with the measurements of COMSAT reported in Reference 9. The values calculated using the C.C.I.R. model are also shown in the figures. The height of the rain filled common volume was 2.2 km for all of these simulation runs.

From these figures it can be seen that the simulation results are in good agreement with the 6 and 12 GHz COMSAT measurements except for percentages of time near 1%. In this region, the shape of the curve is determined by the C.C.I.R. rainrate distribution function for Rain Zone #2 incorporated as a simulation model. For very small percentages of time (0.001%) the simulation predicts transmission losses at 6 and 12 GHz lower than the COMSAT measurements. These differences can probably be attributed to differences between the rainfall rate distribution function used in the simulation calculations and the actual rainfall rate distribution for the locations at which the measurements were made.





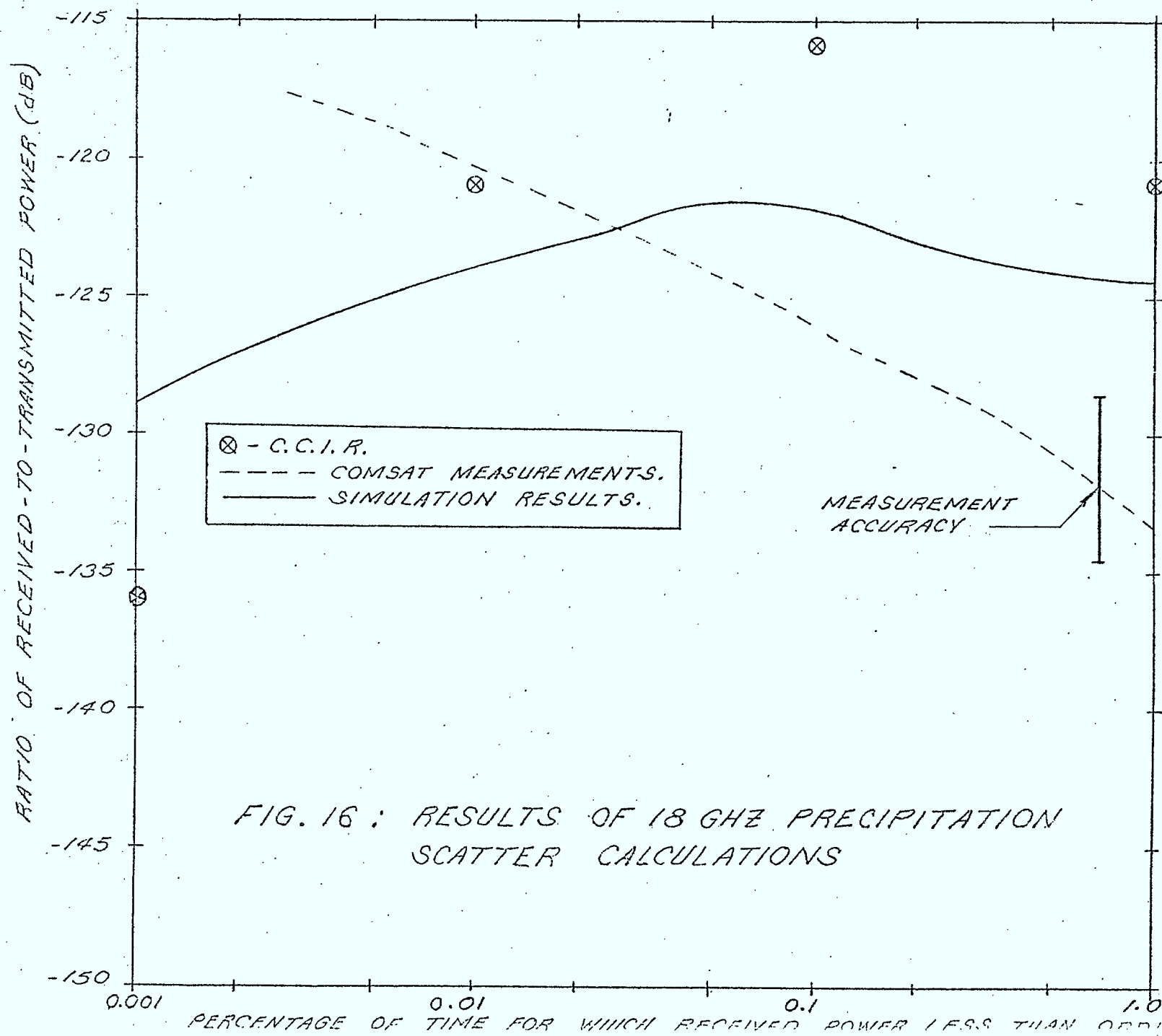


FIG. 16 : RESULTS OF 18 GHZ PRECIPITATION
SCATTER CALCULATIONS

The simulation results at 18 GHz are within 10 dB of the COMSAT measurements but the trend predicted is very different from that shown by COMSAT. For example, the simulation predicts that for high rainfall rates, corresponding to very small percentages of time, the received interference power is less than that at lower rainfall rates. This occurs because of the increased attenuation due to rain along the path from the receiver to the scattering volume associated with the higher rainfall rates. This trend is also evident in the C.C.I.R. model using the same rainfall rate distribution as the simulation.

8.4 Precipitation Scatter Calculations for Various Separation Distances

8.4.1 Introduction

A series of simulation runs were performed to study the effect of precipitation scatter interference on the performance of a satellite communications link. The calculations were performed at 12 GHz for a receiving site in C.C.I.R. rain zone #2, for the rainfall rate exceeded for 0.01% of the time (i.e. 51 mm/hr). The interference originates from a terrestrial transmitter at various distances from the RX site. For very small site separation distances, both direct and indirect (precipitation scatter) interference is possible, as illustrated in Figure 17. For all of the simulation runs the antenna mainbeams were oriented to be in the same plane, with the same elevation angles for each separation distance. As a result, either mainbeam/mainbeam or sidelobe/mainbeam precipitation scatter interference could occur for various separation distances, as illustrated in Figure 17.

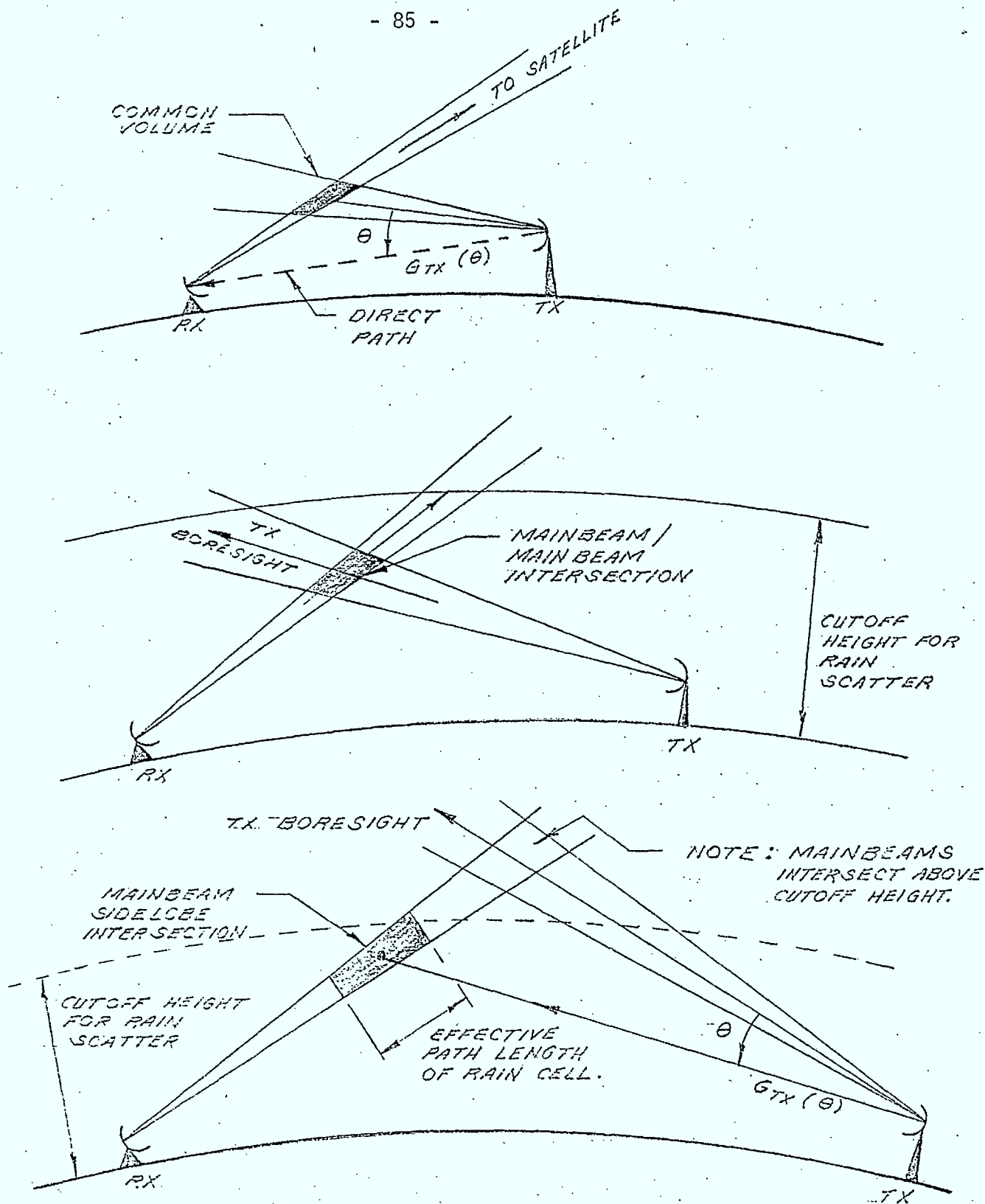


FIG. 17 : PRECIPITATION SCATTER INTERFERENCE CONFIGURATIONS FOR DIFFERENT SITE SEPARATION DISTANCES.

8.4.2 Description of Parameters Used in Simulation Runs

For this series of simulation runs, a single hop communications link was set up between a receiving site located at Ottawa and a geosynchronous satellite located south of the site. The interfering terrestrial transmitter was located south of the receiving site with its antenna directed towards the North. A detailed list of parameters describing the receiver and transmitters follow:

Transmitting Satellite for Link

- Location: longitude = 75.66° W
- Transmitting antenna parameters
 - . Boresight target: Latitude = 45.42° N
Longitude = 75.66° W
 - . Vertical Polarization
 - . On-axis gain = 40 dB
- Carrier Parameters
 - . Carrier frequency = 40 MHz
 - . Type: 4-phase CPSK
 - . Bit rate = 72 Mbits/sec
 - . RF bandwidth = 40 MHz
 - . Output power = 1 watt

Ottawa Receive Site Parameters

- Location: Latitude = 45.42° N
Longitude = 75.66° W
Rain Zone #2

- Receiving Antenna Parameters

- . Points at satellite
(i.e. elevation angle = 37.7°)
- . Diameter = 30 ft.
(gives on-axis gain = 58.5 dB at 12 GHz)
- . Height above ground = 10.0 m

- Receiver Bandwidth = 36 MHz

Terrestrial Transmitter Parameters

- Location: varied from 10 to 500 km south of RX site

- Transmitting Antenna Beam

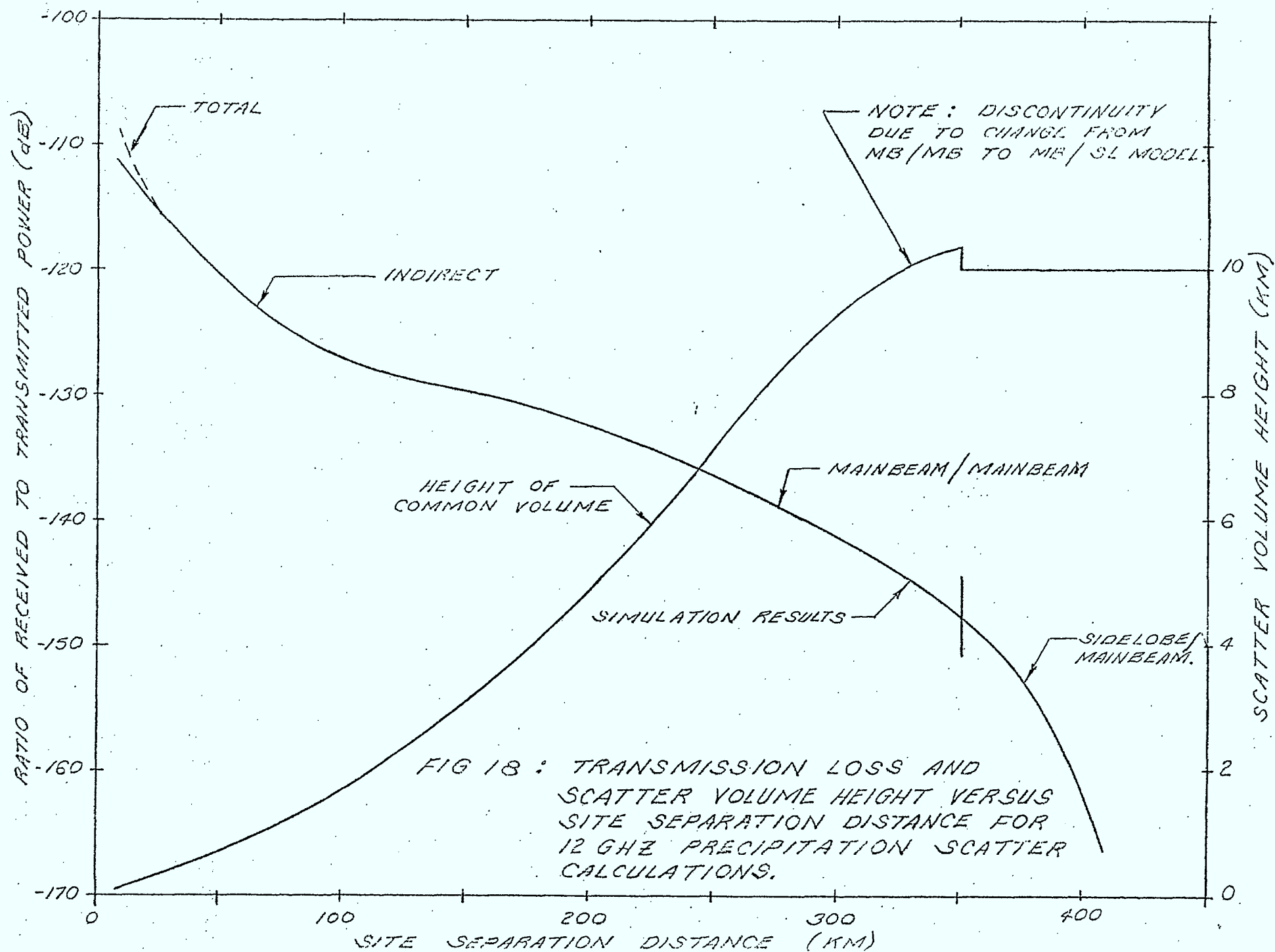
- . Boresight Azimuth = 0° E of N
Elevation = 0.5°
- . Diameter = 8 ft.
(given on-axis gain = 47.1 dB)
- . Height above ground = 30 m

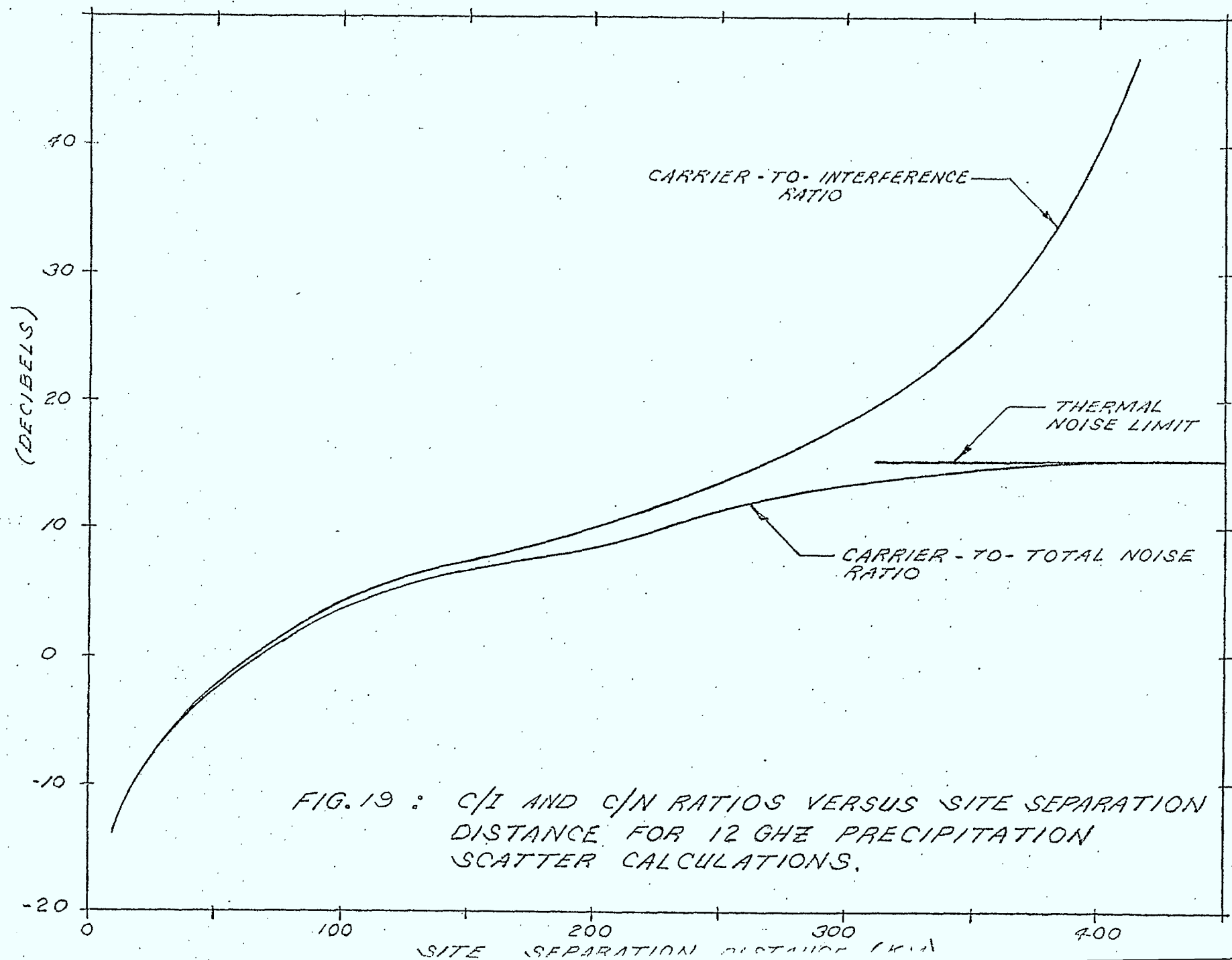
- Carrier Parameters

- . Carrier frequency = 12 GHz
- . Type: FM/TV
- . Peak-to-peak frequency deviation = 16 MHz
- . RF bandwidth = 40 MHz
- . Output power = 10 watts

8.4.3 Results of Simulation Runs

The simulation was run for site separation distances ranging from 10 to 500 km to evaluate the performance of the communications link. The results of these calculations are shown in Figures 18, 19 and 20.





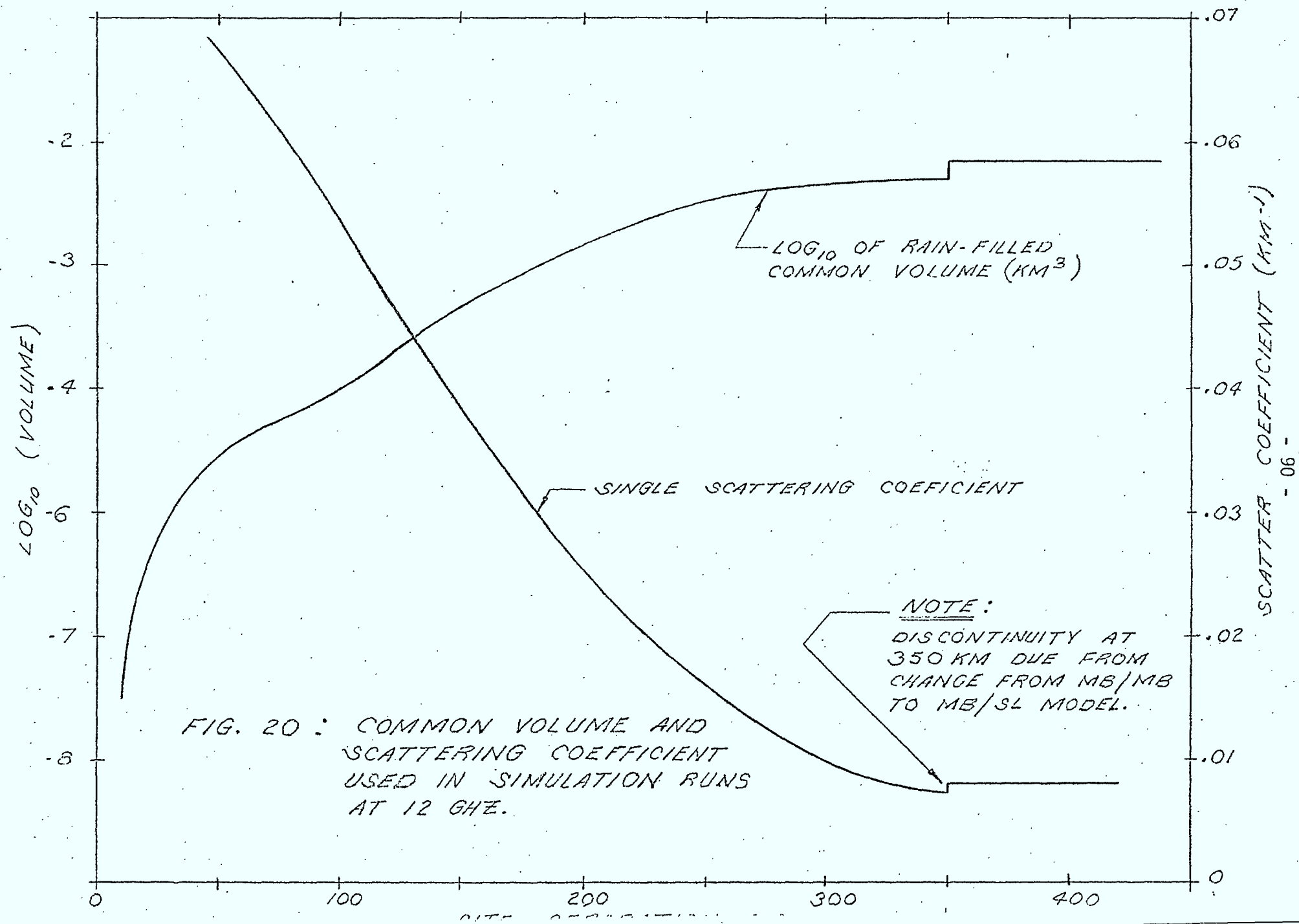


FIG. 20 : COMMON VOLUME AND SCATTERING COEFFICIENT USED IN SIMULATION RUNS AT 12 GHE.

From Figure 18, it can be seen that for separation distances greater than 350 km, the mainbeams of the two antennae intersect above the cutoff height for precipitation scatter for this rain zone (11 km) and the interference mode is sidelobe into mainbeam. A slight discontinuity occurs at this point due to the change from the mainbeam/mainbeam scatter model to the mainbeam/sidelobe model.

For separation distances less than 40 km, both direct and indirect interference may occur. It is found that for separation distances greater than 10 km, precipitation scatter interference is greater than the direct component.

For the communications link, the carrier-to-noise ratio in the absence of interference is 15.3 dB when rain occurs along the receiver boresight. From Figure 19 it can be seen that the carrier-to-interference ratio exceeds this level for separation distances less than 270 km.

The importance of common volume height on the results of these calculations can be seen from Figure 20 in which the rain filled common volume and the single scattering coefficient are plotted. Note that the volume is plotted using a logarithmic scale while the scattering coefficient is plotted using a linear scale. Since the interference power is proportional to the product of the volume and the scattering coefficient it is obvious that the scatter volume height will be an important parameter in precipitation scatter interference calculations.

8.5 Evaluation of Simulation Results

The results of the simulation runs involving precipitation scatter interference have indicated that for frequencies below 12 GHz the simulation model is reasonably consistent with existing measurements and the predictions of the C.C.I.R. model. However, as has been shown, in some cases the simulation predicts results quite different from measurements. At frequencies above 12 GHz the differences between the simulation results and the limited measurements increases.

In most cases it is felt that the differences between the simulation results and actual measurements can be attributed to the difference between the rainfall rate distribution used in the simulation and the actual rainfall rate distribution for the receiving site. Since the simulation model contains the assumption that the surface rainfall rate can be applied to a raincell at any height below the rain scatter cutoff height for a particular climatic zone, the simulation results may become less reliable as the height of the common volume increases.

As has been shown, the simulation is suitable for determining the performance of a satellite communications link. The presence of rain along the downlink receiving antenna boresight affects the link performance in three major ways. First, the wanted carrier is attenuated by the rain. Second, the noise temperature of the receiving antenna increases in proportion to the carrier attenuation, and third, precipitation scatter interference is possible. These and other propagation-related effects are handled by the simulation. As a result of the simulation runs described in this chapter, it is felt that the simulation models are suitable for communication link analyses involving precipitation scatter interference.

9.0 INTERFERENCE BETWEEN TWO DIRECT BROADCASTING-SATELLITE SYSTEMS

9.1 Introduction

In this chapter, the performance of a hypothetical direct television broadcasting satellite system sharing frequencies with a second DBS system serving an adjacent coverage area has been analysed using the simulation. The analysis has been limited to evaluating the signal quality of a television broadcast to a mid-Canada receiving terminal for various inter-satellite spacings. The interference resulting from both co and cross-polarized satellite antennae has been considered.

The simulation was run to analyse a communications link set up between a mid-Canada transmitter, a high power DBS satellite located 110° W of Greenwich and an individual reception terminal using a one meter antenna. The interfering satellite was located at various orbit positions west of the Canadian satellite, as illustrated in Figure 21. The effect of rain attenuation on the downlink was also considered in the simulation runs.

9.2 Description of Parameters Used in Simulation Runs

In this section, a detailed description of the parameters used to describe the DBS satellites and earth terminals is presented.

Canadian DBS Satellite

- Location: longitude = 110° W

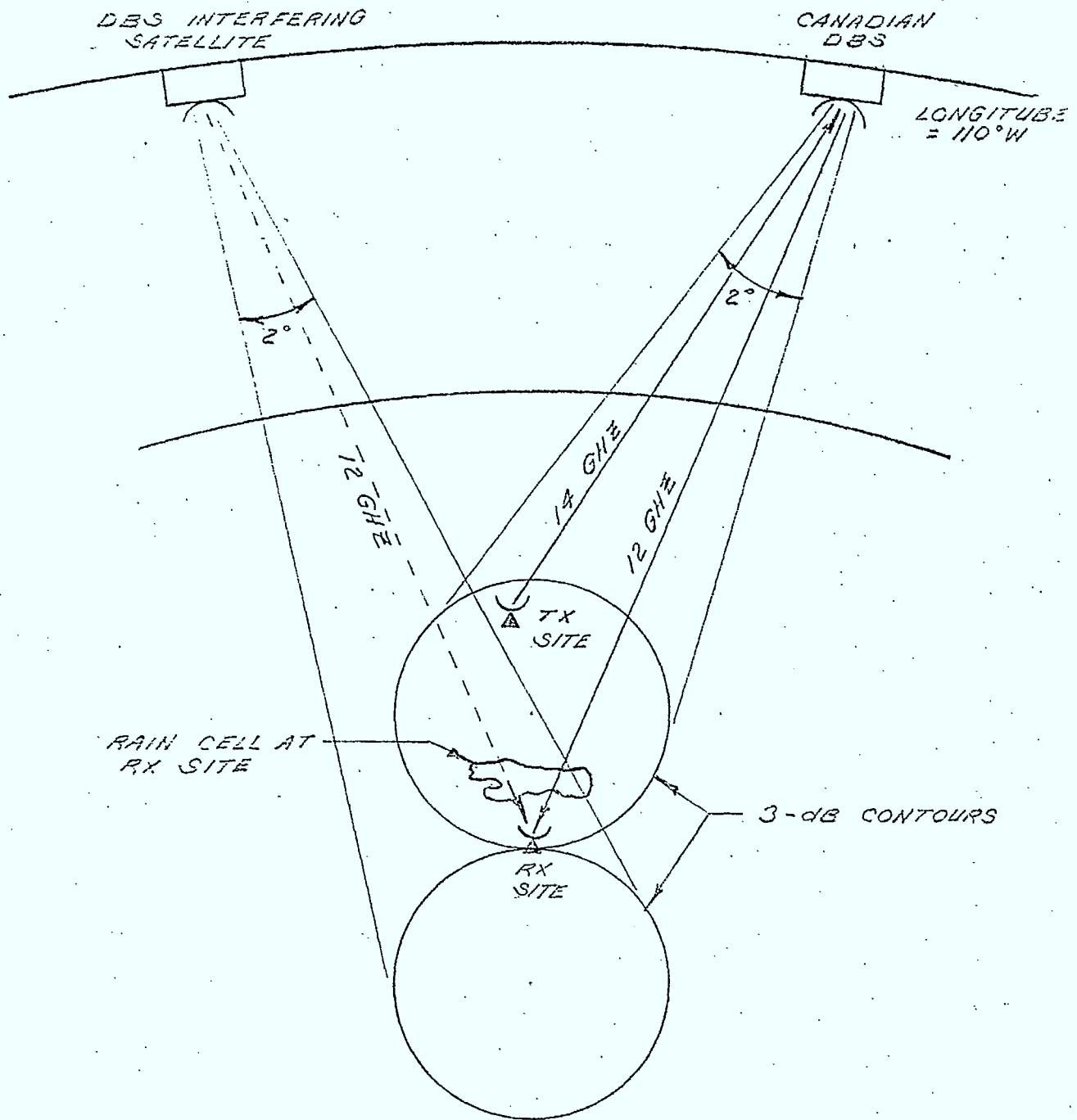


FIG. 21 : RX / TX CONFIGURATION FOR
SIMULATION RUNS INVOLVING TWO
DBS SYSTEMS.

- Transmitting antenna parameters

- . boresight target: latitude = 56° W
 longitude = 100° W
- . 3 dB beamwidth = 2.0°
(ie., gives on-axis gain = 37.5 dB at 12 GHz)
- . Vertical polarization
- . depolarization ratios: main beam = -30 dB
 near-sidelobes = -15 dB
 backlobes = 0 dB

- TX Carrier Parameters

- . Type: FM/TV
- . Carrier frequency = 11914 MHz
- . Peak-to-peak frequency deviation = 8.84 MHz
- . RF bandwidth = 23 MHz
- . output power = 444.6 watts
(ie., satellite E.I.R.P. = 64 dBW)

- Receiving Antenna Parameters

- same as TX beam

- LNA Noise temperature = 1000°K

Uplink TX Site

- ```
- location: latitude = 52° N
 longitude = 106° W
```

- Transmitting Antenna Parameters

- . vertical polarization
- . diameter = 5 m  
(ie., on-axis gain = 55.2 dB at 14 GHz)

- TX Carrier Parameters

- . Type: FM/TV
- . Carrier frequency = 14275 MHz
- . Output power = 86.7 watts

Downlink RX Site

- Location: latitude = 49° N  
                  longitude = 97° W  
                  Rain Zone #2

- RX Antenna Parameters

- . vertical polarization
- . diameter = 1 m  
(ie., on-axis gain = 39.3 dB at 12 GHz)
- . depolarization ratios: same as satellite antennae

- LNA Noise temperature = 2000° K

- RF Noise bandwidth = 18 MHz

Interfering DBS Satellite

- Location: West of Canadian DBS satellite

### - Transmitting Antenna Parameters

- . boresight target: latitude =  $38^{\circ}$  N  
                    longitude =  $100^{\circ}$  W
- . polarization: linear-both vertical and horizontal polarizations were considered.

- Transmitted Carrier parameters

- . same as other DBS satellite

### 9.3 Results of Simulation Runs

The signal quality of the FM/TV communications link connecting the two earth terminals was evaluated using the simulation for inter-satellite spacings from 1 to 20 degrees. The runs were carried out for both co and cross-polarized satellite antennae.

The calculations were performed at 200 step spectral resolution and C.C.I.R. antenna models were used throughout the calculations. For the uplink calculation, clear weather propagation was assumed. It was assumed that the rainfall rate exceeded for 0.5% of the time occurred on the downlink at the receiving site.

The performance of the communications link in the absence of interference is illustrated in Table 9. The effects of interference are illustrated in Figure 22 in which the carrier-to-interference ratio and the carrier-to-total noise ratio are plotted as functions of the satellite spacing for the two polarizations.

Table 9: DBS Communications Link Results

- thermal noise only

Uplink

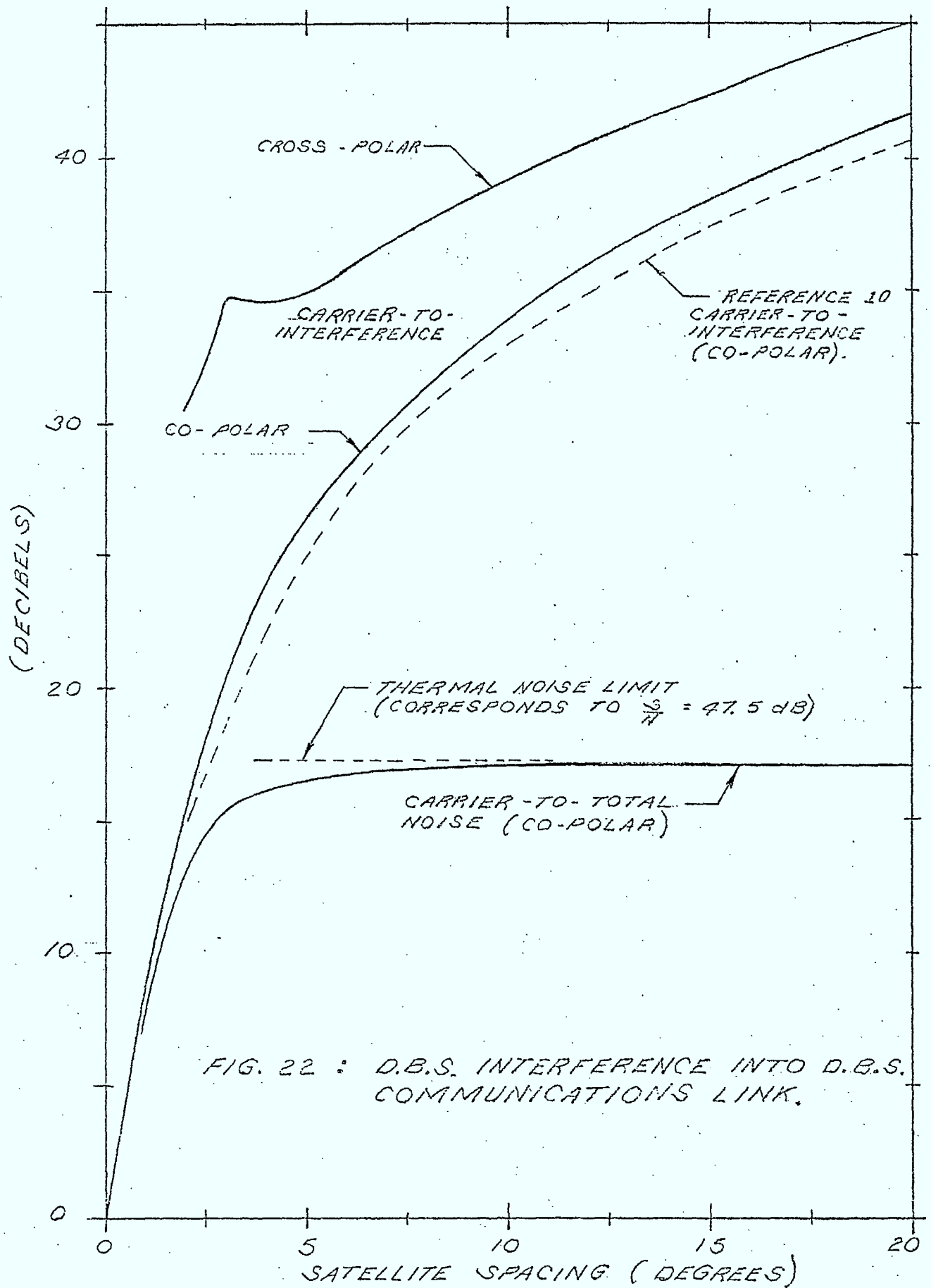
- . Frequency = 11814 MHz
- . carrier-to-noise ratio = 28.2 dB

Downlink

- . Frequency = 14275 MHz
- . rain attenuation = -1.0 dB
- . antenna noise temperature = 86° K
- . carrier-to-thermal noise on downlink = 17.6 dB

Overall Link Performance

- . carrier-to-noise ratio = 17.2 dB
- . peak signal (synch tip included)-to-rms weighted noise ratio = 47.5 dB



In the absence of interference the overall signal quality is determined almost exclusively by the downlink thermal noise. The presence of rain at the receiving site only degrades the signal-to-noise ratio by 1.2 dB with only 0.2 dB of this due to the increase in antenna temperature.

The simulation runs have indicated that when the interfering satellite antenna is cross-polarized, the highest interference-to-carrier ratio occurs when both satellites occupy the same orbit position. This value is determined by the mainbeam depolarization ratios of the receiving earth station and interfering satellite antennae. For all other inter-satellite spacings, the interference-to-carrier ratio is lower than this value due to the small beamwidths of the receiving and transmitting antennae. For large inter-satellite spacings, the carrier-to-interference ratio approaches that predicted for the co-polarized configuration due to the increase in antenna depolarization at large off-axis angles.

When the interfering satellite uses the same polarization as the satellite transmitting the wanted carrier, interference can dominate link noise budget for small inter-satellite spacings. A similar situation involving two DBS satellites has been considered in Reference 10. Although the satellite parameters used in the simulation analysis are slightly different, the results of calculations reported in this reference have been plotted in Figure 22 for comparison. It can be seen that both analyses predict carrier-to-interference ratios with one decibel of each other.

#### 9.4 Evaluation of Simulation Results

The results of these simulation runs indicate that the

simulation can be used to evaluate the performance of a DBS system operating in the presence of interference from another DBS system. These results can be useful in determining minimum inter-satellite spacing for which acceptable signal quality can be obtained.

As a result of these simulation runs, the models used in the simulation can be evaluated for their suitability in this and other analyses of this type:

- . geometric models - adequate
- . antenna models - suitable. It should be noted that when C.C.I.R. models are desired, simulation uses the "community-reception" sidelobe model for small diameter receiving antennae described in Reference 11.
- . antenna depolarization model - suitable. Although the simulation default values for the depolarization ratios have been used in these analyses, actual values should be used for all antennae when they differ from the defaults.
- . spectrum models - the FM/TV model is suitable for calculation of the overall signal-to-noise ratio at the demodulator output.
- . HPA model - suitable. The simulation default values for amplifier distortion parameters were used in these runs. For the analysis of high power DBS satellite systems, actual values should be used since distortion may be important in determining the performance of the system.

- . propagation models - suitable
- . antenna temperature model - suitable
- . demodulator model - suitable. Note the simulation does not determine the signal-to-noise ratios of audio subcarriers associated with the television signal.
- . de-emphasis/noise weighting models - suitable. Note that the simulation only includes C.C.I.R. models for television basebands and that 525, 625, or 819 line systems can be analysed.

## 10.0 DIRECT BROADCASTING-SATELLITE AND FIXED-SATELLITE INTERFERENCE CALCULATIONS

### 10.1 Calculations

In this chapter the performance of a direct broadcasting satellite system sharing the 12/14 GHz bands with a satellite system in the fixed-satellite service is studied using the simulation. Both uplink and downlink interference into each system is considered in the analysis for a range of inter-satellite spacings.

The two cases which have been studied are illustrated in Figures 23 and 24. Both satellite antenna systems were vertically polarized and had the same eastern Canada coverage zones. The same elliptical receiving antennae and circular transmitting antennae were used for each satellite system. In all of the simulation runs the DBS satellite was located at a longitude of 105° W. The position of the fixed-satellite was varied from 2.5 to 30 degrees east of the DBS satellite.

Two communications links were analysed for each inter-satellite spacing. The first was an FM/TV broadcast from a transmitting site in southern Ontario receiving station using a one meter diameter antenna. The second was a digital (PSK) transmission from a southern Ontario transmitting site; via the fixed-satellite, to a northern Ontario receiving site. Both heavy-route, high bit rate and low bit rate thin-route carriers were considered. For the thin-route analysis, a smaller receiving antenna was used. The interference into the DBS system was either the thin-route or the heavy-route PSK carrier while the FM/TV carrier was the interference

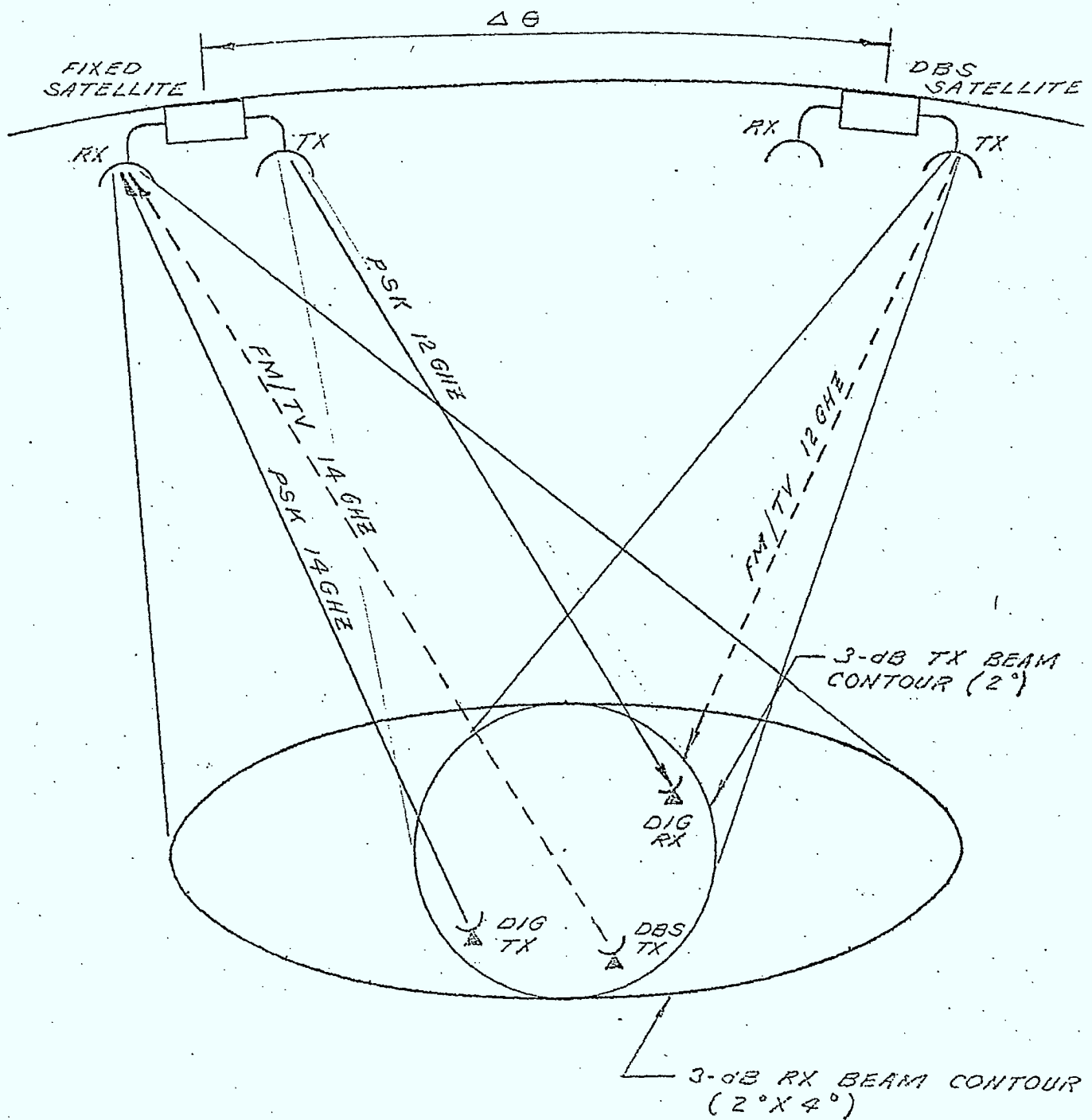


FIG. 23 : INTERFERENCE FROM A DBS SYSTEM INTO A FIXED-SATELLITE LINK.

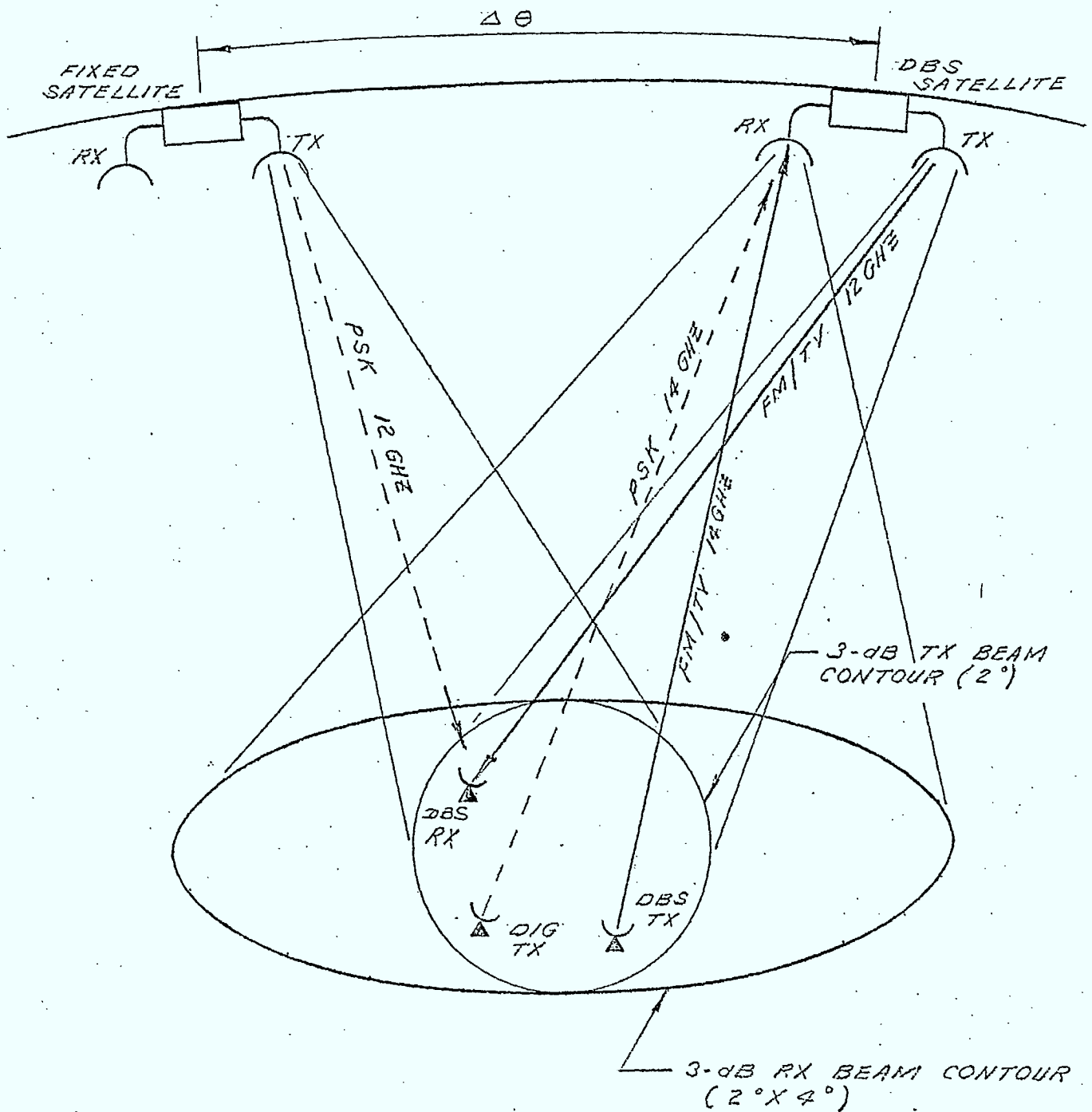


FIG. 24: INTERFERENCE FROM A FIXED-SATELLITE SYSTEM INTO A DBS LINK.

into the fixed-satellite system.

The only propagation effect considered in these analyses was clear weather tropospheric absorption.

## 10.2 Description of Parameters Used in Simulation Runs

In this section, a detailed list of the parameters used to describe the transmitters and receivers used in the simulation runs is presented.

### A. DBS System Parameters

#### Uplink transmit site parameters

- location: latitude =  $45^{\circ}$  N  
                  longitude =  $80^{\circ}$  W

#### transmitting Antenna Parameters

- . points at DBS satellite
- . vertical polarization
- . diameter = 5 m  
(ie. on-axis gain = 54.8 dB at 14 GHz)

#### TX carrier parameters

- . Type: FM/TV
- . carrier frequency = 14275.0 MHz
- . RF bandwidth = 18 MHz
- . peak-to-peak frequency deviation = 8.84 MHz
- . output power = 323 watts  
(ie. gives uplink E.I.R.P. = 79.9 dBW)

Downlink Receiving Site Parameters

- location: latitude =  $55^{\circ}$  N  
                  longitude =  $95^{\circ}$  W
- RX Antenna Parameters
  - . Vertical polarization
  - . diameter = 1 m  
(ie., on-axis gain = 39.3 dB)
- LNA Noise temperature =  $2000^{\circ}$  K
- Receiver Noise bandwidth = 18 MHz

DBS Satellite Parameters

- location: longitude =  $105^{\circ}$  W
- TX Antenna Parameters
  - . boresight target: latitude =  $50^{\circ}$  N  
                                          longitude =  $85^{\circ}$  W
  - . vertical polarization
  - . 3 dB beamwidth =  $2.0^{\circ}$   
(on-axis gain = 37.5 dB)
  - . output power = 445 watts  
(ie., gives E.I.R.P. = 64 dBW)
- RX Antenna Parameters
  - . boresight target: same as TX beam

- . reference target on
  - major-axis of beam: latitude =  $50^{\circ}$  N
  - longitude =  $80^{\circ}$  W
- . vertical polarization
- . major-axis beamwidth =  $4^{\circ}$
- . minor-axis beamwidth =  $2^{\circ}$
- . on-axis gain = 33.7 dB
- . LNA Noise temperature = 1000° K
- . receiver bandwidth = 18 MHz

B. Fixed-Satellite System Parameters

Uplink Transmitting Site

- location: latitude =  $45^{\circ}$  N
- longitude =  $90^{\circ}$  W
- transmitting antenna parameters
  - . points to fixed-satellite
  - . vertically polarized
  - . diameter = 30 ft.
  - (ie., on-axis gain = 60 dB at 14 GHz)
- transmitted carrier parameters
  - . the following parameters characterize both the heavy-route and the thin-route carriers:
    - . 4-phase CPSK
    - . carrier frequency = 14275.0 MHz

- . 2-pole Butterworth filter on modulator output
- . 3 dB filter bandwidth = 1/2 bit rate

|                  | <u>HEAVY-ROUTE CARRIER</u> | <u>THIN-ROUTE CARRIER</u> |
|------------------|----------------------------|---------------------------|
| Bit Rate:        | 61.248 Mbits/sec.          | 0.064 Mbits/sec.          |
| RF bandwidth:    | 40 MHz                     | 0.06 MHz                  |
| Output power:    | 398 watts                  | 0.5 watts                 |
| Uplink E.I.R.P.: | 86 dBW                     | 57 dBW                    |

Downlink Receiving Site

- location: latitude = 55° N  
longitude = 75° W

- Receiving Antenna parameters

- . HEAVY ROUTE: Diameter = 30 ft.  
(on-axis gain = 58.5 dB at 12 GHz)
- . THIN ROUTE: Diameter = 9.8 ft.  
(on-axis gain = 48.7 dB at 12 GHz)
- . Vertical polarization

- LNA Noise temperature

- . HEAVY ROUTE: 160° K
- . THIN ROUTE: 300° K

- Receiver Noise Bandwidth:

. HEAVY ROUTE: 40 MHz

. THIN ROUTE: 0.06 MHz

Satellite Parameters

- location: east of DBS satellite

- transmitting Antenna Parameters

. same as DBS TX antenna

- TX carrier parameters

. carrier frequency = 11914 MHz

. output power:

. HEAVY ROUTE = 3.5 watts

(E.I.R.P. = 42 dBW)

. THIN ROUTE = 0.024 watts

(E.I.R.P. = 21 dBW)

Receiving Antenna Parameters

. same as DBS RX antenna

- LNA Noise temperature = 1120° K

### 10.3 Results of Simulation Runs

The performance of each of the communications links was evaluated using the simulation for a range of inter-satellite spacings. The C.C.I.R. antenna models were used for all of the simulation runs. Two hundred step resolution was used in evaluating the RF spectra of the wanted carrier and interferor.

The performance of each link in the absense of interference is shown in Tables 10 and 11. In the case of the digital link, the thermal noise performance is dependent on the location of its satellite. This is due to the fact that the receiving site is near the edge of the satellite coverage zone and at the receiving site the flux from the satellite changes sightly with satellite position.

The performance of the DBS link with either thin-route PSK or the heavy-route PSK interference is illustrated in Figure 25. Since only a single thin-route carrier was considered in this analysis, the interference-to-carrier ratio on either the uplink or the downlink due to this carrier is negligible in comparison with the carrier-to-thermal noise ratio. When the interference into the DBS link consists of the heavy-route digital carrier, the interference contributes only slightly to the overall noise budget. At a satellite separation angle of 2.5 degrees, the total interference power is only 2% of the thermal noise power.

The performance of the digital links is illustrated in Figures 26 and 27. It can be seen that in each case,

TABLE 10: PERFORMANCE OF DBS LINK IN ABSENCE  
OF INTERFERENCE

UPLINK

. carrier-to-thermal noise ratio = 30.0 dB

DOWNLINK

. carrier-to-thermal noise ratio due to  
downlink only = 15.8 dB

. antenna noise temperature = 16.9° K

TOTAL

. RF carrier-to-noise ratio into demodulator = 15.7 dB

. peak signal (synch tip included)-to-rms  
weighted noise ratio = 46.0 dB

TABLE 11 PERFORMANCE OF PSK LINKS IN  
ABSENCE OF INTERFERENCE

| SATELLITE<br>LONGITUDE = 75° W              | HEAVY ROUTE | THIN ROUTE |
|---------------------------------------------|-------------|------------|
| uplink carrier-to-<br>Thermal noise ratio   | 32.4 dB     | 31.7 dB    |
| downlink carrier-to-<br>Thermal noise ratio | 21.7 dB     | 16.1 dB    |
| carrier-to-total<br>noise ratio             | 21.4 dB     | 16.0 dB    |
| error probability                           | negligible  | negligible |

| SATELLITE<br>LONGITUDE = 102.5° W           | HEAVY ROUTE | THIN ROUTE |
|---------------------------------------------|-------------|------------|
| uplink carrier-to-<br>Thermal noise ratio   | 32.8 dB     | 32.0 dB    |
| downlink carrier-to-<br>Thermal noise ratio | 23.9 dB     | 18.3 dB    |
| carrier-to-total noise<br>ratio             | 23.3 dB     | 18.1 dB    |
| error probability                           | negligible  | negligible |

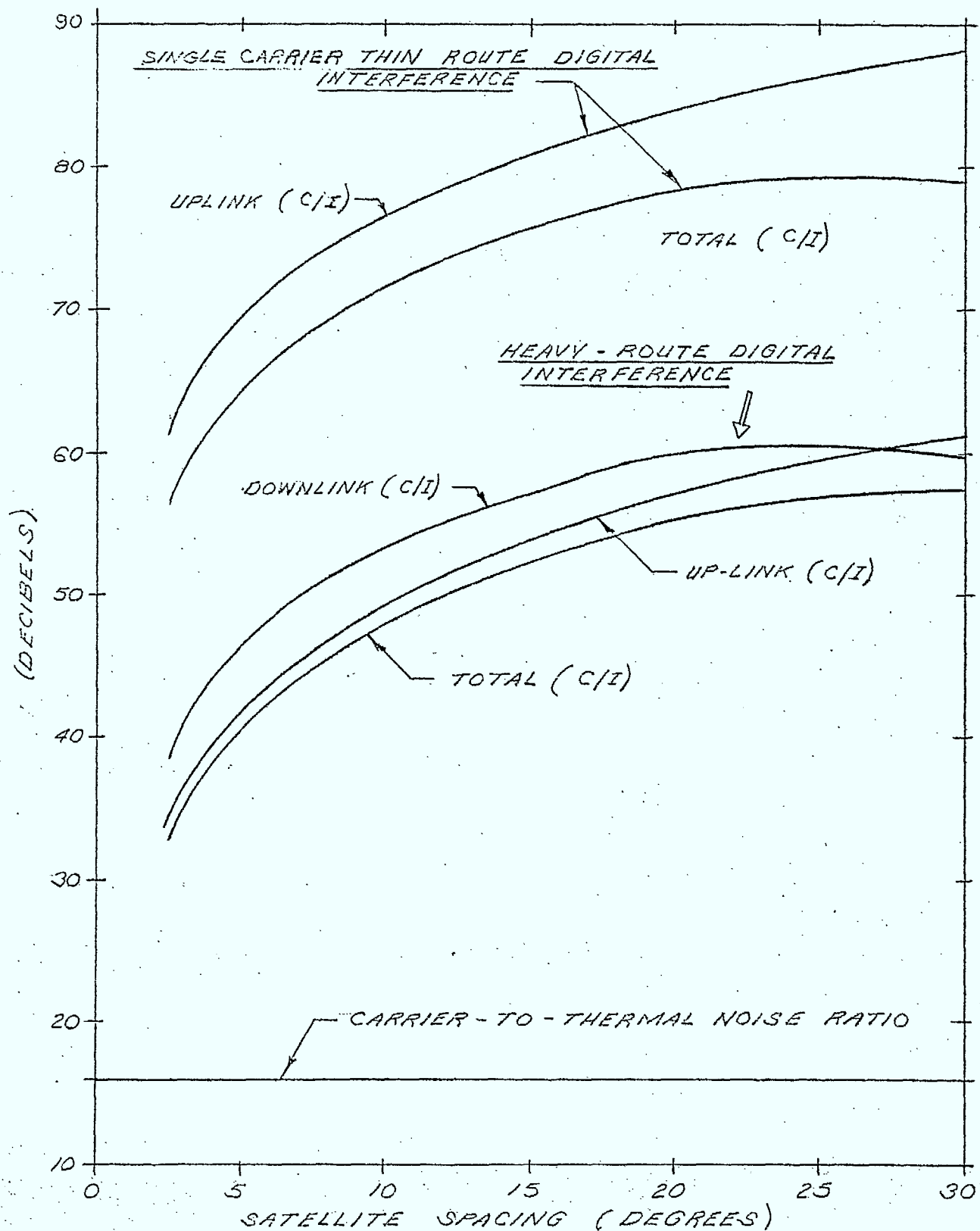


FIG. 25 : PERFORMANCE OF DBS LINK IN PRESENCE OF THIN-ROUTE AND HEAVY-ROUTE PSK INTERFERENCE

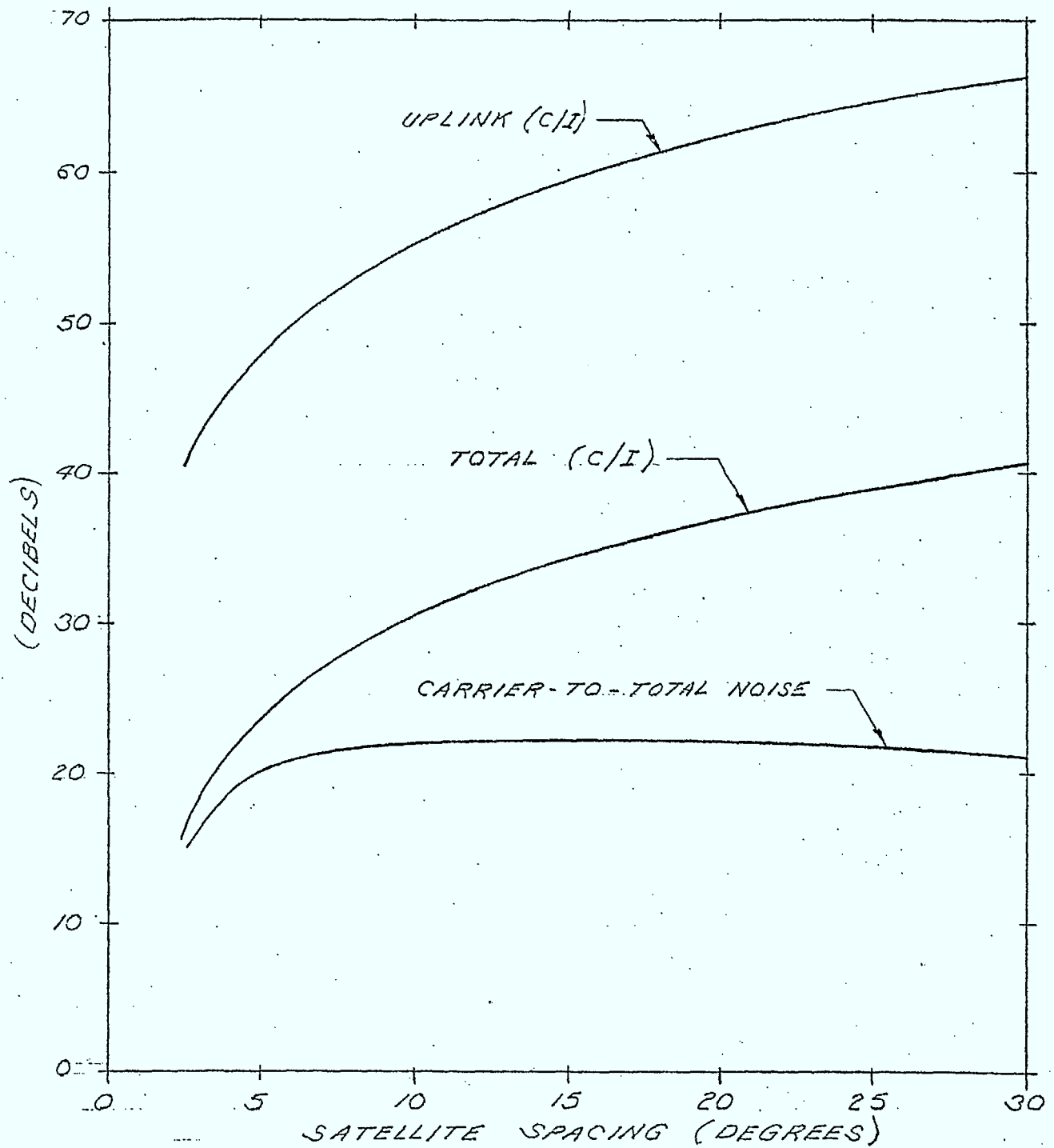


FIG. 26 : PERFORMANCE OF HEAVY-ROUTE PSK SYSTEM IN PRESENCE OF INTERFERENCE FROM A DBS SYSTEM

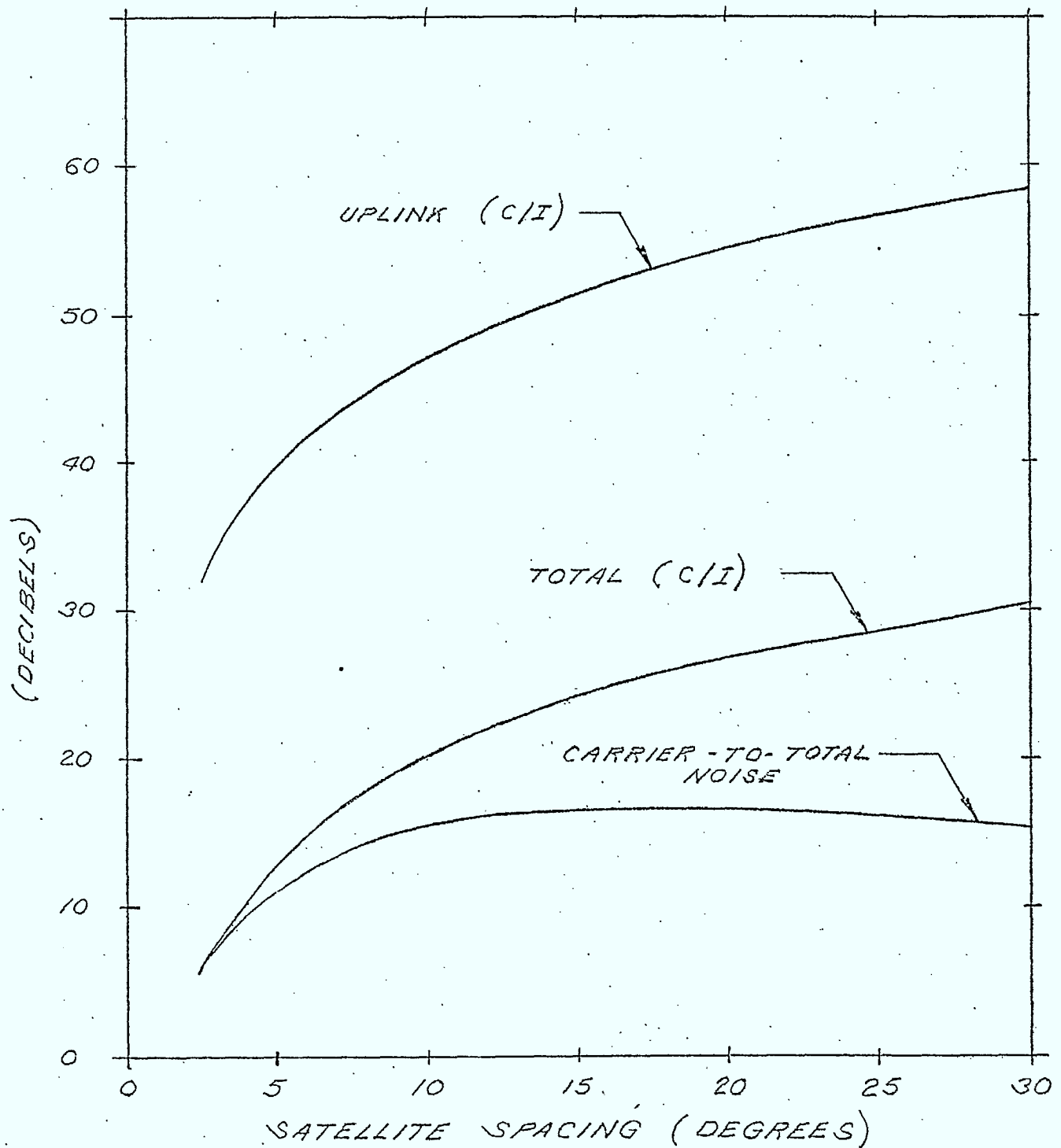


FIG. 27: PERFORMANCE OF THIN-ROUTE PSK SYSTEM IN PRESENCE OF INTERFERENCE FROM A DBS SYSTEM

the uplink interference-to-carrier ratio is at least 25 dB below the downlink interference-to-carrier ratio. Unlike the DBS link, the total interference power can exceed the thermal noise level for small inter-satellite spacings.

Of the three links analysed, the performance of the thin-route PSK link is degraded by interference sooner than the heavy-route PSK or the DBS link, in agreement with the calculations of Reference 10. The least susceptible to interference was the DBS link, also in agreement with the results of Reference 10.

#### 10.4 Evaluation of Simulation Results

The results of these simulation runs are consistent with previous analyses, and illustrate the usefulness of the simulation as an aid in determining compatible orbital spacings for satellites in the different services.

As a result of these simulation runs the models used in the simulation can be evaluated for their suitability in this and other analyses of this type:

- . geometric models - suitable
- . antenna models - suitable
- . spectrum models - suitable. Note that at the spectral resolution used for these analyses, the thin-route carrier is approximated by a rectangular spike for interference calculations since its RF bandwidth is comparable to the spectral resolution of the simulation. When the thin-route link was analysed, much finer

resolution was used and the PSK spectrum model was used. The FM/TV interference spectrum model used in the thin-route link analysis may under-estimate the spectral density over the narrow RF bandwidth of the thin-route receiver. This is not a problem in the heavy-route PSK analysis.

- . propagation models - suitable.
- . demodulator model - suitable for FM/TV link analyses. For PSK links, the error probability models predict error probabilities much too low, as noted in Chapter 7.

NOT RELEVANT TO  
ISSUE #2 ORO'S  
PROGRAM.

## 11.0 CONCLUSIONS AND RECOMMENDATIONS

### 11.1 Conclusions

As a result of the simulation runs and associated analysis described herein it can be concluded that:

1. The models and algorithms incorporated in the simulation are adequate for the analysis of a wide variety of orbit/spectrum interference problems.
2. The simulation results are consistent with those of other analyses and experimental measurements in those cases for which comparison is possible.

### 11.2 Recommendations

A number of recommendations are presented based on the results of these simulation runs:

1. The simulation should now be applied to the analysis of practical problems involving more complicated interference situations for which simulation techniques are required. Two possible studies of immediate interest are:
  - . the effects of earth terminal antenna diameter on orbit utilization.
  - . the effects of SCPC thin-route carriers on both the fixed-satellite and the

direct broadcasting-satellite service,  
and the effect of DBS interference into  
SCPC thin-route systems.

2. As noted in the report, the PSK demodulator models should be improved to more accurately model non-ideal, real, demodulators.
3. A spectrum model suitable for modelling the RF spectrum of a channel containing many demand access thin-route carriers be added to the simulation.
4. More realistic, non-linear, amplifier characteristics should be incorporated in the HPA model for IF-type channels to more accurately model past-link signal attenuation.
5. A model should be added for the gain pattern of real spacecraft antenna to allow more accurate modelling of real systems.

Other simulation model revisions and extensions have been identified and are listed below:

- . inclusion of ionospheric effects such as Faraday rotation and scintillation.
- .. inclusion of low angle refractive bending.
- . inclusion of transhorizon ducting.
- . improvement of HPA distortion model.
- . site shielding effects.

In addition, other program oriented simulation extensions are outlined in Reference 4.

REFERENCES.

1. SED 0710-44-TR-102, Issue 2; "Orbit Frequency Utilization Simulation - Volume 1 - Analytical Foundation", April 30, 1976.
2. SED 0710-44-SW-103, Issue 1; "Orbit Frequency Utilization Simulation - Volume 2 - Program Description", April 30, 1976.
3. SED 0710-SW-104, Issue 1; "Orbit Frequency Utilization Simulation - Volume 3 - Program Listing", April 30, 1976.
4. SED 0710-SW-105, Issue 1; "Orbit Frequency Utilization Simulation - Volume 4 - User's Guide", April 30, 1976.
5. Jeruchim, M.C., and Kane, D.A., "Orbit/Spectrum Utilization Study", Vol. IV, Doc. No. 70SD4293, General Electric, Space Systems Organization, December 31, 1970.
6. "Multi-Beam SHF Satellite Communications System for Canada (1977-1985)", Final Report, Bell-Northern Research, Ottawa, Canada, October 1972.
7. Reinhart, E.E., "Orbit-Spectrum Sharing Between the Fixed-Satellite and Broadcasting-Satellite Services with Applications to 12-GHz Domestic Systems", R-1463-NASA, the RAND Corp., May 1974.
8. "Virginia Precipitation Scatter Experiment - Data Analysis", R.K. Crane, X-750-73-55, November 1972, Goddard Space Flight Center, Greenbelt, Maryland.
9. C.C.I.R. Report 339-1 (Rev. 72), "Influence of Scattering from Precipitation on the Siting of Earth and Terrestrial Stations".

10. "Feasibility of Frequency sharing between the Broadcasting-Satellite Service and the Fixed-Satellite service in the Band 11.7 GHz - 12.2 GHz", DOC 4/233-E, November 7, 1973.
11. C.C.I.R. Report 213-3, "Broadcasting-Satellite Service: Sound and Television", 1974.



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