coverage area of a hub. This distance is 0.707 R, where R is the cell radius. (The area of the hub coverage is πR^2 and the area within the circle bounded by 0.707 R is $(0.707)^2\,\pi R^2 = 0.5\,\pi R^2$.) Hence the average CPE TX power is 3 dB less than the power at maximum range; hence the PSD is also 3 dB less:

$$\overline{PSD_{EIRP}} = PSD_{EIRP} - 3\text{ dB}$$

The next step is to determine the average area associated with each subscriber which causes interference into the satellite so as to determine the PSD area density. The first step toward this objective is to determine the average number of subscribers associated with a hub which can be transmitting on the same frequency. This is simply the total number of subscribers supported by a hub divided by the number of unique frequency channels.

N = (Total No. Subscribers/hub)/(Number of frequency channels)

The average number of subscriber or CPE antennas which couple with the satellite antenna is simply the ratio of the CPE antenna beamwidth, θ , to 360 degrees multiplied by N:

$$n = N\theta/360$$

Now the average area associated with an interfering subscriber can be computed. It is the total area, A, served by a hub (with cell radius R), divided by n:

$$A = \pi R^2$$
$$A' = A/n = \pi R^2/n$$

Now the desired Power Spectral Area Density, ψ , can be calculated:

$$\psi = \overline{PSD_{EIRP}} - 10\log(\pi R^2/n)$$

The units of ψ are dBW/MHz-km^2. This value assumes that all subscribers transmit with a 100% duty factor. This is the case for some systems (e.g., Endgate Technology). However others are able to serve the stated number of subscribers based on a duty factor. In those cases, the Power Spectral Area Density value must be adjusted for the duty factor:

$$\psi' = \psi + 10\log(\text{duty factor})$$

This is the average value associated with a single hub. The next step is to adjust the value for the wide area covered by the satellite footprint. Since the value is per unit area, it is only necessary to adjust the value based on ratio of coverage. The following factors are applied:

P_1	Percent of CPE signals having same polarization as satellite	50%	- 3 dB
P_2	Percent of CPEs having clear LOS path to satellite	50%	- 3 dB
P_3	Percent of CPEs simultaneously active	50%	- 3 dB
P_4	Percent of Hub coverage		
	For 200 X 400 km footprint	25%	- 6 dB
	For 2000 X 400 km footprint	10%	-10 dB

$$\Psi = \psi' + P_1 + P_2 + P_3 + P_4$$

The final Power Spectral Area Density, Ψ , is the effective value for the LMDS CPEs located within a specific satellite footprint (either 200 X 400 km, or 2000 X 400 km). It represents the worst case (realistic) power spectral area density seen by a satellite located at an elevation angle of 2.5 degrees and "seeing" the CPEs located within a CPE antenna beamwidth. This does not include any CPE sidelobe radiation, but only the radiation from the CPE main beam.

The analysis was implemented using a spread sheet to perform the calculations. The results are tabulated in Table Seven.

Table Seven. Typical CPE/Iridium Satellite Direct Beam Interaction Analysis

	TI Sys 1	CV Sys 2	HP Sys 3	EG Sys 4
No Sub Ch in 150 MHz BW	60	150	150	6
No Sub/Node in 150 MHz BW	5760	14400	3600	120
Subscriber Duty Cycle	0.04	0.04	0.04	1
Sub Ant Gain, dB	34	31	35	39
Sub Ant Beam Width, Deg	2.5	4	3	2.5
Sub TX Bandwidth, MHz	2.5	1	1	24
Sub TX Power, dBW	-17	-23	-19.6	-13
Hub Spacing, km	5	5	2	2.2
Avg PSD/MHz	10.02	5.00	12.40	9.20
Psi, dBW/MHz-sq km	-10.69	-13.67	-5.58	-11.2
Psi with duty factor applied	-24.67	-27.65	-19.56	-11.2
PSAD, Small Footprint	-39.67	-42.65	-34.56	-26.2
PSAD, Large Footprint	-43.67	-46.65	-38.56	-30.2

The analysis was completed for the four types of systems and for two footprint areas. The results are summarized in Table Eight.

Table Eight: Typical LMDS CPE/Iridium Main Beam Interaction Analysis

System	Power Spectral Area Density, $dBW/MHz\text{-}km^2$ For 200 km X 400 km Area	Power Spectral Area Density, $dBW/MHz\text{-}km^2$ For 2000 km X 400 km Area
Texas Instruments (Sys 1)	-39.67	-43.67
CellularVision (Sys 2)	-42.65	-46.65
Hewlett Packard (Sys 3)	-34.56	-38.56
Endgate Technology (Sys 4)	-26.2	-30.2

The results indicate that the Power Spectral Area Densities are below the levels necessary to provide the required C/I ratios at the satellite for the large foot print case, even under the worst case scenario. Even when combined with the interference caused by CPE antenna sidelobes, the levels are well below the tolerable levels (-26 $dBW/MHz\text{-}km^2$) for the satellite. When the satellite is well above the horizon, the main beam coupling will be significantly reduced. Therefore it is concluded that LMDS CPEs will not cause sufficient interference into the satellite to degrade performance of the satellite even under worst case conditions. This is achieved without any system constraints other than antenna sidelobe control, EIRP control and PSD control.

CONCLUSIONS

The C/I ratio results using the statistical approach for CPE distribution and return link operation, and the direct beam interaction analysis shows that the Iridium satellite receiver is not affected by the CPE return link transmission. In addition, the direct beam interaction analysis yielded power spectral densities lower than the specified -26 $dBW/MHz\text{-}km^2$. Thus, one can conclude that LMDS systems designed for the terrestrial applications can co-exist with the Iridium system and not cause harmful interference to the Iridium satellite receivers when the 29.1 to 29.25 GHz spectrum is used as return links from the LMDS CPEs to the hubs.

Appendix A. Statistical Program Description

For analysis of the aggregate power emanating from a large area, the program written by FCC engineer Harry Ng was used with modifications to accommodate subscriber (CPE) transmissions. Modifications include the addition of subscriber antenna patterns, random subscriber-to-hub distance, power control, and a random azimuth for CPE transmission. The subscriber-to-hub distance is based on a maximum and minimum hub range. Subscriber antenna elevation angle is calculated from hub tower height and distance from the hub. Following is a description of the program calculations.

Inputs to the program are as follows.

- satellite altitude
- satellite half power beam width and antenna pattern
- satellite elevation angle at the edge of the half power beam width
- satellite earth station feeder link radiated power density
- CPE radiated power density at maximum range to the hub
- hub or CPE spacing within the footprint
- hub or CPE spacing outside the footprint
- hub tower height
- maximum CPE range to hub
- angle where CPE path blocking is expected

The program loops through latitude swaths equal to the CPE spacing. For each swath, the power as seen by the satellite antenna, is computed for each simultaneous CPE transmission. A matrix of latitude and longitude calculations is performed and the power is accumulated to obtain the aggregate power into the satellite. Each latitude swath is summarized in the output with the angle from the CPE to the satellite in 5 degree bins.

To accurately model the subscriber radiated power directed toward the satellite, the pointing angle of each subscriber antenna is randomly selected over 360 degrees with a uniform distribution. The azimuth and elevation angle of the subscriber antenna is used to calculate antenna pattern gain and the look-angle to the hub.

Look-angle to the hub is determined from the tower height and subscriber to hub distance. Based on the maximum range to the hub, the distance to the hub is randomly selected using square root of uniform distribution. The square root applies because subscriber density varies by area and the area varies by the square of the distance from the hub. Once the look-angle is calculated, the angle to the satellite is calculated from the satellite geometry and the subscriber antenna pattern is interpolated to find the radiated power density directed toward the satellite.

Subscriber power is based on the distance from the hub. Radiated power is reduced by the 20*log the ratio of the randomly selected distance to the hub and the maximum range.

Blocking is expected for low elevation angles of subscriber transmission such that line of sight to the satellite is blocked for 50% of the subscribers.

The aggregate power at the satellite is computed for locations in the half power beamwidth and outside the half power beam width. The total from both inside and outside the beamwidth is compared to the feeder power density to determine the C/I ratio.

The number of hubs in the footprint is geometrically computed from the SV antenna beamwidth, SV altitude and elevation angle to satellite and is provided as an output. The number of hubs outside the half power beamwidth is also an output.

Appendix B. Population/Subscriber Density Calculations

The number of simultaneously transmitting subscribers is based on the hub circuit capacity. To determine the number of subscribers (CPEs) transmitting simultaneously within the SV footprint, high density areas of the United States were used to calculate the number of hubs required. Footprint orientations of North-South along the Northeastern seaboard and East-West from the Northeast seaboard are summarized by state in the table below.

Table B.1 Population and Area for North-South and East-West Footprints

State	North-South	Population (millions)	Area x1000 (Sq Km)	East-West	Population (millions)	Area (K Sq Km)
NH	X	1.1	24.2			
VT	X	0.6	24.9			
MA	X	6.0	27.3	X	6.0	27.3
RI	X	1.0	4.0	X	1.0	4.0
CT	X	3.3	14.4	X	3.3	14.4
NY	X	18.2	139.8	X	18.2	139.8
NJ	X	7.8	22.6	X	7.8	22.6
PA	X	12.0	119.3	X	12.0	119.3
DC	X	0.6	.2			
DE	X	0.7	6.4			
MD	X	5.0	32.1			
VA	X	6.4	110.8			
WV	X	1.8	62.8			
SC	X	3.6	82.9			
GA	X	6.9	154			
OH				X	11.1	116.1
MI				X	9.5	250.7
IL				X	11.7	150.0
IN				X	5.7	94.3
WI				X	5.0	169.0
Totals		75	825.7		43	780.1

From the table above, the worst case footprint density would be North to South covering the Northeast and Mid-Atlantic coast. The area approximates a footprint of 400x2000 km^2 and contains a population of 75 million people. Using an average 3 people per household, the number of households would be 25 million.

Based on the upstream circuit capacity of the hub, the number of hubs required to serve the densely populated Northeastern area is described above. The number of subscribers transmitting is determined by the hub capacity. Worst case busy hour maximum loading is assumed such that all frequencies of all hubs are 100% active. The worksheet table below provides the calculation for average hub spacing for the satellite footprint. This table, for example, is for the TI system which uses the following system parameters.

a) Take rate factor = 0.25. This factor is a conservative estimate of the number of subscribers (CPEs) that would desire 2-way service.

b) Concentration = 4. This is the system circuit concentration (inverse of Erlang).

c) Frequency reuse = 4. The hub frequency is reused 4 times by providing 4 sectors with alternating polarization. In order to account for all CPE frequencies active at one time the spacing is based on 4 times the number of hubs.

d) Capacity of each hub is the worst case if the entire 150 MHz were loaded with RF channels.

e) Active CPE refers to the number of reused frequencies at the hub.

Table B.2 Calculation Worksheet for Determining Hub Spacing

1	B	C	D	E	F
2	ITEM INPUT	CALC	INPUT	RESULT	UNITS
3	Total Households		2.50E+07		Households
4	Take Rate Factor	D3*D4	0.25	6250000	Subscribers
5	Circuit concentration	E4/D5	4	1562500	Circuits required
6	Capacity of each Hub	D5/E6	5760	271	Hubs required
7	Frequency reuse factor	E6/D7	4	1085	CPEs
8	** For 400x2000 Sq. Km. footprint: **				
9	Area of population		800000		Sq. Km.
10	Average area per active CPE	D9/E7		737	Sq. Km./CPE
11	Average spacing (400x2000)	E10^0.5		27	Km.
12	** For original 200x1400 Sq. Km. footprint: **				
13	Original footprint area		280000		Sq. Km.
14	Average area per active CPE	D13/E7		258	Sq. Km./CPE
15	Average spacing (200x1400)	E14^0.5		16	Km.

Table note: The original spacing for 200x1400 footprint did not include ME, SC and GA due to the smaller footprint and was based on a CPE spacing of 17 Km.. The aggregate power calculations use 17 Km. spacing and was not changed to reflect the 27 Km. spacing now being predicted for the larger footprint.

Hub and CPE density outside the footprint is based on similar calculations for the continental US.

The number of CPEs transmitting on any frequency is equal to the hub capacity to receive the circuits. The hub density and average CPE spacing was calculated for the TI system for use in interference calculations. Other systems may be correlated to the results by applying a factor for the difference between system densities. For example, for the CellularVision system the average spacing for the large footprint (row 11, column E of Table B2) would be 43 km, resulting in an additional margin for the C/I ratio. This density also assumes worst case of 100% suitability for LMDS. In actuality, not all area or populous is suited for LMDS due to coverage, competition from other services or for economic reasons.

RULES FOR
LMDS SUBSCRIBER TRANSCEIVERS
IN THE
29.1-29.25 GHZ BAND

§101. Limitations on LMDS subscriber transceivers in the 29.1-29.25 GHz band:

a) shall not transmit an effective isotropically radiated power in excess of 20 dBW/MHz in clear air and shall reduce EIRP, as a minimum, for distances of less than the maximum distance from the hub in accordance with the following formula,

$$P(EIRP, dBW/MHz) = 20\ dBW/MHz + 20 \log d/D$$

where d = transceiver distance to the hub
D = maximum transceiver distance to the hub

b) shall not transmit an effective isotropically radiated power in excess of 14 dBW/MHz in clear air if power control in accordance with the formula in (a) is not used,

c) shall have an antenna pattern that shall meet the requirements of that shown in the antenna mask figure with the following characteristics:

and/ or as follows,

equivalent isotropically radiated power on antenna boresight as limited in (a) or (b) shall be reduced for angles of boresight in accordance with the following characteristics:

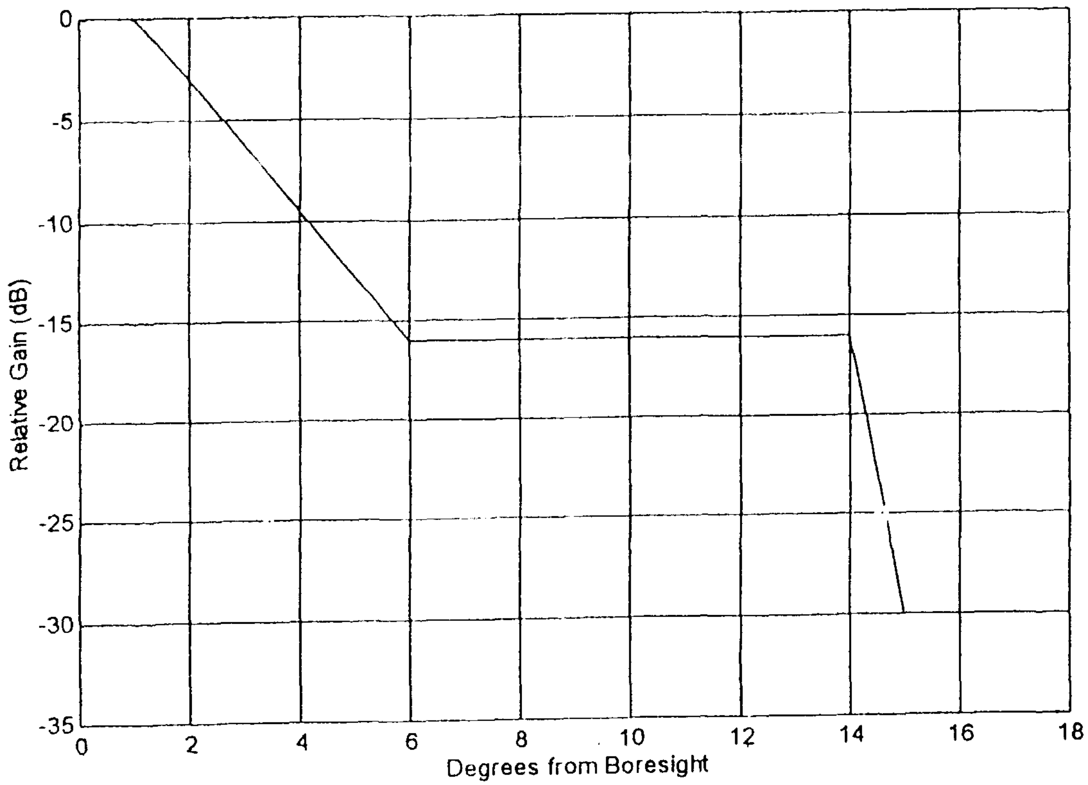
ATTACHMENT C

RULES FOR LMDS SUBSCRIBER TRANSCEIVERS IN THE 29.1-29.25 GHZ BAND

Degrees from Boresight	Relative Gain/EIRP in dB Azimuth	Elevation
0	0.00	0.00
1	0.00	0.00
2	-3.00	-3.00
3	-6.25	-6.25
4	-9.50	-9.50
5	-12.75	-12.75
6	-16.00	-16.00
14	-16.00	-16.00
15 ≤ 90	-30.00	-30.00

LMDS SUBSCRIBER TRANSCEIVERS
29.1-29.25 GHZ BAND

ANTENNA EIRP/MASK



LMDS TRANSCEIVER
SYSTEMS PARAMETER/OPERATION
SUMMARY

PARAMETER	TI	HP	EG*	CV
Transmit Power (dBW)	-17.0	-19.6	-13.0	-23.0
RF Bandwidth (MHz)	2.5	1.0	24.0	1.0
Antenna Gain	34.0	35.0	39.0	31.0
EIRP (dBW/Hz)	-47.0	-44.6	-47.8	-52.0
EIRP (dBW/MHz)	13.0	15.4	12.2	8.0
Maximum Range (Km)	5.0	2.0	2.2	5.0
Tower Height (Meters)	30.0	15.0	20.0	30.0
Hub Spacing in HPBW (Km)	17.0	17.0	17.0	17.0
out of HPBW (Km)	68.0	68.0	68.0	68.0
Max El angle, 50% blk (deg)	5.0	5.0	5.0	5.0
Aggregate C/I (dB)	35.4	41.9	27.6	36.7
Satellite System Margin	14.5	20.0	6.7	15.8

* Includes 10 dB for rain

LMDS TRANSCEIVER
SYSTEMS PARAMETER/OPERATION
WITH RULES PARAMETERS

PARAMETER	TI	HP	EG**	CV
Transmit Power (dBW)	-10.0	-15.0	-5.2	-11.0
RF Bandwidth (MHz)	2.5	1.0	24.0	1.0
Antenna Gain	34.0	35.0	39.0	31.0
EIRP (dBW/Hz)	-40.0	-40.0	-40.0	-40.0
EIRP (dBW/MHz)	20.0	20.0	20.0	20.0
Maximum Range (Km)	5.0	2.0	2.2	5.0
Tower Height (Meters)	30.0	15.0	20.0	30.0
Hub Spacing in HPBW (Km)	17.0	17.0	17.0	17.0
out of HPBW (Km)	68.0	68.0	68.0	68.0
Max El angle, 50% blk (deg)	5.0	5.0	5.0	5.0
Aggregate C/I (dB)	23.3	23.9	22.7	21.8
Satellite System Margin*(dB)	2.4	3.0	1.8	0.9

* Satellite System Margin in excess of 20.9 dB required.

** Includes 10 dB for rain

MAXIMUM EIRP
AND
POWER CONTROL

- THE STATISTICAL ANALYSIS PROGRAM WAS CONDUCTED WITH THE RULES PARAMETERS WHICH INCLUDED A 20 dBW/MHz MAXIMUM EIRP AND POWER CONTROL ACCORDING TO THE FOLLOWING FORMULA

  P(dBW/MHZ) = 20 + 20 LOG d/D

  WHERE d = DISTANCE TO THE HUB
  D = MAXIMUM DISTANCE TO THE HUB

- C/I RATIOS OF 21.8 TO 23.3 dB WERE OBTAINED WITH A 20 dBW/MHz EIRP AND POWER CONTROL.

- STATISTICAL ANALYSIS WAS CONDUCTED FOR EIRP LEVELS OF 20 dBW/MHz, 17 dBW/MHz, AND 14 dBW/MHz.
  - ACCEPTABLE C/I RATIOS OF 20.4, 22.9 AND 25.8 DB WERE OBTAINED FOR THESE EIRP LEVELS.

- IF POWER CONTROL IS NOT IMPLEMENTED THEN LIMIT THE MAXIMUM TRANSPONDER EIRP TO 14 dBW/MHZ.

TRANSCEIVER DENSITY LIMITATIONS

- THE MOST DENSE AREA OF THE U.S. (NEW HAMPSHIRE TO GEORGIA) WAS USED TO ENCOMPASS THE SATELLITE FOOTPRINT
  -RESULTING IN 25 MILLION HOUSEHOLDS.

- WITH 80 PERCENT OF THE LOCATIONS SUITABLE FOR LMDS, (LINE OF SIGHT), A TOTAL OF 20 MILLION HOUSEHOLDS ARE SUITABLE FOR LMDS SERVICE.

- MAXIMUM RETURN LINK UTILIZATION FOR DENSITY PURPOSES IS MODELED WITH TELEPHONE CIRCUITS THAT HAVE A MAXIMUM TAKE RATE OF 25 PERCENT AND 4:1 MINIMUM CONCENTRATION,
  -RESULTING IN 1.25 MILLION ACTIVE DSO CIRCUITS.

- FOR 1.25 MILLION CIRCUITS IN 150 MHZ BANDWIDTH, THE NUMBER OF CIRCUITS PER MHZ IS 8,333.

- USING 64 KBPS AND A CIRCUIT EFFICIENCY OF 0.6, WHICH INCLUDES SIGNALING AND CONTROL,
  -RESULTS IN 890 TRANSMITTERS PER MHZ.

- INDIVIDUAL SYSTEM ANALYSIS YIELDED ACCEPTABLE C/I RATIOS WITH 14.5 TO 20 DB MARGINS.

- TRANSCEIVER DENSITY LIMITATIONS RULES ARE NOT REQUIRED SINCE SUITABLE C/I RATIO MARGINS ARE ACHIEVED USING THE MOST DENSE AREA OF THE U.S. TO ENCOMPASS THE SATELLITE FOOTPRINT.

ANTENNA ORIENTATION

THE STATISTICAL PROGRAM WAS MODIFIED TO ALLOW EVERY Nth TRANSPONDER ANTENNA TO HAVE A RANDOM ELEVATION ANGLE FROM 0 TO 90 DEGREES.

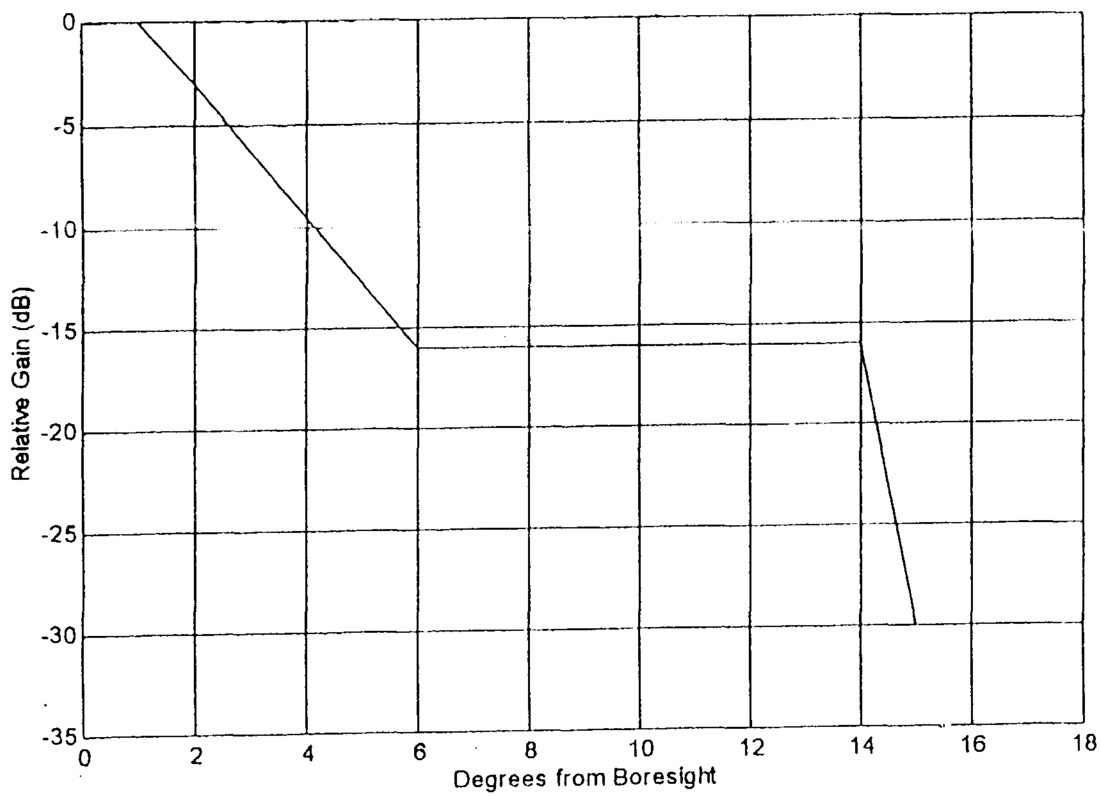
- THE STATISTICAL PROGRAM WAS RUN WITH N = 5, 10 AND 100 WITH THE RULES PARAMETERS WITH 20 DBW/MHZ POWER RESULTED IN THE FOLLOWING SATELLITE C/Is RESULTING.

N	% DISTRIBUTION	C/I
5	20	21.6
10	10	21.8
100	1	23.2

- RESULTS SHOW THAT ACCEPTABLE C/I RATIOS ARE OBTAINED WITH 20 PERCENT OF THE POPULATION HAVING MISALIGNED ANTENNAS.

- CONCLUSIONS ARE THAT INTERLOCKS ARE NOT REQUIRED TO PREVENT UNACCEPTABLE SATELLITE C/I RATIOS.

ANTENNA BEAMWIDTH/SIDELOBES



DENSITY

ATTACHMENT D

- SV Footprint Population Base NE & Mid-Atlantic — 75 million
  - Households, 3 per household — 25 million
  - LMDS Coverage 0.8 — 20 million
  - Subscribers (Take Rate, 25%) — 5 million
    - 4:1 Concentration — 1.25 million

- Subscribers per MHz for 150 MHz

$$\frac{1.25 \times 10^6}{150 \text{ MHz}} \qquad 8333$$

- Number of Circuits per MHz
  - data rate for DS0 64Kbs
    - eff. of 0.6 $\frac{1 MHz}{64 KBS} \times .6 = \underline{890}^*$

* Maximum loading exclusive of hub sectors! "CIRCUITS AVAILABLE"

- Number of systems pointing in the direction of the satellite.

$$890 \times \frac{\text{CPE Beamwidth}}{360°}$$

$$890 \times \frac{4}{360} = 9.9 \sim \underline{\underline{10}}$$

SATELLITE/GATEWAY PARAMETERS

- Gateway Transmitter EIRP 43.2 dBW$_i$

- Spaceloss at
  - 2747 Km, 5° EL −189.6 dB
  - 780 Km, 90° EL −179.6 dB

- Satellite Antenna Gain 30.1 dB

- Satellite Rec. Noise Floor, N_0 −197.5 dB

- Satellite Sig Level

		@ Ant.	@ Rec
@ 2747 Km	43.2−189.6 →	−146.4	−116.3
@ 780 Km	43.2−179.6 →	−136.4	−106.3

- Data Bit Rate; 1/2 Rate
  - Code rate 6.25 MB/s
  - Info rate of 3.125 MBPS −65 dB

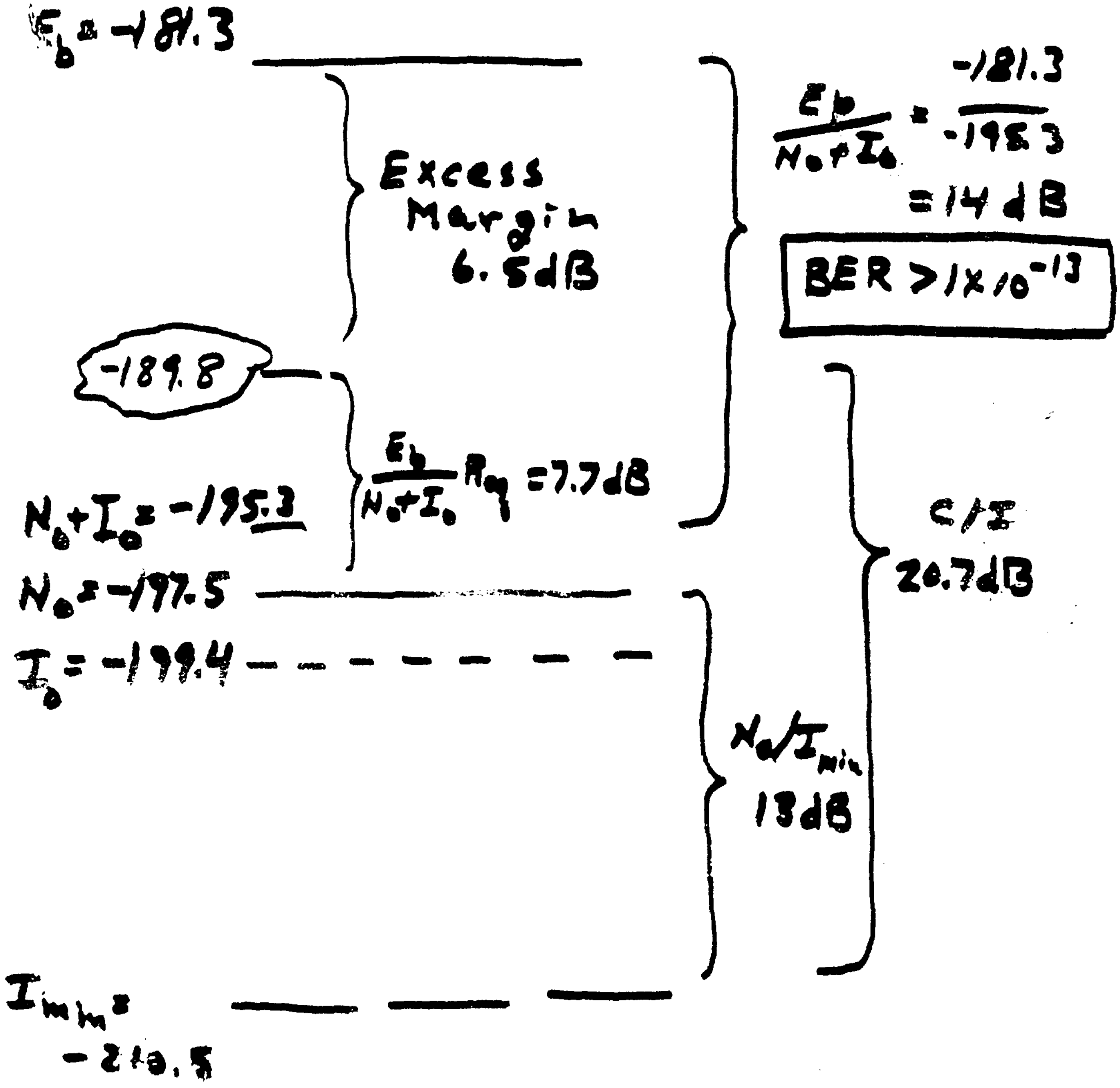
- Satellite Receiver, E_b
  - @ 2747 km $E_b = (-116.3) + (-65) = -181.3$
  - @ 780 km $E_b = (-106.3) + (-65) = -171.3$

LMDS PARAMETERS

- TRANSMIT EIRP — -40 dBW/Hz
- Space Loss
  - @ 2747 Km, 5° EL — -189.6 dB
  - @ 780 Km, 90° EL — -179.6 dB

LMDS Sig Level	I @SV Ant	I_o @SV Rec
@ 2747 Km		
-40 -189.6	-229.6	-199.4
@ 780 Km		
-40 -179.6	-219.6	-189.4

MAX RANGE / MIN SIGNAL
(2747 Km / -181.3 dB)



MAX RANGE

MULTIPLE CPE's

- $I_0' \Rightarrow$ 10 CPE's ; 100% at max Range

$I_0' = I_0 + 10\,dB = -199.4 + 10 = -189.4$

$I_0' + N_0 = (-189.4) + (-197.5) = -188.7$

$$\frac{E_b}{N_0 + I_0'} = \frac{-181.3}{-188.7} = 7.4\,dB$$

BER = 0.8×10^{-8} ✓

- $I_0'' \Rightarrow$ 5 CPE's ; 50% blockage at max Range.

$I_0'' = I_0 + 7\,dB = -199.4 + 7 = -192.4$

$I_0'' + N_0 = (-192.4) + (-197.5) = -191.2$

$$\frac{E_b}{N_0 + I_0''} = \frac{-181.3}{-191.2} = 9.9\,dB$$

BER = 1×10^{-12}

MIN RANGE / SIGNAL
(780 Km / -171.3)

E_b = -171.3

$I_0 + N_0$ = -188.8

I_0 -189.4

N_0 = -197.5

$$\frac{E_b}{I_0 + N_0} \quad \frac{-171.3}{-188.8} = 17.5\,dB$$

BER > 1X10$^{-\infty}$

$$\frac{E_b}{N_0 + I_0} = \frac{-171.3}{-188.8} = 17.5\,dB$$

BER > 1 x 10$^{-\infty}$ ✓

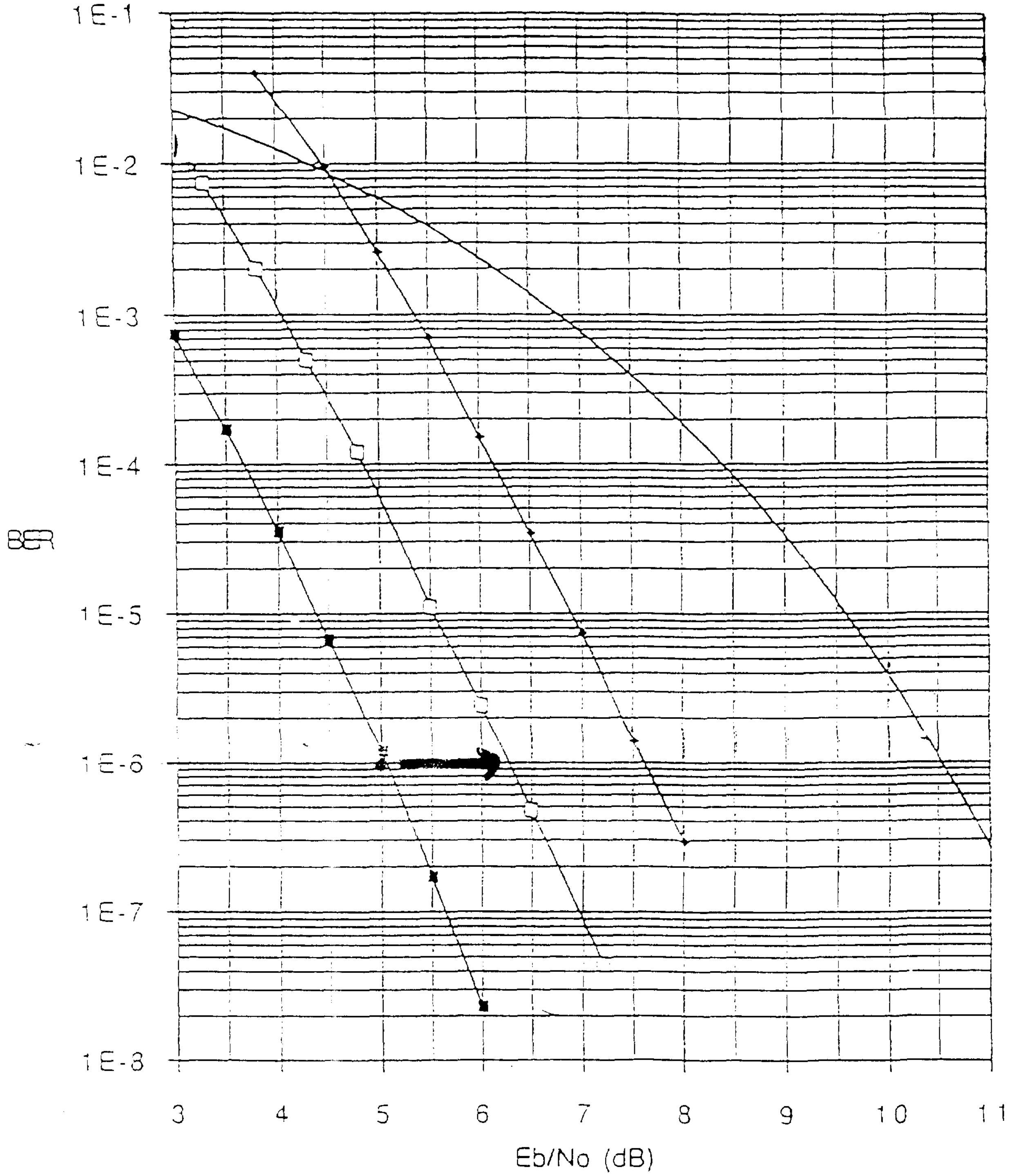
- $I_0' > 10$ CPE's

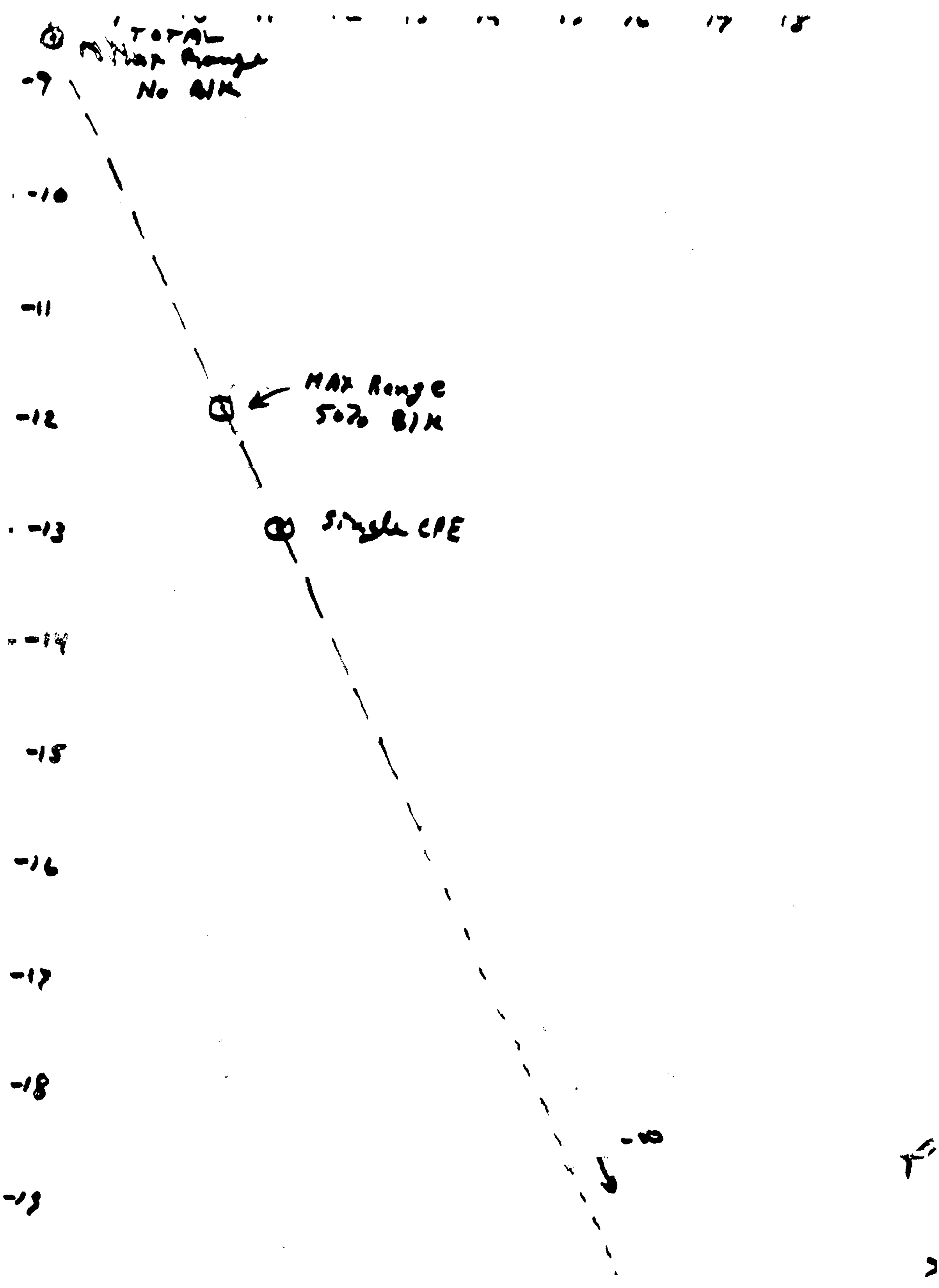
$I_0' = I_0 + 10 = -189.4 + 10 = -179.4$

$N_0 + I_0' = (-197.5) + (-179.4) = -179.3$

$$\frac{E_b}{N_0 + I_0'} = \frac{-171.3}{-179.3} = 8\,dB$$

BER = 0.4 x 10^{-9} ✓


1E-1
1E-2
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
BER
3
4
5
6
7
8
9
10
11
Eb/No (dB)


TOTAL
Max Range
No BIK
-9
-10
-11
Max Range
50% BIK
-12
Single CPE
-13
-14
-15
-16
-17
-18
-19
17
18