NUMERICAL PARAMETERS FOR RADIO LOCAL AREA NETWORK

Coverage Areas as a Function of Reuse Factor and Site Pitch

Signal to Interference Ratio as a Function of Reuse and Propagation Factors

CONCLUSIONS

The following paper submitted to IEEE 802.4L supports the following conclusions for the fixed to mobile transmission plan:

1. For the purpose of digital, megabit rate, BUS mode, short-range radio local area network design, **a frequency, code or time reuse plan based on 16 discrete communication channels should be used.**

2. This conclusion is based on 11 dB/octave mean distance attenuation for interfering stations.

3. The resulting mean signal-to-noise ratio in a worst-case position of a mobile station in a regular, infinite model is 20 dB. Since successful digital detection will require only 11-14 dB S/I, the balance of the margin is available for statistical variation to obtain better than 95% probability at locations which are only a small fraction of the operating area.

4. If the extents of the total system are non-infinite, a small improvement in S/I will result from a smaller number of interferers.

5. In a system where the square grid site spacing is 250 feet, the required maximum radio range is 177 feet. **The area covered by one R.F.=16 system without frequency reuse is more than 562,000 square feet.**

6. Several special technical properties are necessary to support these conclusions which are not specifically stated. Examples are:

   A. The mobile receiver is always using the signal from the nearest or best fixed transmitter.

   B. The detection process used is within a few dB of optimum.

   C. Sufficient forward error correction will be used so that the raw bit error rate does not need to be better than 1 in 10^{-4}.

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PROBLEM DESCRIPTION

Early in the selection of a system plan, a major decision must be made on the physical dimensions and the method of avoiding cochannel interference. The definition of BUS mode requires that: *When any one station transmits, all other stations within the same network hear it.* A radio system in repeater mode can fulfill this requirement easily with a single fixed transmitter-receiver (FXTR) and with multiple FXTR using transmitters all on different operating channels. When one channel is used for two or more FXTR, then cochannel interference must be considered. Efficient system design has been shown to require that cochannel radio stations be sufficiently close together that the system design is controlled by the tolerable level of interference.

The work in this study is based on FXTR positioned at the intersections of a square grid. The grid is assumed infinite in extent for the purpose of calculation of worst case interference. One objective is to determine at what point is an FXTR so distant that its interference effect can be neglected.

With a square plan, regular steps are obtained when one side of a square group is 2 to 6 squares before the pattern of channel assignments is repeated.

A channel assignment group might contain 4, 9, 16, 25 or 36 independent channel assignments (called **Reuse Factor** in this paper) using frequency, time or code division for that independence. If the useful range for the radio tranmsmitter is a constant, then an R.F.=36 will cover 4 times the area of group of R.F.=9.

Models

Models of the constant pitch site location arrangement are shown on the following pages for Reuse Factors of 16 and 25. FXTR sites are label Fn. All sites with the same designator are cochannel. At the center of the left edge, the reference **F1** site is shown bold and emphasized.

Rings of Interferers

Using these models, it is possible to characterize the interfering cochannel FXTRs as rings around the center containing 4 or 8 interferers.

The Signal to Interference Calculation

All dimensions are related to the pitch or distance between closest adjacent FXTRs. The maximum radio range required is half way to the diagonally opposite site or .707 times the spacing. A series of additional steps and estimates are required.

The power addition of all interferers is performed at the center of the pattern; and then the approximation is made that this level is constant throughout the coverage of the reference FXTR. This result was determined empirically after analysis more complex computations. As the calculation point is moved off center some sites get closer and others further making the variations of second order magnitude.

MODEL FOR REUSE FACTOR = 16

F1	F2	F3	F4	F1	F2	F3	F4	F1	F2	F3	F4
F5	F6	F7	F8	F5	F6	F7	F8	F5	F6	F7	F8
F9	F10	F11	F12	F9	F10	F11	F12	F9	F10	F11	F12
F13	F14	F15	F16	F13	F14	F15	F16	F13	F14	F15	F16

4 PLACES @ DISTANCE 4.0

F1	F2	F3	F4	F1	F2	F3	F4	F1	F2	F3	F4

4 PLACES @ DISTANCE 5.7

F5	F6	F7	F8	F5	F6	F7	F8	F5	F6	F7	F8
F9	F10	F11	F12	F9	F10	F11	F12	F9	F10	F11	F12
F13	F14	F15	F16	F13	F14	F15	F16	F13	F14	F15	F16

4 PLACES @ DISTANCE 8.0

F1	F2	F3	F4	F1	F2	F3	F4	F1	F2	F3	F4
F5	F6	F7	F8	F5	F6	F7	F8	F5	F6	F7	F8
F9	F10	F11	F12	F9	F10	F11	F12	F9	F10	F11	F12
F13	F14	F15	F16	F13	F14	F15	F16	F13	F14	F15	F16

8 PLACES @ DISTANCE 8.9

F1	F2	F3	F4	F1	F2	F3	F4	F1	F2	F3	F4
F5	F6	F7	F8	F5	F6	F7	F8	F5	F6	F7	F8
F9	F10	F11	F12	F9	F10	F11	F12	F9	F10	F11	F12
F13	F14	F15	F16	F13	F14	F15	F16	F13	F14	F15	F16
F1	F2	F3	F4	F1	F2	F3	F4	F1	F2	F3	F4

MODEL FOR REUSE FACTOR = 25

F1	F2	F3	F4	F5	F1	F2	F3	F4	F5	F1

8 PLACES @ DISTANCE 11.2

F6	F7	F8	F9	F10	F6	F7	F8	F9	F10	
F11	F12	F13	F14	F15	F11	F12	F13	F14	F15	
F16	F17	F18	F19	F20	F16	F17	F18	F19	F20	
F21	F22	F23	F24	F25	F21	F22	F23	F24	F25	

4 PLACES @ DISTANCE 5.0

F1	F2	F3	F4	F5	F1	F2	F3	F4	F5	F1

4 PLACES @ DISTANCE 7.1

F6	F7	F8	F9	F10	F6	F7	F8	F9	F10	
F11	F12	F13	F14	F15	F11	F12	F13	F14	F15	
F16	F17	F18	F19	F20	F16	F17	F18	F19	F20	
F21	F22	F23	F24	F25	F21	F22	F23	F24	F25	

4 PLACES @ DISTANCE 10.0

F1	F2	F3	F4	F5	F1	F2	F3	F4	F5	F1
F6	F7	F8	F9	F10	F6	F7	F8	F9	F10	
F11	F12	F13	F14	F15	F11	F12	F13	F14	F15	
F16	F17	F18	F19	F20	F16	F17	F18	F19	F20	
F21	F22	F23	F24	F25	F21	F22	F23	F24	F25	
F1	F2	F3	F4	F5	F1	F2	F3	F4	F5	F1
F6	F7	F8	F9	F10	F6	F7	F8	F9	F10	
F11	F12	F13	F14	F15	F11	F12	F13	F14	F15	
F16	F17	F18	F19	F20	F16	F17	F18	F19	F20	
F21	F22	F23	F24	F25	F21	F22	F23	F24	F25	
F1	F2	F3	F4	F5	F1	F2	F3	F4	F5	F1

This approximation becomes inaccurate if the calculation point gets closer to one of the interfering stations.

To implement this approximation, it is first necessary to determine the total interfering signal power at the pattern center; and this is expressed as a ratio of the power level from the center at the distance .707. At this point the distance function of signal level is needed.

Digression on Radio Propagation

Radio signal level is a complex statistical calculation highly dependent on considering details of the environment. The design level at a distance is considered a sum of several components:

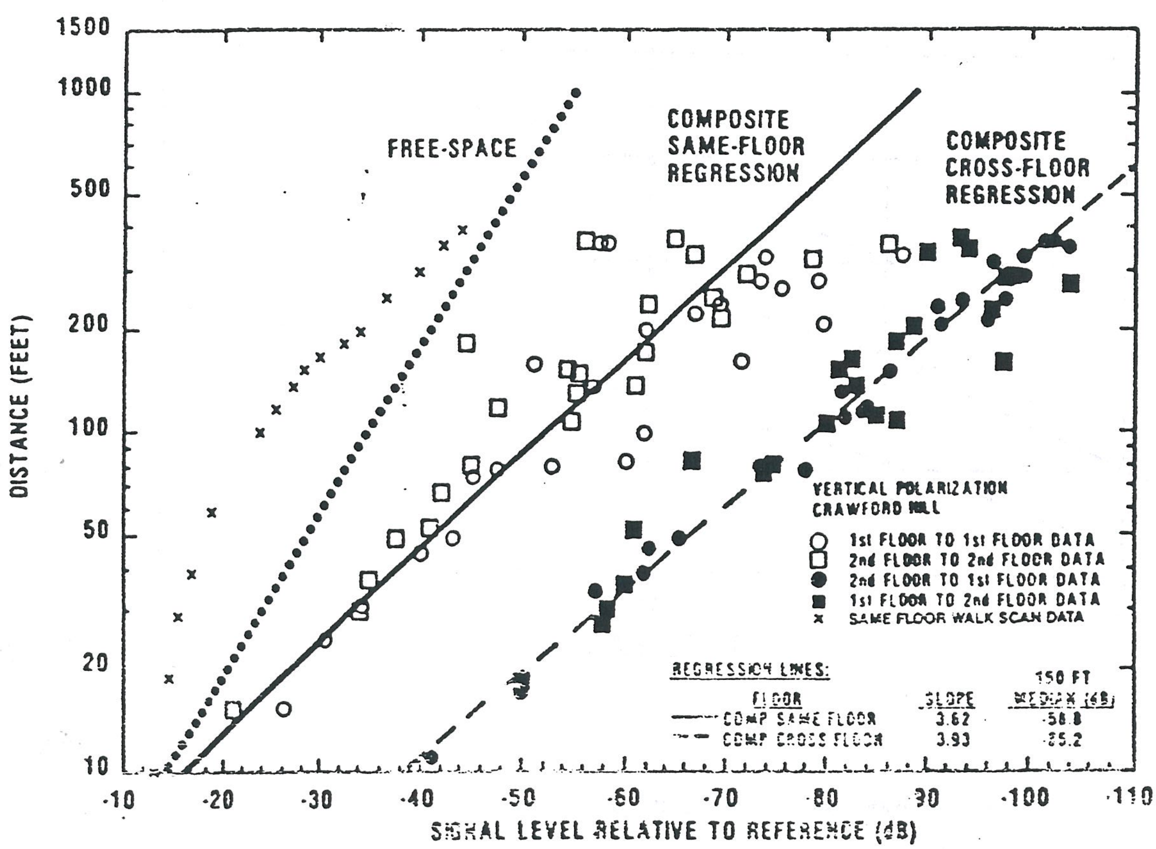
A most comprehensive review of the state of propagation analysis is given in the following document:

"The Portable Radio Propagation Environment," Input to Document CCIR IWP 8/13-27, Rev. 3, Draft Report, Document US 8/13-3 Rev 1, 27 Jan 87, submitted by P. Porter, Bell Communication Research.

Shown below is a reproduction of Figure 9 from this reference displaying the results of an in-building propagation loss study. The slope of the solid line is given at -3.62 which corresponds to 36.2 dB/decade or 10.9 dB/octave.

The x line is a walk down a hallway with direct line of sight between antennas. There is a suggestion of walking inside of a waveguide when loss is less than free space. Clearly, the situation of cochannel sites at opposite ends of a long enclosed hallway should be avoided. If the environment is uncluttered with radio obstacles, there is certainly a short distance possibility of free space loss which is 6 dB/octave. In the best of all worlds, the path from distant sites is cluttered while the best path to the portable is unobstructed. This may be a commonplace occurence, but is risky for worst case design.

Other reports of in-building propagation show distance loss between free space and 12 dB/octave.



8

The Signal to Interference Calculation Continued

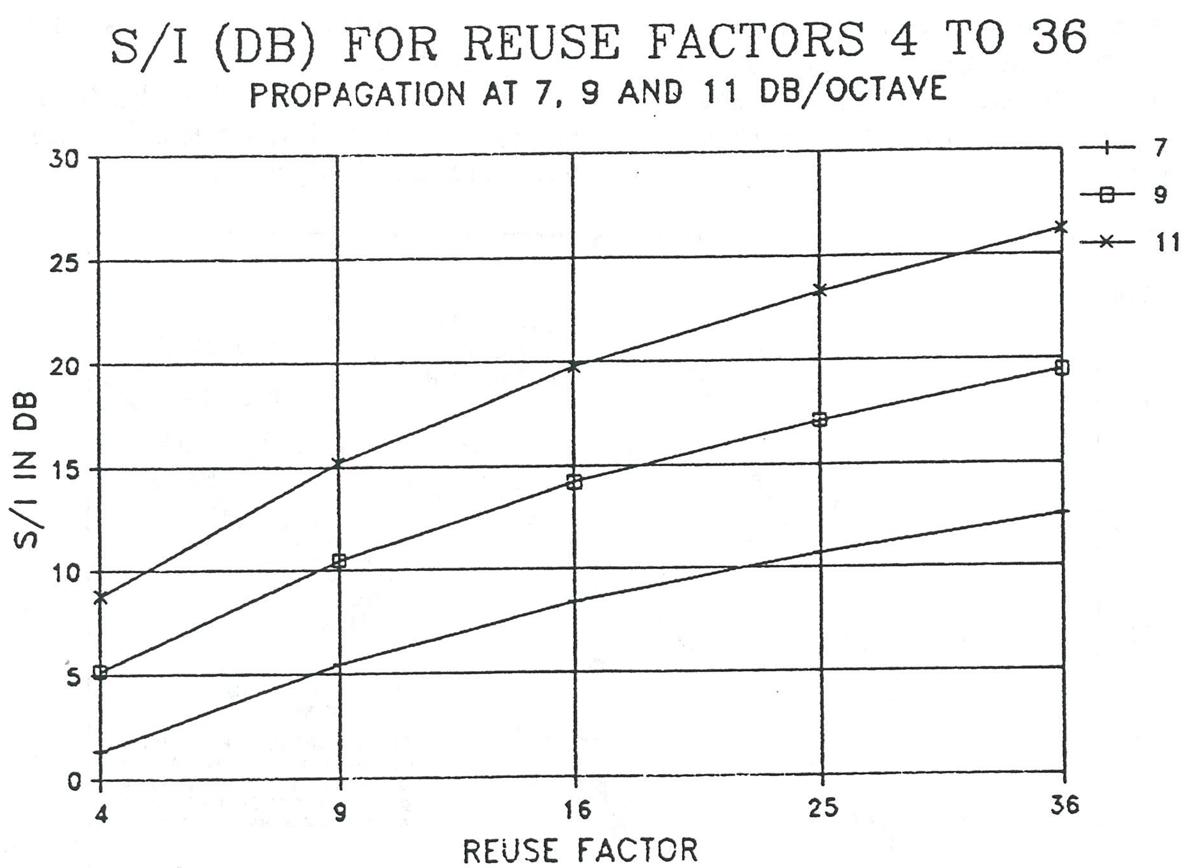
The ratio of power between the desired signal distance at .707 and the interference signal at the reference point can now be calculated in db relative. Assuming a unit power at .707, an absolute interfering power can be calculated. This step is necessary to combine multiple interferers. The actual process is to assume 4 interferers at the same distance quadruple the interference energy or increase it 6 dB, and 8 interferers increase it 9 dB.

This calculation was performed independently for distance functions of 7, 9 and 11 dB per octave. The result is shown in the figure below.

Mechanics of Calculation

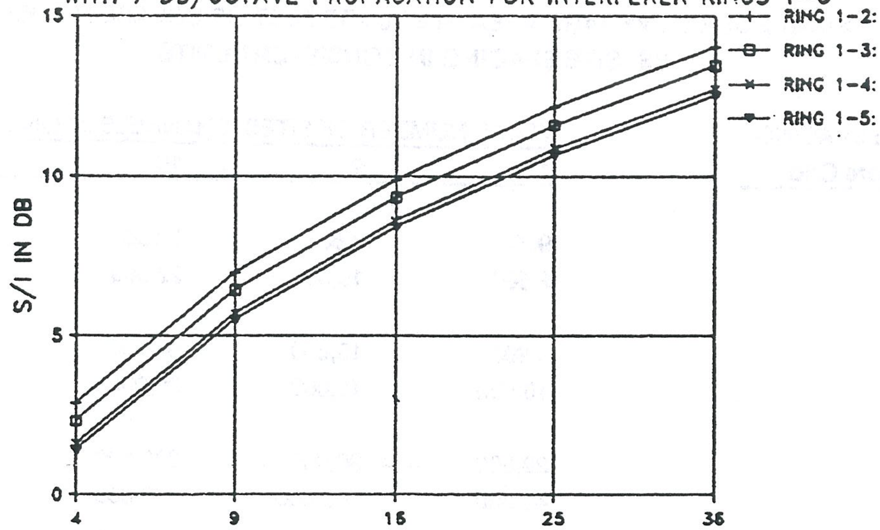
As shown on the last three pages, these calculations were performed using a spread sheet with calculation functions entered in cells. The distance of each ring was expressed as a function of the Reuse Factor and Pythagorean formula. The log functions were used as needed.

The combined interference power for each ring was calculated, and then additions for the first two rings up to 5 rings were made. This enables evaluation of the effect of more distant interfering stations. **The greater the distance attenuation, the smaller the effect of the more distant interfering sites as shown on the graphs on the following page.**

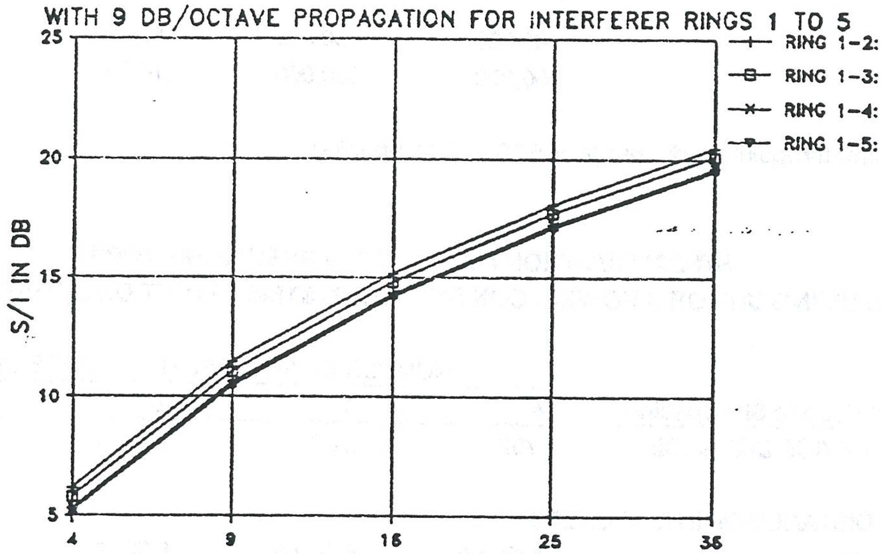


S/I (DB) FOR REUSE FACTORS 4 TO 36

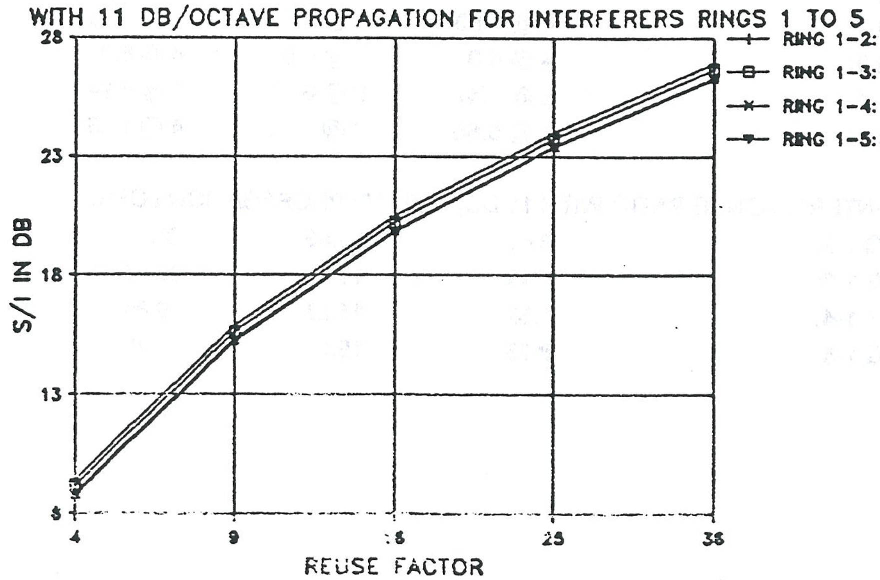
WITH 7 DB/OCTAVE PROPAGATION FOR INTERFERER RINGS 1-5



WITH 9 DB/OCTAVE PROPAGATION FOR INTERFERER RINGS 1 TO 5



WITH 11 DB/OCTAVE PROPAGATION FOR INTERFERERS RINGS 1 TO 5



SINGLE USE COVERAGE AREA IN SQUARE FEET OR SQUARE METERS VS. SITE SPACING IN CONSISTENT UNITS

SITE SPACING	TOTAL NUMBER OF SITES/CHANNELS IN ONE SYSTEM			
Square Grid	4	9	16	25
30	900	3,600	9,100	14,400
50	2,500	10,000	22,500	40,000
70	4,900	19,600	44,100	78,400
100	10,000	40,000	90,000	160,000
150	22,500	90,000	202,500	360,000
200	40,000	160,000	360,000	640,000
250	62,500	250,000	562,000	1,000,000
300	90,000	360,000	810,000	1,440,000

Minimum required radio range = 0.707 * Site Spacing

S/I CALCULATION FOR VARIOUS RESUSE FACTORS ASSUMING UNIFORM POWER, CONTINUOUS SYSTEM LAYOUT ON SQUARE GRID

	NUMBER OF SITES WITH SEPARATE CHANNELS			
Distances as Ratio to Site Spacing	4	9	16	25
MAXIMUM SERVICE DISTANCE:	.707	.707	.707	.707
NUMBER & DISTANCE OF INTERFERERS				
Ring 1:	4 @ 2.0	4 @ 3.0	4 @ 4.0	4 @ 5.0
Ring 2:	4 @ 2.83	4 @ 4.24	4 @ 5.66	4 @ 7.07
Ring 3:	4 @ 4.0	4 @ 6.0	4 @ 8.0	4 @ 10.0
Ring 4:	8 @ 4.47	8 @ 6.71	8 @ 8.94	8 @ 11.18
Ring 5:	4 @ 5.66	4 @ 8.48	4 @ 11.31	4 @ 14.14
SIGNAL TO INTERFERENCE RATIO WITH 11 DB/OCTAVE PROPAGATION LOSS:				
RING 1-2:	9.40	15.85	20.43	23.99
RING 1-3:	9.14	15.59	20.17	23.73
RING 1-4:	8.82	15.27	19.85	23.41
RING 1-5:	8.75	15.21	19.79	23.34

SIGNAL TO INTERFERENCE (SIR) RATIO CALCULATION WORK SHEET
FILE: S4L836--6 MARCH 88

ATTEN. IN DB/OCTAVE:	11.00	11.00	11.00	11.00	11.00
REUSE FACTOR:	4	9	16	25	36
SERVICE RANGE MAX.:	.71	.71	.71	.71	.71
RING 1					
NO. INTERFERERS:	4	4	4	4	4
DISTANCE:	2.00	3.00	4.00	5.00	6.00
POWER FROM ONE IFR.:	-16.49	-22.95	-27.53	-31.08	-33.99
POWER ALL RING 1 IFR:	-10.47	-16.93	-21.51	-25.06	-27.97
RING 2					
NO. INTERFERERS:	4	4	4	4	4
DISTANCE:	2.83	4.24	5.66	7.07	8.48
POWER FROM ONE IFR.:	-22.01	-28.46	-33.05	-36.60	-39.50
POWER ALL RING 2 IFR:	-15.99	-22.44	-27.03	-30.58	-33.48
RING 3					
NO. INTERFERERS:	4	4	4	4	4
DISTANCE:	4.00	6.00	8.00	10.00	12.00
POWER FROM ONE IFR.:	-27.53	-33.99	-38.57	-42.12	-45.02
POWER ALL RING 3 IFR:	-21.51	-27.97	-32.55	-36.10	-39.00
***RING 4**					
NO. INTERFERERS:	8	8	8	8	8
DISTANCE:	4.47	6.71	8.94	11.18	13.42
POWER FROM ONE IFR.:	-29.31	-35.76	-40.34	-43.90	-46.80
POWER ALL RING 4 IFR:	-20.28	-26.73	-31.31	-34.87	-37.77
RING 5					
NO. INTERFERERS:	4	4	4	4	4
DISTANCE:	5.66	8.48	11.31	14.14	16.97
POWER FROM ONE IFR.:	-33.05	-39.50	-44.08	-47.64	-50.54
POWER ALL RING 5 IFR:	-27.03	-33.48	-38.06	-41.62	-44.52
ADD POWER FROM RINGS	ASSUMES LINEAR ADDITION OF POWER AT ORIGIN				
PWR RING 1:	.08972	.02029	.00707	.00312	.00160
PWR RING 2:	.02519	.00570	.00198	.00088	.00045
PWR RING 3:	.00707	.00160	.00056	.00025	.00013
PWR RING 4:	.00939	.00212	.00074	.00033	.00017
PWR RING 5:	.00198	.00045	.00016	.00007	.00004
PWR RING 1-2:	.11491	.02598	.00905	.00399	.00205
PWR RING 1-3:	.12198	.02758	.00961	.00424	.00217
PWR RING 1-4:	.13136	.02970	.01034	.00456	.00234
PWR RING 1-5:	.13335	.03015	.01050	.00463	.00237
SIGNAL TO INTERFERENCE RATIO (SIR) IN DB					
RING 1-2:	9.40	15.85	20.43	23.99	26.89
RING 1-3:	9.14	15.59	20.17	23.73	26.63
RING 1-4:	8.82	15.27	19.85	23.41	26.31
RING 1-5:	8.75	15.21	19.79	23.34	26.24

SIGNAL TO INTERFERENCE (SIR) RATIO CALCULATION WORK SHEET
FILE: S4L836--6 MARCH 88

ATTEN. IN DB/OCTAVE:	9.00	9.00	9.00	9.00	9.00
REUSE FACTOR:	4.00	9.00	16.00	25.00	36.00
SERVICE RANGE MAX.:	.71	.71	.71	.71	.71
RING 1					
NO. INTERFERERS:	4.00	4.00	4.00	4.00	4.00
DISTANCE:	2.00	3.00	4.00	5.00	6.00
POWER FROM ONE IFR.:	-13.49	-18.78	-22.52	-25.43	-27.81
POWER ALL RING 1 IFR:	-7.47	-12.76	-16.50	-19.41	-21.79
RING 2					
NO. INTERFERERS:	4.00	4.00	4.00	4.00	4.00
DISTANCE:	2.83	4.24	5.66	7.07	8.48
POWER FROM ONE IFR.:	-18.01	-23.29	-27.04	-29.94	-32.32
POWER ALL RING 2 IFR:	-11.99	-17.27	-21.02	-23.92	-26.30
RING 3					
NO. INTERFERERS:	4.00	4.00	4.00	4.00	4.00
DISTANCE:	4.00	6.00	8.00	10.00	12.00
POWER FROM ONE IFR.:	-22.52	-27.81	-31.55	-34.46	-36.84
POWER ALL RING 3 IFR:	-16.50	-21.79	-25.53	-28.44	-30.82
***RING 4**					
NO. INTERFERERS:	8.00	8.00	8.00	8.00	8.00
DISTANCE:	4.47	6.71	8.94	11.18	13.42
POWER FROM ONE IFR.:	-23.98	-29.26	-33.01	-35.92	-38.29
POWER ALL RING 4 IFR:	-14.95	-20.23	-23.98	-26.88	-29.26
RING 5					
NO. INTERFERERS:	4.00	4.00	4.00	4.00	4.00
DISTANCE:	5.66	8.48	11.31	14.14	16.97
POWER FROM ONE IFR.:	-27.04	-32.32	-36.07	-38.98	-41.35
POWER ALL RING 5 IFR:	-21.02	-26.30	-30.05	-32.96	-35.33

ADD POWER FROM RINGS ASSUMES LINEAR ADDITION OF POWER AT ORIGIN

PWR RING 1:	.17896	.05302	.02237	.01145	.00663
PWR RING 2:	.06330	.01876	.00791	.00405	.00234
PWR RING 3:	.02237	.00663	.00280	.00143	.00083
PWR RING 4:	.03201	.00949	.00400	.00205	.00119
PWR RING 5:	.00791	.00234	.00099	.00051	.00029
PWR RING 1-2:	.24225	.07178	.03028	.01550	.00897
PWR RING 1-3:	.26462	.07841	.03308	.01694	.00980
PWR RING 1-4:	.29664	.08789	.03708	.01898	.01099
PWR RING 1-5:	.30455	.09024	.03807	.01949	.01128

SIGNAL TO INTERFERENCE RATIO (SIR) IN DB

RING 1-2:	6.16	11.44	15.19	18.10	20.47
RING 1-3:	5.77	11.06	14.80	17.71	20.09
RING 1-4:	5.28	10.56	14.31	17.22	19.59
RING 1-5:	5.16	10.45	14.19	17.10	19.48

SIGNAL TO INTERFERENCE (SIR) RATIO CALCULATION WORK SHEET
FILE: S4L836--6 MARCH 88

ATTEN. IN DB/OCTAVE:	7.00	7.00	7.00	7.00	7.00
REUSE FACTOR:	4	9	16	25	36
SERVICE RANGE MAX.:	.71	.71	.71	.71	.71
RING 1					
NO. INTERFERERS:	4	4	4	4	4
DISTANCE:	2.00	3.00	4.00	5.00	6.00
POWER FROM ONE IFR.:	-10.49	-14.60	-17.52	-19.78	-21.63
POWER ALL RING 1 IFR:	-4.47	-8.58	-11.50	-13.76	-15.61
RING 2					
NO. INTERFERERS:	4	4	4	4	4
DISTANCE:	2.83	4.24	5.66	7.07	8.48
POWER FROM ONE IFR.:	-14.01	-18.11	-21.03	-23.29	-25.14
POWER ALL RING 2 IFR:	-7.98	-12.09	-15.01	-17.27	-19.12
RING 3					
NO. INTERFERERS:	4	4	4	4	4
DISTANCE:	4.00	6.00	8.00	10.00	12.00
POWER FROM ONE IFR.:	-17.52	-21.63	-24.54	-26.80	-28.65
POWER ALL RING 3 IFR:	-11.50	-15.61	-18.52	-20.78	-22.63
***RING 4**					
NO. INTERFERERS:	8	8	8	8	8
DISTANCE:	4.47	6.71	8.94	11.18	13.42
POWER FROM ONE IFR.:	-18.65	-22.76	-25.67	-27.93	-29.78
POWER ALL RING 4 IFR:	-9.62	-13.73	-16.64	-18.90	-20.75
RING 5					
NO. INTERFERERS:	4	4	4	4	4
DISTANCE:	5.66	8.48	11.31	14.14	16.97
POWER FROM ONE IFR.:	-21.03	-25.14	-28.05	-30.31	-32.16
POWER ALL RING 5 IFR:	-15.01	-19.12	-22.03	-24.29	-26.14

ADD POWER FROM RINGS ASSUMES LINEAR ADDITION OF POWER AT ORIGIN

PWR RING 1:	.35694	.13858	.07083	.04208	.02750
PWR RING 2:	.15905	.06175	.03156	.01875	.01225
PWR RING 3:	.07083	.02750	.01405	.00835	.00546
PWR RING 4:	.10918	.04239	.02166	.01287	.00841
PWR RING 5:	.03156	.01225	.00626	.00372	.00243
PWR RING 1-2:	.51599	.20034	.10239	.06083	.03975
PWR RING 1-3:	.58682	.22784	.11644	.06918	.04521
PWR RING 1-4:	.69600	.27023	.13810	.08205	.05362
PWR RING 1-5:	.72756	.28248	.14437	.08577	.05605

SIGNAL TO INTERFERENCE RATIO (SIR) IN DB

RING 1-2:	2.87	6.98	9.90	12.16	14.01
RING 1-3:	2.31	6.42	9.34	11.60	13.45
RING 1-4:	1.57	5.68	8.60	10.86	12.71
RING 1-5:	1.38	5.49	8.41	10.67	12.51