A Study Of Parasitic Cellular Frequency Reuse

BY

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(ABSTRACT)

Indoor parasitic cellular systems are in-building stand alone cellular networks that use the concept of simultaneously reusing the frequencies of cellular systems outside the building for wireless communications inside the building. The objective of this thesis is to provide an analysis to determine the frequency reuse possible between in-building and outside cellular systems. The amount of frequency reuse currently available for an urban office building is presented based on field strength measurements made inside the building. In addition, this thesis describes the simulation code written which models a growing cellular system for the purpose of analyzing the effect that a growing cellular system will have on in-building frequency reuse. Future in-building frequency reuse is predicted in three month intervals for a time period of six years based on the results of the simulation code.

Acknowledgments

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1. Introduction

The objective of this research is to provide an analysis to determine the frequency reuse possible between in-building and outside cellular systems which use identical frequency bands. Indoor *parasitic* cellular systems are in-building stand alone cellular networks that use the concept of simultaneously reusing the frequencies of cellular systems outside the building for wireless communications inside the building. The amount of future frequency reuse in a parasitic indoor system will be predicted in three month intervals for a time period of six years based on subscriber growth projections, the effects of base station antenna downtilt, and outdoor cellular system growth. Field strength measurements were taken by the sponsor of this research on different faces and floors of a large office building. These measurements indicate the amount of frequency reuse currently available in the building for indoor parasitic systems that use the cellular band. This report describes the data processing required to determine the amount of frequency reuse possible based on the field strength measurements. The results of this data processing are presented. In addition, this report describes an elaborate C program written to simulate a growing cellular system for the purpose of analyzing the effect that a growing cellular system will have on in-building frequency reuse. This code assumes realistic cellular subscriber growth, and performs logical cell splits based on this customer growth. As cells split, new cells are formed which have smaller transmitter powers and downtilted antennas. In-building signal vs. floor models are used to analyze

the effect of these new cells on in-building frequency reuse as a function of floor. Numerous results are presented graphically as well as in table form, based on the simulation.

The past decade has seen a phenomenal growth in cellular communications. More and more people are using small handheld or pocket wireless devices to meet their voice and data communication needs. Cellular radio systems, paging systems, mobile satellite systems, cordless telephones, and the future personal communications systems (PCS) all aim to provide ubiquitous access without regard for the location of the user. In spite of numerous standards for each of these wireless systems, there has been a 30-50% growth for the companies involved in providing such services. With a projected 100 million users in the year 2000 [1], wireless providers must offer smaller, cheaper, and easy to use personal communication devices.

In cellular systems, the coverage region is divided into smaller areas called cells. Each cell has its own base transmitter and set of frequencies. To increase spectrum utilization, cellular systems use the concept of frequency reuse in which one frequency (or set of frequencies) can be used again in a different cell. Two such cells (called co-channel cells) mush be separated by a minimum distance to keep co-channel interference below acceptable limits. As cellular systems mature, their capacity can be increased to accommodate more users by cell splitting where each cell is split into smaller cells with a

lower transmitter power and perhaps downtilted antennas. Thus, cell size decreases, and in densely populated areas, the cell size may be small (<1 km radius) enough to be considered a *micro-cell*.

Buildings attenuate outdoor cellular transmissions such that it is possible to have self-controlled indoor cellular systems which use the same frequencies as the cellular system outside the building. Such indoor cellular systems are isolated from the outdoor cellular system by the building, and use *sniffer* receivers (receivers that can scan all of the cellular channels) to determine which channels have external signals that are at a low enough level to be used for indoor communications. For indoor systems that rely on unused channels from the external cellular systems, the frequency reuse plan and the growth of the outdoor cellular system as it reaches maturity will determine the reliability and performance capabilities of the indoor parasitic system.

With the recent allocation of frequency bands for PCS, many industry experts believe that PCS will be the system that will provide wireless access to a wide range of network services in the near future. Parasitic cellular systems may be used by the cellular carrier to compete with PCS for providing wireless communications in a densely populated area, particularly office buildings, busy market places, etc. For such systems, building penetration plays a significant role. To be able to reuse the outdoor cellular frequencies

inside the building for PCS, it is important to know the characteristics of building penetration loss and the factors it depends on.

Chapter 2 of this report describes the analysis of the forward channel field strength measurements of an outdoor cellular system as measured on different floors of a high rise building in an urban area. A model for path loss as a function of building floor based on these measurements will be used to predict the performance of an indoor parasitic cellular system as the outdoor cellular system matures. The model must consider the frequency allocation scheme of the external cellular system, as well as the power, location, antenna height and antenna pattern of each cell site in the entire coverage area. The propagation environment and location of the receiver within the building must also be taken into account.

Chapter 3 gives a brief overview of the C code simulations which are used to model the growth of an outdoor cellular system over a six year period. This chapter summarizes the approach taken to model subscriber growth in the cellular system, the cell splitting algorithm used to increase capacity in the cellular system, and the parameters used for simulating 2nd, 3rd, and 4th generation cells.

Co-channel interference calculations are performed as cells split in order to evaluate the degradation of the overall system performance over time. Chapter 4 describes the

approach to modeling co-channel interference. Interference calculations provide a way of quantifying the performance of a growing cellular system, and enable us to properly choose frequency assignments for future cells. As the simulations described in this report are executed, cell splits are simulated over time to accommodate the simulated increase in the number of cellular subscribers. The interference modeling detailed in Chapter 4 provides a means of describing the overall performance of the outdoor cellular system as cells split and frequency reuse distances become smaller. The average C/I within the cellular system, and the average frequency separation distance, are shown graphically to decrease with time, while the overall call blocking percentage remains below the maximum acceptable value of 2%.

Chapter 5 describes the approach taken to modeling capacity in the outdoor cellular system. The capacity model used is based on two-tiered uniform growth projections. The cellular Metropolitan Statistical Area (MSA) under study is broken into two areas. Cells in the two areas are given two different uniform growth rates to account for higher growth in the urban core of the city. These growth rates determine how the number of subscribers in the cells increase, and directly impact how often the cells need to be split in the future. The algorithm which implements the cell spitting is described in detail in this chapter.

Chapter 6 summarizes the results of this study by predicting channel availability as a function of time and a function of floor. These predictions show the number of cellular channels which can be reused with a parasitic indoor system as a function of year and floor of the building.

Here is a summary of the operation of the simulations used to determine results in this study:

1) Determine a propagation model based on the measurements made inside a large urban office building. For in-building channel availability, the model is based on distance and the floor of the building. For cell splits, the model is only dependent on distance.

2) Use the propagation model to find C/I in the cellular system inherited from the sponsor of this research. The results of the C/I analysis determines how cell coverage is modeled as cells split.

3) Use the parameters of grade of service (GOS), downtilt, and number of subscribers to model the growth of the cellular system over time.

4) Split cells in intervals of three months and use the propagation model on the new cells to determine the number of channels which can be reused inside the building, as a function of time and floor.

2. In-Building Measurements and Model Derivations

Field strength measurements were made by the sponsor of this research in a large multi-story office building located in the urban core of a large city. These measurements were made to quantify the number of cellular channels available today for an in-building parasitic cellular system. The signal strength of outdoor cellular voice channels were measured on different floors of the building to determine how received signal strength varies inside the building. This thesis uses the results of these measurements to create an in-building path loss model to characterize how signals attenuate on different floors of the building under study.

2.1. Measurement Equipment

All in-building measurements were made with a Grayson Electronics CELLSCOPE 2000 cellular system monitor and a Hewlett Packard 8562A spectrum analyzer. Measurements were taken with both pieces of equipment to provide an extensive database of measurements, as well as to provide a means to "double check" any suspicious measurements recorded by either piece of equipment.

The CELLSCOPE 2000 is a cellular system monitor capable of scanning and logging the received signal strengths of all control and voice channels in the cellular band. CELLSCOPE has several settings which control the way in which these channels are scanned. These settings were logged at the time of the measurements, but were

determined in post processing by examining the output file produced by CELLSCOPE. Table 2-1 shows a list of the relevant CELLSCOPE settings used during the in-building measurements.

Table 2-1: CELLSCOPE Measurement Settings

CELLSCOPE Parameter	Setting
Channels to be scanned	all B-side forward voice channels
Scan Time	200 ms
Wait Time	0 sec

The *scan time* is the minimum amount of time CELLSCOPE waits on a channels before measuring the received signal strength. CELLSCOPE requires that the scan time be at least 200 ms.

The *wait time* is the amount of time CELLSCOPE waits on a channel after the scan time has elapsed. This allows the user to record multiple signal strength readings before CELLSCOPE moves onto the next channel. Setting the wait time to 0 seconds allows for the fastest possible scanning.

A discone (omni-directional) antenna was used with the CELLSCOPE for all measurements.

The HP spectrum analyzer was set up to log all B-side forward channels. Table 2-2 shows the spectrum analyzer settings used during the measurements.

Table 2-2: HP 8562 Measurement Settings

8562 Parameter	Setting
Reference Level	-50 dBm
Resolution BW	10 kHz
Sweep Rate	200 ms
Frequency Span	30 kHz

The *reference level* refers to the maximum signal level shown on the spectrum analyzer screen. The *resolution BW* is the bandwidth of the IF filter used in the spectrum analyzer during the measurement process. *Sweep rate* is the rate at which the spectrum analyzer sweeps through the *frequency span*. The *frequency span* is the bandwidth of interest. Using a frequency span of 30 kHz and a sweep rate of 200 ms, it would take about 90 seconds to scan all 416 B side forward channels.

The spectrum analyzer used the same discone antenna as the CELLSCOPE.

2.2. The Measurement Procedure

All measurements were performed by the sponsor using the CELLSCOPE 2000 and the HP spectrum analyzer configured as described in **Section 2.1 Measurement Equipment**. The measurements were made between June 28, 1993 and July 1, 1993 and were provided to MPRG in the Fall of 1993 for analysis. In order to determine the strongest outdoor cellular signal penetration into the building, all of the measurement locations were located close to windows. Windows attenuate RF energy much less than the

external walls of the building. For this reason, no building penetration loss was considered in the propagation modeling, and "worst case" interference may be assumed from the measurements and the resulting model.

The building where the measurements were performed is 48 stories tall, rectangular, and located in an urban, high cellular traffic area. All measurements inside the building were taken at stationary points. Measurements were taken on floors 6, 12, 18, 24, 30, 36, 42, and the roof. On each of these floors (except the roof), measurements were taken at the North, South, East, and West faces of the building. On the roof, measurements were taken in the North-West and South-East corners, but the CELLSCOPE measurements for the North-West corner of the roof were not provided by the sponsor. For each measurement location, the spectrum analyzer and CELLSCOPE measurements were made within minutes of each other. The same antenna and antenna feed were used for all measurements. The measurement interval at each measurement location during the CELLSCOPE measurements was approximately six minutes. With a scan time of 200 ms and 395 forward voice channels scanned, four measurement samples per channel could be taken with the CELLSCOPE in six minutes. The measurement interval at each measurement location for the spectrum analyzer was long enough to allow three separate signal strength readings for each of the forward channels. Table 2-3 shows the date and time of the measurements taken in the building at each location. As can be seen in Table 2-3, most of the measurements were not taken during the busiest cellular hours. If all of

the measurements *had* been made during the busiest two or three hours of the day, it could have been assumed that at least one voice channel in a cellular sector was on at a specific time. Worst case channel availability statistics inside the building are based on the situation where all voice channels are constantly being used throughout the city. If at least one voice channel in a sector could be considered to be transmitting at any time, the channel availability data processing would have been simplified since the received power of every channel in the sector could be assumed to be equal to the received power of the transmitting channel. It is for this reason that only forward *control channel* measurements were used to determine the path loss models for the external cellular system, since control channels constantly transmit. Typically, control channels broadcast a 2 to 3 dB weaker signal than voice channels. A slightly weaker control channel signal helps ensure that mobile phones inside the cell covered by the control channel do not initiate calls on a voice channel which is too weak to provide decent voice quality. Although a control channel broadcasts a weaker signal, its received power is reflective of the expected received powers of its corresponding voice channels, since both the control and voice channels use the same antennas. The sponsor provided control channel measurements from the spectrum analyzer only.

Table 2-3: Date and Time of CELLSCOPE and Spectrum Analyzer Measurements at Different Locations of the Building

Face	Floor	Date	Time	Face	Floor	Date	Time
EAST	06	07/01/93	10:02 AM	NORTH	06	07/01/93	11:32 AM
EAST	12	07/01/93	12:55 PM	NORTH	12	07/01/93	03:19 PM
EAST	18	06/30/93	12:30 PM	NORTH	18	06/30/93	11:24 AM
EAST	24	06/30/93	02:04 PM	NORTH	24	06/29/93	03:46 PM
EAST	30	06/29/93	03:31 PM	NORTH	30	06/29/93	12:59 PM
EAST	36	06/29/93	11:28 AM	NORTH	36	06/29/93	11:12 AM
EAST	42	06/28/93	03:31 PM	NORTH	42	06/28/93	04:13 PM
WEST	06	07/01/93	08:34 AM	SOUTH	06	07/01/93	09:42 AM
WEST	12	07/01/93	02:14 PM	SOUTH	12	07/01/93	02:05 PM
WEST	18	06/30/93	11:14 AM	SOUTH	18	06/30/93	12:41 PM
WEST	24	06/30/93	02:53 PM	SOUTH	24	06/30/93	02:42 PM
WEST	30	06/29/93	02:00 PM	SOUTH	30	06/29/93	02:22 PM
WEST	36	06/29/93	09:49 AM	SOUTH	36	06/29/93	12:41 PM
WEST	42	06/28/93	01:57 PM	SOUTH	42	06/28/93	03:13 PM

2.3. Description of RAW Data

In addition to the measurement log files produced by the CELLSCOPE and spectrum analyzer, a CELLS file describing the cell site parameters and the locations of all cell sites in the area under study were provided by the sponsor.

The CELLS file is a database of cell sites which has records for 54 cell sites which service the MSA and surround the building where the measurements were made. Each of

these records has a parameter field and three sector fields. The parameter field has sub-fields for the cell site number, location (latitude, longitude), and height above sea level. Each of the three sector fields have sub-fields for the sector face (horizontal antenna direction measured counter clockwise with respect to due North), antenna height above ground, antenna type (each antenna type is associated with an antenna pattern) downtilt (vertical antenna direction measured with respect to the horizon), effective radiated power, supervisory audible tone (SAT), control channel, and voice channel set. **APPENDIX A: The Cell Site Database** lists the entire database of cell sites provided by the sponsor. Figure 2-1 shows the location of all of the cell sites with respect to the building where the measurements were made. The numbers next to the cell sites correspond to the unique number assigned by the cellular operator to each cell site. These numbers can be found in the cell site database.

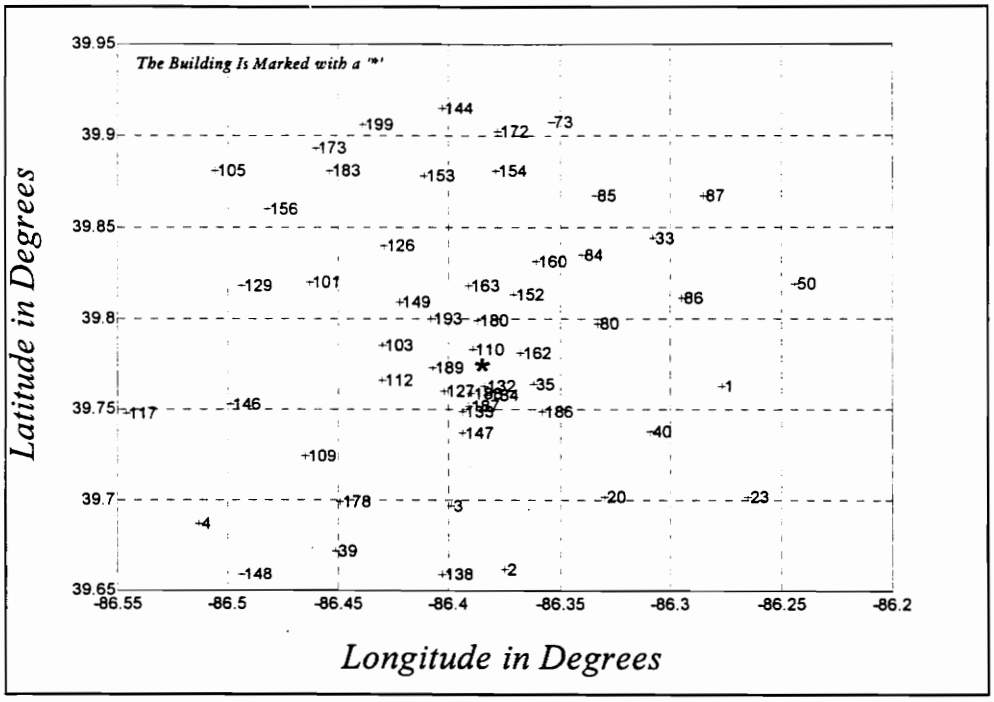


Figure 2-1: Location of Cell Sites with Respect to the Building

Figure 2-2 shows a sample CELLSCOPE log file line. Each line has a date and time stamp, followed by the channel being scanned, an instantaneous signal strength reading, and a minimum, average and maximum signal strength reading. CELLSCOPE measures signal strength every 9 ms. The instantaneous reading corresponds to the first signal strength sample taken over the measurement interval. The minimum reading is the weakest signal strength made over the measurement interval. The average reading is the average (averaged in dB) of all 9 ms signal strength measurements made over the measurement interval. A scan time of 200 ms allows for 22 measurements for each scan. The MAX reading is the strongest 9 ms signal reading made during the 200 ms measurement interval, the MIN reading is .the weakest 9 ms signal reading made during

the 200 ms measurement interval, and the AVG reading is the average (log average) of all the 9 ms readings made of the 200 ms measurement interval.

```
07/01/93 10:02:48.87 ch: 566F -109dBm SCAN: 566 Min:-109, Avg:-109, Max: -97
```

Figure 2-2: Sample CELLSCOPE Log File Line

Figure 2-3 shows a sample spectrum analyzer log file line. Each line contains a frequency and an average received power level in dBm. Each frequency corresponds to a cellular channel number, *n*, given by:

$$n = \frac{f - 870.0}{0.030}, \text{ where } f \text{ is frequency in MHz.} \qquad \textbf{Eq. -12-1}$$

```
880.020        -97.2
```

Figure 2-3: Sample Spectrum Analyzer Log File Line

2.4. Channel Availability Analysis

2.4.1. Validity of CELLSCOPE and Spectrum Analyzer Measurements

As explained in **Section 2.2 The Measurement Procedure**, two independent sets of data were taken at each measurement location in the building. One set was taken with the CELLSCOPE the other with the spectrum analyzer. Figure 2-4 is a histogram which shows the variation of the signal strengths (in dB) received by the CELLSCOPE and spectrum analyzer for all valid measurement locations. Two measurement locations are invalid due to a corrupted CELLSCOPE file (18th floor, South Face) and a missing CELLSCOPE file (North-West roof); data taken from these two measurement locations

were not used in the analysis. The CELLSCOPE data file for the 18th floor- South face contained only one sample per channel for 231 of the 395 voice channels, and zero samples for the other 164 channels. Examining this file revealed that the interval over which the channels were measured in this location was less than one minute (the average time interval for all other locations is 6 minutes). The CELLSCOPE data file for the North-West roof was not provided.

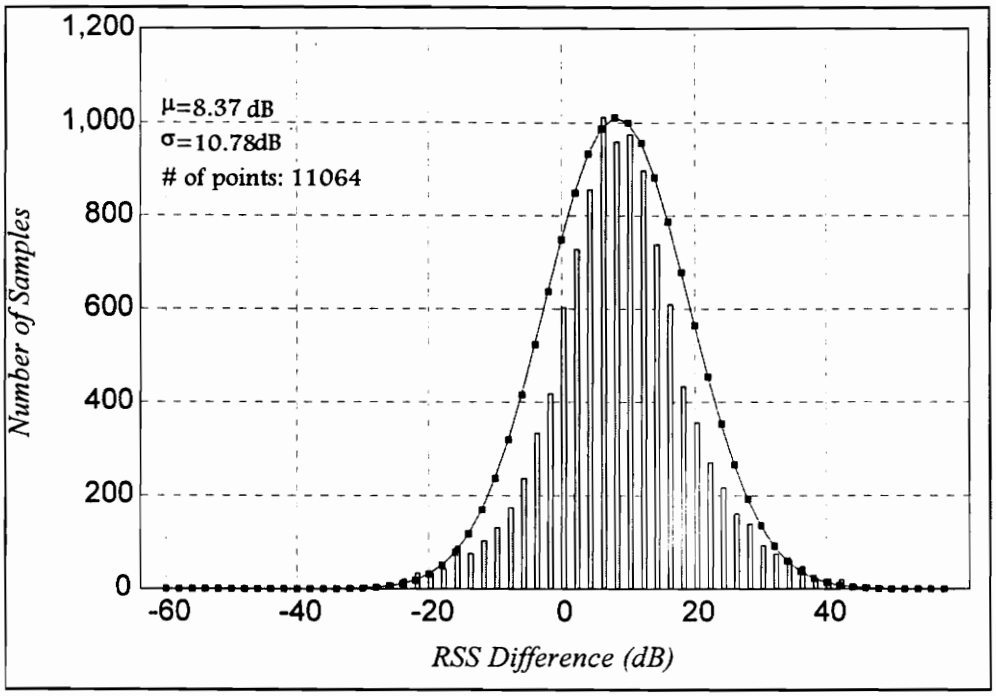


Figure 2-4: Difference Between CELLSCOPE and Spectrum Analyzer Measurements For All Valid Measurement Locations in the Building

There are four measurement locations per floor of the building. The measurements were taken on seven floors (and the roof), and 395 voice channel measurements were taken at each measurement location (the spectrum analyzer also measured the 21 B-side forward

control channels). Defining a measurement sample as a signal strength value corresponding to a particular face, floor, channel, and instrument yields $395 \cdot (4 \cdot 7 + 2) = 11850$ measurement samples. Subtracting the measurement samples of the two corrupted measurement locations yields a total of 11060 measurement samples. A measurement sample was obtained from the data files by averaging (in watts) all measurements made on a single channel. Each measurement for a channel was recorded, on average, two minutes apart from all other measurements of the same channel. The difference between all corresponding CELLSCOPE and spectrum analyzer measurement samples make up the histogram in Figure 2-4.

Figure 2-4 shows that the average difference in the CELLSCOPE and spectrum analyzer measurement is 8.37 dB (the CELLSCOPE measurements, on average, were 8.37 dB stronger than the spectrum analyzer measurements), with a standard deviation of 10.78 dB. The mean indicates that on average, the CELLSCOPE was reading 8.37 dB stronger than the spectrum analyzer for a specific channel. Due to the number of samples, this large mean cannot be explained by channels being active during CELLSCOPE measurements and inactive during spectrum analyzer measurements. The standard deviation indicates that there was a wide variation in the difference of the CELLSCOPE and spectrum analyzer measurements made a specific location. Channels going from an

active state to an inactive state may explain the large variance to some degree. RSSI calibration of the two instruments is the most likely source of the error.

2.4.2. Forward Channel Availability for the Building

The raw signal strength measurements taken at various locations inside the building provide a large database from which channel availability can be determined. Channel availability at a particular location (face and floor) is based on the signal strength readings at that location. A channel is assumed to be available for reuse inside the building if the measurement sample for that channel is below a certain threshold level. Four values for the threshold level were chosen: -80 dBm, -85 dBm, -90 dBm, and -95 dBm. Channel availability processing was performed for both CELLSCOPE and the spectrum analyzer data using these thresholds.

As stated above, each channel was scanned four times by the CELLSCOPE and three times by the spectrum analyzer at each measurement location. Each of the scans for a channel was separated by about two minutes. Within two minutes, a voice channel can change from active to inactive, and vice versa. Therefore, forward voice channel signal strengths at the same location can vary by several tens of dB over the measurement interval. To take this into account, the statistics shown below are based on the strongest of the three (or four) signal strength readings for each measured channel at each location. For CELLSCOPE data, the strongest of the average signal strength readings is used for

determining channel availability. This gives a practical worst case channel availability estimate. Each CELLSCOPE scan provides a minimum (MIN), maximum (MAX), and average (AVG) signal strength reading (see Figure 2-2). Using the MAX signal level would provide the most pessimistic channel availability statistics, but since this reading is based on a 9 ms sample, it could have possibly been affected by spurs and other transients, and therefore was not used. The channel availability results based on the CELLSCOPE measurements were determined by using the strongest of all the AVG signal strength readings for a particular channel. Although this provides pessimistic results, the results are accurate since all transient signal readings have been averaged out.

Figure 2-5 shows the number of available channels on the North face of the building as a function of floor. This data is based on a -95 dBm threshold. As mentioned above, this data is also based upon the worst case (strongest) of the average signal strength measurements measured by the two pieces of measurement equipment. As can be seen in Figure 2-5, the number of available channels decreases as the number of floors increases. This is to be expected since there will be fewer buildings blocking a direct line of sight between the base stations and the measurement equipment. On the upper floors, there may even be a direct line of sight (through a window) between some base stations and the measurement equipment.

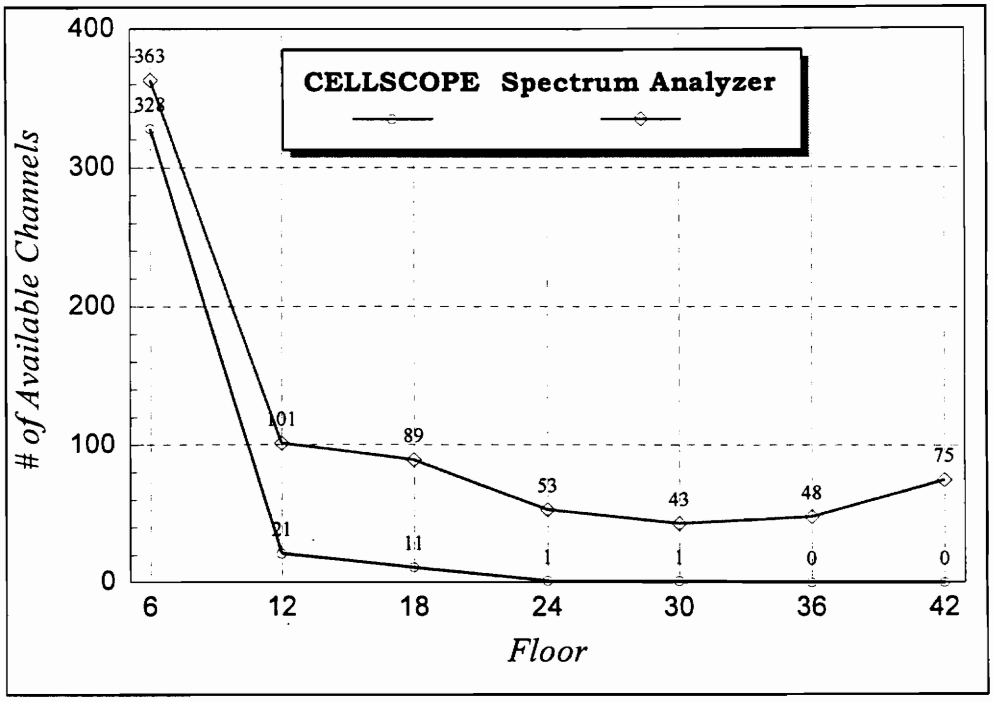


Figure 2-5: Channels Available by Floor for the North Face of the Building Based on a Threshold of -95 dBm

The CELLSCOPE has a dynamic measurement range of about 100 dB and uses a 6 bit quantizer to digitize the received signal strength. This yields a resolution of about ±1.5 dB. Therefore, the CELLSCOPE data was processed using thresholds of both -95 dB and -93 dB to take this quantization into account. The results of this processing show that the quantization of CELLSCOPE's signal strength measurements did not affect the channel availability statistics.

It is clear from Figure 2-5 that there is a substantial difference in the number of available channels based on the CELLSCOPE measurements and the spectrum analyzer measurements. This is similar to the channel availability statistics for the other faces of

the building, and is due to the inherent difference between the CELLSCOPE and the spectrum analyzer raw data values. The stronger signals measured by CELLSCOPE result in fewer channels having signal levels weaker than the in-building threshold. Figure 2-6, Figure 2-7, and Figure 2-8 show the number of channels available on the South, East, and West faces of the building, respectively. These figures also show large differences in the number of channels available due to the differences in the raw measurements.

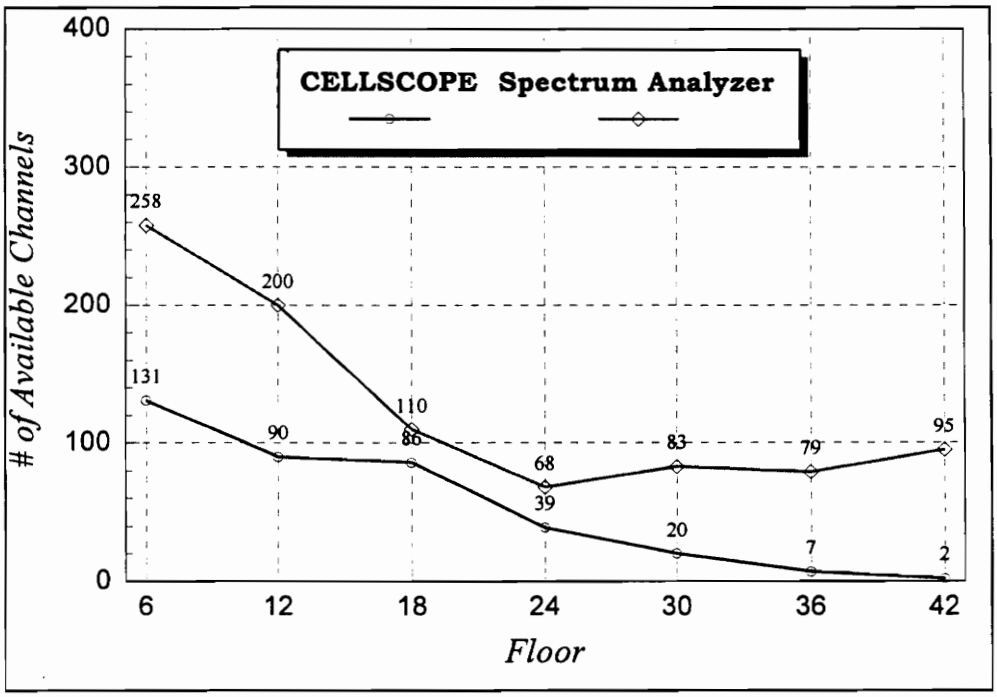


Figure 2-6: Channels Available by Floor for the South Face of the Building Based on a Threshold of -95 dBm

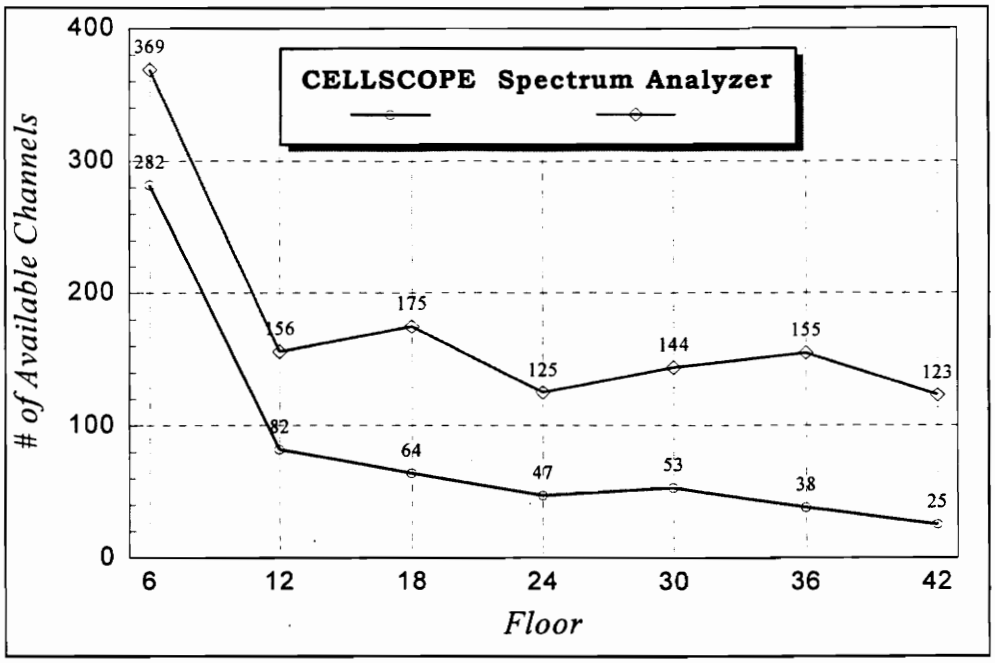


Figure 2-7: Channels Available by Floor for the East Face of the Building Based on a Threshold of -95 dBm

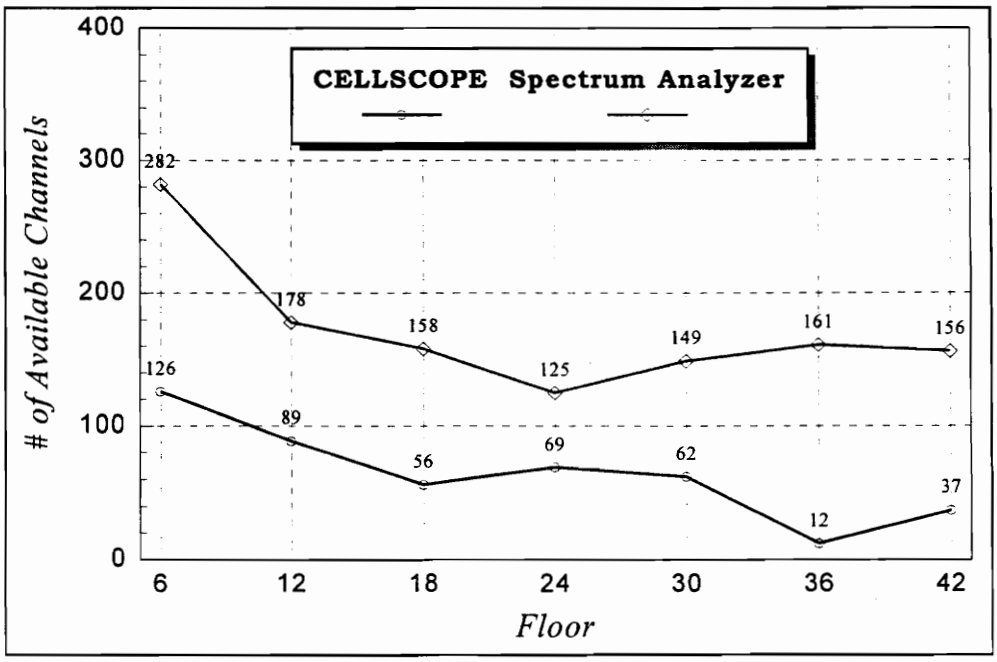


Figure 2-8: Channels Available by Floor for the West Face of the Building Based on a Threshold of -95 dBm

2.5. *The In-Building Signal vs. Floor Model Derivation*

In order to predict the future capacity of parasitic systems, this thesis predicts received signal strength on different floors of a high rise building in an urban area (there are several smaller (<20 stories) buildings surrounding this building.) A model for received signal strength in the building as a function of floor is needed in order to accurately predict signal strength inside the building. This section describes the derivation of this propagation model which is based in the measurements described in this chapter.

Figure 2-1 shows the building under study surrounded by 54 cell sites ranging from a distance of 2 km to 20 km (approx.) away from the building. All but two of the cell sites are further sub-divided into three sectors, and voice channels are assigned to each of the sectors. Since more than one cell can have the same channel, there is no definite method of attributing a field strength measurement made at a location inside the building to a particular cell site. To determine a reliable propagation model, the system design was consulted to determine the cell site which would have the maximum signal contribution to a measurement at a particular location within the building. A cell was determined to have the maximum contribution to a field strength measurement if the cell was located much closer to the building than all other co-channel cells, and the orientation of the transmitting antenna was such that it was pointing directly toward the building. Measurements were made on all voice channels with the CELLSCOPE, and all control and voice channels with the spectrum analyzer. Because only control channels constantly

transmit, the following analysis and resulting propagation models are based on the spectrum analyzer control channel measurements only.

From the spatial distribution of cell sites in Figure 2-1, it can be observed that there are three rings of cells around the building. The first ring consists of the cells closest to the building (cell sites 184, 187, 188, 189, and 110). The second ring of cells includes cell sites 33, 40, 80, and 85. The third ring of cells are the furthest away from the building (examples include cell sites 117, 144, and 148). The effective radiated power from a cell site can have three different values: 16 W, 40 W, and 100 W. All sector antennas are oriented either 2, 120, or 240 degrees counter-clockwise from due North.

The database of cell sites inherited from the sponsor was examined, and measurements from eight cell sites were selected to form the in-building penetration model. These cell sites include almost all types of base stations, while at the same time have co-channel cells which are located much further away from the building. Cell sites with antennas directed at the South face, North-West face, and North-East face were selected. These cells beam one or two faces of the building depending on the location of the cell site with respect to the building. If a cell site beams towards two faces of the building, then the field measurements taken on each of the faces inside the building were included in the analysis. It may be noted that terrain height on the North-East side of the building is about 100 feet lower than the rest of the terrain surrounding the building. This results in

a smaller effective antenna height for cells in the North-East area surrounding the building.

The model used to predict signal strength inside the building due to a cell site was determined by following the steps given below:

1) Signal strength variation with floor was determined for the control channels of each of the eight cell sites used. The signal strength variation with floor was determined with respect to the sixth floor of the building. The average variations are given in Table 2-4 for floors 12, 18, 24, 30, 36, and 42.

Table 2-4: Average Increase in Received Signal Strength as a Function of Building Floor with Respect to the Sixth Floor

	Floor 12	Floor 18	Floor 24	Floor 30	Floor 36	Floor 42
Average Signal Strength Increase (dB)	14.21	16.41	18.14	18.72	19.13	19.13

2) A difference of 14.2 dB was observed for signal strength measurements between the sixth and twelfth floors. Based on this measurement, a best guess for the signal strength difference between the sixth floor and the ground level outside the building is 25 dB. This difference is roughly based on a 4 dB per floor decrease in building penetration loss found in [13]. Since measurements were not made at the ground level, it is not possible to determine an exact relationship between signal strength at ground level.

3) The path loss model is based on a d^n model, where the parameter, n, is determined using linear regression analysis on the signal strength estimates on the ground floor

outside of the building, based on measurements from the eight selected cell sites. Eq. 2-2 shows the form of the path loss model.

$$P_r = P_0 \cdot \left(\frac{d_0}{d}\right)^n \text{, where} \qquad \textbf{Eq. 2-2}$$

P_r is the received power at a distance d from the transmitter (in watts)

d is the distance from the transmitting antenna to the point of interest (in meters)

n is the path loss exponent (unitless)

d_0 is the distance from the transmitting antenna to a close-in free space reference point (in meters)

P_0 is the received power at the close-in reference point (in watts)

P_o is the received power at the close-in reference point. All d^n calculations reference the power at the close-in free space reference point. The close-in reference point is an unobstructed location which is located outside of the far field of the transmitting antenna, but is much closer than practical coverage distances. All received power calculations must reference a known power which is outside of the far field of the antenna [4]. This ensures that all calculated powers are due to radiation only. Free space path loss is assumed between the cell site and the close-in reference point. Eq. 2-3 shows how received power is calculated at the close-in reference.

$$P_0 = \frac{P_t \cdot G_t \cdot G_r \cdot \lambda^2}{(4 \cdot \pi \cdot d_0)^2} \text{, where} \qquad \textbf{Eq. 2-3}$$

P_t is the power of the transmitter (in watts)

G_t is the gain of the transmitting antenna in the direction of the point of interest (in

dB)

G_r is the gain of the receiver (in dB), and is assumed to be unity

λ is the wavelength of the signal

The path loss exponent, n, is determined by solving Eq. 2-2 and Eq. 2-3 for n given P_t, G_t, λ, P_r, d, d_0, and P_0. This is done for all eight cell sites (11 measurements) and linear regression analysis was used to determine a "best fit" n. P_t is the power of the cell site transmitter and is tabulated for all eight cell sites in the cell site database. G_t is the gain of the transmitting antenna in the direction of the building and is taken to be the maximum gain of the antenna for each of the cell sites (i.e. each antenna's bore sight is assumed to be pointing directly at the building). λ is held constant at 0.33 meters (900 MHz) P_r is the received power at the ground level of the building. As mentioned above, the received power at ground level is determined by subtracting 25 dB from the measured signal power on the sixth floor of the building. Table 2-5 shows the P_r value used for each of the path loss exponent calculations. d is the distance from the cell site to the building. d_0 is held constant at 100 meters [6], and P_0 is the received power at d_0 based on the free space path loss equation (Eq. 2-3). Table 2-6 shows the values of P_t, G_t, and d for the path loss exponent calculations. These values were obtained from the data base of cell sites.

Table 2-5: Estimated Received Power on the Ground Level Outside of the Building for Path Loss Exponent Calculation

Cell Site (Building Face)	Measured Received Power on 6th Floor (dBm)	Estimated Received Power on Ground Level Outside of the Building, Pr (dBm)
80 (North)	-96.0	-121.0
80 (East)	-95.2	-120.2
112 (West)	-71.8	-96.8
20 (East)	-99.3	-124.3
187 (South)	-91.3	-116.3
188 (South)	-78.3	-103.3
193 (North)	-98.5	-123.5
193 (West)	-71.7	-96.7
180 (North)	-98.2	-123.2
162 (East)	-89.7	-114.7
162 (North)	-79.2	-104.2

Table 2-6: Cell Site Parameters Used for the Path Loss Exponent Calculations

Cell Site	Sector	Control Channel	ERP (Pt Gt) (watts)	Distance from the Building, d (meters)
80	3	349	40.0	6540
112	2	341	15.8	4750
20	1	350	16.0	9960
187	1	344	16.0	2270
188	1	347	16.0	1520
193	2	348	6.3	3820
180	3	351	16.0	2900
162	3	352	15.8	2310

Signal levels at ground level are important for the propagation models since the simulations rely of the signal level on the ground level to determine coverage areas. Since newly created cells must have a well defined coverage region, as well, the propagation model must be developed for ground level. Once this is done, it is a simple matter to add additional signal level values which are a function of floor (see Table 2-4). In Chapter 6, the availability of channels inside the building as a function of floor is found by determining the interference offered at ground level and then adding the various signal gains introduced by the increasing floor number within the building.

Performing linear regression analysis on the eleven sample data points specified in Table 2-5 and Table 2-6, using Eq. 2-2 and Eq. 2-3 yields a best fit path loss exponent, n, of **3.45** with a standard deviation of **6.8 dB**. This value of n was used in Eq. 2-2 in

conjunction with the signal strength floor variations in Table 2-4 to calculate signal penetration loss into the building as a function of floor. This analysis is shown graphically in Figure 2-9, which shows the best fit curve for data in Table 2-5 and Table 2-6.

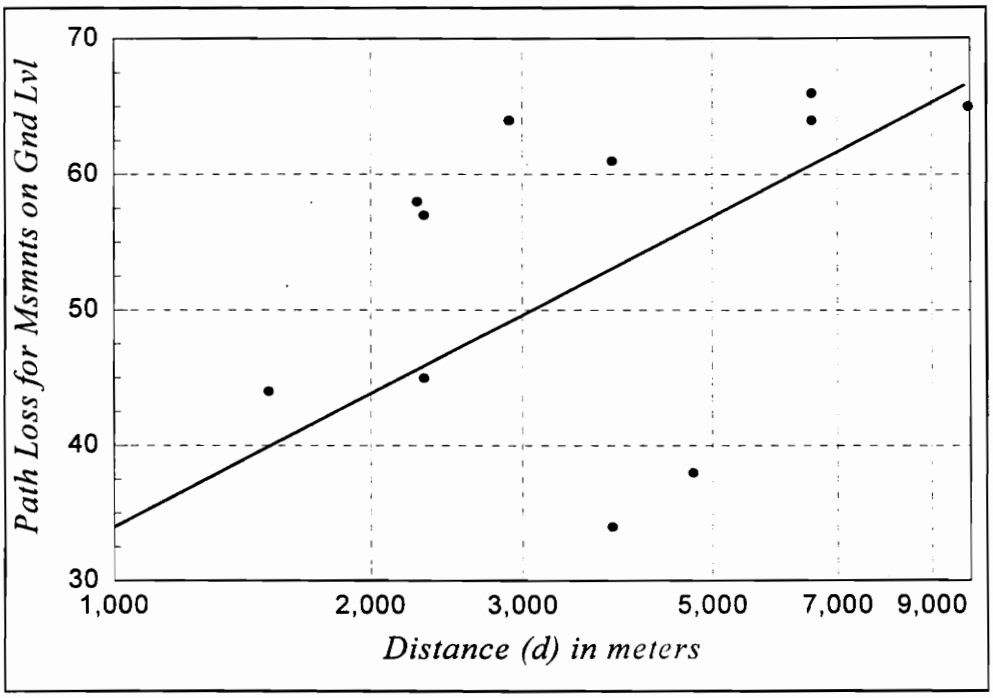


Figure 2-9: Best Fit Curve for the Selected Measurements Made on the 6th Floor of the Building, with 25 dB Subtracted From Each Measurement to Reflect Signals at Ground Level

2.6. Cell Site Coverage Analysis

A cell is defined by the area surrounding a base station antenna where the received power at any point inside the area is stronger than or equal to a particular coverage threshold. The coverage area is important because this is assumed to be the boundary of service for any cell. C/I analysis (described in **Section 4-4 Worst Case C/I Interference Modeling**)

was performed on all of the cell sites inherited from the sponsor in order to determine the best coverage signal threshold parameter for use in this study. As the coverage signal threshold becomes stronger, the size of the cell becomes smaller since the area where the received power is greater than or equal to this threshold is smaller. C/I calculations were performed using coverage thresholds of -95 dBm, -90 dBm, -85 dBm, and -80 dBm. The results of these calculations show that the average C/I in a cell increases as the coverage signal threshold increases. In this study, C/I calculations are performed along the perimeter of each cell, where C/I is the poorest. In this manner, it is possible to ensure proper cell splits and to rank the availability of channels based on worst case interference. If the cell boundary is farther away from the base station, then interference is going to have a much stronger impact than if the boundary was located closer to the base station.

Table 2-7 shows how the average of the worst case (minimum) C/I calculations for all of the cell sites inherited from the sponsor changes with coverage threshold. The C/I calculations were performed at uniform steps along each cell site's coverage boundaries on all of the *derived* channel sets which comprise the cell site's voice channel set (this is described in detail in **Section 4.4 Worst Case Interference Modeling**). The average of these calculations are tabulated in Table 2-7. In addition, the average C/I (worst case) was found by neglecting the single worst channel set, the two worst channel sets, and three worst channel sets. A channel set was deemed to be the worst channel set for a cell if it had the smallest C/I as compared to the other channel sets. As can be seen in Table

2-7, if the coverage threshold is -95 dBm, the average of the worst case C/I calculations is -8.09 dB (assuming that none of the channel set C/I calculations were ignored). This value is much too small to be considered realistic (the interference is 8.09 dB stronger than the desired signal at the cell border), and it can be concluded that a coverage threshold of -95 dBm is too weak of a coverage threshold. A coverage threshold of -90 dBm yielded an average worst case C/I of 1.31 dB. This is also much too weak to be considered realistic. The last two coverage thresholds of -85 dBm and -80 dBm provide more realistic C/I results. A coverage threshold of -80 dBm provides the most realistic C/I calculations since cellular systems with 7 cell reuse are designed to have an average C/I of 18 dB and as shown in [4], a worst case C/I of 17 dB when n=4, fitting well to the average of the worst case C/I calculations of 17.54 dB using a -80 dBm coverage threshold. However, the system under study has a path loss exponent which is less than 4, which implies that C/I will be less than 17 dB. Also, a coverage threshold of -80 dBm is too strong of a coverage threshold (base stations can cover areas where the received power for the base station is less than -80 dBm). Therefore, a coverage threshold of -85 dBm was chosen for use in this thesis. A coverage threshold of -85 dBm is a realistic coverage boundary and provides reasonable C/I predictions for the cell sites inherited from the sponsor.

Table 2-7: Average of all of the Worst Case C/I Calculations for the Inherited Cell Sites For Coverage Thresholds of -95 dBm, -90 dBm, -85 dBm, and -80 dBm, Based on a d^n Path Loss Model With n=3.45, and d_0=100 m

	Worst Case C/I (dB)	
-95 dBm Coverage Threshold		
C/I_{min}	-8.09	all voice channel sets processed.
C/I_{min}	-5.34	single worst voice channel set ignored
C/I_{min}	-3.88	worst 2 voice channel sets ignored
C/I_{min}	-1.93	worst 3 voice channel sets ignored.
-90 dBm Coverage Threshold		
C/I_{min}	1.28	all voice channel sets processed.
C/I_{min}	3.86	single worst voice channel set ignored
C/I_{min}	5.59	worst 2 voice channel sets ignored
C/I_{min}	6.89	worst 3 voice channel sets ignored.
-85 dBm Coverage Threshold		
C/I_{min}	10.29	all voice channel sets processed.
C/I_{min}	12.87	single worst voice channel set ignored
C/I_{min}	13.96	worst 2 voice channel sets ignored
C/I_{min}	15.31	worst 3 voice channel sets ignored.
-80 dBm Coverage Threshold		
C/I_{min}	17.51	all voice channel sets processed.
C/I_{min}	20.94	single worst voice channel set ignored
C/I_{min}	21.43	worst 2 voice channel sets ignored
C/I_{min}	22.84	worst 3 voice channel sets ignored.

3. Overview of the In-Building Cellular Frequency Reuse Study

From Chapter 2 it is clear that fewer channels are available to a parasitic indoor cellular system as the floor number increases. Thus, the growth of the outdoor system will directly impact the capacity of an indoor system over time. If in-building cellular is implemented as a stand alone service in order to provide PCS services, the effect of a maturing outdoor cellular system on in-building frequency reuse must be projected. This chapter describes an approach which uses simulations to predict the growth of an outdoor cellular system over a six year period. "Snapshots" of the maturing outdoor cellular system are taken at three month intervals during the six year period, and are processed to determine the number of channels that would be available for a particular floor within an in-building system.

The following information was provided by the sponsor of this research: a database of the cells in the current urban cellular system, an estimate of the current number of subscribers, a database of the antenna patterns which characterize the various base station antennas, and the location and floor heights of an urban office building in which in-building channel availability will be examined. In addition, standard antenna height and downtilt angle was provided for all future generation cells. The database of the current cellular system consists of a list of cell site entries. Each entry contains the location of the base station (latitude, longitude, and height above sea level), the transmitter power,

antenna type, antenna orientation, antenna downtilt, control channel, and voice channel set for each of the base station's sectors. The database of antenna patterns contains a graphical representation of the horizontal and vertical antenna patterns for all of the antennas used in the cellular system. The cellular system data provided by the sponsor describes a typical mature cellular system which is operated in one of the largest US markets.

The approach taken to predicting in-building frequency reuse first models the current cellular system. The cell site database and the antenna pattern database are examined, and the simple but accurate propagation model from Chapter 2 is used to determine interference between co-channel cells in the current system. It was observed that downtilt is not currently implemented in the cellular system, so the effects of downtilt are ignored at this stage of the study (the current cellular system is referred to as the 1st generation, since no growth is yet simulated).

In order to model a maturing cellular system over time, cellular traffic must be modeled. The sponsor did not provide the exact number or distribution of cellular subscribers in the area under study, but provided reasonable estimates of 70,000 calls during busy hour with an average call duration of 1.5 minutes. The sponsor projected 40% growth in the urban core and 20% in the suburban areas of the city. This study assumes a uniform call blockage percentage across the current system, and bases the number of initial subscribers

on the number of voice channels available throughout the system. For an initial uniform blockage of 2%, the initial number of subscribers during a busy hour can be shown to be approximately 20,000. This is based on an average call length of 1.5 minutes and two calls per hour per subscriber. Details of this analysis are presented in Chapter 5.

The simulations in this study use a two tiered subscriber distribution model to model growth. Subscribers located in cells close to the center of the city (cells within 6 km of the building) are given a growth rate of 40%, while subscribers in cells located away from the center of the city are given a growth rate of 20% (see Figure 3-1). The simulations grow the number of subscribers in a step-function fashion in three month intervals. After each of these three month intervals, the number of subscribers in the cell are counted, and the grade of service (GOS) for each of the cells are computed. The GOS is computed using the Erlang-B formula. The Erlang-B formula returns the percentage of call blockage based on the number of subscribers in a cell and the number of voice channels allocated to the cell. The simulations examine each cell, and split any cell which has a call blockage greater than 5%. Each cell is split into four new cells when any of its sectors exceed a 5% GOS.

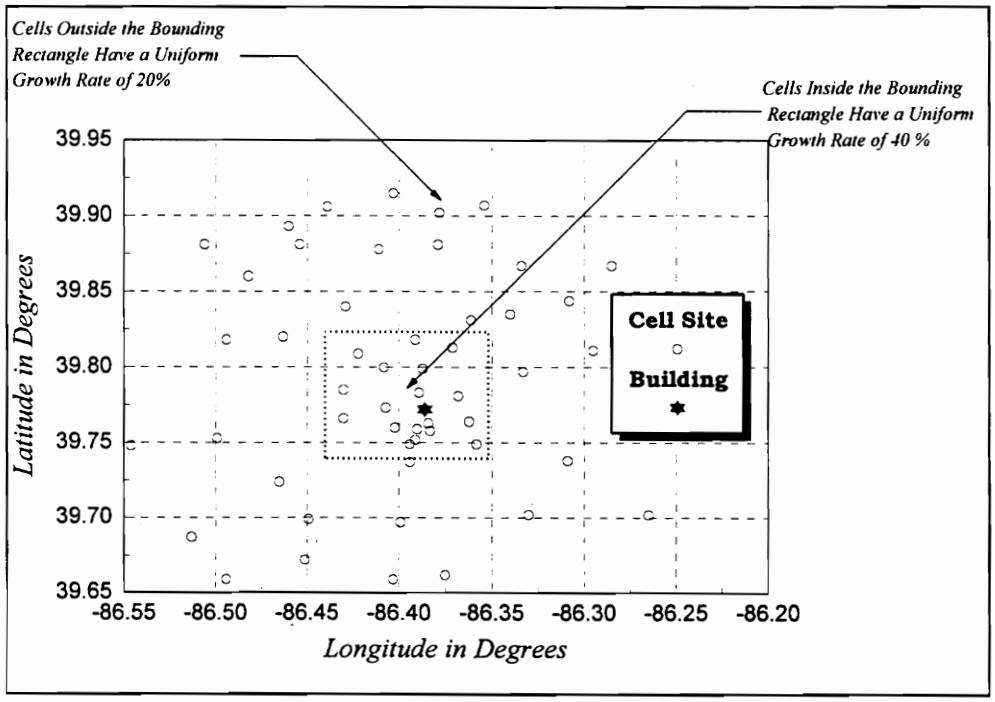


Figure 3-1: Distribution of Uniform Growth Rates in the Cellular System

The simulation cell splitting technique is loosely based on Lee's cell splitting algorithm [3]. The coverage area of each sector in the cell is determined using a propagation model, the transmitter power, antenna pattern, and a coverage threshold of -85 dBm. The coverage of each cell included only the area around the cell where the received power is greater than or equal to the coverage threshold. The cell splitting algorithm removes the original base station and replaces it with four new base stations. The new base stations are given omni-directional antennas. Antenna height and downtilt are assigned to the new base stations based on how many times the base station has been previously split (i.e. its cell generation number). Table 3-1 shows the downtilt and antenna height rules provided by the sponsor. The transmitter power and location of the four new base

stations are set so that the area covered by each of the sectors of the original base station is covered by the four new base stations. This is explained in detail in Chapter 5.

Table 3-1: Antenna Downtilt and Antenna Height as a Function of Cell Generation Number

Cell Generation	Antenna Downtilt	Antenna Height
1st Generation Cell	0 Degrees	as specified
2nd Generation Cell	6 Degrees	60 feet
3rd Generation Cell	10 Degrees	30 feet

The simulations continue to grow the number of subscribers in three month intervals over a six year period. Cells continue to split as the simulation time progresses. The simulations produce a comprehensive log file describing every action performed by the simulation code. This log file is included in **Appendix D: The Simulation Log File**. The simulations also internally store "snapshots" of the cellular system after each of the three month intervals. Each snapshot holds the location and parameters of all of the cell sites in the cellular system. An AutoCad interface was written to allow these snapshots to be plotted in a geographically related manner. Plots of the cellular system are provided at years zero (present conditions) through year six.

Once a cellular system has been grown for six years, post processing code is used to evaluate the interference between cells in the cellular system, as well as to estimate the number of cellular channels which could be re-used inside the large office building. The location of this building was provided by the sponsor, and is shown relative to the cell

sites in Figure 3-1. The forward channel interference for every cell is calculated and tabulated based on the distance between co-channel cells, the transmitter power of the co-channel cells, as well as the antenna pattern, antenna height, and antenna downtilt of the co-channel cells. These interference calculations provide a means of determining the overall performance of the cellular system as the cells split and become located closer together. The interference calculation also provides a means to validate the algorithm which the simulations use to choose voice channel sets for the newly formed cells. If a voice channel allocation algorithm chooses voice channels poorly, it is apparent in the results of the interference calculations, since the C/I becomes much less than the required 18 dB as called for by the US AMPS standard.

Three month cellular system snapshots which are stored internally by the simulations are used to determine the number of channels available inside the building as a function of time. Each snapshot holds the locations of all of the cell sites in the outdoor cellular system, as well as their parameters (transmitter power, antenna type, antenna height, etc.) A cellular channel is deemed to be available for re-use inside the building if the received power inside the building due to the outdoor cellular system is below a specific threshold. The simulations analyze indoor channel availability based on thresholds of -95 dBm, -90 dBm, -85 dBm, and -80 dBm.

The received power for a particular channel is determined by summing the received powers from all cell sites which reuse the channel (the received power due to each of the cell sites is calculated as described in Chapter 4). because the location and parameters of the cell sites are recorded in the cell site snapshots at three month intervals, channel availability statistics can also be estimated at three month intervals. The received power inside the building due to a cell site is calculated by first calculating the received power at the base of the building. This calculation is based on transmitter power, antenna pattern, antenna height, antenna downtilt, and the distance between the cell site and the building. This calculation is repeated for all other cells re-using the channel of interest. The results of these calculations are summed to provide an aggregate received power at the base of the building. As described in **Section 2-5 The In-Building Signal vs. Floor Model**, a building gain constant (either 0 dB or 25 dB) is added from the received power at the base of the building to get the sixth floor signal levels, and a floor dependent constant is also added to yield an upper and lower bound on received power inside the building as a function of floor. Both the upper and lower bound on received power is compared to a channel availability signal threshold. The channel is considered available for re-use inside the building if the power is weaker than the signal threshold. The results of this procedure are tabulated for all channels, on all floors of the building, at three month intervals, for the channel availability thresholds mentioned above.

3.1. The Derived Channel Sets

Chapter 4 discusses the approach taken to model interference in a growing cellular system. Before this can be discussed, the method used to keep track of all channels and all cells in an urban cellular system must first be understood.

The sponsor supplied a database containing all the relevant parameters for all the cell sites in the area under study (refer to **Section 2-3 Description of RAW Data** for more information on this database). Each cell site in the database is broken into sectors, and each sector is assigned a varying number of voice channels. These voice channels are chosen by the operator from the 395 available voice channels, and they have been carefully chosen so as to minimize the co-channel and adjacent channel interference in the system. This is referred to as a frequency allocation scheme. Cellular operators normally use expensive, intricate software packages and high priced consultants to determine a frequency allocation scheme. In order to properly represent the frequency re-use scheme currently in place, the 395 voice channels are broken up into a discrete number of *derived channel sets*. A derived channel set is defined to be a set of voice channels derived by the simulations which have the unique property of being reused throughout the cellular system as a group. The frequency allocation scheme in the database of cells determines how the derived channel sets are determined. It is imperative to the capacity modeling simulations that it is known exactly how the frequency allocation scheme was created. It is only after the frequency allocation scheme is known

that new cells can be created which will conform to the existing frequency allocation scheme.

As an example, consider a derived channel set containing voice channels 355, 376, and 397. In the frequency reuse scheme, if a voice channel 355 is assigned to a particular sector then the voice channels 376, and 397 will be assigned to that sector, as well. All simulations use the derived channel sets, and *not* the individual voice channels. This not only allows the frequency allocation scheme to be maintained, but it also decreases the required number of interference calculations required during simulations. The number of interference calculations are reduced because an interference calculation for any one voice channel in a derived channel set can be assumed to be the same as all other voice channels in that derived channel set. Thus, instead of computing interference for each of the voice channels, it is only necessary to compute the interference for one of voice channel in each of the derived channel sets. For all simulations, interference calculations are performed for one channel in a derived channel set, and that calculation is implied to be the same for all other channels in the derived set.

The first step in predicting interference is to produce a derived channel set structure for the current cellular system. Figure 3-2 shows a flowchart describing the method of producing the unique channel sets from the voice channels in the cell site database. The goal of this algorithm is to produce a discrete number of derived channel sets from the

frequency allocation scheme given in the database of cells. Once the derived channel sets have been determined, all of the simulations will reference these channel sets instead of the individual voice channels. The algorithm begins by clearing the derived channel set structure and initializing all variables (step 1). Next, a loop is established which loops through all 395 voice channels (step 2). This loop is necessary because each voice channel must be examined individually to determine which derived channel set it is a member of. The loop variable, *i*, denotes the voice channel currently being examined. Step 3 checks to see whether or not voice channel *i* has already been assigned to a derived channel set. If it has, then no further processing needs to be performed on the voice channel, and the algorithm can move onto the next voice channel. If it has not been assigned to a derived channel set, processing of the voice channel continues. Step 4 creates a new derived channel set. The step allocates an array of *MAX_VCHAN* integers, where *MAX_VCHAN* is a constant denoting the maximum number of voice channels which can be assigned to a sector. This constant is set to 75 for the simulations, however the number of voice channels which comprise a derived voice channel set does not exceed 9 or 10 in practice. Initially however, all voice channels are placed in the new derived channel set array. Step 5 initializes a loop which examines all of the cell sites in the cellular system. The loop variable, *j*, denotes the cell site currently being examined. Step 6 examines cell site *j* to see whether or not it contains voice channel *i*. If so, then the algorithm continue; otherwise, the loop continues with the next cell site. Step 7 is

reached once a cell site is found which has a voice channel set containing voice channel *i*. Step 7 of the algorithm determines the intersection of the derived channel set created in Step 3 and the voice channel set of cell site *j*, and stores the result of this intersection in the derived channel set. Initially, the derived channel set contains all 395 voice channels. The first time step 7 is performed, the 395 voice channels are replaced with only the voice channels belonging to cell site *j*'s voice channel set. As the loop established in Step 5 is iterated, the intersection performed in Step 7 masks out all voice channels not consistently reused throughout the cellular system. Step 8 tests the conditions of the loop established in Step 5. If all cell sites in the cellular system have been examined, the algorithm moves on to Step 9; otherwise it returns to Step 5 and the looping process continues. Once Step 9 is reached, a derived channel set which contains voice channel *i* is complete. This channel set contains the voice channel *i*, and all of the other voice channels which are reused consistently throughout the cellular system. Step 9 tests to see if all 395 voice channels have been processed. If all of the voice channels have been processed then the algorithm moves on to Step 10; otherwise, the algorithm continues with the next voice channel. Step 10 saves all of the derived channel sets created by the algorithm in an array of derived channel sets.

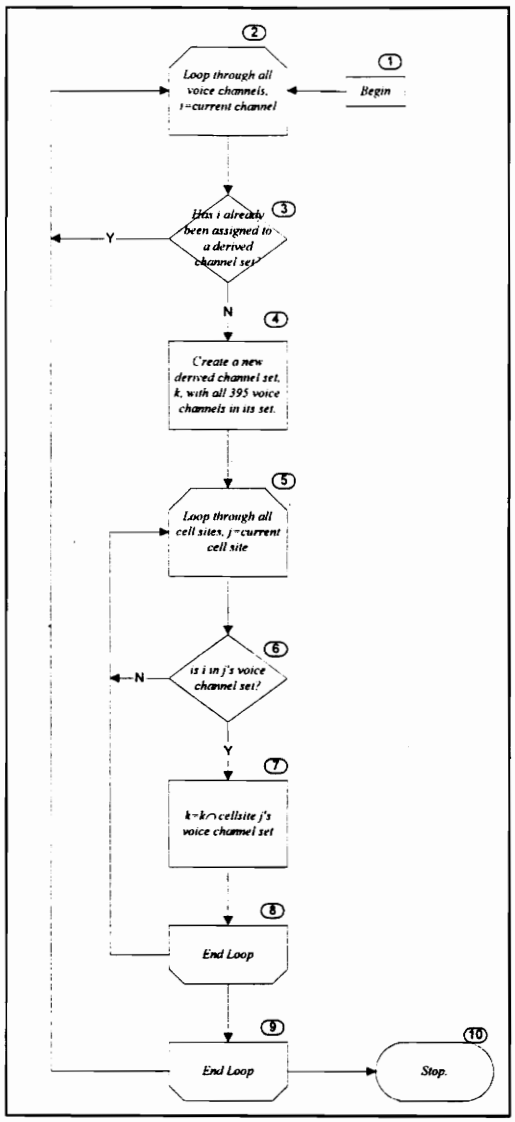


Figure 3-2: The Derived Channel Set Algorithm Flowchart

Figure 3-3 shows the first 50 derived channel sets in the derived channel set structure created with the algorithm above. This array of channel sets is unique to the current cellular system under study, and shows the way in which channels are reused. The numbers in bold indicate the derived channel set number, and the list of numbers to the

right of the derived channel set number are the voice channels which make up the derived channel set. As can be seen in Figure 3-3, in general, there are not many voice channels in a derived channel set. This is because all of the voice channels must be reused together everywhere in the cellular system. If, for example, voice channel 439 was reused with voice channels 355, 376, 397, and 418 (derived channel set 1) throughout the cellular system, except for in one cell, then that one cell would cause voice channel 439 to be omitted from the derived channel set, even through it was reused almost everywhere. For a complete listing of the derived channel sets for the current cellular system, see **APPENDIX E: The Derived Channel Sets**.

1) 355 376 397 418	26) 443
2) 356 377 398 419 440 461 482 503 524	27) 445
3) 357 378 399 420 441 462 483	28) 446
4) 358 379 400 421 442	29) 450
5) 359 380 401 422	30) 454
6) 360 381 402 423 444	31) 457 478 499
7) 361 382 403 424	32) 460 481
8) 362 383 404 425	33) 463
9) 363 384 405 426 447 468 489	34) 464 485
10) 364 385 406 427 448 469	35) 465
11) 365 386 407 428 449 470 491	36) 466
12) 366 387 429	37) 467
13) 367 388 409 430 451 472 493	38) 471 492
14) 368 389 410 431 452	39) 473
15) 369 390 411 432 453 474 495	40) 475 496 517 538 559 580
16) 370 391 412 433	41) 479
17) 371 392 413 434 455 476 497	42) 480 501
18) 372 393 414 435 456 477 498	43) 484
19) 373 394 415 436	44) 486
20) 374 395 416 437 458	45) 487
21) 375	46) 488 509 530
22) 396 417	47) 490
23) 408	48) 494
24) 438 459	49) 500 521
25) 439	50) 502

Figure 3-3: Partial Listing of the Derived Channel Set Structure Created With the Derived Channel Set Algorithm

Notice the number of derived channel sets with only one voice channel in their sets. Each voice channel found in a derived channel set with only one voice channel was never consistently reused with any other voice channel. Examining the cell site database closely reveals that most of these voice channels were reused with a set of voice channels everywhere except for in one or two isolated instances. It is these isolated instances, though, which cause the voice channels to be contained in their own derived channel set. There are two possible explanations for the large number of derived channel sets

containing only one voice channel. First, if a cell did not have enough voice channels to handle the traffic in its coverage region, an additional voice channel (or channels) could have been added to the cell's channel set to temporarily solve the capacity problem. Adding a voice channel to an overloaded cell without additionally adding the other voice channels in its derived channel set, effectively removes the added voice channel from its derived channel set, since the voice channel is not consistently reused with the other voice channels in its derived set. *Dynamic channel allocation*, can also cause a large number of derived voice channels which contain only one voice channel. A dynamic channel allocation scheme allows certain voice channels to be used in different cells at different times of the day. For example, more voice channels can be assigned to the cells that cover the major highways of a city during the rush hours to handle the increase in cellular traffic along the highways, while during the rest of the day, the voice channels are used in cells within the city to accommodate the cellular users who are using their phones there. Because the cell which contains a dynamically changing voice channel is unknown, the dynamic voice channel will need to be contained in its own derived channel set.

3.2. Simulation Parameters

Table 3-2 shows a list of all of the parameters used in the simulations in this study.

Table 3-2: Simulation Parameters

Parameter	Value
# of Interference Points for C/I at Cell Boundary	25
Coverage Threshold	-85 dBm
Path Loss Model	d^n, $n=3.45$, $d_0=100$ m
Subscriber Distribution	Two Tiered
Annual Growth Rate of Tier 1	40%
Annual Growth Rate of Tier 2	20%
Upper Left Hand Corner of Tier 1's Bounding Rectangle	(86°26'0"W, 39°49'0"N)
Lower Right Hand Corner of Tier 1's Bounding Rectangle	(86°21'0"W, 39°44'0"N)
Resolution of the Capacity Simulations	3 months
Average # of Calls Per Subscriber Per Hour	2 calls
Average Time Per Call	1.5 minutes
Initial Call Blockage	2%
Maximum Allowable Blockage	5%
Stop Time of the Simulations	6 years, 0 months
1st Generation Cell's Downtilt	0°, h^t as specified
2nd Generation Cell's Downtilt	6°, h^t = 60 ft
3rd Generation Cell's Downtilt	10 h^t = 30 ft

The *Number of Interference Points* specifies the number of points along the boundary of a cell where C/I calculations are performed. The larger this value, the more accurate the C/I calculations are, however the simulation time becomes much longer for a large number of interference points. This parameters is discussed in more detail in Chapter 4.

Coverage Threshold defines the coverage region for a cell. The coverage region of a cell includes all areas around the cell where the received power due to the cell's transmitter is greater than or equal to this threshold. The value was derived in Chapter 2 as -85 dBm.

Path Loss Model is the model used by the simulations for all path loss predictions. Path loss predictions are made during C/I analysis as well as for in-building channel availability analysis. The model is a d^n model with n=3.45 and d_0=100 meters. This model was derived in Chapter 2.

Subscriber Distribution describes the distribution of cellular growth in the area under study. The two-tiered value indicates that the cellular area is broken into two separate areas with each area having a different subscriber growth rate.

Annual Growth Rate of Tier 1 is the uniform increase in the number of subscribers which use the cells located in Tier 1. Tier 1 is defined to include the urban core of the city, and has a higher growth rate than Tier 2. The parameter of 40% indicates that each year, the number of subscribers using the cells in Tier 1 will increase 140%.

Annual Growth Rate of Tier 2 is the uniform increase in the number of subscribers which use the cells located in Tier 2. Tier 2 is defined to include areas outside of the urban core, and has a growth rate of 20%.

The *Upper Left Hand Corner of Tier 1's Bounding Rectangle* and the *Lower Right Hand Corner of Tier 1's Bounding Rectangle* describe Tier 1's size an location. All cells located within the rectangle specified by these two corners are considered to be in Tier 1 and have the growth rate associated with Tier 1 (40%). All other cells are consider to reside in Tier 2 and have the growth rate associated with Tier 2 (20%).

Resolution of the Capacity Simulations indicates how often the cellular system is examined by the simulations in order to perform cell splitting, GOS calculations, in-building channel availability analysis, etc. The larger this value, the faster the simulations will execute, however, a large value indicates that cell splitting, and other necessary processes are not done as often, and as a result the order in which the processes should have occurred is lost. This value is set to three months. Three months provides adequate resolution for the analysis.

Average Number of Calls Per Subscriber Per Hour is the average number of calls made by a cellular subscriber per hour during busy hour. 2 calls per hour was provided by the sponsor as a reasonable value for this parameter.

Average Time Per Call is the average length of a cellular phone call during busy hour. 1.5 minutes was provided by the sponsor as a reasonable value for this parameter.

Initial Call Blockage is the assumed GOS for all cells at year 0 (the beginning of the simulations). This value is used to estimate the initial number of subscribers in the system, based on the Erlang-B formula, the *Average Number of Calls Per Subscriber* parameter, the *Average Time Per Call* parameter, and the number of voice channels in the cellular system. The value of 2% was provided by the sponsor.

Maximum Allowable Blockage is the greatest probability of a blocked call a cell can sustain before the simulation splits it into four new cells The value of 5% was provided by the sponsor.

Stop Time of the Simulations is the amount of time starting from the present day that the simulations will predict cellular growth and in-building channel availability. This parameter is set at 6 years.

1st Generation Cell Downtilt describes the downtilting parameters initially given to all cells in the system. Currently, downtilt is not used.

2nd Generation Cell Downtilt describes the downtilting parameters given to all cells which were created from 1st generation cells (the cells inherited from the sponsor).

3rd Generation Cell Downtilt describes the downtilting parameters given to all cells which were created from 2nd generation cells.

4. Approach To Modeling Interference

This chapter describes the approach used to model co-channel interference in the outdoor cellular system as the system matures (adjacent channel interference is not taken into consideration). Interference degrades the performance of a cellular system. Interference in a cell is caused by co-channel cells elsewhere in the system. Therefore, the location of all co-channel cells with respect to each other directly affects the amount of interference seen by a cell. If interference can be quantified, it can give a direct correlation between the layout of the cells in the cellular system and the expected grade of service (GOS) of the system as a whole. This is important because this thesis aims to predict the logical progression of cell splits in the cellular system, and a means of evaluating the best cell splits in terms of system performance is required to properly predict capacity over time.

In practical cellular systems, one must be concerned with both co-channel interference and adjacent channel interference. The co-channel interference ratio (C/I) is the ratio of the power of a desired channel to the sum of the powers of all of the interfering co-channels. As this ratio increases, the interfering co-channels have less of an impact on the desired channel, and the quality of service increases. The adjacent channel interference ratio is the ratio of the power in the desired channel to the sum of the powers of the channels spaced in the spectrum immediately above and

below the desired channel. The minimum spacing between voice channels in a voice channel set is a simulation parameter, and is set at 7 for the interference simulations. These two types of interference calculations are important because they provide a way of determining how the coverage of a cellular system is affected by cell splitting.

4.1. Antenna Pattern Modeling an its Effect on Cellular Coverage

An antenna pattern describes the way an antenna distributes RF energy as a function of space. This research uses antenna patterns to model the way in which RF energy from one base station affects the coverage of other base stations (co-channel interference) as well as the way in which RF energy propagates to the building under study. Figure 4-1 and Figure 4-2 show typical horizontal and vertical antenna patterns used in the cellular system under study (these are actual horizontal and vertical antenna patterns for the LPD-7905 antenna). The horizontal antenna pattern displays the way RF energy is radiated from the antenna with respect to the orientation of the antenna on the horizon. The vertical antenna pattern displays the way RF energy is radiated from the antenna with respect to the angle above or below the horizon.

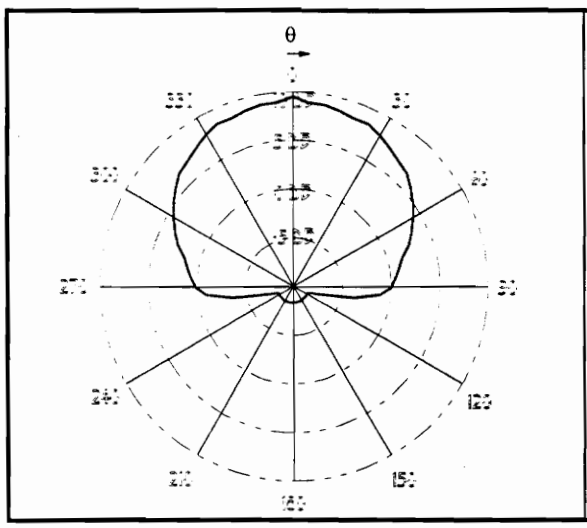


Figure 4-1: Typical Horizontal Antenna Pattern (Actual Antenna Pattern for Antenna LPD-7905)

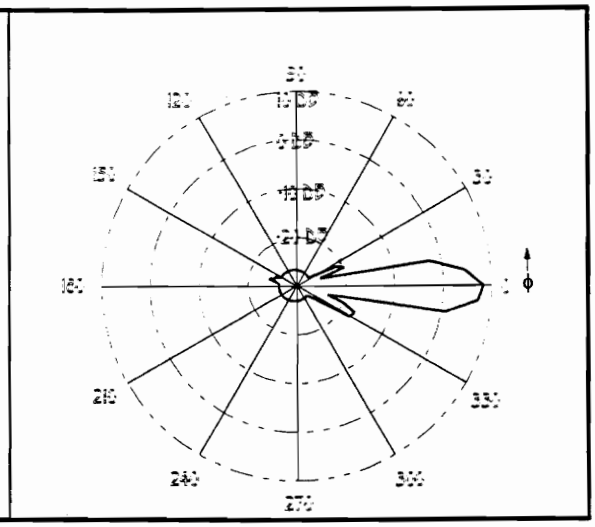


Figure 4-2: Typical Vertical Antenna Pattern (Actual Antenna Pattern for Antenna LPD-7905)

The angle θ in Figure 4-1 indicates the angle around the antenna with respect to the antenna face, while the radial distance from the center of the plot indicates the relative gain of the antenna (in dB). Figure 4-1 shows the horizontal pattern of an antenna with a maximum gain of just under 10 dB. This occurs at 0 degrees relative to the face of the antenna. Compare this to the gain at the back lobe of the antenna (the small lobe at θ = 180 degrees). The maximum gain of the back lobe of the antenna is about -8 dB. This indicates that this antenna has a front to back ratio of 18 dB. A narrow lobe with high gain implies that the antenna is highly directional, since most of the energy from the antenna is emitted in this narrow lobe. The size of the lobe can be quantified by the angle between the two 3 dB points around the face of the antenna. This is known as the horizontal 3 dB beam width. The 3 dB points are the locations on the plot where the received power is 3 dB down from the maximum

radiated power. For the antenna pattern in Figure 4-1, the horizontal beam width is about 90 degrees since the 3 dB points are about 45 degrees away from the antenna face on both sides.

4.1.1. Horizontal Antenna Pattern Modeling

To allow the simulations to use the antenna gain at any point in space, a closed form analytical expression is required to model the actual antenna patterns used in the cellular system. This thesis models horizontal antenna patterns as cardiods. Plots of the horizontal and vertical antenna patterns of all of the different types of antennas used in the cellular system under study were provided by the sponsor. All of the horizontal antenna patterns (except for the omni-directional antenna patterns) have plots similar to the plot in Figure 4-1, but with different beam widths and front to back ratios. In order to model these horizontal antenna patterns, the patterns were assumed to have a perfect cardiodal shape. Eq. 4-1 shows the equation for a cardiod,

$$r(\theta) = \alpha \cdot \left[1 + \sin\left(\theta + \frac{\pi}{2}\right)\right] \qquad \textbf{Eq. 4-1}$$

where r is the gain of the antenna at a particular angle, θ is the angle of interest, and α is a scaling constant and is described below. The factor of $\frac{\pi}{2}$ is added to θ so that the maximum gain of the cardiod occurs at $\theta = 0$, as seen in the plot in Figure 4-1. Figure

4-3 compares the real antenna pattern shown in Figure 4-1 (the real horizontal antenna pattern for the LPD-7905 antenna) with the cariod approximation of Eq. 4-1.

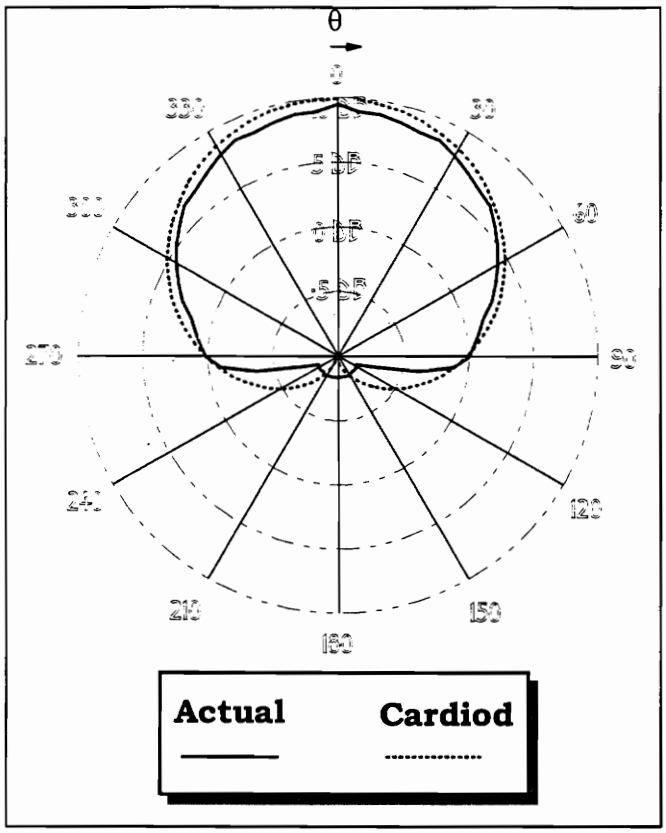


Figure 4-3: Comparison of an Actual Horizontal Antenna Pattern (Horizontal Antenna Pattern for LPD-7905 Antenna) With the Cardiod Approximation

The simulations model a cell site antenna with four different parameters: the horizontal antenna pattern, the vertical antenna pattern, the effective radiated power (ERP) of the transmitter (in units of watts), and the angle between the antenna and a point of interest with respect to the face of the antenna. The point of interest is a location somewhere within the cellular system where the received power from the

antenna is to be determined. The ERP for all cell sites is known and is referenced in the cell site database. It is assumed that the ERP listed for any particular cell site is the maximum power radiated from that cell site (the maximum gain of the antenna has already been factored into the ERP). Therefore, the simulations assume that the power emitted in a direction other that $\theta=0$, is attenuated to reflect that the radiated power is not the maximum radiated power in that direction. As an example, assume that cell site #1 has an antenna with the horizontal antenna pattern shown in Figure 4-1. The ERP of cell site #1 is 100 watts, and the angle between the cell site and the point where the received power is to be determined is 90 degrees with respect to the antenna face (see Figure 4-4). Since the ERP only applies at an angle of 0 degrees, the ERP must be attenuated to compensate for the fact that the angle of interest is 90 degrees. Examining Figure 4-1, reveals that at an angle of 90 degrees, the antenna gain is 10 dB down from the maximum gain. Therefore, the radiated power at 90 degrees should be attenuated 10 dB from the provided ERP values. This attenuated power is the effective power for a received power calculation at the point of interest.

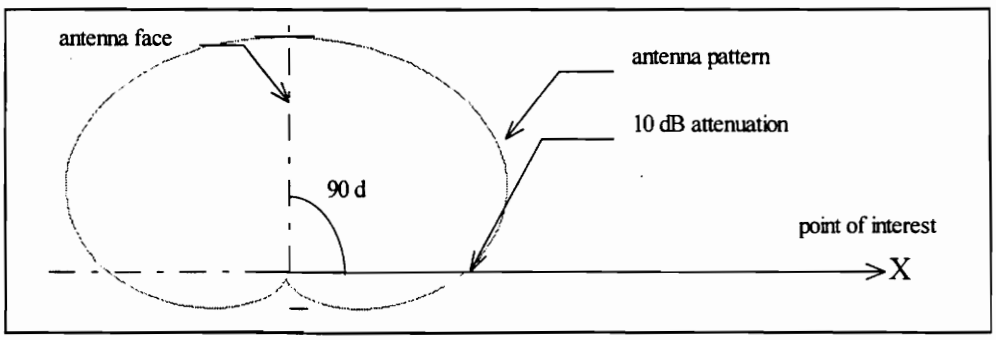


Figure 4-4: Horizontal Antenna Pattern Example

4.1.2. Vertical Antenna Pattern Modeling

A vertical antenna pattern describes how RF energy is emitted from the antenna with respect to the vertical plane passing through the antenna. The angle ϕ on the vertical antenna pattern plot (refer to Figure 4-2) indicates the angle around the antenna with respect to the horizon. The radial distance from the center of the plot indicates the relative gain of the antenna in dB. The vertical antenna pattern shows the downtilt associated with an antenna. Physically tilting the antenna downward corresponds to a clockwise rotation of the antenna pattern in the vertical plane. Essentially, this causes less power to be emitted from the antenna on the horizon, and can dramatically affect the coverage associated with an antenna. This is important because downtiliting reduces the interference between co-channels in the outside cellular system, and also reduces the amount of interference which penetrates inside buildings and would otherwise degrade the performance of an in-building cellular network.

All of the antennas used in the system under study (except the omni directional antennas) have vertical antenna patterns similar to the one shown in Figure 4-2. This pattern is modeled in the simulations as an ellipse, with the cell site located at one of the foci. Figure 4-5 compares the real vertical antenna pattern shown in Figure 4-2 (the actual vertical antenna pattern for LPD-7905 antenna) with the elliptical approximation.

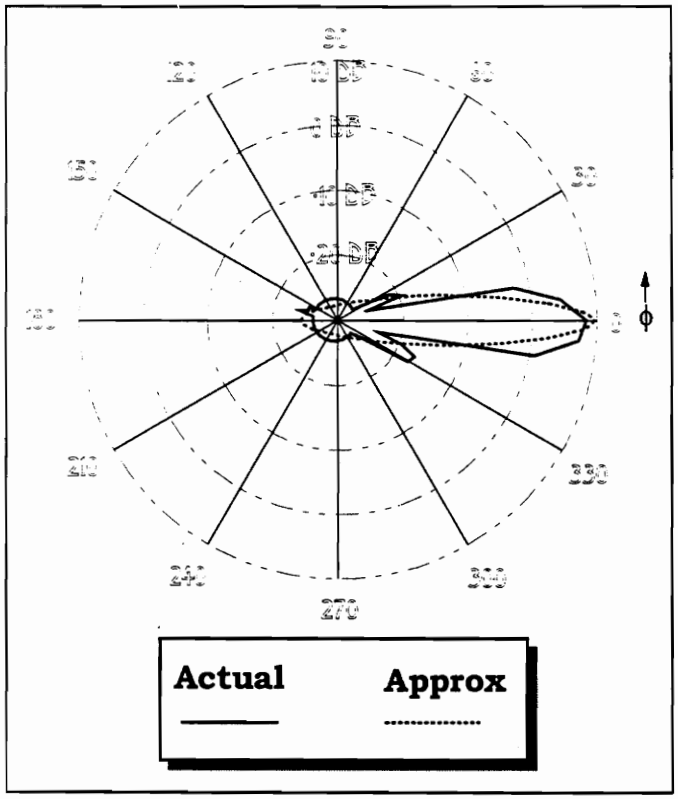


Figure 4-5: Comparison of an Actual Vertical Antenna Pattern (Actual Vertical Antenna Pattern for LPD-7905 Antenna) With the Elliptical Approximation.

Consider the ellipse shown in Figure 4-6. The objective of modeling a vertical antenna pattern is to obtain a relative antenna gain given a vertical angle ϕ. The antenna gain returned from the model is relative to the maximum antenna gain which occurs at θ =0 degrees if there is no downtilting.

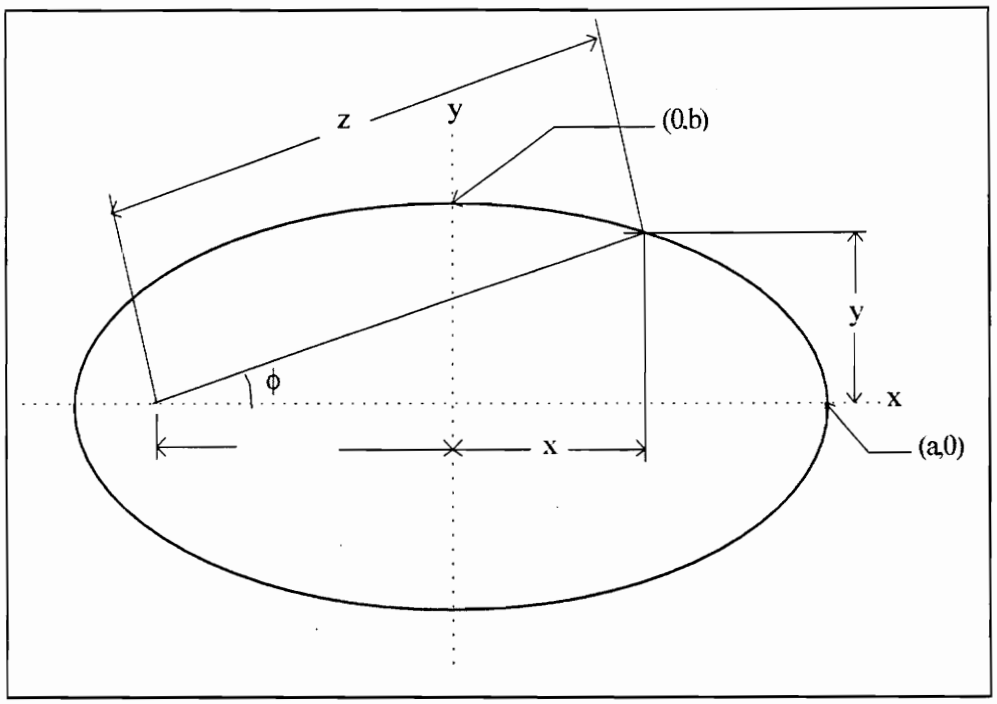


Figure 4-6: Vertical Antenna Pattern Model

The general form of an ellipse is given as:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1, \text{ where} \qquad \textbf{Eq. 4-2}$$

a is arbitrarily set to 1, and *b* is constant specific to each antenna type. The constant *b* defines the width of the main vertical lobe in the antenna pattern, and is determined for each antenna by measuring the widths of the vertical antenna pattern plots provided by the sponsor.

It is clear from Figure 4-6 that

$$\left(x + \sqrt{a^2 - b^2}\right)^2 + y^2 = z^2 \qquad \textbf{Eq. 4-3}$$

$$\left(x+\sqrt{a^2-b^2}\right)^2+y^2=z^2 \qquad \textbf{Eq. 4-4}$$

Combining Eq. 4-3 and Eq. 4-4 and solving for y^2 yields:

$$y^2=\frac{\left(x+\sqrt{a^2-b^2}\right)^2}{\left(\frac{1}{\sin^2(\phi)}-1\right)} \qquad \textbf{Eq. 4-5}$$

Combining Eq. 4-5 with Eq. 4-2 and putting in quadratic form yields:

$$x^2\cdot\left(b^2\cdot\left[\frac{1}{\sin^2(\phi)}-1\right]+a^2\right)+x\cdot\left(2\cdot a\cdot\sqrt{a^2-b^2}\right)+a^2\cdot\left(a^2-b^2-b^2\cdot\left[\frac{1}{\sin^2(\phi)-1}\right]\right)=0 \qquad \textbf{Eq. 4-6}$$

Solving for x using the quadratic equation yields:

$$x(\phi)=\frac{-2\cdot a\cdot\sqrt{a^2-b^2}\pm\sqrt{-4\cdot a^4\left(a^2-b^2\right)-4\cdot\left(b^2\cdot\left[\frac{1}{\sin^2(\phi)}-1\right]+a^2\right)\cdot\left(a^2\cdot\left[a^2-b^2-b^2\cdot\left\{\frac{1}{\sin^2(\phi)}-1\right\}\right]\right)}}{2\cdot\left(b^2\cdot\left[\frac{1}{\sin^2(\phi)}-1\right]+a\right)} \qquad \textbf{Eq. 4-7}$$

Eq. 4-7 forms the basis for the vertical antenna pattern model. For any ϕ , Eq. 4-7 returns x, which, when added to the distance from the center of the ellipse to the cell site ($\sqrt{a^2-b^2}$), yields a relative antenna gain based on an ellipse with a major axis of length 2 and a minor axis of width $2\cdot b$. Antenna downtilt is modeled in this study

with Eq. 4-7. Eq. 4-7 returns relative vertical antenna gain for any vertical orientation of an antenna.

4.2. Cell Site Coverage Modeling

A cell is defined by the area surrounding a base station antenna where the received power at any point inside the area is stronger than or equal to a particular threshold. The threshold is the weakest received power level that a mobile subscriber can receive while still maintaining an adequate grade of service. As discussed in **Section 4.6.1 Interference Simulation Parameters**, this threshold is set at -85 dBm. Figure 4-7 shows the defining area of a typical three-sector cell. A cell may house anywhere from one to six sectors. These sectors may share the same receiving antenna while using separate transmitting antennas. Each transmitting antenna has a footprint which outlines the area where the received power due to the antenna is greater than or equal to the threshold.

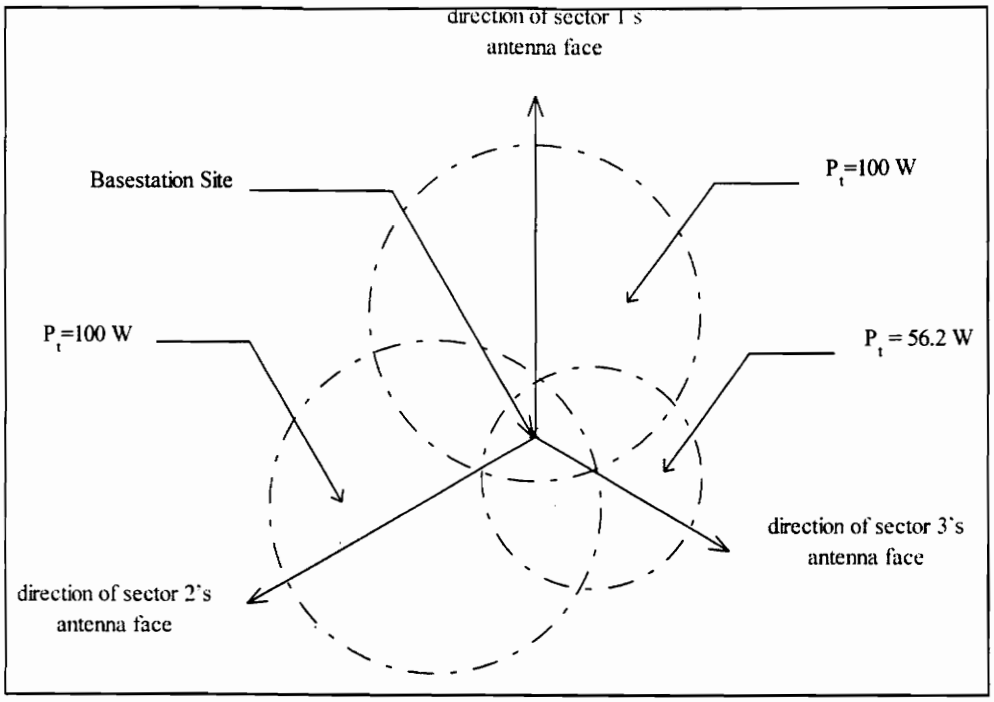


Figure 4-7: A Typical Cell Site's Coverage Area

Received power is predicted using a simple propagation path loss model. A path loss model returns a predicted received power due to a transmitting antenna. A d^n path loss model was used to predict the coverage regions for the sectors in Figure 4-7. This model bases received power on the distance from a transmitting antenna, the pattern of the transmitting antenna, the power of the transmitting antenna, and the downtilt of the transmitting antenna. Each sector's footprint is created by solving for the distance from the transmitting antenna that produces a -85 dBm received power contour. The contour is formed by calculating the signal power at 25 equally spaced points (in angle) around the antenna pattern, and connecting a closed line between the points. The result is plotted in Figure 4-8, where each point is 360/25, or 14.4

degrees apart. The importance of the number of points which make up the footprint is that it is at these discrete points that interference calculations are performed by using the received signal levels from all co-channel sells. If a sector's footprint is too coarse, the interference calculations may not yield a worst case interference measurement along the footprint of the sector.

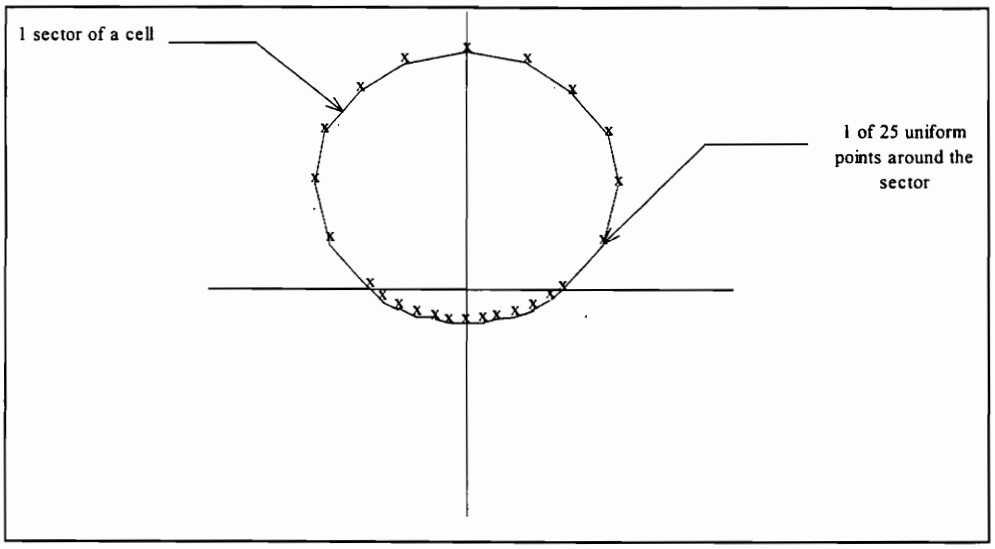


Figure 4-8: Simulation Model of a Sector

4.3. Computing Signal Levels at Ground Level

The path loss model derived in **Section 2.5 The In-Building Signal vs. Floor Model** is used to predict the received power based at ground level for any point, whether it be at a cell boundary (for C/I calculations) or at the base of the building under study (for channel availability calculations). To properly predict signals, the simulations must use the base station's transmitter power, antenna pattern, antenna height,

antenna downtilt, and proximity to the point of interest. The derived path loss model is re-shown as Eq. 4-8.

$$P_r = \frac{P_t \cdot G_t \cdot (0.33)^2}{(4 \cdot \pi \cdot 100)^2} \cdot \left(\frac{100}{d}\right)^{3.45}, \text{ where} \qquad \textbf{Eq. 4-8}$$

P_r is the received power at the base of the building (in watts)

P_t is the power of the base station transmitter (in watts)

G_t is the antenna gain in the direction of interest (in dB)

d is the distance from the base station to the point of interest (in meters)

Figure 4-9 illustrates how a base station's antenna height, antenna pattern, and distance from the point of interest (shown as the base of the building under study) impacts the received power at the point of interest. The antenna gain in the direction of the building (G_t) is a function of antenna height, antenna downtilt, and the distance from the base station to the building. As can be seen in Figure 4-9, the angle between the antenna and the location of the building, relative to the horizon is $\alpha+\phi$. The relationship between this angle and the height of the base station is given in Eq. 4-9.

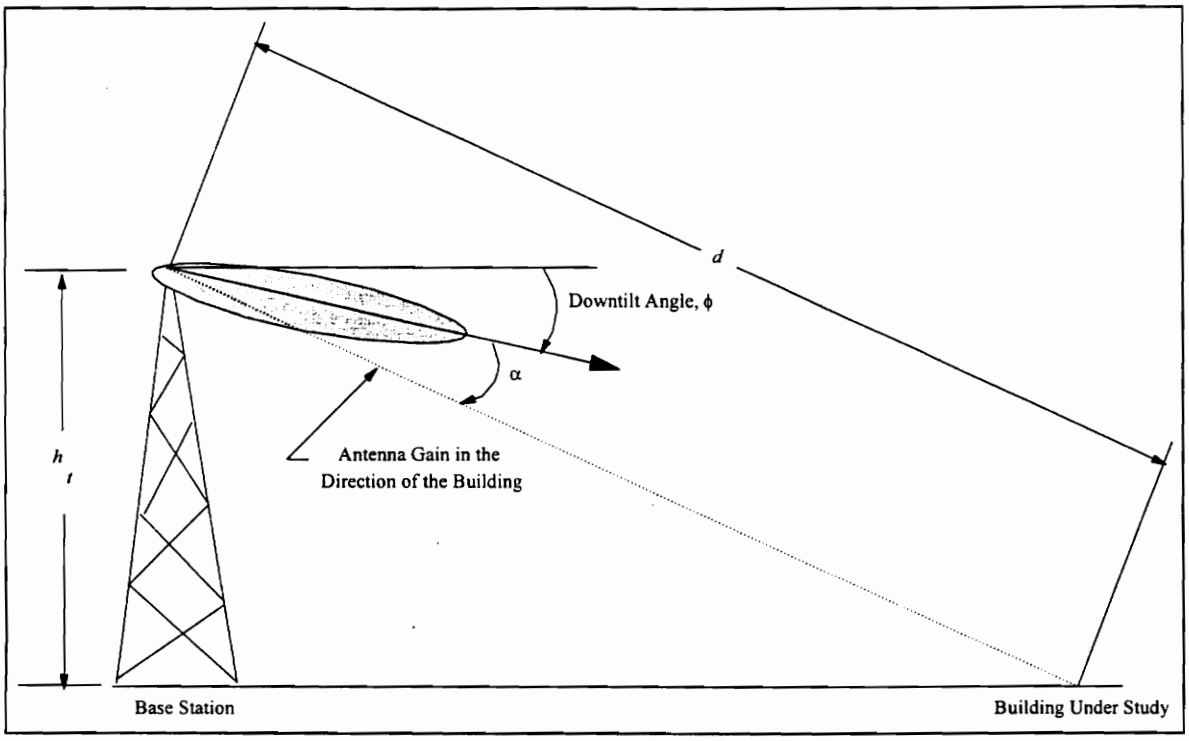


Figure 4-9: Illustration of How Received Power is Calculated at the Base of the Building

$$\phi + \alpha = Sin^{-1}\left(\frac{h_t}{d}\right)$$, where ϕ is the antenna downtilt. **Eq. 4-9**

Solving for α yields:

$$\alpha = Sin^{-1}\left(\frac{h_t}{d}\right) - \phi$$ **Eq. 4-10**

Eq. 4-10 returns the angle, α, which is the angle from the antenna face to the location of the building, relative to the antenna face. Substituting α into the vertical antenna pattern model (see **Section 4.1.2 Vertical Antenna Pattern Modeling**) yields the antenna gain in the direction of the building. Note that the same technique is used to

compute the gain of co-channel cellular base stations as they radiate on a cell boundary for purposes of calculating C/I of each base station.

Once the antenna gain is calculated, the received power at the base of the building of the cell boundary can be determined with Eq. 4-8. The power received at the cell boundary is determined from the equation, whereas the signal inside the building on a particular floor is determined by following the steps outlined in **Section 2.5 The In-Building Signal vs. Floor Model Derivation**. That is, 25 dB is added to the received power at the base of the building to determine the signal strength on the sixth floor, and a floor gain factor is added to this value in accordance with the values given in Table 2-4.

4.4. Worst Case C/I Interference Modeling

In order to determine a cell's coverage quality, C/I predictions must be performed. The C/I will vary depending on a user's location within a cell, but C/I generally decreases as the distance from the transmitter increases. In order to get a worst case, C/I calculations are made along the cell's boundary or footprint. To be complete, C/I ratios must be calculated for every voice channel in the voice channel set belonging to the cell. Since the voice channels are re-used together in derived channel sets, C/I ratios need only be calculated for a single channel within each derived channel set belonging to a cell. As an example, in cell site #110, sector 1 has 23 voice channels

in its voice channel set, but these voice channels are contained in 8 derived channel sets: derived channel set #2, #80, #94, #115, #121, #137, #149, and #138. The C/I for one voice channel in each of these derived channel sets is computed, and this C/I is assumed to be the same for all other voice channels in the derived channel set. This method of calculating C/I reduces the number of C/I calculations from 23 to 8 in this example.

As mentioned above, C/I calculations for a cell are made along the cell's footprint. At discrete points along this footprint, the C/I is calculated for each derived channel set belonging to the cell, and the worst case C/I is returned for each derived channel set. This is defined as the smallest C/I at any of the 25 points along the footprint.

The algorithm used for determining C/I for all of the cells in the system is shown in Figure 4-10. The algorithm begins by initializing all variables (step 1). Step 2 establishes a loop which loops through all cell sites in the system. This is the main loop of the algorithm. This loop allows C/I to be determined for all cells in the system. *i* is the cell site loop variable. Step 3 establishes a loop which allows the algorithm to examine a set number of points equally spaced around the cell's boundary footprint. The number of points is a simulation parameter (*NUM_INT_POINTS*) and is set to 25 for the simulations. C/I measurements are performed at each of these points for all of the derived channel sets in the cell site *i*'s

voice channel set. The worst case C/I (the smallest C/I) for all of the interference points is saved for each of the derived channel sets. j is the interference point loop variable. Step 4 establishes the derived channel set loop. This loop loops through all of the derived channel sets which comprise the cell site i's voice channel set. k is the derived channel set loop variable. Step 5 searches the cell site database for all cells which have voice channel sets containing derived channel set k. Figure 4-11 illustrates the C/I calculation for cell #110. For this case, loop variable i=110, loop variable j=1 (the first of the equally spaced interference points), and loop variable k=1 (the first of the derived channel sets comprising cell #110's voice channel set). Figure 4-11 shows all of the cells which have the derived channel set corresponding to k=1. According to the cell site database, cells #110, #146, #147, and #149 all reuse the derived channel set corresponding to k=1, and are therefore co-channel cells. Step 5 established a loop which loops through all of the interfering cell sites determined in step 4. The interfering cell site loop variable is l. Step 7 sums up the interference due to each of the interfering cell sites. This calculation is performed based on a d^n path loss model, the distance between the co-channels, and the interfering channel's antenna pattern. Step 8 loops the algorithm back to step 6 until the sum performed in step 7 includes all of the interfering cell sites. Once step 9 has been reached, the interference associated with cell site i, derived channel set k, and interference point i has been determined. Step 9 calculates the C/I corresponding to loop variables i, j,

and k, by dividing the received power at interference point k due to cell site i by the aggregate interference calculated in step 7. The received power received due to cell site i is determined with a d^n path loss model, the distance from the cell site to the interference point, and the antenna pattern of cell site i. Step 10 saves the C/I ratio determined in step 9. Step 11, loops the algorithm back to step 4 so that all of the C/I for all of the derived channel sets can be determined. Step 12 loops the algorithm back to step 3 so that C/I for all of the derived channel sets can be determined at all of the equally spaced interference points around cell site i. Step 13 loops the algorithm back to step 2 so that C/I measurements can be performed for all cell sites. Step 14 reports all of the C/I measurements saved in step 10 to an output file and halts the algorithm. The format of this output file is described in **Section 4.5 C/I Calculation Results**.

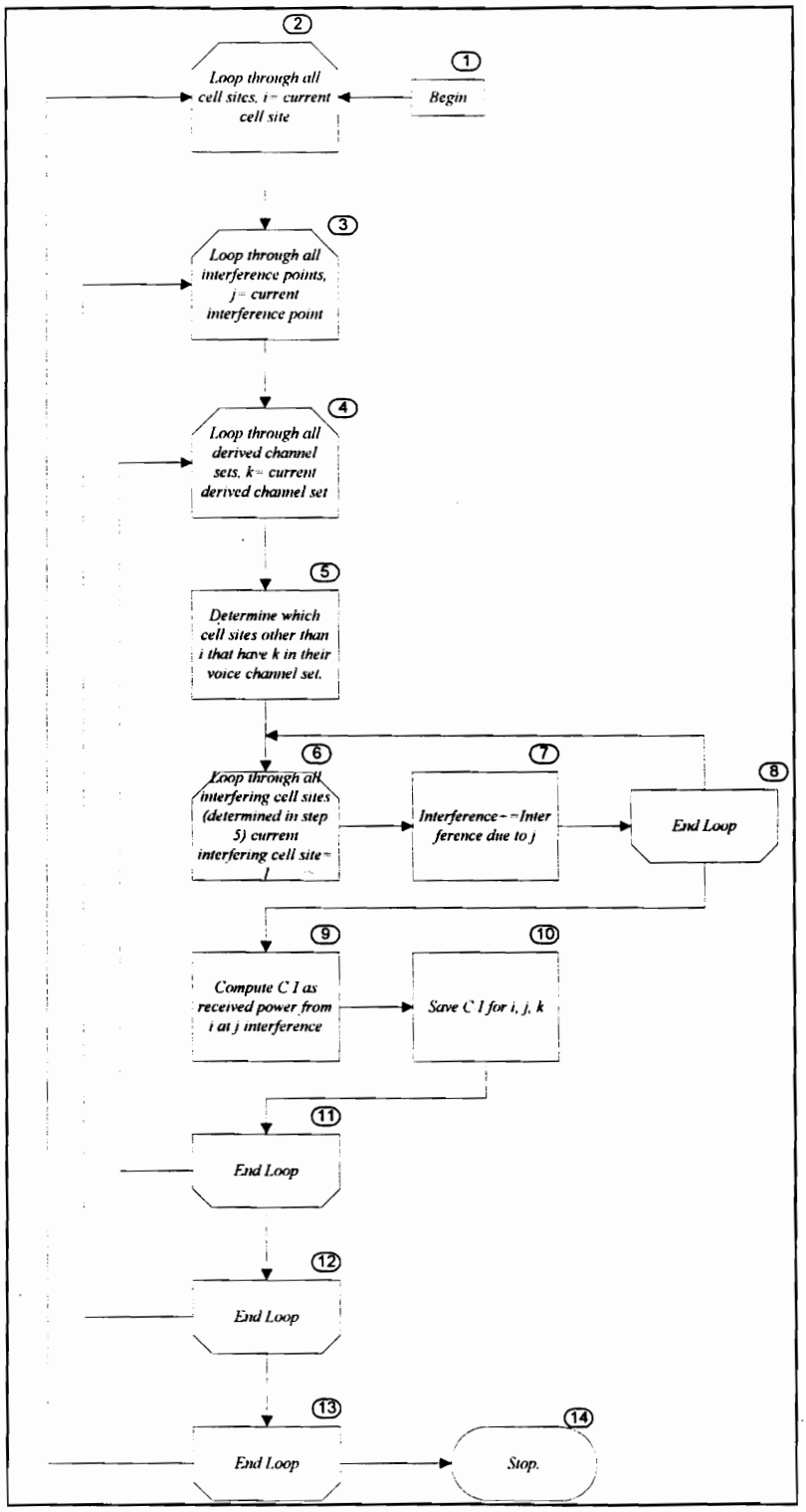


Figure 4-10: The Interference Calculation Algorithm Flowchart

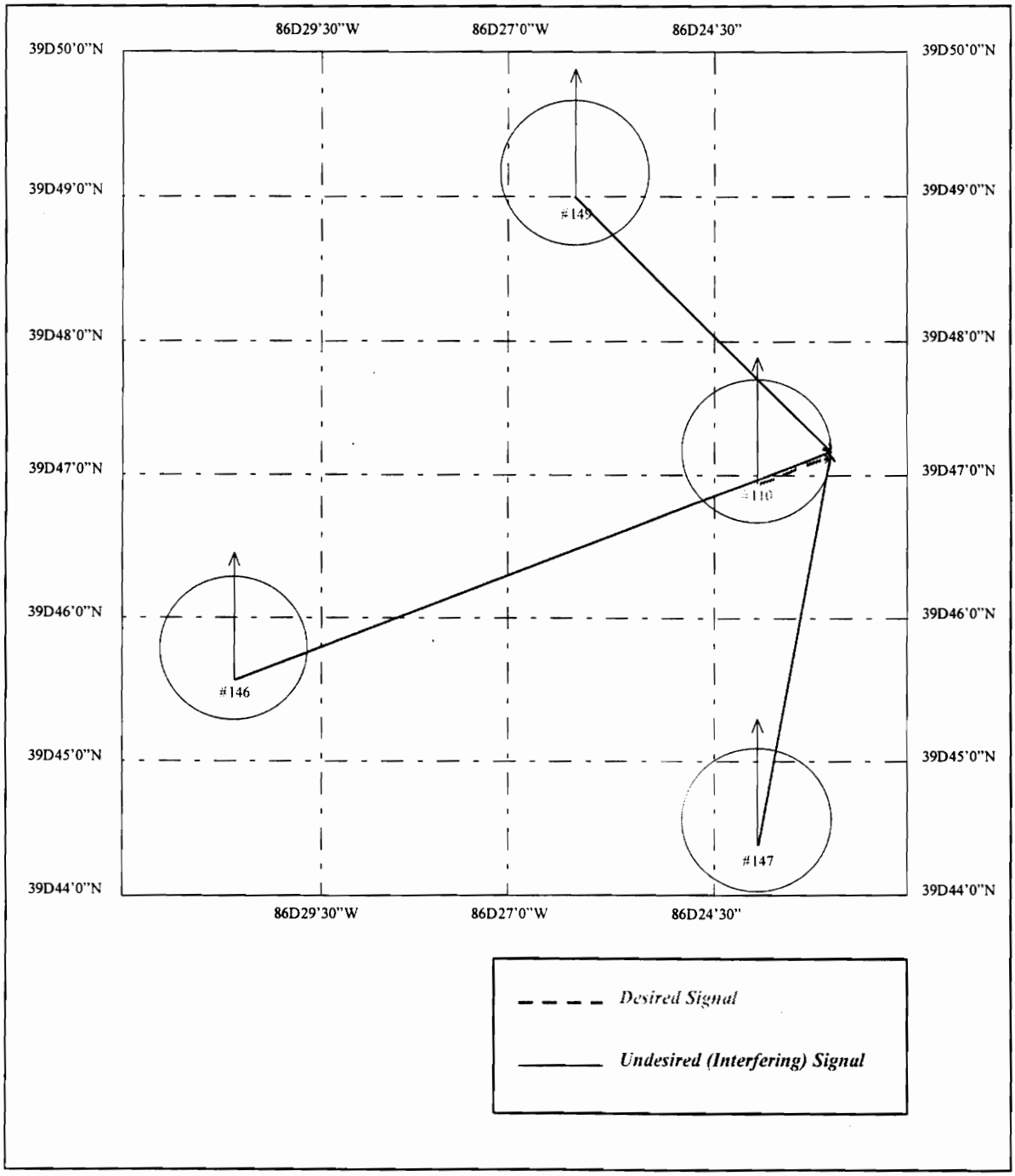


Figure 4-11: A Sample Interference Calculation for the C/I at Cell Site #110. Twenty Five Such Calculations of C/I are Made at Equal Angle Spacing Around the Perimeter of the Coverage Zone of #110, and the Worst Case (Smallest) C/I Value is Used to Select New Voice Channels in Future Generation Cells.

4.5. C/I Calculation Results

The results of the C/I calculations described in **Section 4.4 Worst Case C/I Interference Modeling** are tabulated in a spreadsheet format and were performed at one year intervals over the six year simulation.

Table 4-1 shows a portion of a C/I calculation file created by the algorithm described in **Section 4.4 Worst Case C/I Interference Modeling** at year 0 of the simulations. The left hand column lists the cell site. Each of the cell sites is broken down by sector number. The columns to the right of the cell site column list both the derived channel sets which comprise the cell's voice channel set, and their calculated C/I, in dB. The last column lists the smallest C/I of all of the derived channel sets for a given row. As can be seen in the table, all of the predicted C/I measurements are fairly large (any C/I above 18 dB is acceptable). This is expected at year 0 of the simulations, since it is assumed that the inherited cellular system given by the sponsor has an acceptable quality of service.

Table 4-1: A Portion of a C/I Measurement File

Cell Site #, Sector #	Derived Set, C/I	Derived Set, C/I	Derived Set, C/I	Derived Set, C/I	Worst Case C/I
Cell # 1:– Sec 1	6 , 26.33	35 , 26.51	44 , 26.81	54 , 35.07	26.33
Cell # 1:– Sec 2	119 , 34.82	127 , 30.18	134 , 30.19	147 , 31.57	30.18
Cell # 1:– Sec 3	102 , 18.78	113 , 18.67	0 , 0.00	0 , 0.00	18.67
Cell # 2:– Sec 1	103 , 59.46	115 , 52.17	0 , 0.00	0 , 0.00	52.17
Cell # 2:– Sec 2	8 , 36.03	28 , 35.94	37 , 36.16	46 , 0.00	35.94
Cell # 2:– Sec 3	15 , 22.18	62 , 33.36	0 , 0.00	0 , 0.00	22.18

4.6. Interference Simulation Parameters and Simulation Results

4.6.1. Interference Simulation parameters

Table 4-2 shows the simulation parameters relevant to the interference calculations. The number of interference points specifies the number of points equally spaced around a cell where C/I is calculated. A small number of interference points decreases the time needed to perform the interference calculations, however the results may not be accurate since C/I may be poor within an area of the cell which does not contain any interference points. Different numbers of interference point values were tested with the simulations. It was observed that as few as 25 interference points could be used while still maintaining the same results that were observed with 180 interference points. 25 interference points corresponds to a C/I calculation every 14.4 degrees around the cell site.

Table 4-2: Interference Simulation Parameters

Simulation Parameter	Value
Number of Interference Points	25
Cell Coverage Threshold	-85 dBm
Path loss Model	d^n, $n=3.45$
Minimum Spacing Between Voice Channels In A Channel Set	7

The cells coverage threshold is set at -85 dBm. The cell coverage threshold is the minimum power which can be received by a mobile subscriber if it is to be considered to be within the cell's coverage area. The significance of the cell coverage threshold is that it determines the cell's footprint, and it is around the perimeter of this footprint that C/I calculations are performed.

The path loss model used for all received power calculations is a d^n model with n=3.45. This model was derived in **Section 2.5 The In-Building Signal Vs. Floor Model** based on the field strength measurements made in the building under study.

The minimum spacing between voice channels in a channel set specifies the minimum number of 30 kHz voice channels which must separate any two voice channels in a cell's voice channel set. This parameter is important because it guarantees that adjacent channel interference in a voice channel set can only occur between two channels at least 210 kHz apart (actually, adjacent channel interference

also occurs in the channel combiner at the base station, but this is not taken into consideration by the simulations).

4.6.2. Interference Simulation Results

This section shows how the cells split over time, and illustrate how the average power and downtilt angle of each cellular base station changes over time, as well. Figure 4-12 shows when cell splitting occurs over the 6 six year simulation period. As can be seen in the figure, most of the cell splitting occurs before year 2 of the simulations. This corresponds to the 1st generation cells splitting into 2nd generation cells. The cell splits between years 4 and 6 correspond to 2nd generation cells which have reached capacity and have split into 3rd generation cells. 4th generation cells arise in years 8-10 (not shown here).

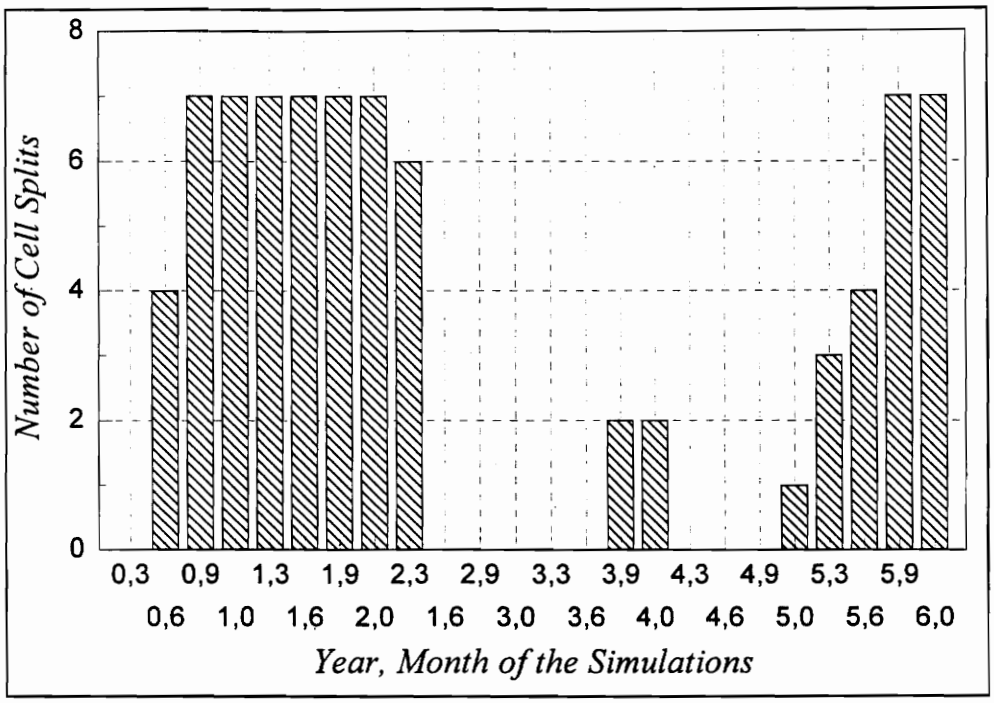


Figure 4-12: Number of Simulated Cell Splits as a Function of Time

Figure 4-13 shows how the effective radiated power of the base station transmitters within the cellular system decreases with time. Initially, the average transmitter power is 35.3 watts. This was calculated by averaging the ERP values for all of the sectors inherited from the sponsor. As the cells split and cover smaller areas, the transmitter power immediately begins to decline, and levels off at around 11 watts at year 6.

It is interesting to note that the existing cellular system uses sectored antennas with a broad vertical radiation pattern, whereas the simulations assume all new cells use omni-directional antennas with very tight vertical radiation patterns (se the omni

direction antenna patterns in **APPENDIX B**). Both antenna types offer the same gain, approximately 10 dB in the simulations.

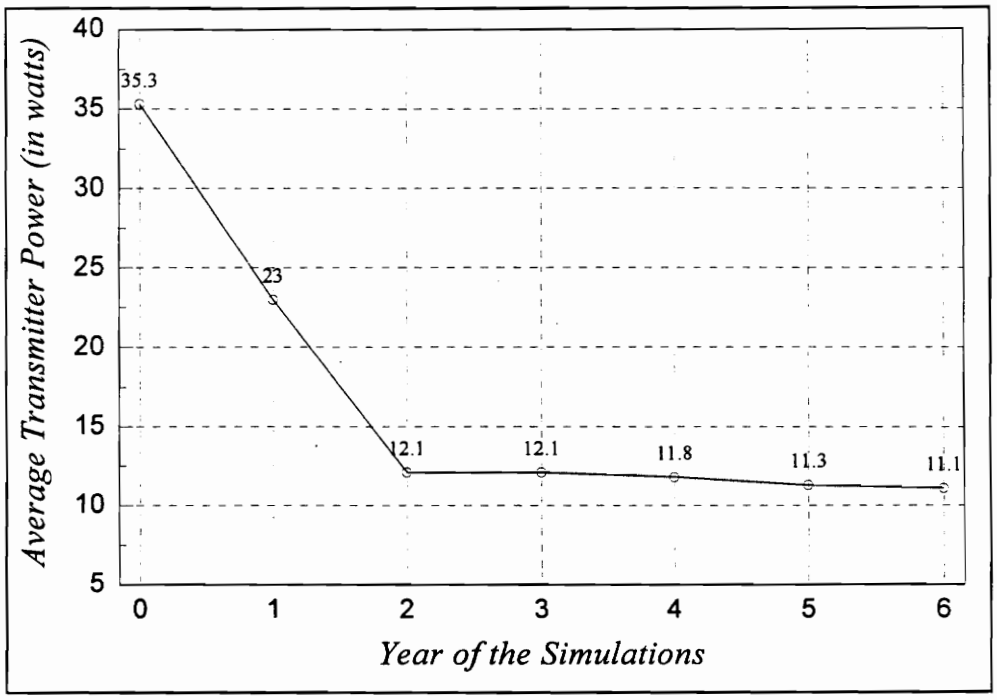


Figure 4-13: Average Base Station Transmitter Effective Radiated Power in Watts as a Function of Year

Figure 4-14 shows how the average base station antenna downtilt changes with year. Initially, (at year 0 of the simulations), none of the base stations use antenna downtilt. However, as the original cells split into 2nd generation cells, the average downtilt throughout the system increases because 2nd generation cells are given a downtilt of 6 degrees. Figure 4-14 clearly shows when the cells in the system begin to split from generation to generation. By year 4, most of the cells in the system are 2nd generation cells based on the average downtilt, but between years 5 and 6, these 2nd

generation cells are splitting into third generation cells, since the average downtilt increases from 5.2 degrees to 7.2 degrees, and up to 7.5 degrees by year 6. Based on Figure 4-14, by year 6, half of the cell sites in the system are 2nd generation cells, and the other half are third generation cells. No original cells (1st generation cells) exists by year 6.

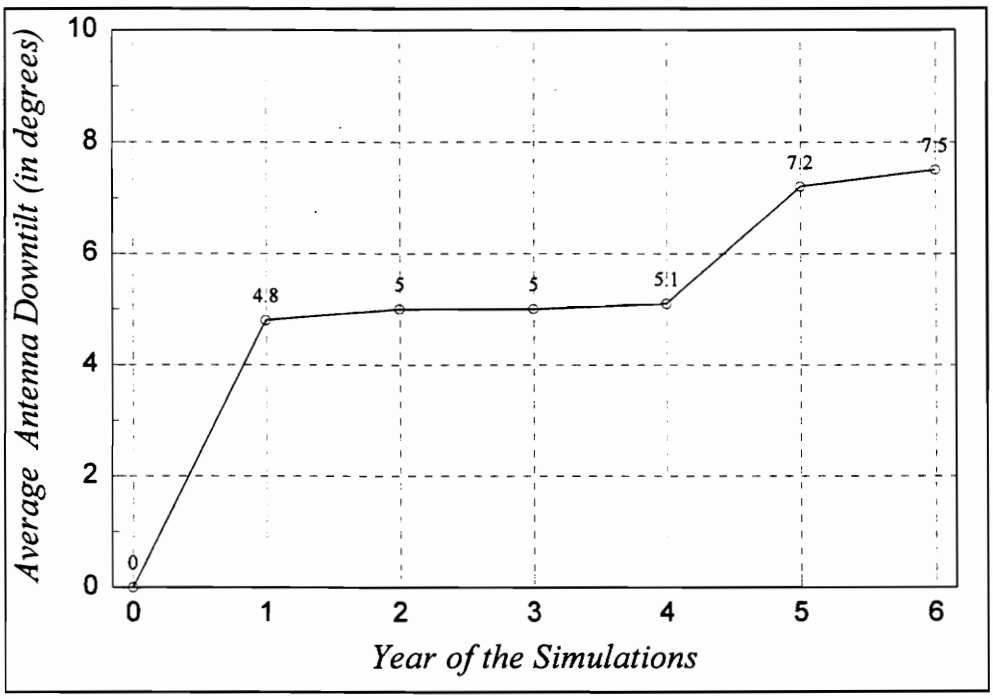


Figure 4-14: Average Base Station Antenna Downtilt (in Degrees) as Function of Year

5. Approach to Modeling Capacity

5.1. Modeling Subscriber Growth in the Cellular System

One key to predicting future cell sites and future growth is predicting where cellular subscribers are using their phones the most, and which cells are more likely to observe an increase in traffic over time. In general, it can be assumed that cellular traffic will increase the fastest in cells covering the major highways of a city, as well as in the urban core of a city. The sponsor provided detailed marketing data to show where cellular traffic is likely to increase the most, but indicated that a simple two-tiered cellular subscriber distribution for the area under study would be a reasonable approximation for modeling subscriber growth. The city under study was broken down into two areas. The first area (tier 1) is centered in the downtown region of the city, and extends outward covering the urban core. The second area (tier 2) covers all areas of the city not covered by tier 1 (see Figure 5-1).

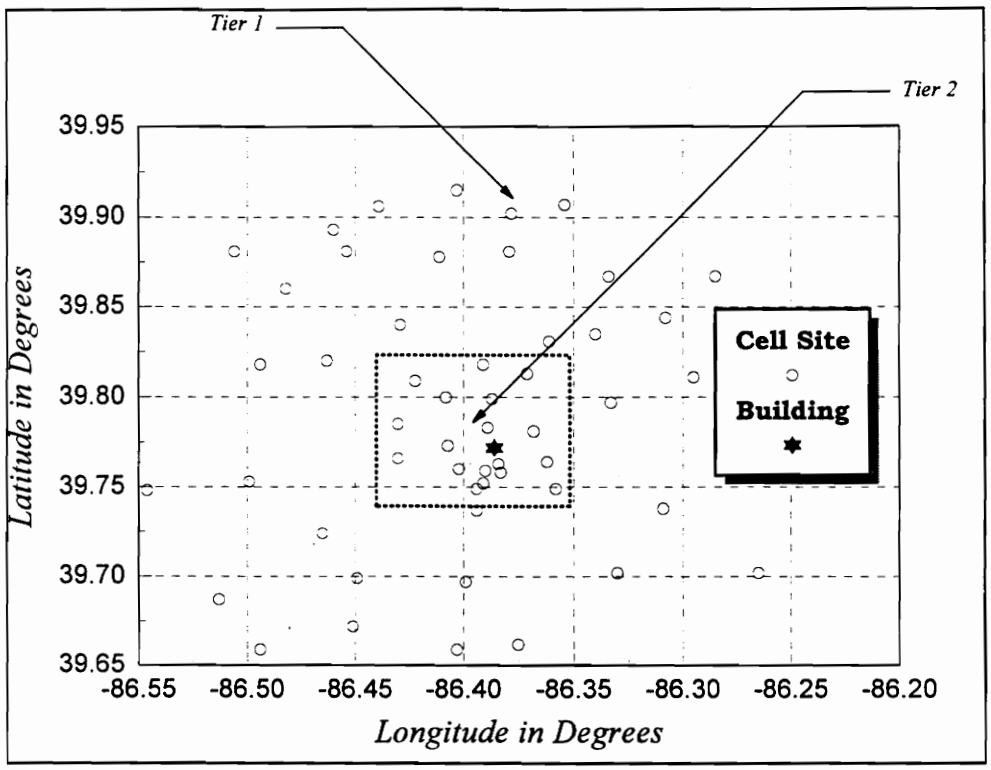


Figure 5-1: Cellular System Under Study

The cells in tier 1 cover the heaviest cellular traffic regions and are therefore more likely to reach capacity and split into new cells. The cells in tier 2 cover areas with less cellular traffic. These cells will reach capacity at a much slower rate then the cells in tier 1. The method for modeling cells in each of these two areas is described in **Section 5.1.2 Modeling Subscriber Growth**.

5.1.1. Modeling the Initial Number of Subscribers

In order to model subscriber growth, an initial number of subscribers must be determined. Since the current number of subscribers was not provided by the sponsor, the initial

number of subscribers was approximated based on the layout of the current cellular system. The cell site database provided by the sponsor presented the number of voice channels assigned to each of the cells in the system under study. Based on the number of channels and assumptions on the average number of calls made per user, the average length per call, and the current grade of service (GOS), the number of cellular customers was estimated.

Erlang-B is a trunking formula which determines the probability of a blocked call based on the maximum number of calls allowed at one time, the number of users attempting to place calls, the average number of calls made per time per user, and the average length of a call. Eq. 5-1 shows the Erlang-B formula [5].

$$P = \frac{A^c}{C!} \Big/ \sum_{k=0}^{C} A^k / k!$$, where **Eq. 5-1**

P is the probability of a blocked call,

C is the number of available voice channels, and

A is the traffic intensity in erlangs

$A = U \cdot \lambda \cdot h$, where **Eq. 5-2**

U is the number of cellular subscribers attempting to use the C voice channels,

λ is the average number of calls attempted per hour per user, and

h is the average time of a call

The initial number of subscribers in a cell can be approximated by solving Eq. 5-1 for U, given P, C, h, and λ. As described in **Section 5.3 The Capacity Simulation Parameters and Simulation Results**, P, h and λ are simulation parameters, and are initially set to 2%, 1.5 minutes, and 2 calls/hour/subscriber, respectively. The capacity simulations use a Newton's method routine for determining the number of subscribers for a cell, U, given P, h, λ, and C, where C is the number of voice channels allocated to the cell. Based on the number of voice channels per cell given in the cell site database, and the above simulation parameters, P, h, and λ, the current number of cellular subscribers during a busy hour was found to be slightly less than 20,000.

5.1.2. Modeling Subscriber Growth

Subscriber growth is modeled in the capacity simulations with a two tiered distribution. Subscribers in cells located within tier 1 (see Figure 5-1) are given one uniform annual growth rate, while subscribers in cells located within tier 2 are given a second uniform annual growth rate. These two growth rates are simulation parameters and are set to 40% for tier 1, and 20% for tier 2. These simulation parameters imply that every year, the number of subscribers in tier 1 will increase to 140% of its current value, and the number of subscribers in tier 2 will increase to 120% of its current value.

Time resolution is another parameter in the capacity simulations. The time resolutions of the simulations is defined as the length of time (in months) between subscriber growth

calculations. If the time resolution is set to twelve months, the number of subscribers in tiers 1 and 2 will increase 140% and 120%, respectively. A twelve month resolution implies that the number of subscribers in each cell would only be known every twelve months. If the simulations predict that the number of subscribers in the cellular system increases during a twelve month period in such a manner that ten cells need to be split, then all ten cells would be split at the same time, when in actuality, three of the cells may have needed to be split after three months, another three cells split after six months, and the remaining four cells split after the entire twelve months. To avoid ambiguities in the ordering of cell splits, the time resolution simulation parameters is set at three month intervals.

Newly split cells are assigned voice channel based on which channels cause the least interference in the newly split cell. If two adjacent cells split, the voice channel sets of the new cells will be dependent on which cell splits first. If time resolution is set too coarsely (e.g. twelve months) it is impossible to determine which cell split first, and this makes the selection of new voice channels extremely difficult. Setting the time resolution of the capacity simulations at three months solves this problem, since all cells which reach capacity at least three months apart will be split in the order in which they reached capacity. A log file detailing the simulations is included in **APPENDIX D The**

Simulation Log File. In this log file, every cell split is documented as to when the split occurred and the new cells which were created by the cell split.

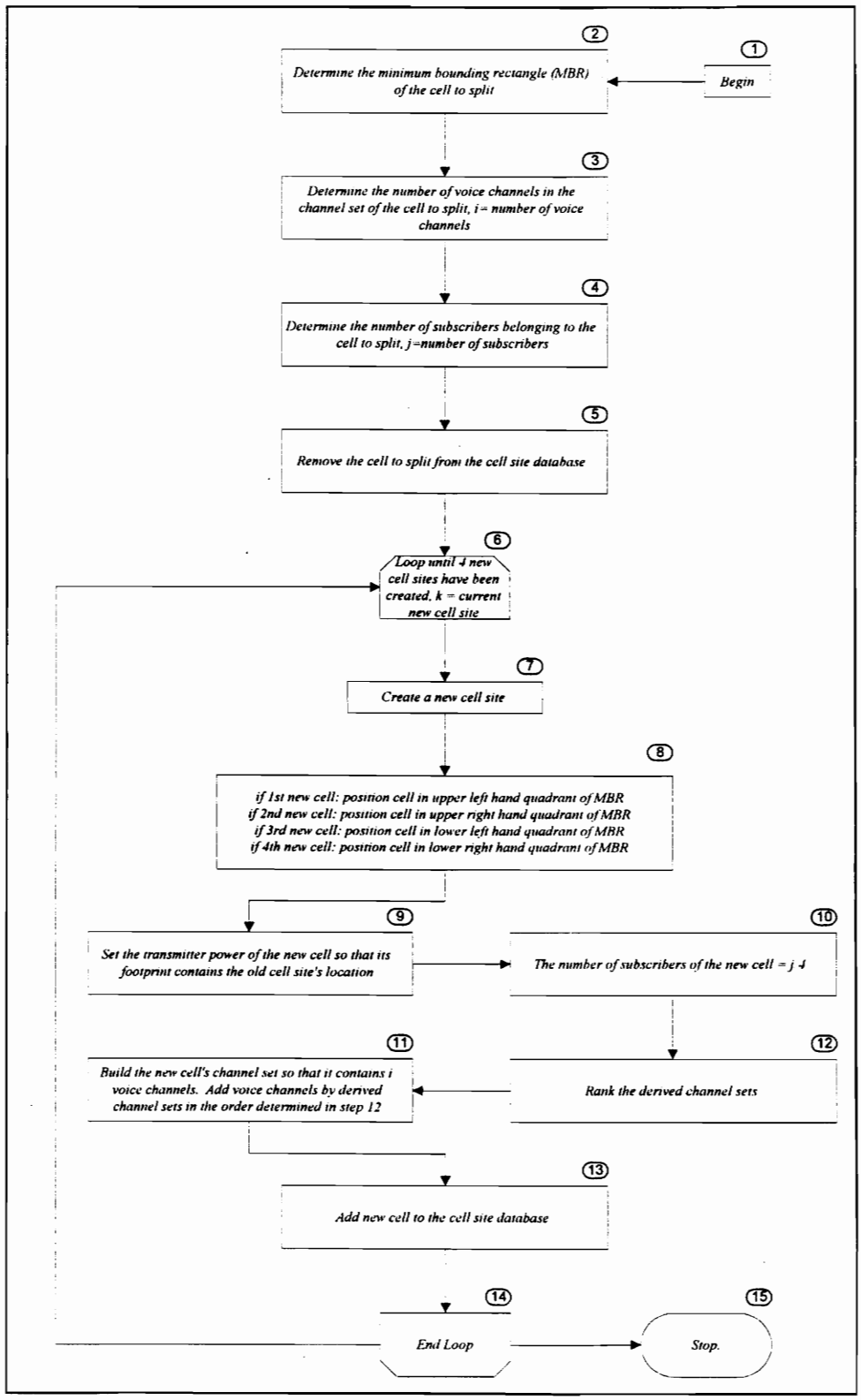
5.2. The Cell Splitting Technique

The capacity simulations perform a cell split once the number of subscribers in a cell increases to the point that the grade of service in that cell becomes unacceptable. The grade of service is determined with the Erlang-B formula (Eq. 5-1). Eq. 5-1 uses the number of subscribers and the number of voice channels for a particular cell, as well as the simulation parameters h and λ. Eq. 5-1 returns the probability of a blocked call. The capacity simulations deem that a cell's grade of service is unacceptable when this probability of blockage reaches or exceeds a maximum allowable blockage. This maximum allowable blockage is a simulation parameter, and was set to 5% for the simulations. This means that cells will split as the number of subscribers increase, in accordance with Erlang-B. For the sake of simplifying the simulations, a cell was split whenever any one of its sectors reached a 5% blocking probability.

By increasing the number of subscribers uniformly throughout the system over time, the simulation computes the blocking statistics for each sector at three month intervals. Once the simulation determines that a cell needs to be split (e.g. a sector exceeds 5% blocking), the cell splitting process begins. This process is based loosely on the Lee cell splitting method. Figure 5-2 shows the flow chart of the cell splitting algorithm. Step 1 of the

flow algorithm initializes all of the variables needed to perform a cell split. Step 2 determines the minimum bounding rectangle (MBR) associated with the cell to split. A cell's MBR is the smallest rectangle which completely covers the coverage area for a cell. An MBR for a cell is determined by examining the distances from the cell site to a discrete number of points (*NUM_INT_POINTS*) along the cells footprint. If a cell contains three sectors then this is repeated for all three sectors. The distances are examined, and the MBR is defined as the smallest rectangle which contains all of the points along the sector footprints. Figure 5-3 shows an MBR for a typical three sectored cell. As can be seen in the figure, the MBR just contains all three sector footprints. The significance of the MBR is that its area is used to define the locations of the new cells once the original cell is split. Step 3 determines the number of voice channels belonging to the cell which is to be split. If a cell contains three sectors, then the number of voice channels belonging to all three sectors is determined. Algorithm variable i holds the number of voice channels. The number of voice channels needs to be saved because the newly created cells will need to have the same number of voice channels as the original cell. This will effectively increase the capacity of the old cell by a factor of 4. Step 4 saves the number of subscribers belonging to the cell to split in algorithm variable j. Step 5 removes the cell to split from the cell site database. Step 6 establishes a loop which loops until 4 new cells have been created. k is the loop variable. Step 7 creates a new cell site. Initially, the cell site structure is cleared. The remaining steps in the loop

determine the appropriate characteristics of this structure. Step 8 sets the latitude and longitude of the cell site. The latitude/longitude of the first new cell (the cell created during the first iteration of the loop established in step 6) is set so that it is positioned in the upper left hand quadrant of the MBR. This step positions new cells 2 through 4 in the upper right quadrant, lower left quadrant, and lower right hand quadrants of the MBR respectively. Step 9 sets the transmitter power of the new cell so that the footprint of the new cell contains the location of the cell to split. This step ensures that the coverage area of the cell to split will be appropriately covered by the new cells. Step 10 assigns the number of subscribers of the new cell to the number of subscribers of the cell to split (j) divided by 4. This effectively splits the subscribers which originally belonged to the cell to split evenly among the new cells. Step 11 ranks the derived channel sets by order of smallest interference seen at the new cell. The steps required to rank the derived channel sets is described below.


1
Begin
2
Determine the minimum bounding rectangle (MBR) of the cell to split
3
Determine the number of voice channels in the channel set of the cell to split, i = number of voice channels
4
Determine the number of subscribers belonging to the cell to split, j =number of subscribers
5
Remove the cell to split from the cell site database
6
Loop until 4 new cell sites have been created, k = current new cell site
7
Create a new cell site
8
if 1st new cell: position cell in upper left hand quadrant of MBR
if 2nd new cell: position cell in upper right hand quadrant of MBR
if 3rd new cell: position cell in lower left hand quadrant of MBR
if 4th new cell: position cell in lower right hand quadrant of MBR
9
Set the transmitter power of the new cell so that its footprint contains the old cell site's location
10
The number of subscribers of the new cell = j /4
11
Build the new cell's channel set so that it contains i voice channels. Add voice channels by derived channel sets in the order determined in step 12
12
Rank the derived channel sets
13
Add new cell to the cell site database
14
End Loop
15
Stop.

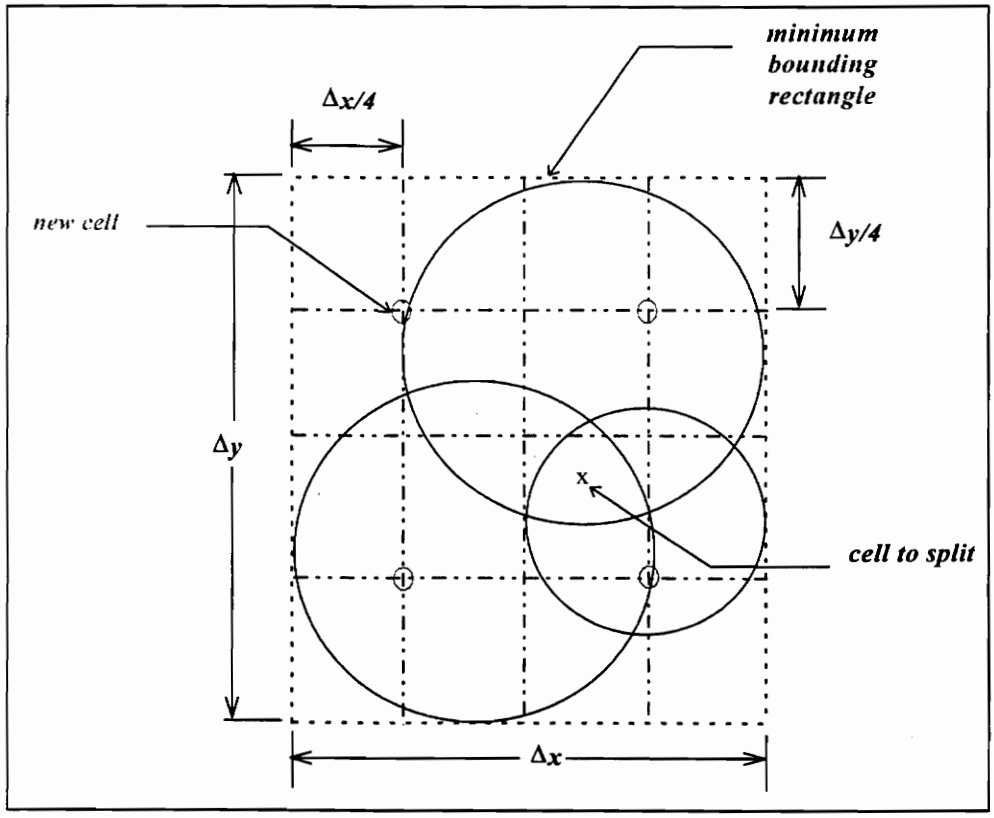


Figure 5-3: Typical Minimum Bounding Rectangle Used to Bound the Coverage Zone of all Sectors in a Cell

Figure 5-4 shows the flowchart of the derived channel set ranking algorithm. This algorithm returns, in order, which derived channel sets would make the best candidates as voice channels sets in a new cell's voice channel set. Step 1 begins the channel set ranking algorithm. Step 2 establishes a loop which loops through all of the derived channel sets. This loop is necessary because each of the derived channel sets needs to be examined separately to determine its interference qualities if assigned to the new cell's voice channel set. The derived channel set loop variable is *i*. Step 3 establishes a loop which loops through all of the interference points. The interference points are a discrete

number of points (*NUM_INT_POINTS*) which are evenly spaced along the footprint of the new cell. It is at these points that a derived channel sets interference is calculated. It is the strongest interference at any of these points along the cell's footprint which determines how good or bad a candidate a derived channel set is to be part of the new cell's voice channel set. The loop variable for interference points is j. Step 4 determines the interference due to derived channel set i, seen at interference point j. The interference is determined in the exact same manner as presented in **Section 4-4 Worst Case C/I Interference Modeling**. Step 5 returns the algorithm to step 3 until interference at all of the interference points has been determined for derived channel set i. Step 6 saves the strongest interference found in step 4 in an interference measurement structure which relates derived channel sets to measured interference. Step 7 returns the algorithm back to step 2 until all of the derived channel sets have been examined. Step 8 sorts the interference measurements structure created with steps 2 through 7 and ranks the derived channel sets in the structure from weakest interference to strongest interference. Step 9 halts the algorithm and returns the sorted derived channel sets.

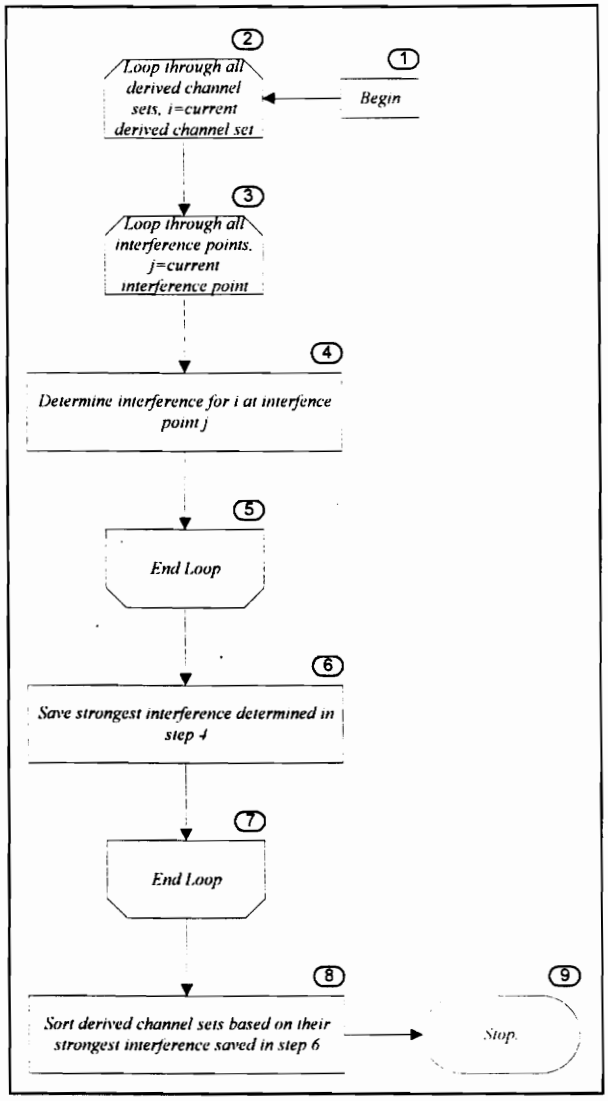


Figure 5-4: Flowchart of the Derived Channel Set Ranking Algorithm

Referring back to Figure 5-2, once the step 11 ranks the derived channel sets by interference, step 12 of the algorithm uses this ranked set to assign voice channels to the new cell. In order to maintain the frequency allocation techniques currently in use in the cellular system, voice channels are assigned to the new cell in blocks of derived channel sets. Derived channel sets are added to the new cell's voice channel set one by one

starting with the best candidate determined in step 11 and continuing with the next best candidate, etc. Derived channel sets are continually added to the new cell's voice channel set until the voice channel set contains the same number of voice channels as the split cell. At this point the new cell's characteristics are complete (Figure 5-5 shows an example of 4 new cells split from the cell shown in Figure 5-3). Its position, transmitter power, and voice channel set have all been determined. Other cell site parameters such as SAT, control channel are not determined since this would be outside the scope of this project. It should be noted that each of the new cells are given omni direction antennas and contain only one sector.

Note that in Figure 5-5, the newly created cells are located in quadrants which are equally spaced from the center of the MBR. Also, the transmitter power for each new cell is adjusted so that the -85 dBm contour passes through the original cell location. The resulting cells offer coverage that clearly exceeds that provided by the original cell.

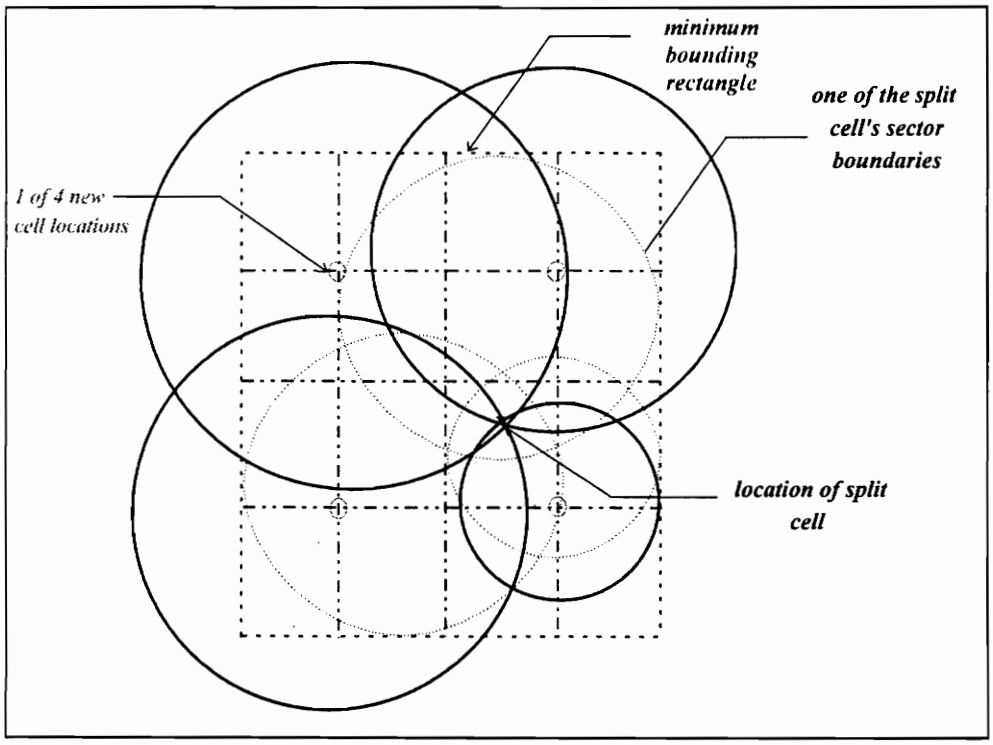


Figure 5-5: Results of a Cell Split

5.3. The Capacity Simulation Parameters and Simulation Results

Table 5-1 summarizes the simulation parameters relating to the capacity simulations. These parameters are replicated from the parameter list detailed in Chapter 3, and have been repeated in Table 5-1 to identify which of the parameters are related to the capacity simulations.

Table 5-1: Capacity Simulation Parameters

Simulation Parameter	Value
Subscriber Distribution	Two-tiered
Annual Growth Rate of Tier 1	40%
Annual Growth Rate of Tier 2	20%
Upper Left Coordinate of Tier 1's Bounding Rectangle	(86°26'0"W,39°49'0"N)
Lower Right Coordinate of Tier 1's Bounding Rectangle	(86°21'0"W,39°44'0"N)
Resolution of the Capacity Simulations	3 months
Initial Call Blockage	1%
Maximum Allowable Blockage	2%
Stop Time of the Simulations	6 years

Figure 5-6 shows the number of cell splits which occurred during each year of the capacity simulations. The time resolution of the simulations is set at three months, thus, the number of cell splits which appear in Figure 5-6 are in three month bins. As can be seen in the figure, many of the cell splits occur during the first two years of the simulations. This is due to the fact that the initial call blocking of all cells is set at 2%, and that the subscriber growth rates of tiers 1 and 2 were 40% and 20 %, respectively. By year three of the simulations, all of the cells inherited from the cell site database provided by the sponsor have been split.

The cell splitting technique detailed in **Section 5.2 The Cell Splitting Technique** increases the capacity of each cell by almost a factor of four (the increase in coverage area of the four new cells implies that the interference offered by the four new cells will

exceed that of the original cell. Thus, while there is a four times increase in the number of channels per area, the increased interference will reduce the capacity increase to something less than four times). For this reason, there are no additional cell splits after the initial group of cell splits until year 3, month 9 of the simulations. It takes almost four years for the number of subscribers in each of the cells to increase to the point where the call blockage again reaches the maximum allowable blockage (5%). The cell splits between year 4 and year 6 represent the cells in the urban core which are again splitting into 3rd generation cells. The line graph overlaid on top of the cell splits shows how the number of cellular subscribers during a busy hour increases with time. This is based on an average of 2 calls per subscriber per hour with an average call duration of 1.5 minutes.

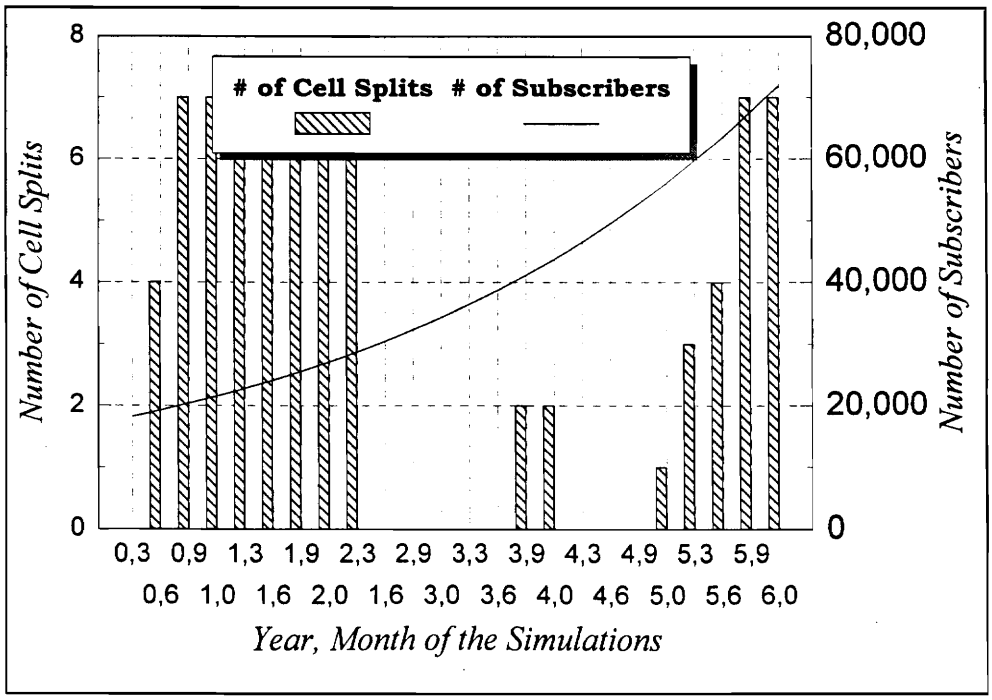


Figure 5-6: Number of Simulated Cell Splits vs. Time

Grade of service (GOS) calculations were performed for all of the sectors every three months in the simulations. The GOS calculations return the probability of a blocked call based on the Erlang-B formula (Eq. 5-1). The capacity simulations create GOS text files after every simulation iteration. These files contain a listing of all of the sectors in the cellular system, the number of subscribers in each of the sectors, and the probability of a blocked call in the sectors based on the Erlang-B formula. Table 5-2 shows a portion of the GOS file produced after two simulation years. The first and third columns contain the cell site and sector numbers, while columns two and four contain the number of subscribers in the sector and the probability of a blocked call. The capacity simulations increase the number of subscribers in each of the sectors based on the subscriber growth simulation parameters, while the Erlang-B probability calculations are based on the number of subscribers in the sectors, as well as the average number of calls placed per time by each subscriber, and the average length of each call.

Table 5-2: A Portion of a Simulation Grade of Service File. First 10 cells in Cellular System at Year 2, Month 0

Cell # - Sector #	# of Subscribers, Prob. of a Blocked Call (%)	Cell # - Sector #	# of Subscribers, Prob. of a Blocked Call (%)
Cell # 1:-- Sec 1	50, 1.377	Cell # 23:-- Sec 1	72, 1.510
Cell # 1:-- Sec 2	41, 1.503	Cell # 23:-- Sec 2	50, 1.377
Cell # 1:-- Sec 3	15, 1.562	Cell # 23:-- Sec 3	62, 1.596
Cell # 2:-- Sec 1	15, 1.562	Cell # 33:-- Sec 1	72, 1.510
Cell # 2:-- Sec 2	85, 1.729	Cell # 33:-- Sec 2	30, 1.223
Cell # 2:-- Sec 3	62, 1.596	Cell # 33:-- Sec 3	109, 1.830
Cell # 3:-- Sec 1	62, 1.596	Cell # 35:-- Sec 1	78, 2.88
Cell # 3:-- Sec 2	41, 1.503	Cell # 35:-- Sec 2	44, 2.035
Cell # 3:-- Sec 3	133, 1.844	Cell # 35:-- Sec 3	54, 1.973
Cell # 4:-- Sec 1	30, 1.223	Cell # 39:-- Sec 1	22, 1.327
Cell # 4:-- Sec 2	72, 1.510	Cell # 39:-- Sec 2	85, 1.729
Cell # 4:-- Sec 3	50, 1.377	Cell # 39:-- Sec 3	96, 1.690
Cell # 20:-- Sec 1	30, 1.223	Cell # 40:-- Sec 1	30, 1.233
Cell # 20:-- Sec 2	85, 1.729	Cell # 40:-- Sec 2	22, 1.327
Cell # 20:-- Sec 3	30, 1.223	Cell # 40:-- Sec 3	62, 1.596

Figure 5-7 shows how the average GOS changes in the cellular system as a function of time. Initially all sectors are given an initial call blockage probability of 2%. This determines the initial number of subscribers in each of the sectors. As the capacity simulations progress, the number of subscribers in each of the sectors increase. This, in

turn, causes an increase in the probability of call blockage. This is shown graphically in Figure 5-7 as the number of cell splits increases as the probability of call blockage increases.

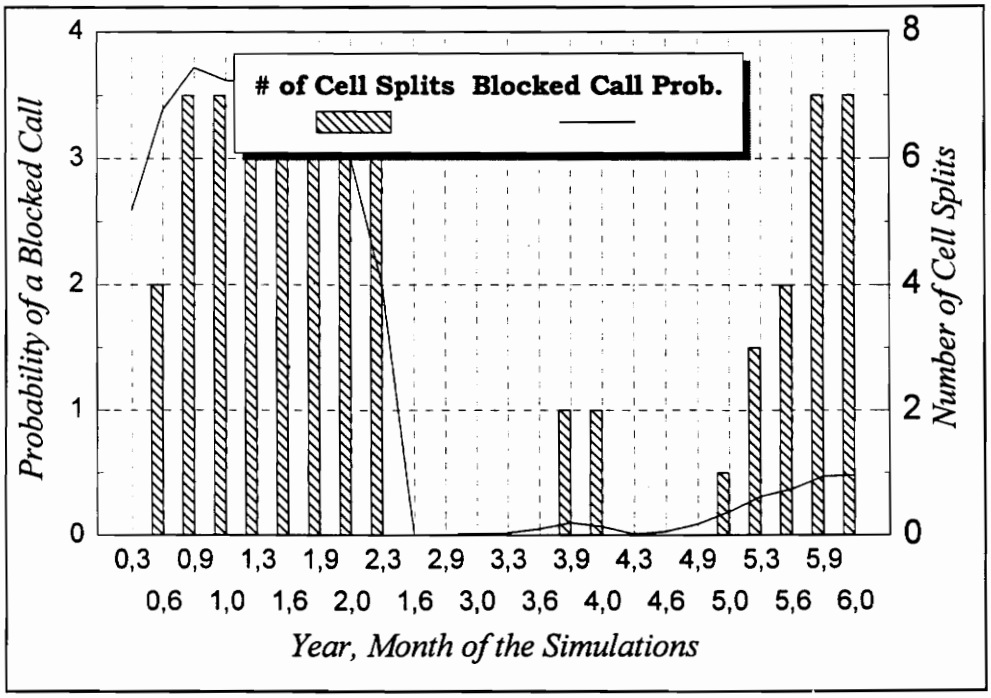


Figure 5-7: Average Probability of a Blocked Call for all Sectors in the Cellular System vs. Time

6. Future In-Building Channel Availability Results and Conclusions

6.1. Future In-Building Channel Availability Results

As the cells split, and become geographically spaced closer to the building, in-building channel availability analysis was performed on the building under study to determine how these cells splits affected the number of channels available.

The analysis was performed by examining the availability of each derived channel set separately. The aggregate received power on the ground level for each derived channel set was calculated using the method described in **Section 4.3 Computing Signals at Ground Level**. Two constants of 0 dB and 25 dB (two cases were examined) were added to the computed ground level signal to obtain signal levels on the 6th floor, and a gain factor which is a function of floor in the building (see Table 2-4) was added to compensate for signal gain on the higher floors of the building.

Analysis was performed using the two separate gain constants (0 dB and 25 dB). This was done to provide an upper and lower bound on channel availability. A gain constant of 0 dB indicates that the signal on the ground floor is the same as the signal on the 6th floor. This provides an upper bound on the number of channels available in the building since on the 6th floor the signal level, in actuality, will be greater than the signal on the ground floor. Even with low base station antenna heights in 3rd generation cells, the

ground clutter is likely to attenuate received signals when compared to levels received on the 6th floor.

The gain constant of 25 dB indicates that the signal level on the ground floor is 25 dB less than the signal level on the 6th floor. This provides a lower bound on the channel availability since the signal level difference between the ground floor and the sixth is most likely to be 25 dB or less, given downtilted antennas.

The remainder of this section presents, in graphical form, the future in-building channel availability results. Results are shown based on year, floor, signal level threshold, and the gain constant used.

These results are a culmination of all of modeling, analysis, and simulation techniques presented heretofore.

Estimated Channel Availability By Floor For Year 0

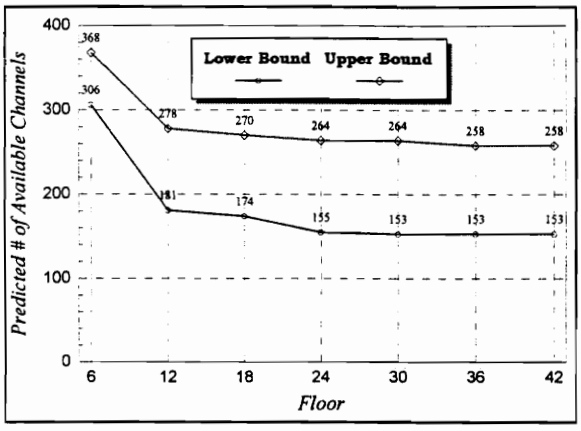


Figure 6-1: Estimated Number of Channels Available at Year 0 by Floor Based on a -95 dBm Threshold

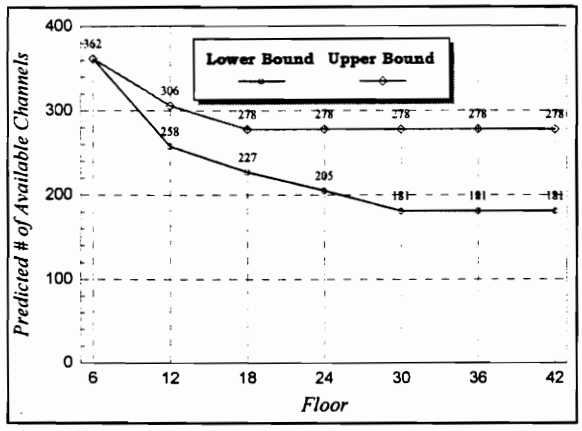


Figure 6-2: Estimated Number of Channels Available at Year 0 by Floor Based on a -90 dBm Threshold

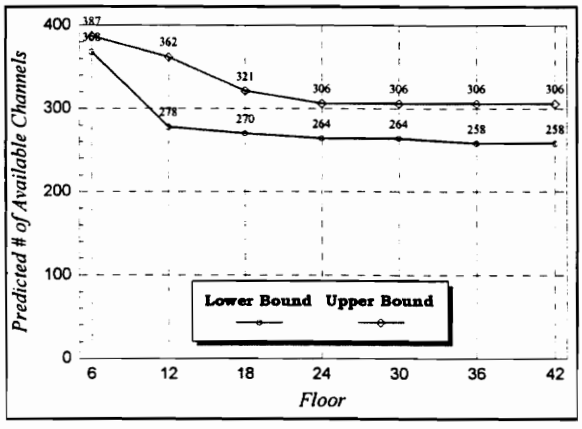


Figure 6-3: Estimated Number of Channels Available at Year 0 by Floor Based on a -85 dBm Threshold

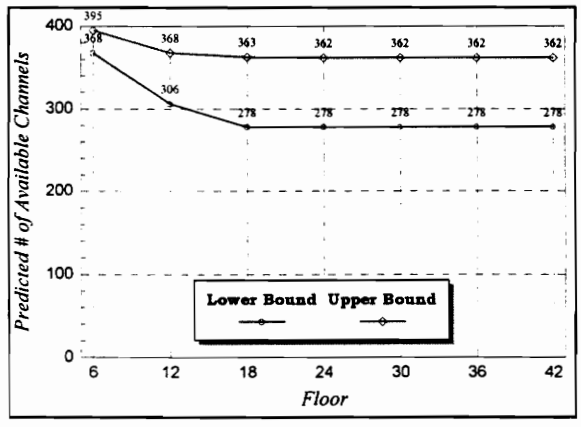


Figure 6-4: Estimated Number of Channels Available at Year 0 by Floor Based on a -80 dBm Threshold

Estimated Channel Availability By Floor For Year 1

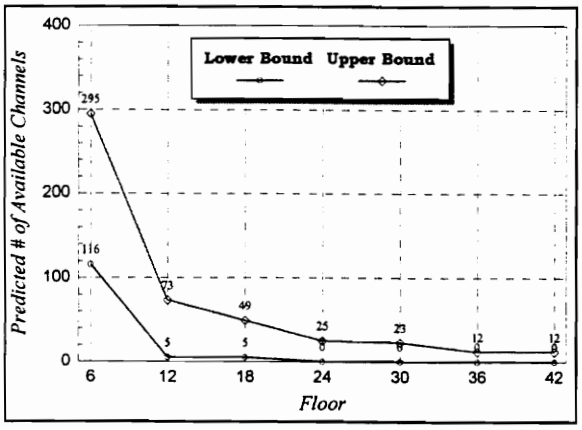


Figure 6-5: Estimated Number of Channels Available at Year 1 by Floor Based on a -95 dBm Threshold

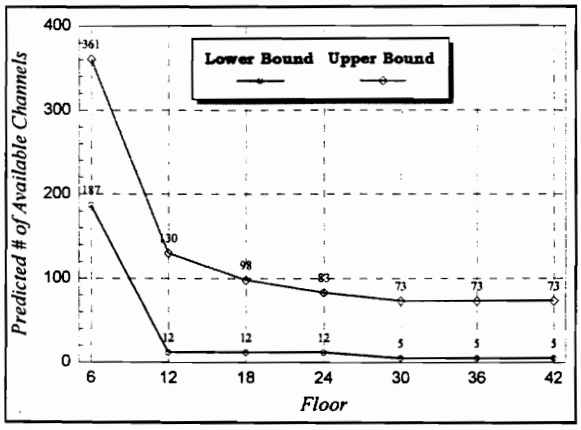


Figure 6-6: Estimated Number of Channels Available at Year 1 by Floor Based on a -90 dBm Threshold

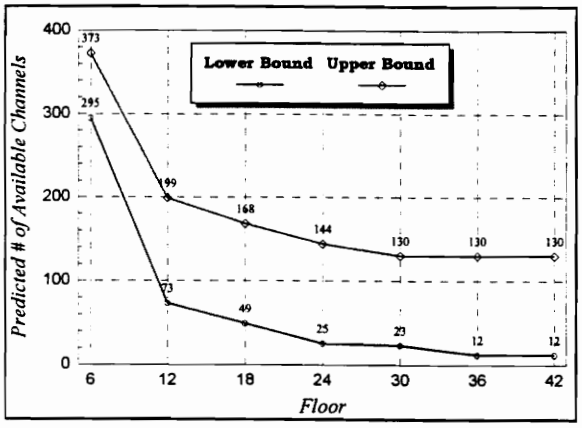


Figure 6-7: Estimated Number of Channels Available at Year 1 by Floor Based on a -85 dBm Threshold

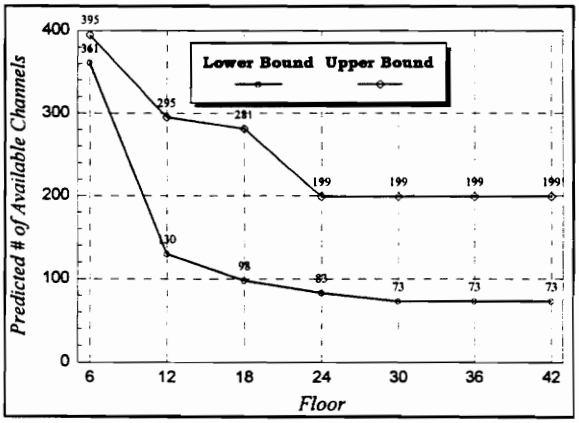


Figure 6-8: Estimated Number of Channels Available at Year 1 by Floor Based on a -80 dBm Threshold

Estimated Channel Availability By Floor For Year 2

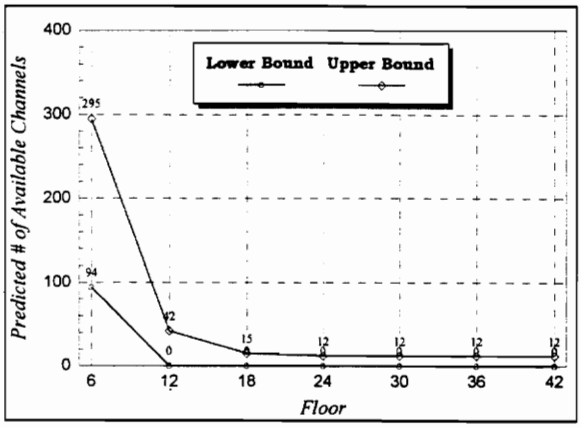


Figure 6-9: Estimated Number of Channels Available at Year 2 by Floor Based on a -95 dBm Threshold

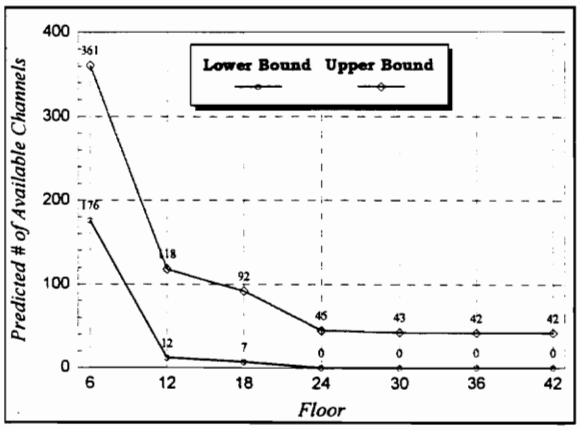


Figure 6-10: Estimated Number of Channels Available at Year 2 by Floor Based on a -90 dBm Threshold

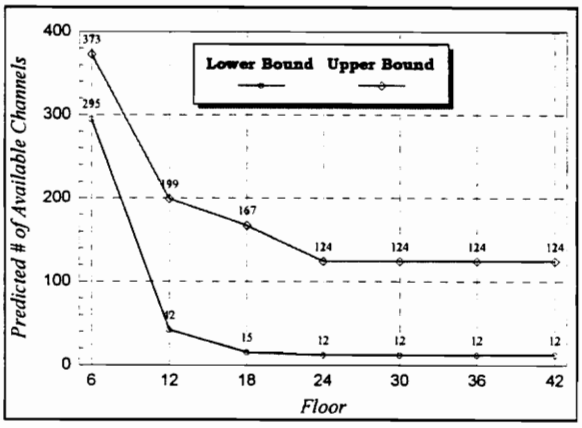


Figure 6-11: Estimated Number of Channels Available at Year 2 by Floor Based on a -85 dBm Threshold

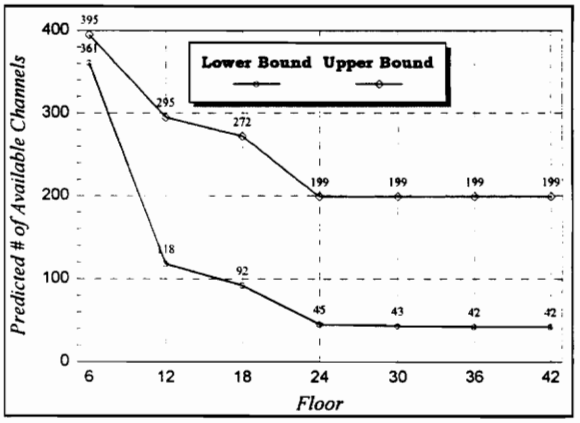


Figure 6-12: Estimated Number of Channels Available at Year 2 by Floor Based on a -80 dBm Threshold

Estimated Channel Availability By Floor For Year 3

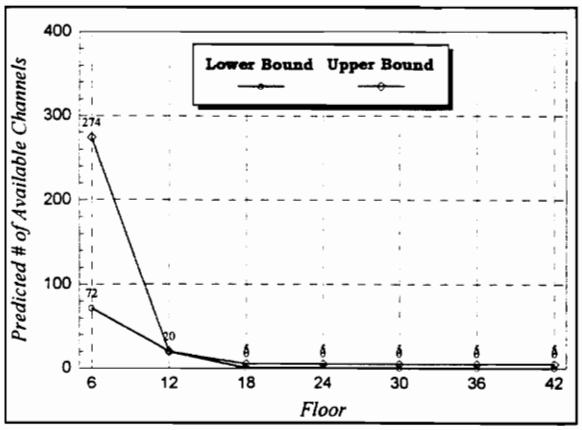


Figure 6-13: Estimated Number of Channels Available at Year 3 by Floor Based on a -95 dBm Threshold

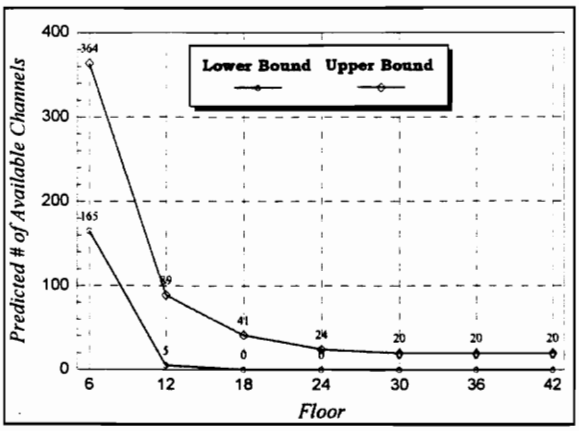


Figure 6-14: Estimated Number of Channels Available at Year 3 by Floor Based on a -90 dBm Threshold

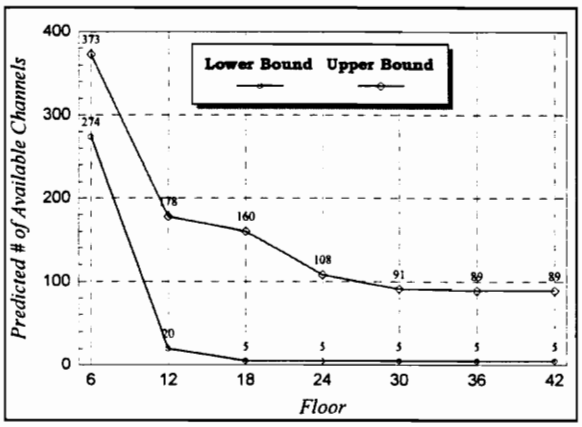


Figure 6-15: Estimated Number of Channels Available at Year 3 by Floor Based on a -85 dBm Threshold

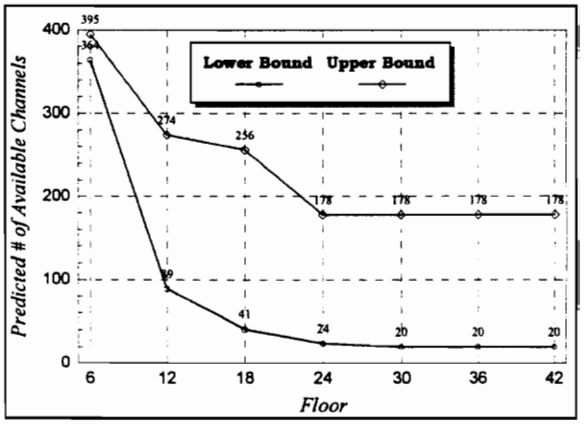


Figure 6-16: Estimated Number of Channels Available at Year 3 by Floor Based on a -80 dBm Threshold

Estimated Channel Availability By Floor For Year 4

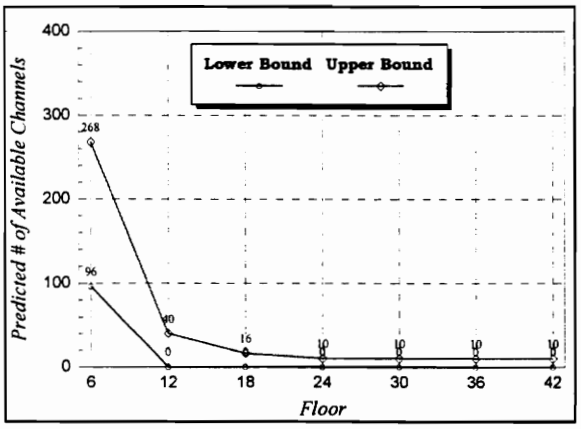


Figure 6-17: Estimated Number of Channels Available at Year 4 by Floor Based on a -95 dBm Threshold

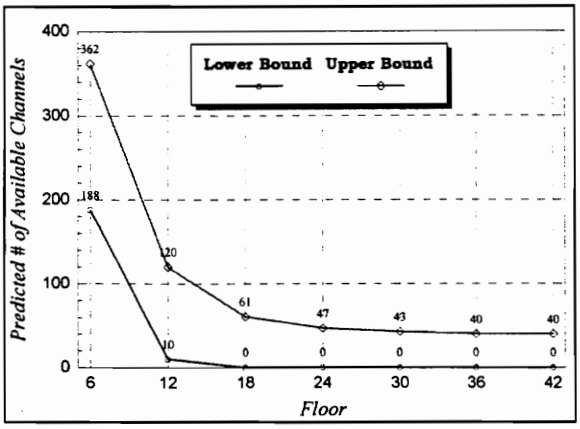


Figure 6-18: Estimated Number of Channels Available at Year 4 by Floor Based on a -90 dBm Threshold

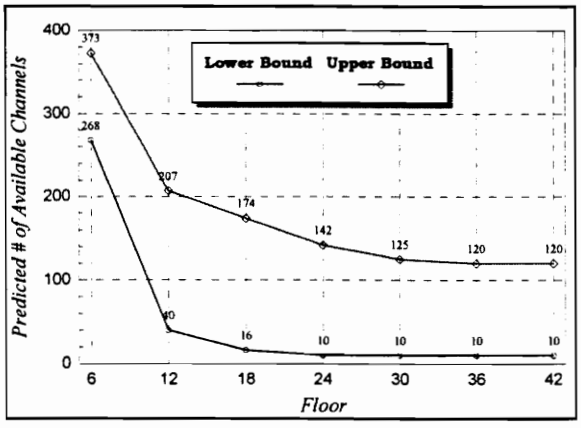


Figure 6-19: Estimated Number of Channels Available at Year 4 by Floor Based on a -85 dBm Threshold

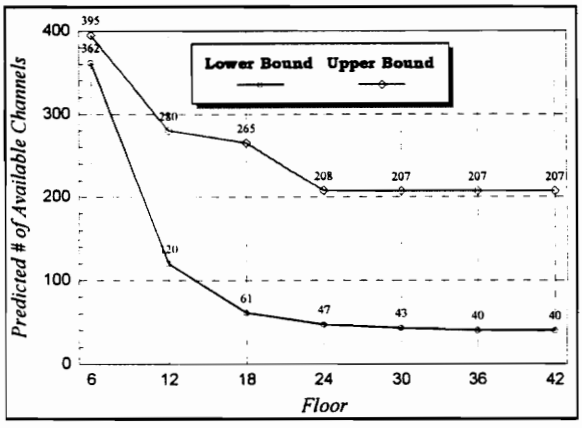


Figure 6-20: Estimated Number of Channels Available at Year 4 by Floor Based on a -80 dBm Threshold

Estimated Channel Availability By Year For The 6th Floor

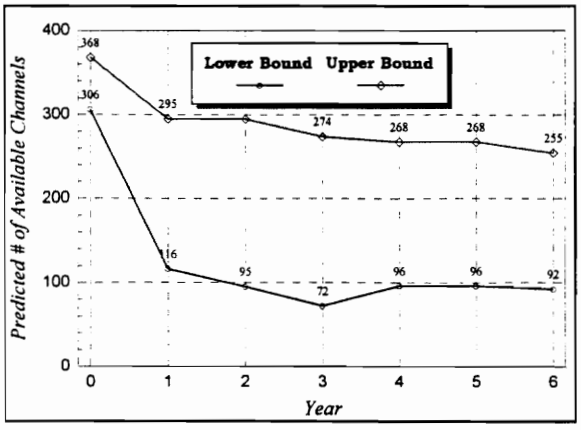


Figure 6-21: Estimated Number of Channels Available on the 6th Floor by Year Based on a -95 dBm Threshold

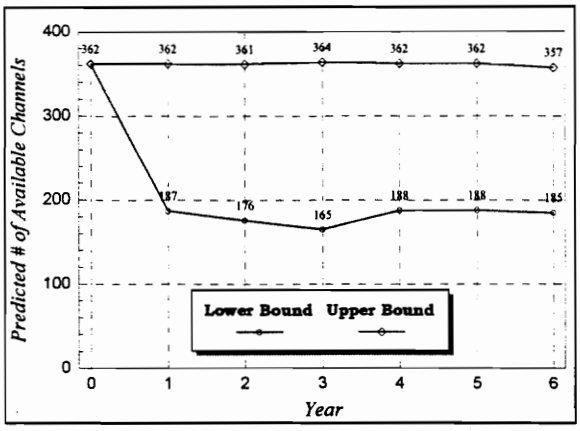


Figure 6-22: Estimated Number of Channels Available on the 6th Floor by Year Based on a -90 dBm Threshold

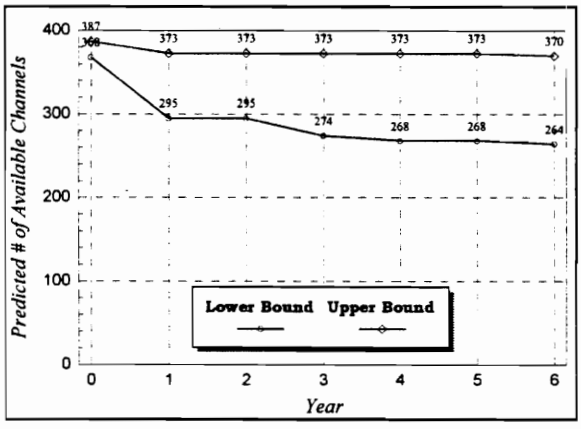


Figure 6-23: Estimated Number of Channels Available on the 6th Floor by Year Based on a -85 dBm Threshold

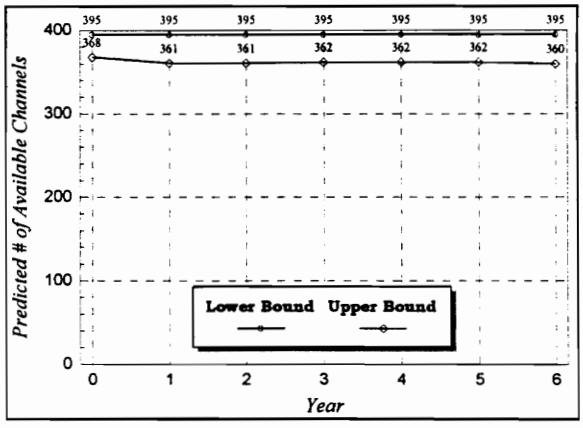


Figure 6-24: Estimated Number of Channels Available on the 6th Floor by Year Based on a -80 dBm Threshold

Estimated Channel Availability By Year For The 12th Floor

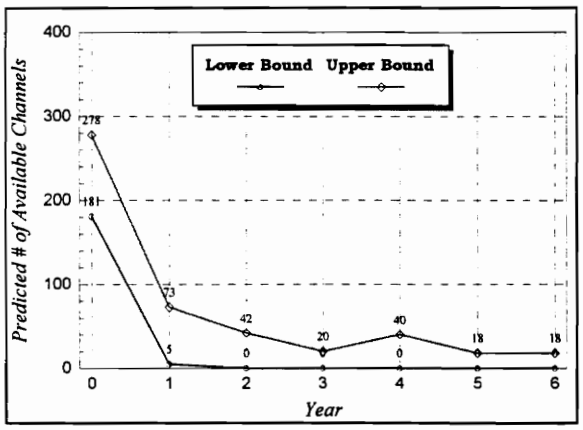


Figure 6-25: Estimated Number of Channels Available on the 12th Floor by Year Based on a -95 dBm Threshold

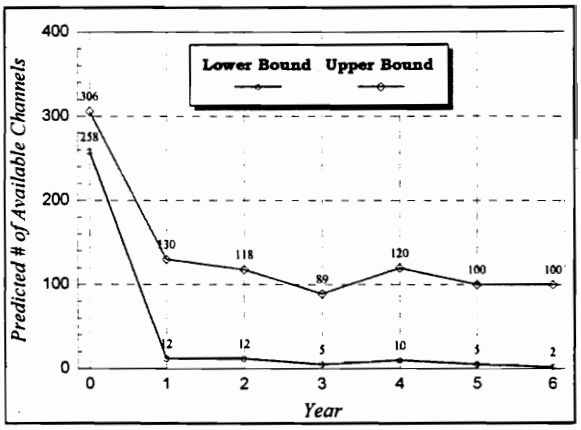


Figure 6-26: Estimated Number of Channels Available on the 12th Floor by Year Based on a -90 dBm Threshold

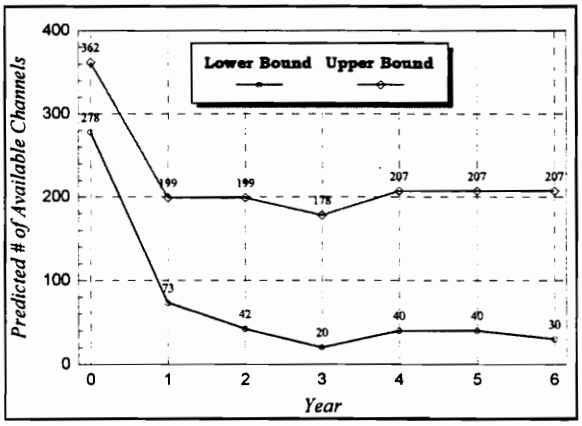


Figure 6-27: Estimated Number of Channels Available on the 12th Floor by Year Based on a -85 dBm Threshold

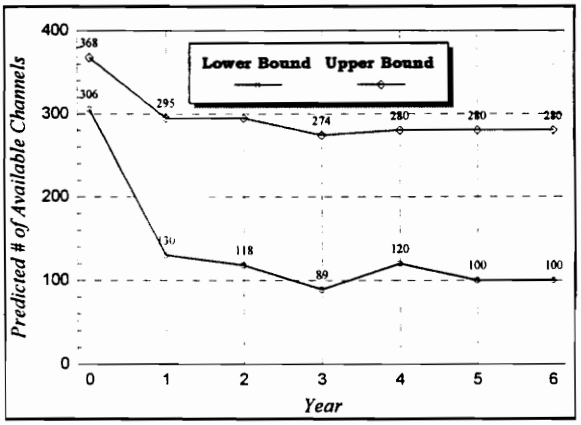


Figure 6-28: Estimated Number of Channels Available on the 12th Floor by Year Based on a -80 dBm Threshold

Estimated Channel Availability By Year For The 18th Floor

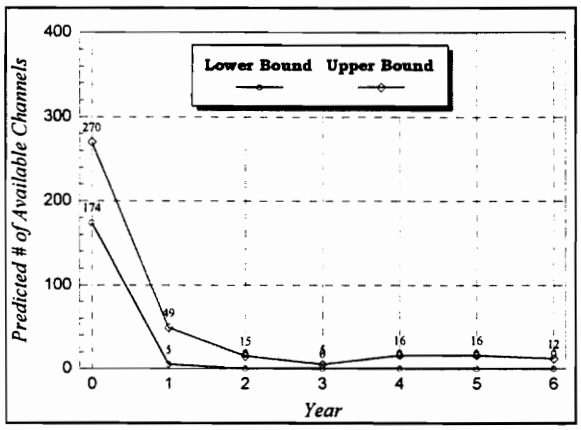


Figure 6-29: Estimated Number of Channels Available on the 18th Floor by Year Based on a -95 dBm Threshold

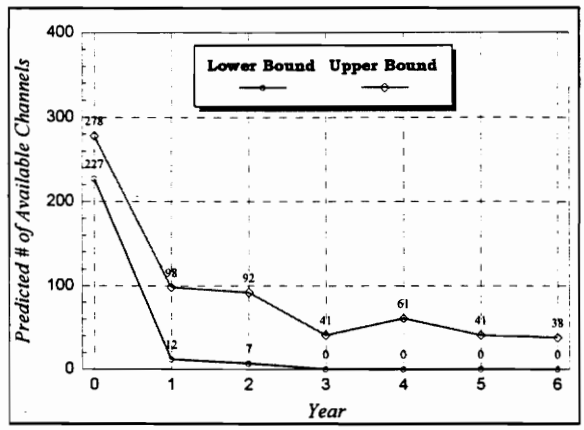


Figure 6-30: Estimated Number of Channels Available on the 18th Floor by Year Based on a -90 dBm Threshold

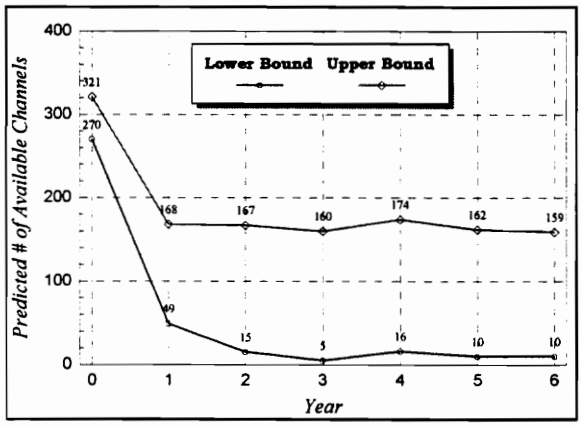


Figure 6-31: Estimated Number of Channels Available on the 18th Floor by Year Based on a -85 dBm Threshold

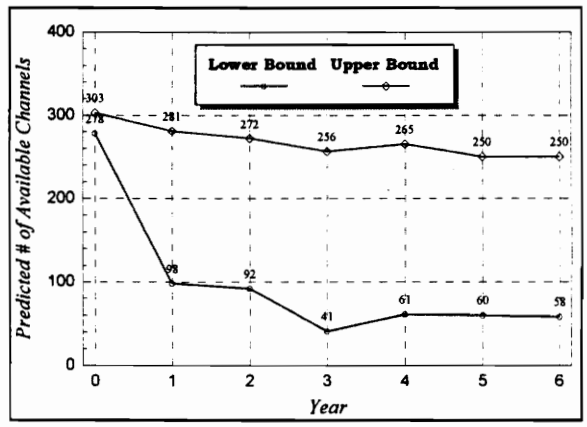


Figure 6-32: Estimated Number of Channels Available on the 18th Floor by Year Based on a -80 dBm Threshold

Estimated Channel Availability By Year For The 24th Floor

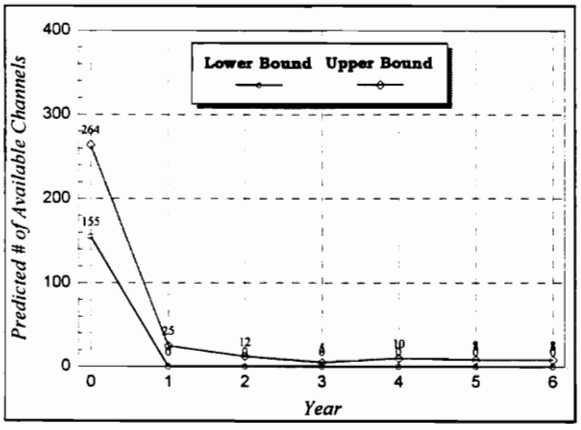


Figure 6-33: Estimated Number of Channels Available on the 24th Floor by Year Based on a -95 dBm Threshold

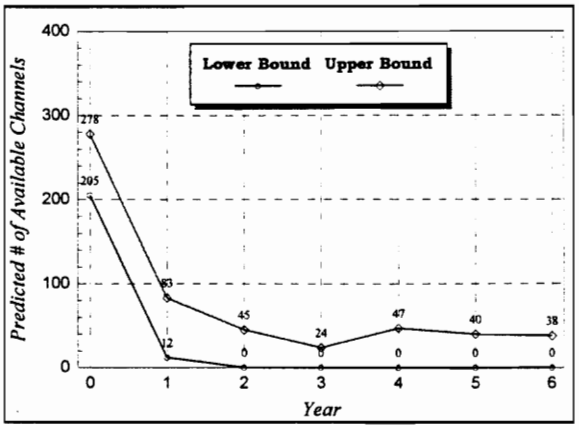


Figure 6-34: Estimated Number of Channels Available on the 24th Floor by Year Based on a -90 dBm Threshold

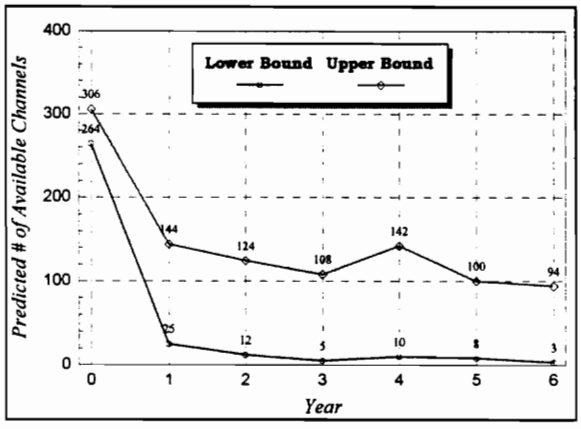


Figure 6-35: Estimated Number of Channels Available on the 24th Floor by Year Based on a -85 dBm Threshold

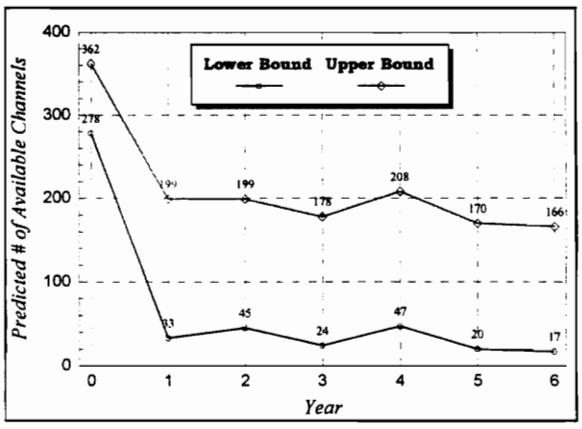


Figure 6-36: Estimated Number of Channels Available on the 24th Floor by Year Based on a -80 dBm Threshold

Estimated Channel Availability By Year For The 30th Floor

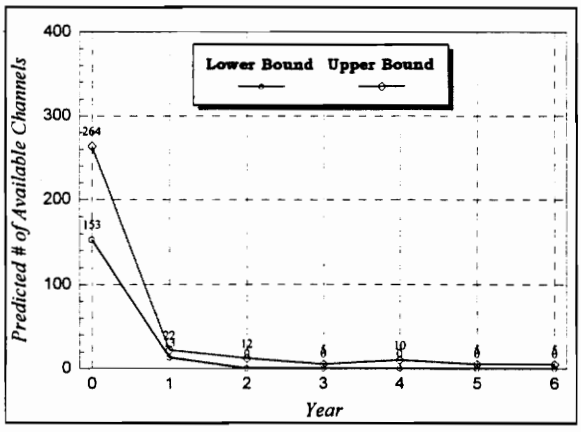


Figure 6-37: Estimated Number of Channels Available on the 30th Floor by Year Based on a -95 dBm Threshold

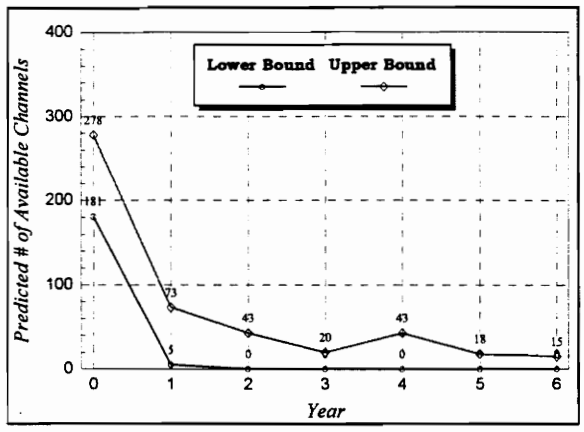


Figure 6-38: Estimated Number of Channels Available on the 30th Floor by Year Based on a -90 dBm Threshold

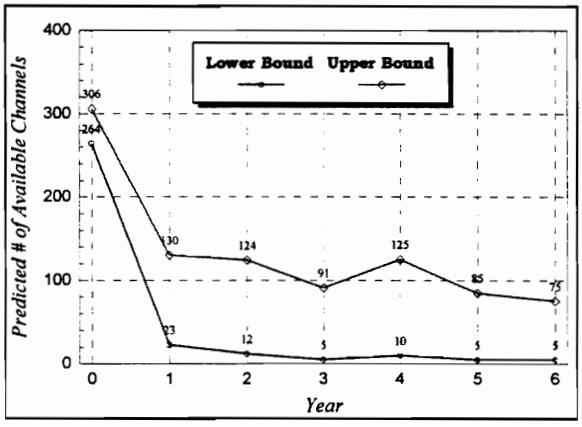


Figure 6-39: Estimated Number of Channels Available on the 30th Floor by Year Based on a -85 dBm Threshold

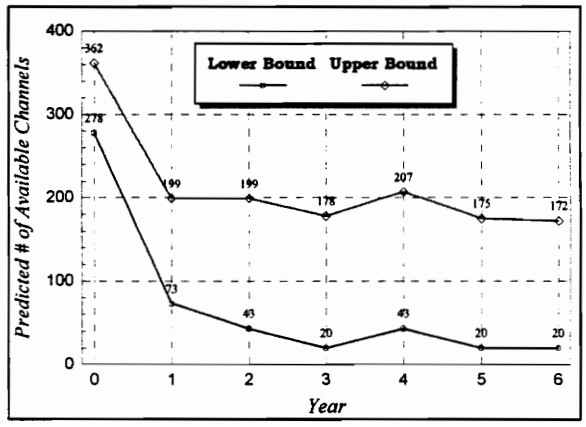


Figure 6-40: Estimated Number of Channels Available on the 30th Floor by Year Based on a -80 dBm Threshold

Estimated Channel Availability By Year For The 36th Floor

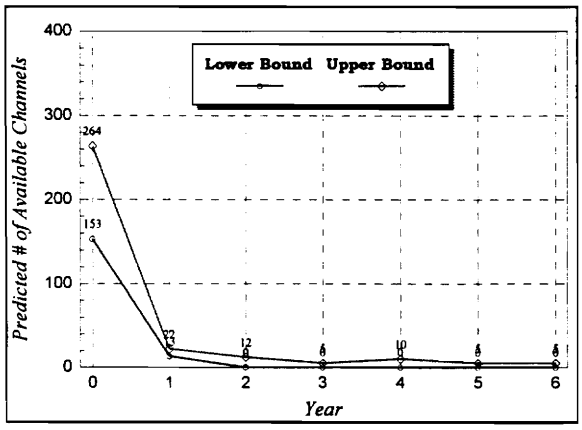


Figure 6-41: Estimated Number of Channels Available on the 36th Floor by Year Based on a -95 dBm Threshold

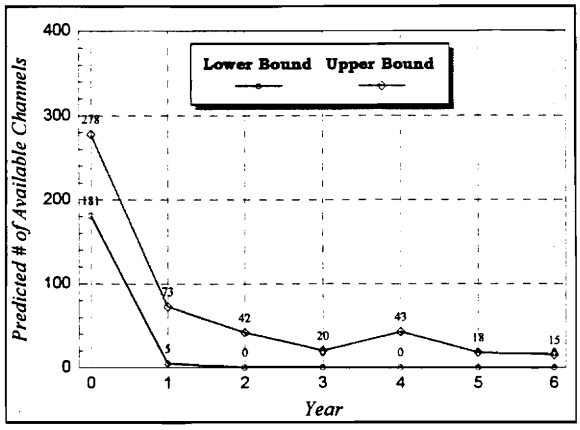


Figure 6-42: Estimated Number of Channels Available on the 36th Floor by Year Based on a -90 dBm Threshold

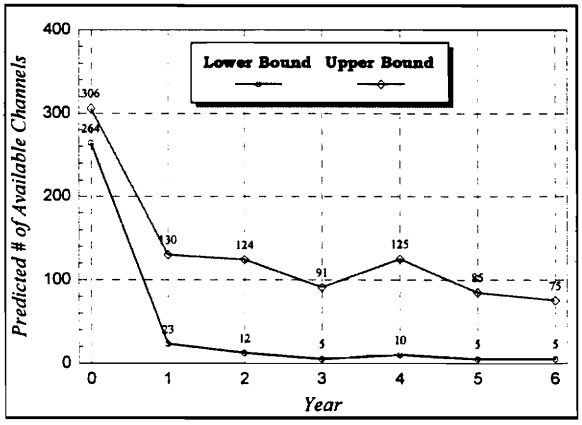


Figure 6-43: Estimated Number of Channels Available on the 36th Floor by Year Based on a -85 dBm Threshold

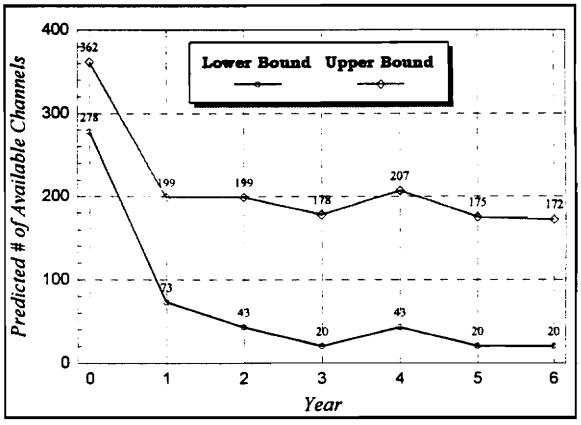


Figure 6-44: Estimated Number of Channels Available on the 36th Floor by Year Based on a -80 dBm Threshold

Estimated Channel Availability By Year For The 42nd Floor

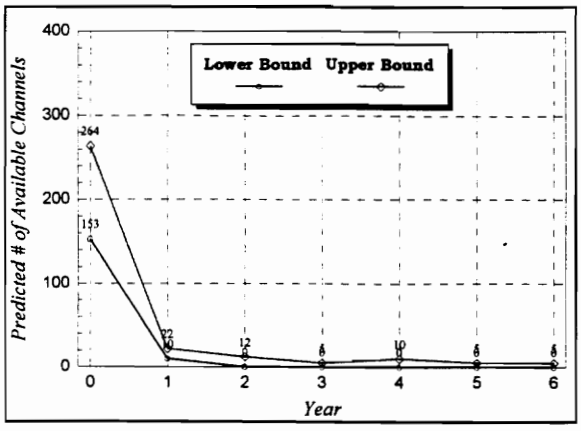


Figure 6-45: Estimated Number of Channels Available on the 42nd Floor by Year Based on a -95 dBm Threshold

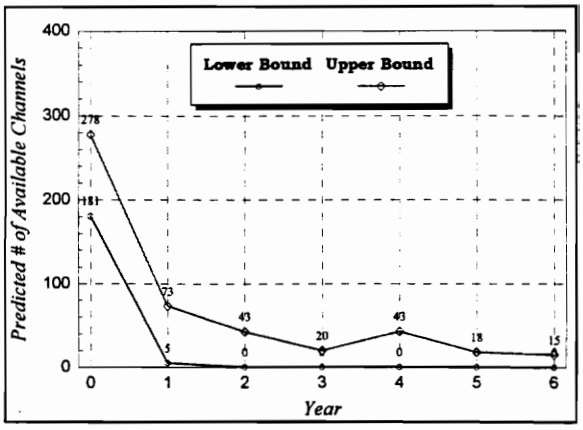


Figure 6-46: Estimated Number of Channels Available on the 42nd Floor by Year Based on a -90 dBm Threshold

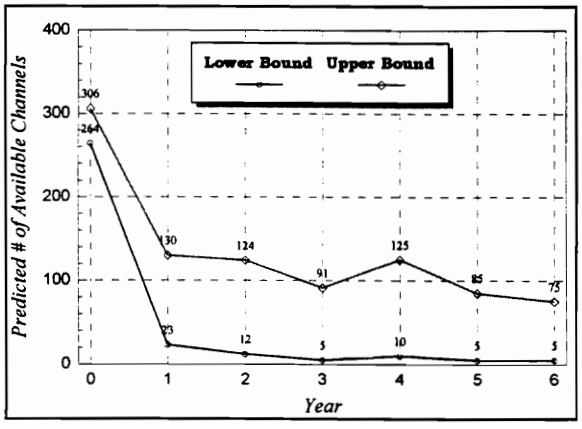


Figure 6-47: Estimated Number of Channels Available on the 42nd Floor by Year Based on a -85 dBm Threshold

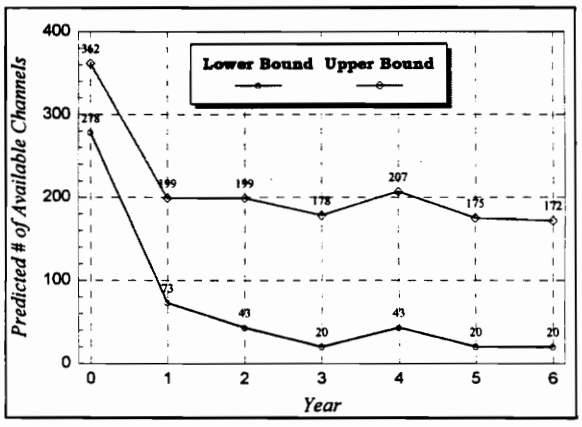


Figure 6-48: Estimated Number of Channels Available on the 42nd Floor by Year Based on a -80 dBm Threshold

6.2. Conclusions

Based upon the measurements made by the sponsor and the channel availability predictions for year 0 (Figure 6-1 - Figure 6-4), it is clear that there is currently plenty of frequency reuse possible between an in-building parasitic cellular system and an outdoor cellular system regardless of floor, even if a threshold of -95 dBm is required. The lower floors of the building have an estimated 200 to 300 channels available for reuse, while the upper floors have between 50 and 100 channels available.

Based upon the channel availability predictions, the amount of frequency reuse possible between an in-building parasitic cellular system and the outdoor cellular system is significantly reduced as the outdoor cellular system matures and cells split. According to the simulations, the lower floors of the building under study (floors 1 through 6) are, for the most part, unaffected by the growth of the cellular system. This can be attributed mainly to the local building clutter which surrounds the building. Figure 6-21 - Figure 6-24 show how the predicted channel availability changes as a function of year on the 6th floor for the thresholds of -95 dBm, -90 dBm, -85 dBm, and -80 dBm, respectively. As can be seen in Figure 6-24, after 6 years of outdoor cellular growth, the predictions indicate that there are at least 92 channels available for reuse on the 6th floor. The upper floors of the building (floors 12 and up) have much different channel availability statistics than floors 1 through 6. Figure 6-25 shows how predicted channel availability changes on the 12th floor as a function of year using a threshold of -95 dBm. Comparing this

figure to Figure 6-21 clearly shows how building height affects channel availability over time. According to the simulations, the 6th floor has at least 92 channels available for reuse at year 6, while on the 12th floor, according to the simulations, there are at most, 18 channels available for reuse. This is referenced to a -95 dBm threshold. The channel availability statistics get worse as floor number increases. Figure 6-45 shows the number of channels available as a function of year using a threshold of -95 dBm for the 42nd floor of the building. This figure shows that by year 6 there will be at most 5 channels available for reuse. This indicates that essentially there is no frequency reuse possible on the 42nd floor after 6 years of the outdoor cellular system maturing, unless a weaker threshold can be used.

The 42nd floor simulation values show the worst case channel availability statistics for the building since it is the highest floor of the building. Figure 6-45 - Figure 6-48 show the channel availability statistics for the 42nd floor as a function of year for thresholds of -95 dBm, -90 dBm, -85 dBm, and -80 dBm, respectively. As can be seen in these figures, channel availability increases drastically as the signal threshold is increased. If a cellular channel whose signal is as strong as -80 dBm can be successfully reused inside the building, the channel availability statistics become much improved. After 6 years of outdoor cellular growth, as many as 172 channels are available for reuse on the 42nd floor if a reference threshold of -80 dBm is used. Compare this to 5 available channels if a threshold of -95 dBm is used.

The channel availability statistics for the upper floors of the building indicate that, in the future, an indoor parasitic cellular system operating in the building under study will not have the frequency reuse it requires if a -95 dBm threshold is required. In order for a parasitic system to be effective in the future, channels whose received power is as strong as -85 dBm or -80 dBm must be able to be reused without sufficiently degrading the quality of service of the indoor parasitic system.

7. References

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APPENDIX A The Cell Site Database

The sponsor provided a database of cell sites which describes the layout of the current cellular system under study. The database includes all relevant parameters of the cellular system and has the format described below. The listing of this database is shown as well.

```
SITE|LOCATION|LAT|LONG|GND_LVL
FACE|ANT_LVL|ANT_TYPE|TILT|ERP|SAT|CC|VC ...
~ = END OF RECORD
```

`SITE` specifies the site number of the cell site and is unique for every cell site. The database shown in this appendix has cell sites with numbers ranging from 1 to 199. New cells added by the simulation begin with a `SITE` number of 200 and increment from there.

`LOCATION` has the exact same meaning as `SITE`.

`LAT` and `LONG` specify the latitude and longitude of the cell site, respectively. It is assumed that the `LONG` entry specifies a longitude in the western hemisphere. In addition, the sponsor has altered these coordinates to keep the exact location of the cellular system unknown. All coordinates have been offset with the same value so that the relative location of all cell sites with respect to each other and the building under study do not change.

GND_LVL specifies the height of the cell site above sea level and has units of feet.

FACE specifies the orientation of a sector's antenna counter-clockwise from due North. FACE has units of degrees.

ANT_LVL specifies the height of a sector's transmitting antenna with respect to the base of the base station. ANT_LVL has units of feet.

ANT_TYPE specifies the sector's antenna type. The name in this field corresponds to one of the antennas listed in **APPENDIX B**.

TILT specifies the degrees of downtilt currently used with the sector's antenna. TILT has units of degrees.

ERP specifies the effective radiated power of a sector's transmitter, and has units of watts.

SAT specifies the supervisory audible tone assigned to a sector. SAT can have values of 0, 1, or 2.

CC specifies the control channel assigned to a sector. Valid B-side control channels range from 334 to 354.

VC contains one or more voice channels which are assigned to a sector's voice channel set.

```
#######################################################################
# SITE|LOCATION|LAT|LONG|GND LVL
# FACE|ANT LVL|ANT TYPE|TILT|ERP|SAT|CC|VC...
# ~ = END OF RECORD
#######################################################################
#
1|CELL SITE  1|39:45:47|86:16:36|1005
2|130|PD10176|0|80.0|1|338|360|381|402|423|444|465|486|507
122|205|PD10176|0|56.2|2|338|619|640|661|724|745|766|787
242|100|PD10176|0|100.0|0|338|584|605|626|647
~
#
2|CELL SITE  2|39:39:44|86:22:29|913
2|140|LPD7905/4-N|0|40.0|2|353|586|607|628|649
122|200|LPD7905/4-N|0|100.0|0|353|362|383|404|425|446|467|488|509|530|551|572
242|200|LPD7905/4-N|0|40.0|1|353|369|390|411|432|453|474|495|516|537
~
#
3|CELL SITE  3|39:41:48|86:23:58|986
2|180|ALP9212|0|15.8|0|346|359|380|401|422|443|464|485|506|527
122|180|ALP9212|0|40.0|0|346|366|387|408|429|450|471|492
242|180|ALP9212|0|15.8|0|346|373|394|415|436|457|478|499|520|541|562|583|604|625|646|730
~
#
4|CELL SITE  4|39:41:13|86:30:48|950
 2|250|LPD7905/4-N|10|100|1|343|630|651|735|756|777|798
122|250|LPD7905/4-N|10|100|0|343|553|574|595|616|637|658|721|742|763|784
227|290|LPD7905/4-N|0|100|0|343|602|623|644|665|728|749|770|791
~
#
20|CELL SITE  20|39:42:08|86:19:48|885
2|230|PD1251|0|16|0|350|630|651|735|756|777|798
122|230|PD1251|0|100|1|350|532|553|574|595|616|637|658|721|742|763|784
242|230|PD1251|0|40|1|350|644|665|728|749|770|791
~
#
23|CELL SITE  23|39:42:07|86:15:54|848
2|180|RWA80012|0|39.8|0|340|550|571|592|613|634|655|718|739|760|781
122|180|RWA80012|0|39.8|1|348|599|620|641|662|725|746|767|788
242|180|RWA80012|0|39.8|1|351|564|585|606|627|648|732|753|774|795
~
#
33|CELL SITE  33|39:50:38|86:18:28|850
2|150|DB833|0|6.3|0|348|546|567|588|609|630|651|735|756|777|798
122|150|DB833|0|16|1|348|364|385|406|427|448|469
242|150|DB833|0|16|1|348|371|392|413|434|455|476|497|518|539|560|581|602|623
~
#
35|CELL SITE  35|39:45:51|86:21:42|963
2|100|LPD7905/4-N|5|16|2|339|357|378|399|420|441|462|483|504|525|546
122|142|LPD7905/4-N|0|100|2|339|364|385|406|427|448|469|490
242|135|ALP9212|0|86.1|2|339|371|392|413|434|455|476|497|518
~
#
39|CELL SITE  39|39:40:18|86:27:03|1033
```

```
2|180|DB833|0|16|0|340|360|381|402|423|444
122|180|DB833|10|40|1|340|535|556|577|598|619|640|661|724|745|766|787
242|180|DB833|0|40|0|340|374|395|416|437|458|479|500|521|731|752|773|794
~
#
40|CELL SITE  40|39:44:16|86:18:34|1002
2|150|RWA80012|0|40|0|337|611|632|653|737|758|779
122|150|RWA80012|0|40|0|346|660|723|744|765|786
242|150|RWA80012|0|100|0|354|562|583|604|625|646|730|751|772|793
~
#
50|CELL SITE  50|39:49:07|86:14:40|1001
2|200|ALP8013|0|6.3|1|344|361|382|403|424|445|466|487|508|529|550|571
122|200|ALP8013|0|40|2|344|494|515|536|557|578|599|620|641|662|725|746|767|788
242|200|ALP8013|0|15.8|0|344|438|459|480|501|522|543|564|585|606|627|648|732|753|774|795
~
#
73|CELL SITE  73|39:54:26|86:21:15|1042
2|106|DB834|0|16|0|342|358|379|400|421|442|463|484|505|526|547|568|589|610|631|652
122|108|DB834|0|40|2|348|365|386|407|428|449|470|491|512|533|554|575|596
242|106|DB834|0|15.8|0|353|372|393|414|435|456|477|498|519|540|561|582
~
#
80|CELL SITE  80|39:47:49|86:20:00|960
2|150|DB833|0|40|2|336|361|382|403|424|445|446|487|508|529
122|150|DB833|0|40|1|342|368|389|410|431|452|473|494|515|536|557
242|150|DB833|0|40|1|349|375|396|417|438|459|480|501|522
~
#
84|CELL SITE  84|39:50:05|86:20:24|880
2|150|ALP8010|0|15.8|1|345|358|379|400|421|442|463
122|150|ALP8010|0|15.8|0|345|365|386|407|428|449|470|491|512|533|554|575|596|617|638|659|722
242|150|ALP8010|0|15.8|1|345|519|540|561|582|603|624|645|666|729|750|771|792
~
#
85|CELL SITE  85|39:52:03|86:20:02|983
2|150|ALP9212|0|16|0|346|360|381|402|423|444|465|486
122|150|ALP9212|0|40|0|346|640|661|724|745|766|787
242|150|ALP9212|0|40|2|346|374|395|416|437|458|479|500|521|542
~
#
86|CELL SITE  86|39:48:39|86:17:42|938
2|200|DB833|0|16|0|351|545|566|587|608|629|650
122|200|DB833|0|16|0|351|363|384|405|426|447|468|489|510|531|552
242|200|DB833|0|16|0|351|454|475|496|517|538|559|580
~
#
87|CELL SITE  87|39:52:01|86:17:07|897
2|152|ALP9209|0|16|0|340|359|380|401|422|443|464|485|506
122|152|DB833|0|15.8|0|340|366|387|408|429
242|152|ALP9209|0|6.3|0|340|583|604|625|646|730|751|772|793
~
#
101|CELL SITE  101|39:49:11|86:27:46|802
2|200|DB833|0|50|0|341|359|380|401|422|443|464|485|506
```

```
122|200|DB833|0|87|0|341|366|387|408|429|450
242|200|DB833|0|64|0|341|520|541|562|583|604|625|646|730|751|772|793
~
#
103|CELL SITE  103|39:47:06|86:25:49|981
2|102|ALP9212|0|40|2|337|355|376|397|418|439|460|481|502
122|102|ALP9212|0|16|0|337|362|383|404|425|446|467
242|102|ALP9212|0|100|1|337|369|390|411|432|453|474|495
~
#
105|CELL SITE  105|39:52:51|86:30:21|1017
2|150|PD1251|0|40|0|353|523|544|565|586|607|628|649|733|754|775|796
122|150|PD1251|0|15.8|1|353|362|383|404|425|446
242|150|PD1251|0|100|2|353|579|600|621|642|663|726|747|768|789
~
#
109|CELL SITE  109|39:43:25|86:27:53|1014
2|153|KT740217|0|40|1|338|361|382|403|424|445|466|487
122|153|KT740217|0|40|1|338|368|389|410|431|452|473|494|515
242|150|KT740217|0|40|1|338|375|396|417|438|459|480|501
~
#
110|CELL SITE  110|39:46:58|86:23:21|994
2|200|LPD7907/2|0|16|2|343|356|377|398|419|440|461|482|503|524|545|566|587|608|629|650|734|755|776|797|736|757|
778|799
122|200|LPD7907/2|0|16|1|343|363|384|405|426|447|468|489|510|531|552|573|594|615|636|657|720|741|762|783
242|200|LPD7907/2|0|16|2|343|370|391|412|433|454|475|496|517|538|559|580|601|622|643|664|727|748|769|790
~
#
112|CELL SITE  112|39:45:57|86:25:49|938
2|100|DB834|0|15.8|0|336|359|380|401|422
122|100|DB834|0|15.8|0|341|639|660|723|744|765|786
242|100|DB834|0|15.8|0|350|373|394|415|436
~
#
117|CELL SITE  117|39:44:52|86:32:47|870
2|105|DB833|0|40|0|347|548|569|590|611|632|653|737|758|779
122|105|DB833|0|100|0|347|660|723|744|765|786
242|105|DB833|0|100|0|347|373|394|415|436|457|478|499
~
#
126|CELL SITE  126|39:50:24|86:25:43|918
2|150|DB833|0|2.6|1|338|360|381|402|423|444|465|486|507|528|549|570|591|612|633|654
122|150|DB833|0|2.5|2|338|514|535|556|577|598|619|640|661
242|150|DB833|0|2.5|0|338|374|395|416|437|458|479
~
#
127|CELL SITE  127|39:45:36|86:24:06|980
180|23|RWA8006-OLD|0|0.0|1|339|596|617|638|659|722|743|764|785|726|747|768|789|730|751|772|793
~
#
129|CELL SITE  129|39:49:05|86:29:38|772
2|170|RWA80012|0|100|2|338|361|382|403|424|445|466|487
122|170|RWA80012|0|100|1|344|368|389|410|431|452|473|494
242|170|RWA80012|0|100|0|349|375|396|417|438|459|480|501
```

```
~
#
132|CELL SITE  132|39:45:46|86:23:01|1001
2|80|RWA80012-OLD|0|16|0|340|592|613|634|655|718|739|760|781
122|80|RWA80012-OLD|0|16|1|345|557|578|599|620|641|662|725|746|767|788
242|80|RWA80012-OLD|0|16|2|354|606|627|648|732|753|774|795
~
#
133|CELL SITE  133|39:44:56|86:23:38|1025
2|60|RWA8006-OLD|0|6|0|338|486|507|528|549|570|591|612|633
122|60|RWA8006-OLD|0|6|1|347|514|535|556
242|60|RWA8006-OLD|0|6|2|352|374|395|416|437|458|479|500|521
~
#
138|CELL SITE  138|39:39:34|86:24:11|990
2|130|LPD7907/4|0|40|2|337|487|508|529|550|571|592|613|634|655|718|739|760|781
122|130|LPD7907/4|0|40|0|344|536|557|578|599|620|641|662|725|746|767|788
242|130|LPD7907/4|0|100|0|348|375|396|417|438|459|480|501|522|543|564|585|606|627|648|732|753|774|795
~
#
144|CELL SITE  144|39:54:55|86:24:12|1047
2|152|LPD7907/4|8|15.8|1|341|360|381|402|423|444|465|486|507|528
122|152|LPD7907/4|10|16|0|341|367|388|409|430|451|472|493|514|535|556|577|598|619|640|661|724|745|766|787
242|152|LPD7907/4|8|15.8|2|341|479|500|521|542|563|584|605|626|647|731|752|773|794
~
#
146|CELL SITE  146|39:45:12|86:29:55|892
2|185|LPD7907/4|0|100|2|345|356|377|398|419|440|461|482|503|524|545|566|587
122|185|LPD7907/4|0|100|2|345|363|384|405|426|447|468|489
242|185|LPD7907/4|0|100|0|345|622|643|664|727|748|769|790
~
#
147|CELL SITE  147|39:44:13|86:23:40|975
2|185|RWA80012-OLD|7|40|0|349|356|377|398|419|440|461|482|503|524|545|566|587|408|629|650
122|185|RWA80012-OLD|0|16|0|349|363|384|405|426|447|468|489|510|531|552|573
242|185|DB833|0|16|1|349|601|622|643|664|727|748|769|790
~
#
148|CELL SITE  148|39:39:34|86:29:40|1008
2|150|KT740217|0|100|1|336|359|380|401|422|443|464|485
122|150|KT740217|0|100|0|344|366|387|408|429|450|471|492
242|150|KT740217|0|100|1|350|373|394|415|436|457|478|499
~
#
149|CELL SITE  149|39:48:31|86:25:18|879
2|100|RWA8009-OLD|0|16|0|340|356|377|398|419|440|461|482|503|524|545
122|100|RWA8009-OLD|0|16|0|353|594|615|636|657|729|741|762|783
242|100|RWA8009-OLD|0|16|0|346|370|391|412|433|454
~
#
152|CELL SITE  152|39:48:47|86:22:17|825
2|250|LPD7907/4|0|15.8|0|335|359|380|401|422|443|464|485|506|527|548|569|590|611|632|653
122|250|LPD7907/4|0|15.8|0|341|555|576|597|618|639|660|723|744|765|786
242|250|LPD7907/4|0|15.8|0|353|373|394|415|436|457|478|499|520|541|562|583|604
~
```

```
#
153|CELL SITE  153|39:52:40|86:24:39|986
2|157|ALP8013-N|0|39.8|2|343|505|526|547|568|589|610|631|652
122|157|ALP8013-N|0|15.8|1|343|365|386|407|428|449|470|491
242|157|ALP8013-N|0|39.8|2|343|582|603|624|645|666|729
~
#
154|CELL SITE  154|39:52:53|86:22:45|923
2|150|ALP9212|0|16|1|350|357|378|399|420|441|462|483|504
122|150|ALP9212|0|16|1|350|364|385|406|427|448|469|490|511|532|553|574|595|616|637|658|721
242|150|ALP9212|0|16|1|350|602|623|644|665|728|749|770|791
~
#
156|CELL SITE  156|39:51:37|86:28:55|1060
2|150|ALP9212|0|11.7|0|351|463|484|505|526|547|568|589|610|631|652|736|757|778|799
122|150|ALP9212|0|11.7|2|351|554|575|596|617|638|659|722|743|764|785
242|150|ALP9212|0|74|1|351|372|393|414|435|456|477|498|519|540|561
~
#
160|CELL SITE  160|39:49:51|86:21:40|935
2|125|LPD7905/4-N|0|16|2|342|528|549|570|591|612|633|654|717|738|759|780
122|125|LPD7905/4-N|0|16|0|352|367|388|409|430|451|472|493|514
242|125|LPD7905/4-N|0|2.5|1|354|605|626|647|731|752|773|794
~
#
162|CELL SITE  162|39:46:51|86:22:06|902
2|121|RWA8006-OLD|10|15.8|1|337|360|381|402|423|444|465|486
122|121|RWA8006-OLD|10|15.8|1|346|577|598|619|640|661|724
242|121|RWA8006-OLD|10|15.8|0|352|500|521|542|563|584|605|626|647
~
#
163|CELL SITE  163|39:49:03|86:23:28|790
2|100|RWA8009-OLD|0|15.8|0|336|357|378|399|420|441|462|483
122|100|RWA8009-OLD|0|15.8|0|338|637|658|721|742|763|784
242|100|RWA8009-OLD|0|15.8|0|345|371|392|413|434|455|476|497
~
#
172|CELL SITE  172|39:54:09|086:22:42|1042
2|50|RWA8009-OLD|0|16|1|354|439|460|481|502|523|544|565|586|607|628|649
122|50|RWA8009-OLD|0|16|2|336|551|572|593|614
242|50|RWA8009-OLD|0|16|0|350|369|390|411|432|453|474|495
~
#
173|CELL SITE  172|39:53:36|86:27:36|915
2|115|RWA8009-OLD|10|16|2|338|508|529|550|571|592|613|634|655|718|739|760|781
122|115|RWA8009-OLD|10|16|1|340|557|578|599|620|641|662|725|746|767|788
242|115|RWA8009-OLD|10|16|0|349|480|501|522|543|564|585|606|627|648|732|753|744|795
~
#
178|CELL SITE  178|39:41:57|86:26:57|928
2|180|RWA80012|0|100|0|339
12|180|RWA80012|0|100|0|341
242|180|RWA80012|0|100|0|354
~
#
```

```
180|CELL SITE  180|39:47:55|86:23:12|939
2|100|RWA80012|0|16|1|339|502|523|544|565|586|607|628|649|733|754|775|796
122|100|RWA80012|0|16|2|344|551|572|593|614|635|656|719|740|761|782
242|100|RWA80012|0|16|0|351|516|537|558|579|600|621|642|663|726|747|768|789
~
#
183|CELL SITE  183|39:52:51|86:27:14|939
2|150|ALP9212|8|16|1|337|566|587|608|629|650|734|755|776|797
122|150|ALP9212|0|16|1|337|363|384|405|426|447|468|489|510|531|552|573|594|615|636|657|720
242|150|ALP9212|0|16|2|337|475|496|517|538|559|580|601|622|643|664|727|748|769|790
~
#
184|CELL SITE  184|39:45:27|86:22:59|1009
2|80|LPD7905/4-N|0|16|0|346|359|380|401|422
122|80|LPD7905/4-N|0|16|0|350|366|387|408|429|450|471|492|513
242|80|LPD7905/4-N|0|16|0|336|604|625|646|730|751|772|793
~
#
186|CELL SITE  186|39:44:56|86:21:28|1012
2|100|RWA80012|8|16|1|334|361|382|403|424|445|466
122|100|RWA80012|0|16|0|344|368|389|410|431|452|473|494|515
242|100|RWA80012|0|16|2|341|375|396|417|438|459|480|501
~
#
187|CELL SITE  187|39:45:07|86:23:29|1040
2|85|RWA80012|0|16|0|344|355|376|397|418|439
122|85|RWA80012|0|16|1|348|593|614|635|656|719|740|761|782
242|85|RWA80012|0|16|2|353|542|563|584|605|626|647
~
#
188|CELL SITE  188|39:45:31|86:23:24|1042
2|98|RWA8009-OLD|0|16|2|347|505|526|547|568|589|610|631|652
122|98|RWA8009-OLD|0|16|1|335|533|554|575|596|617|638
242|98|RWA8009-OLD|0|16|0|351|540|561|582|603|624|645|666|729|750|771|792
~
#
189|CELL SITE  189|39:46:23|86:24:25|988
2|80|KT740217|0|15.8|0|350|360|381|402|423|444|465
122|80|KT740217|0|15.8|2|342|367|388|409|430|451|472|493
242|80|KT740217|0|15.8|1|354|374|395|416|437|458
~
#
193|CELL SITE  193|39:48:00|86:24:30|898
2|180|ALP8010|0|6.3|1|348|445|466|487|508|529|550|571|592|613|634|655|718|739|760|781
122|180|ALP8010|0|6.3|2|348|473|494|515|536|557|578|599|620|641|662|725|746|767|788
242|180|ALP8010|0|6.3|1|348|396|417|438|459|480|501|522|543|564|585|606|627|648|732|753|774|795
~
#
199|CELL SITE  199|39:54:23|86:26:19|1015
2|140|LPD7905/4-N|0|59.8|0|352|464|485|506|527|548|569|590|611|632|653|737|758|779
122|140|LPD7905/4-N|0|15.8|0|352|513|534|555|576|797|618|639|660|723|744|765|786
242|140|LPD7905/4-N|0|15.8|0|352|373|394|415|436|457|478|499|520|541|562|583|604|625|646|730|751|772
```

~

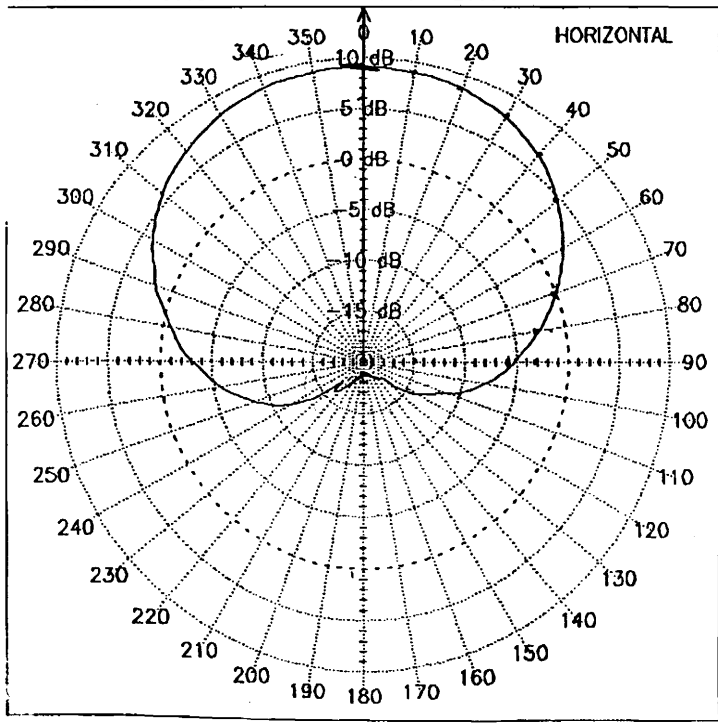
APPENDIX B The Antenna Pattern Database

The sponsor provided a copy of all of the antenna patterns used by the cellular base stations in their current system. Copies of these antenna patterns are provided below. As detailed in Chapter4, the horizontal antenna patterns are modeled as caridiods, and the vertical antenna patterns are modeled as ellipses.

MANF: CELWAVE
NAME: PD10176

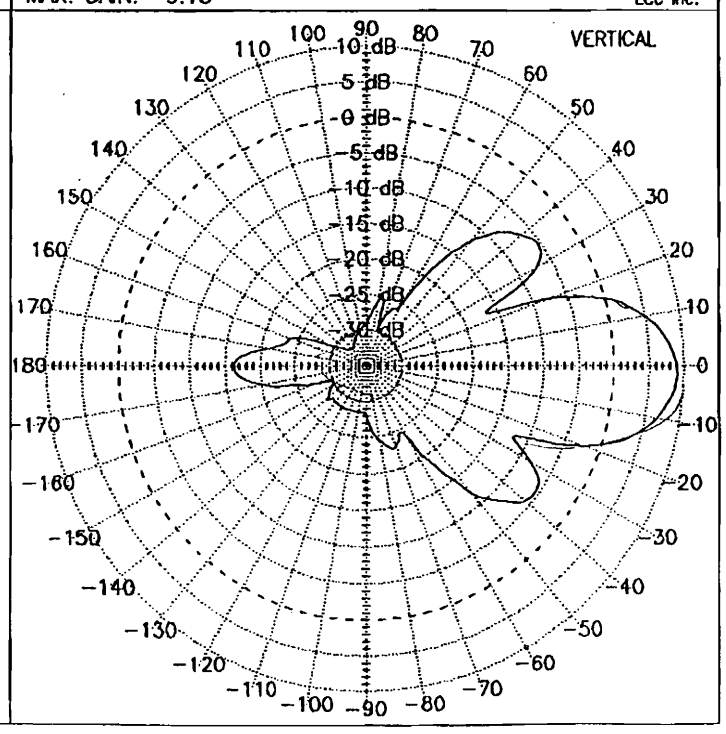
MODEL: PD10176
COV (deg): 100.0
MOUNT:
Tilt Angle: 0
Tilt Type:

MAX. GAIN: 9.10 F-B: 27.86



MAX. GAIN: 9.13

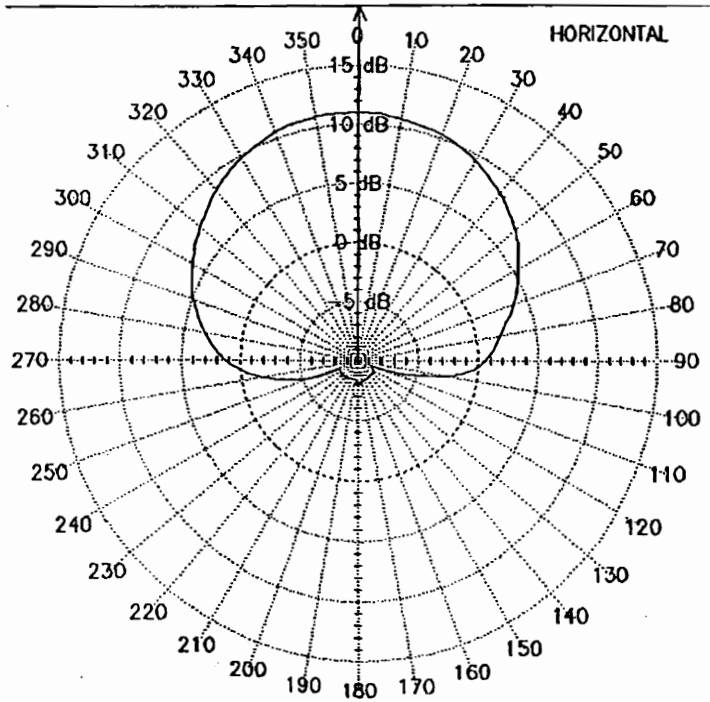
LCC Inc.



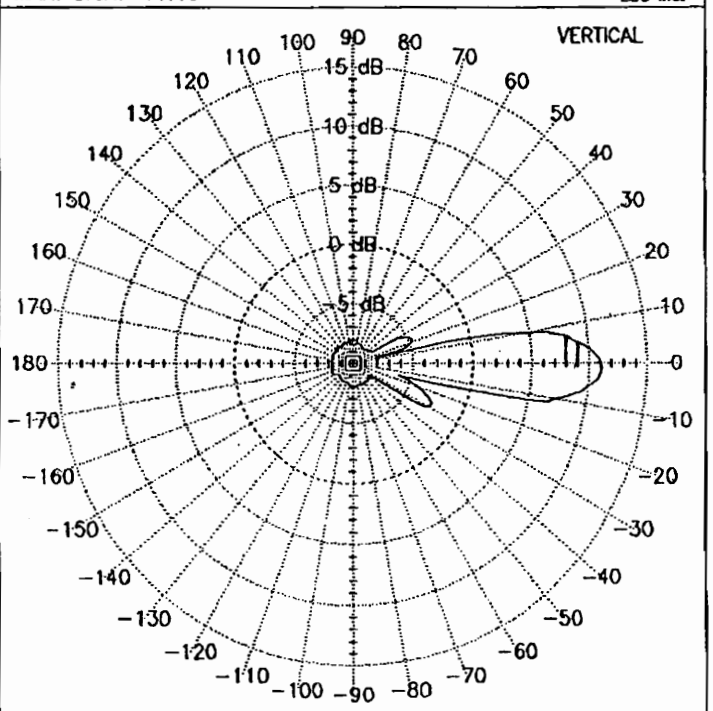
P.03 404 847 3315 BMI NETWORK-REGION 2 JUN-23-1993 02:22

MANF: ANTEL
NAME: LPD7905/4-N
LPD7905/4
MODEL: LPD7905/4
COV (deg):092.0
MOUNT:
Tilt Angle: 0
Tilt Type:

MAX. GAIN: 11.00 F-B: 19.01



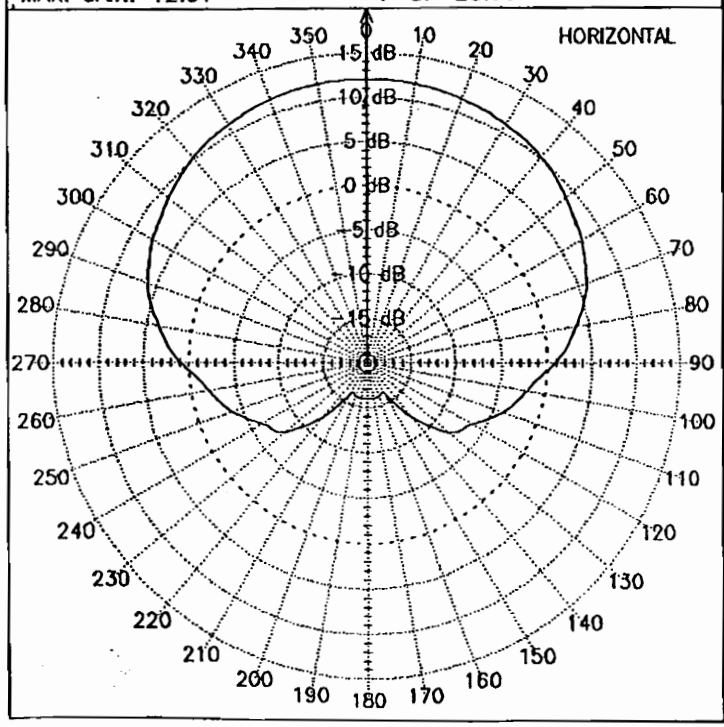
MAX. GAIN: 11.10 LCC Inc.



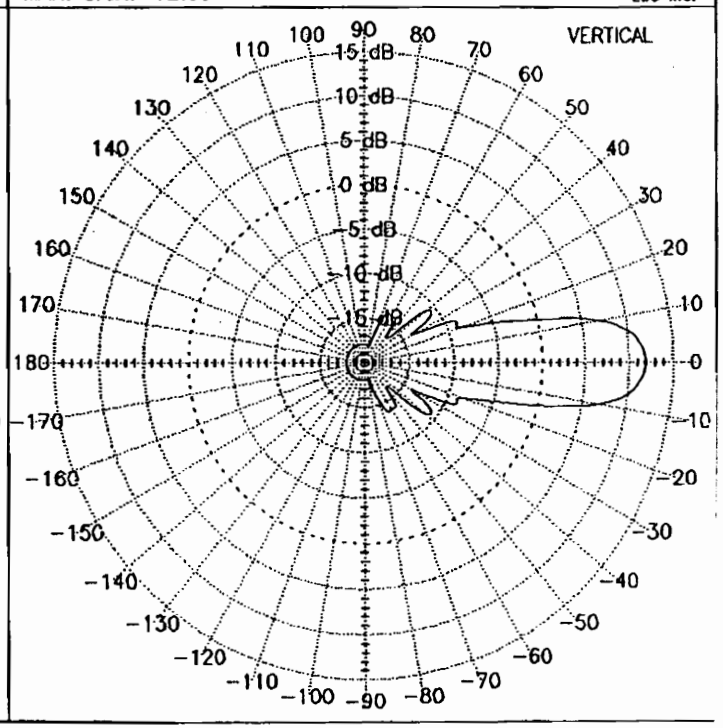
MANF: SWEDCOM
NAME: ALP9212

MODEL: ALP9212
COV (deg):092.0
MOUNT:
Tilt Angle: 0
Tilt Type:

MAX. GAIN: 12.01 F-B: 28.00



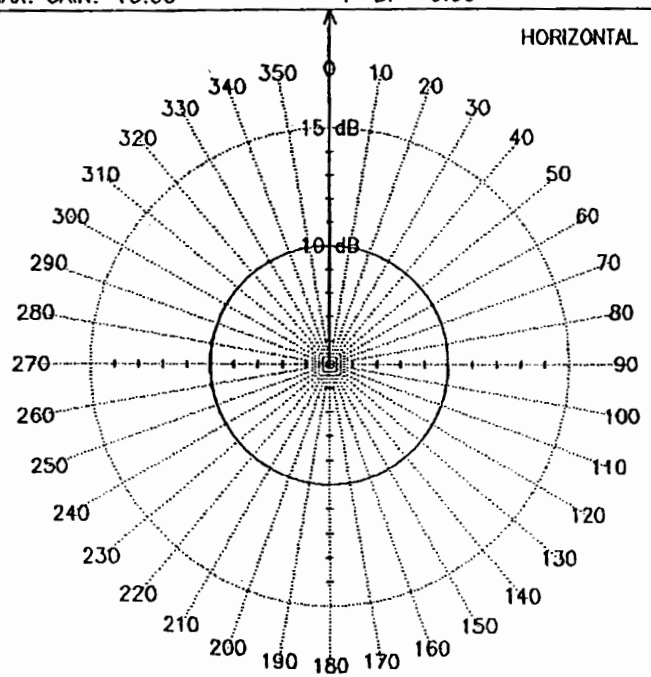
MAX. GAIN: 12.00 LCC Inc.



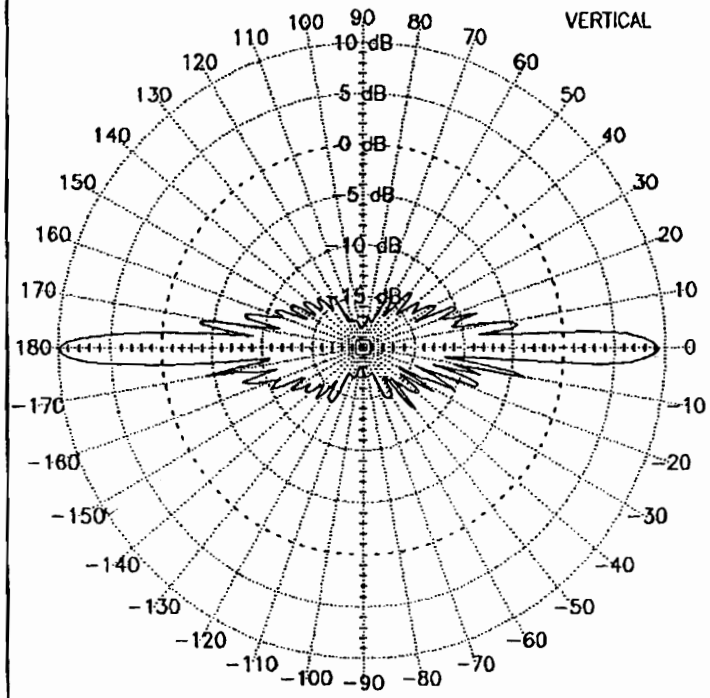
MANF: DECIBEL PRODUCTS, INC.
NAME: DB810

MODEL:
COV (deg):000.0
MOUNT:
Tilt Angle: 0
Tilt Type:

MAX. GAIN: 10.00 F-B: 0.00

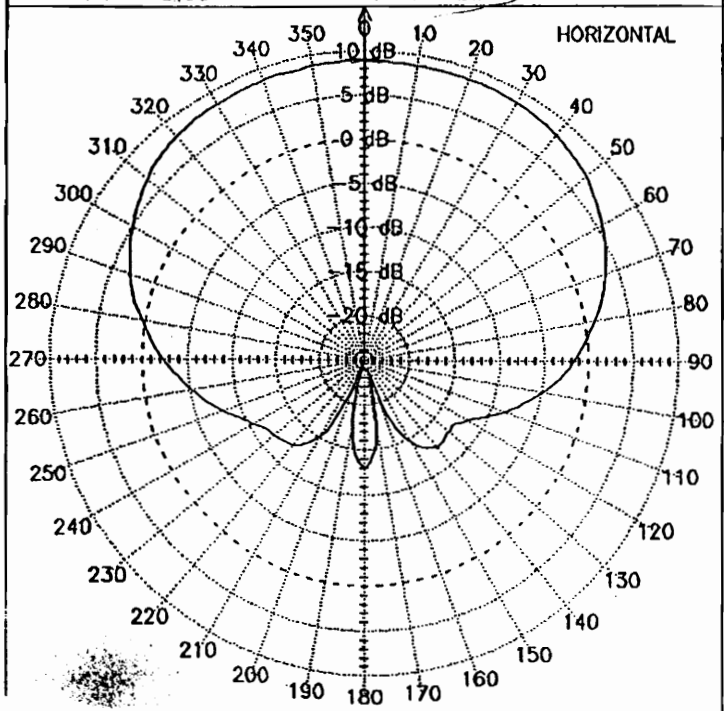


MAX. GAIN: 9.80 LCC Inc.



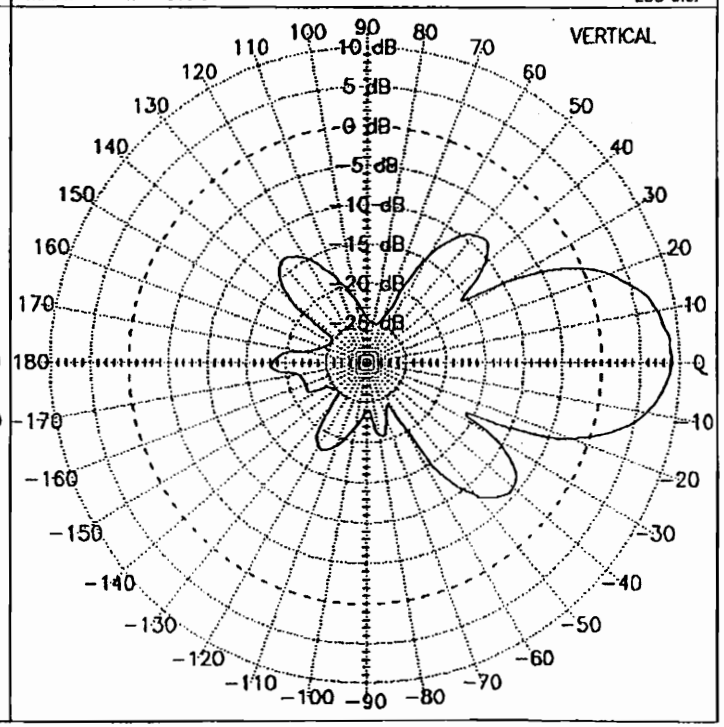
MANF: Celwave
NAME: PD1251
MODEL: PD1251
COV (deg): 105.0
MOUNT:
Tilt Angle: 0
Tilt Type:

MAX. GAIN: 9.00 (F-B: 22.14)



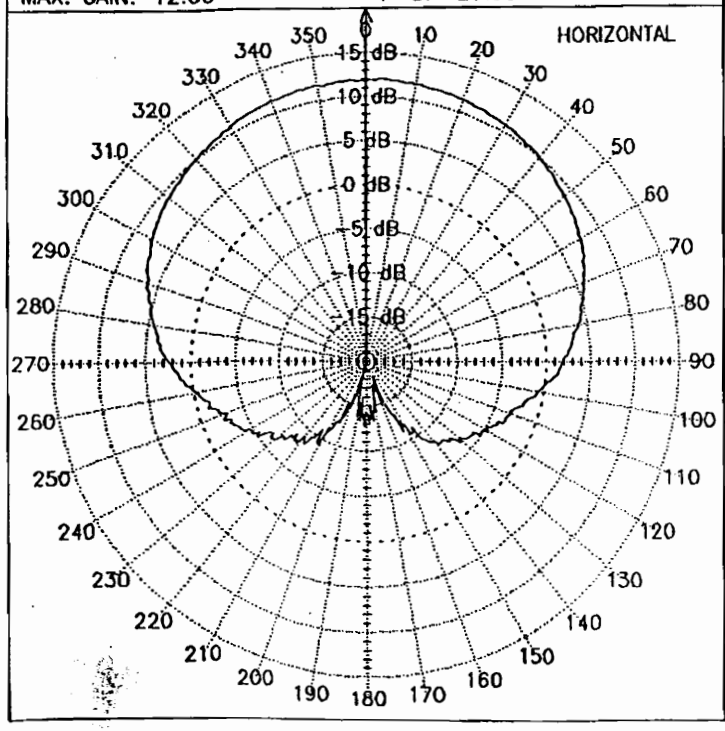
MAX. GAIN: 9.00

LCC Inc.

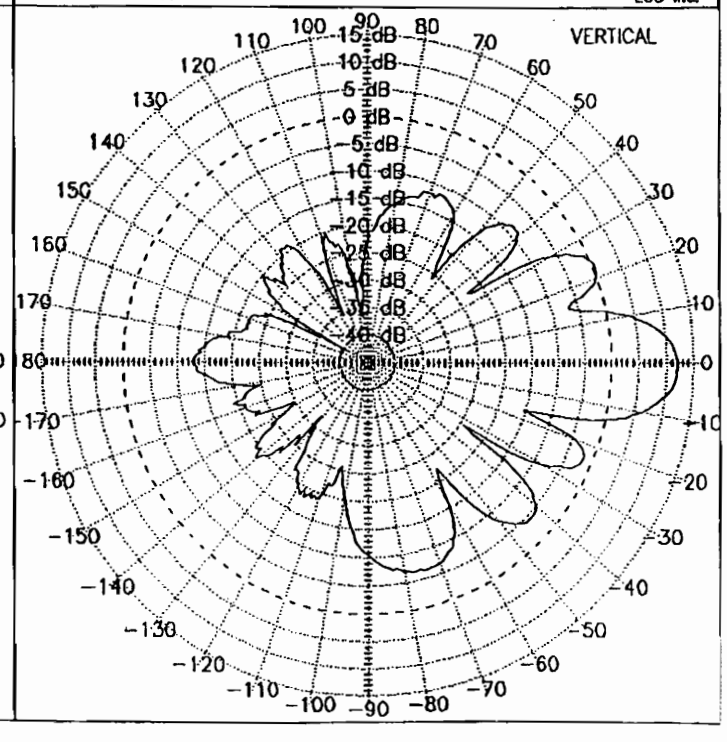


MANF: ANTELNINTL INC (815) 399 0001
NAME: RWA 80012
12 dBd SECTOR PANEL, 800-960 MHz
MODEL: RWA 80012
COV (deg): 102.0
MOUNT: SIDE
Tilt Angle: 0
Tilt Type:

MAX. GAIN: 12.00 F-B: 25.90

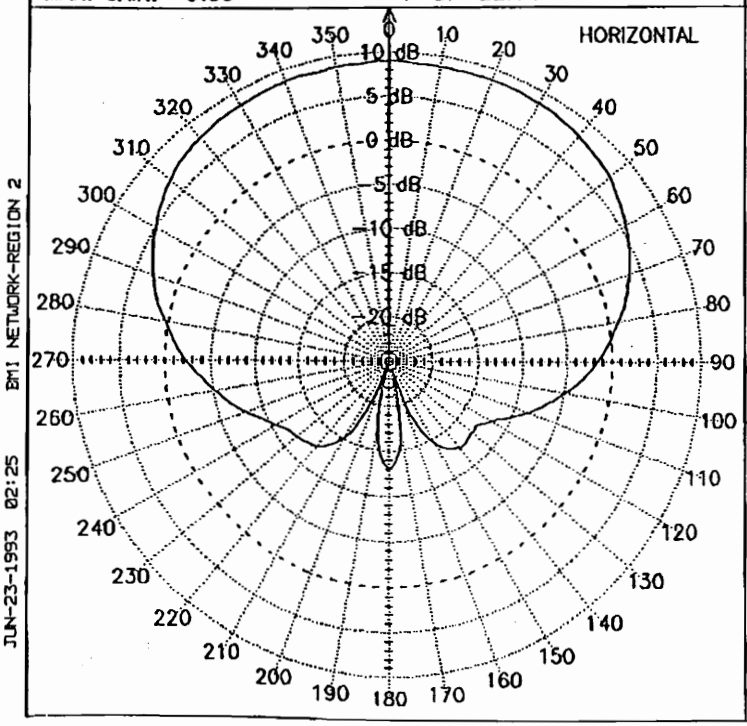


MAX. GAIN: 12.00 LCC Inc.

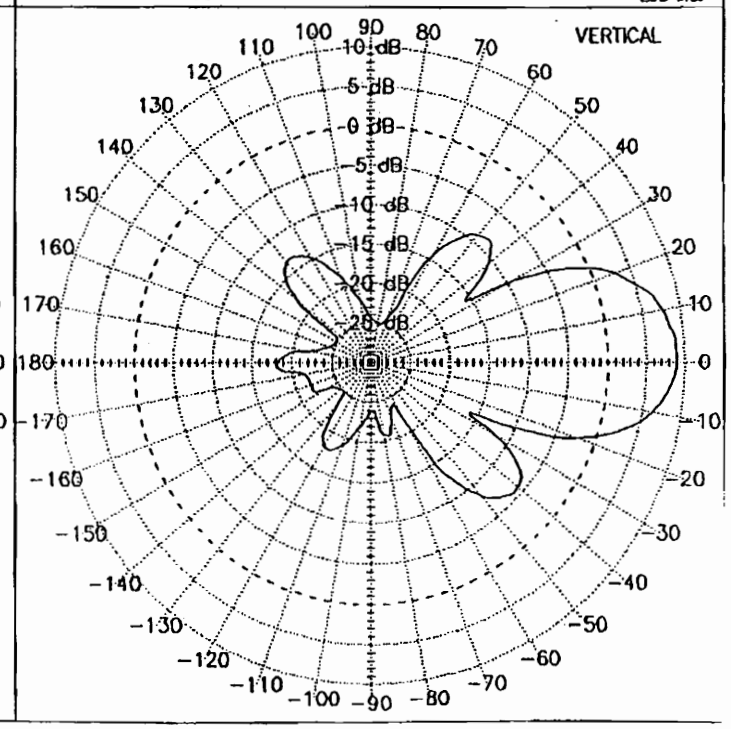


MANF: DECIBEL
NAME: DB-833
MODEL: DB-833
COV (deg): 105.0
MOUNT:
Tilt Angle: 0
Tilt Type:

MAX. GAIN: 9.00 F-B: 22.14



MAX. GAIN: 9.00 LCC Inc.

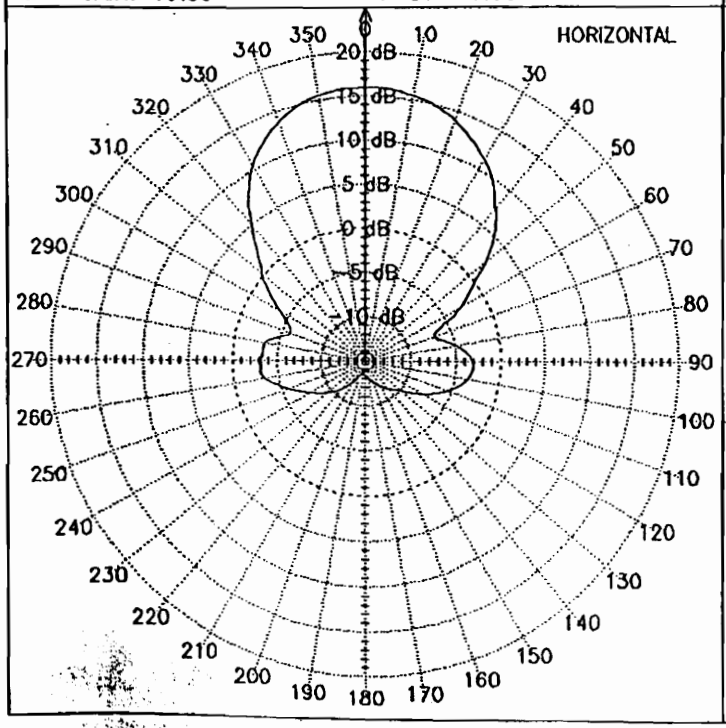


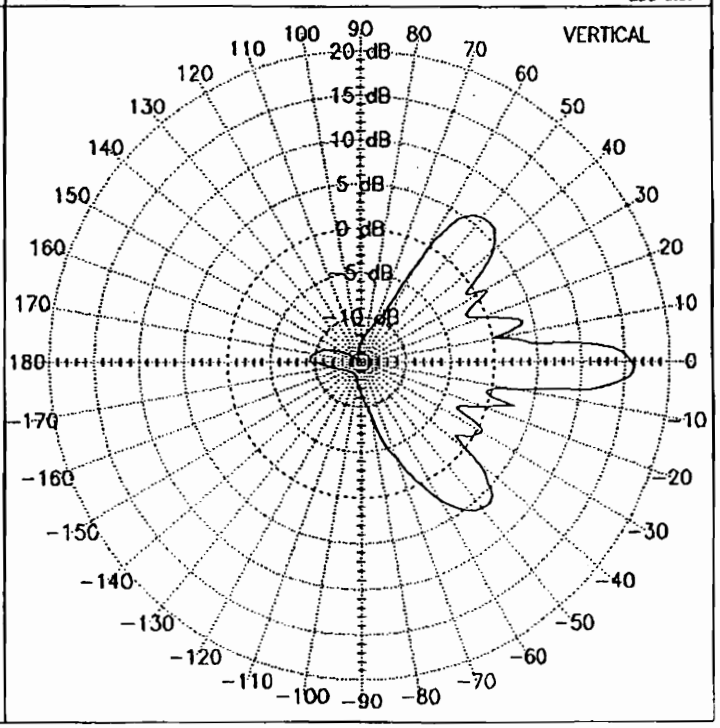
MANF: KATHREIN
NAME: KT740215

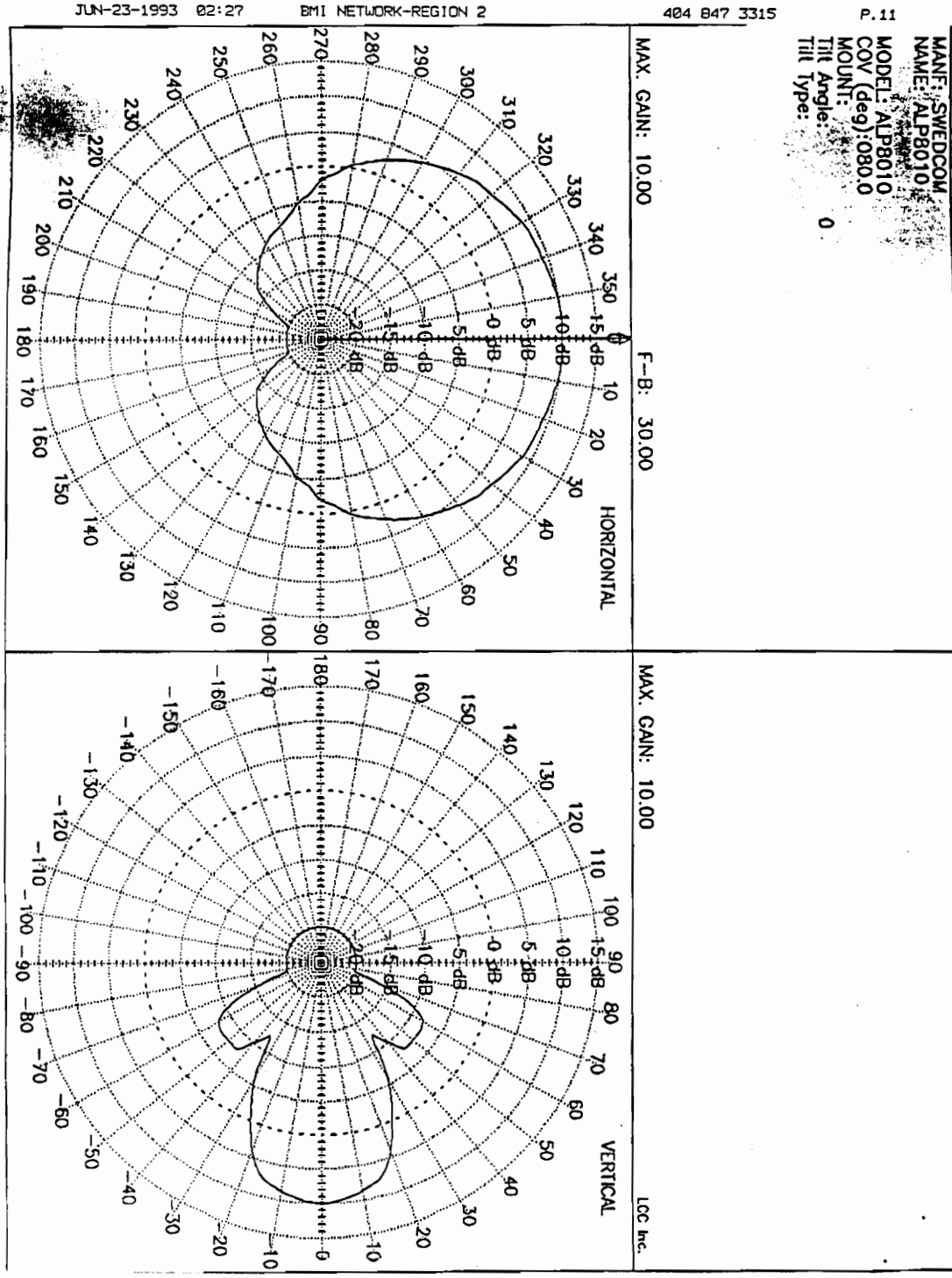
MODEL: KT740215
COV (deg):048.0
MOUNT:
Tilt Angle: 0
Tilt Type:

MAX. GAIN: 16.00 F-B: 29.35

MAX. GAIN: 15.98 LCC Inc.

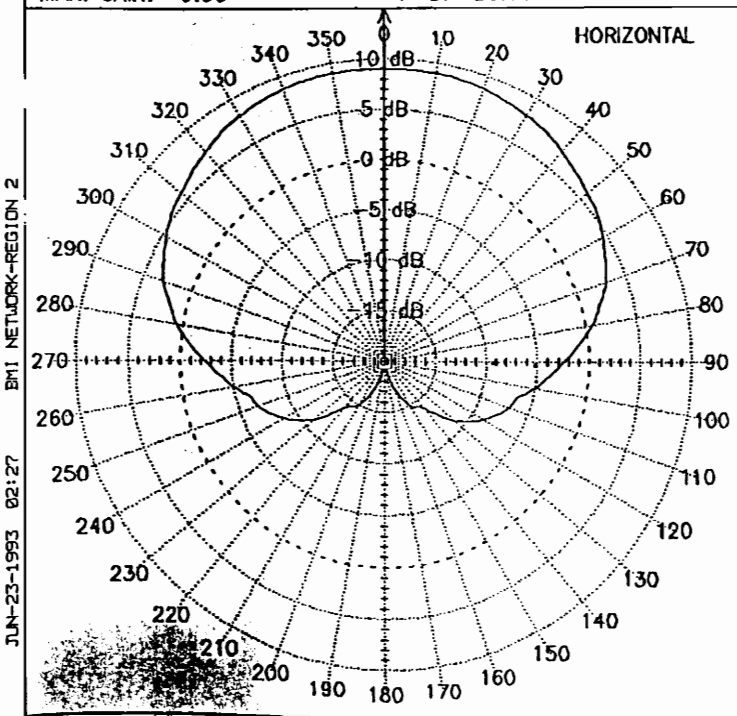




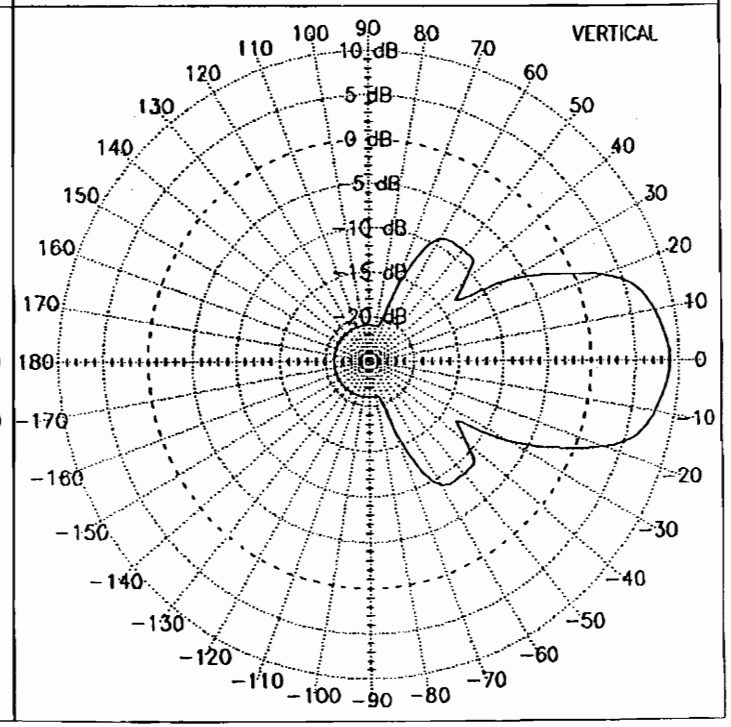

MANF: SWEDCOM
NAME: ALP8010
MODEL: ALP8010
COV (deg):080.0
MOUNT:
Tilt Angle: 0
Tilt Type:
MAX. GAIN: 10.00
F-B: 30.00
HORIZONTAL
MAX. GAIN: 10.00
VERTICAL
LCC Inc.

MANF: SWEDCOM
NAME: ALP9209
MODEL: ALP9209
COV (deg): 092.0
MOUNT:
Tilt Angle: 0
Tilt Type:

MAX. GAIN: 9.00 F-B: 28.00

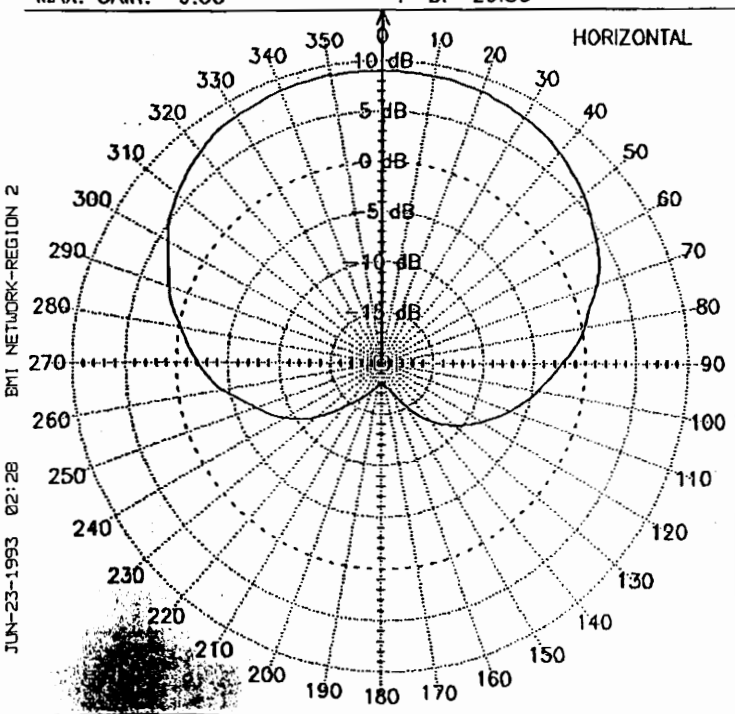


MAX. GAIN: 9.00 LCC Inc.



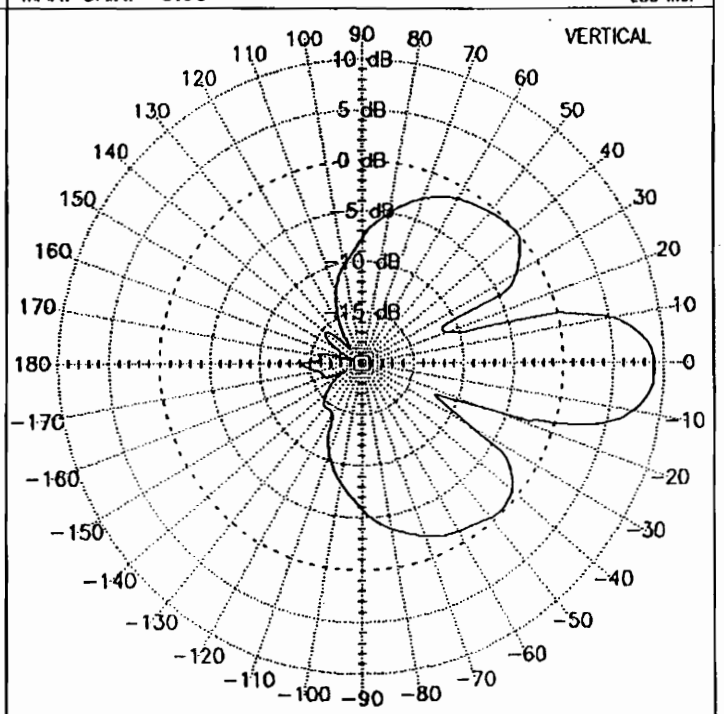
MANF: KATHREIN
NAME: KT740217
MODEL: KT740217
COV (deg): 105.0
MOUNT:
Tilt Angle: 0
Tilt Type:

MAX. GAIN: 9.00 F-B: 26.80



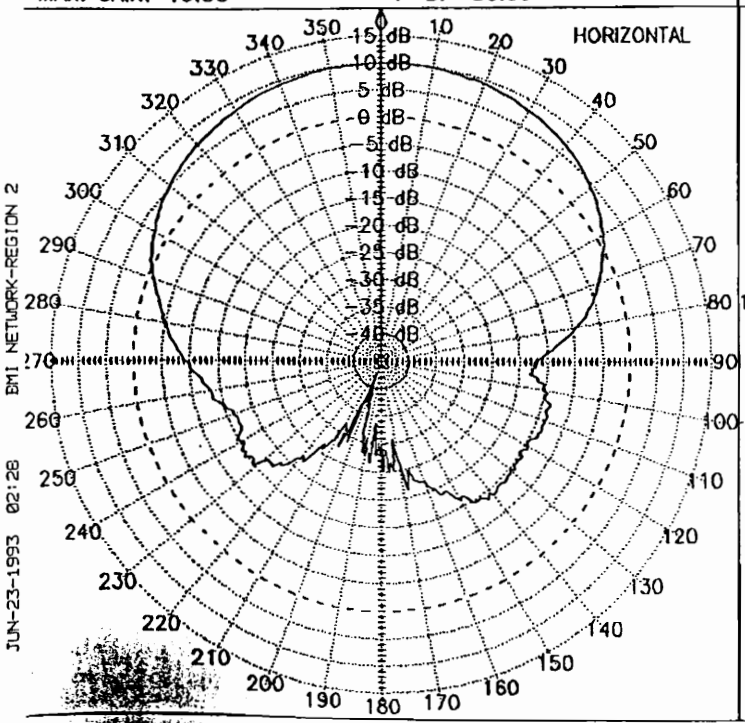
MAX. GAIN: 9.00

LCC Inc.

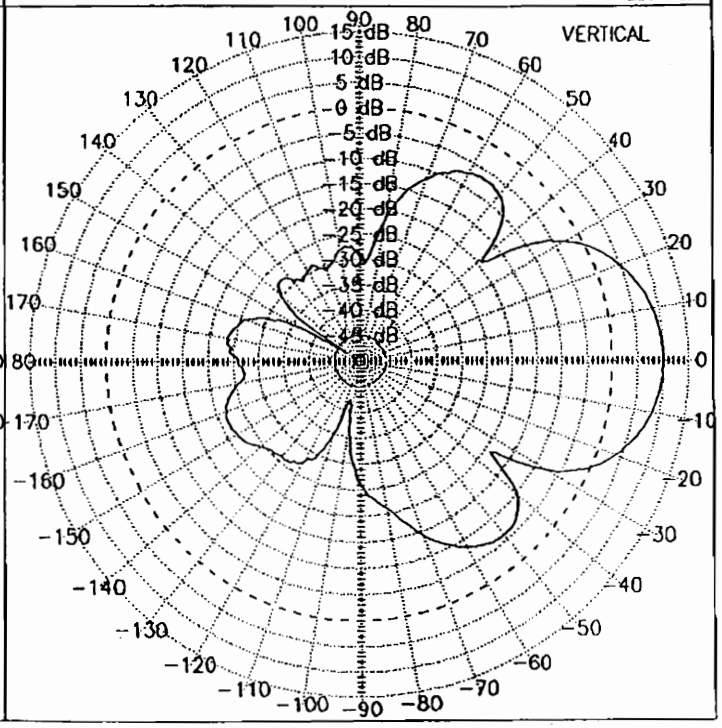


MANF: ANTEL INT'L INC (815) 399 0001
NAME: LPD 7907/2
10 dBd SECTOR 790-960 MHz
MODEL: LPD 7907/2
COV (deg):080.0
MOUNT: SIDE
Tilt Angle: 0
Tilt Type:

MAX. GAIN: 10.00 F-B: 39.90

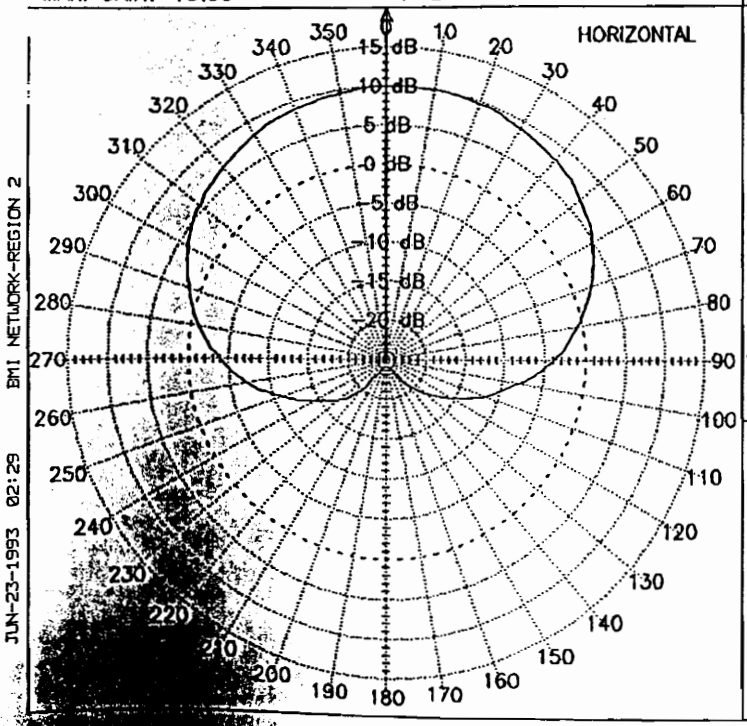


MAX. GAIN: 10.00 LCC Inc.



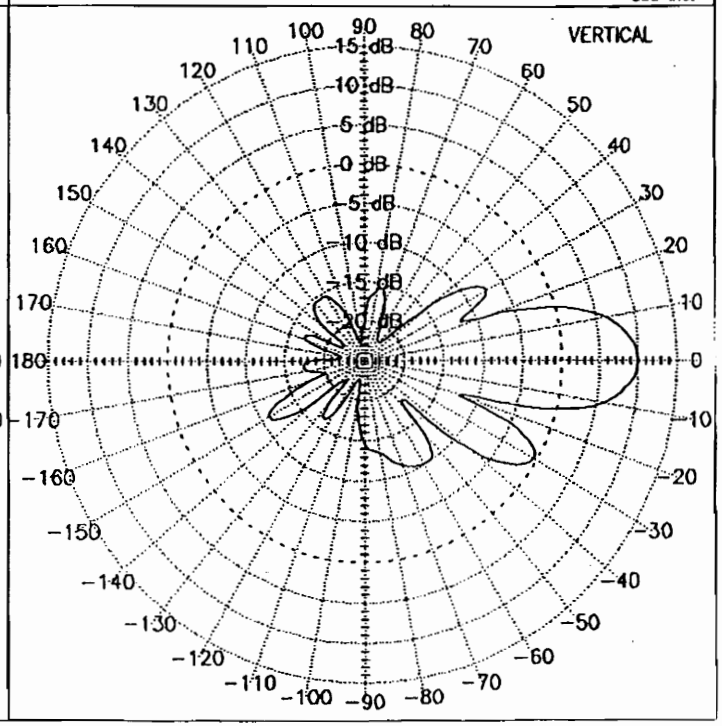
MANF: DECIBEL
NAME: DB834
MODEL: DB834
COV (deg): 105.0
MOUNT:
Tilt Angle: 0
Tilt Type:

MAX. GAIN: 10.00 F-B: 34.02



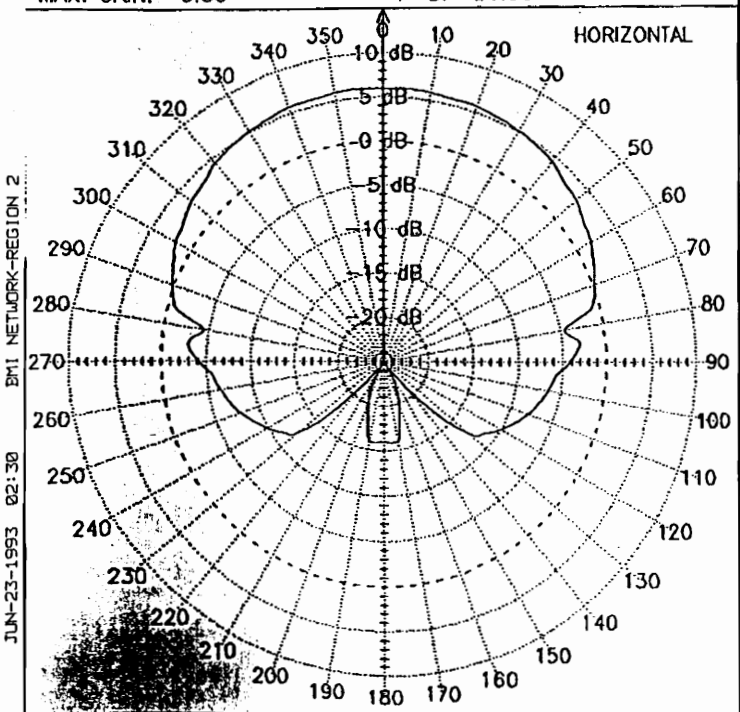
MAX. GAIN: 10.00

LCC Inc.

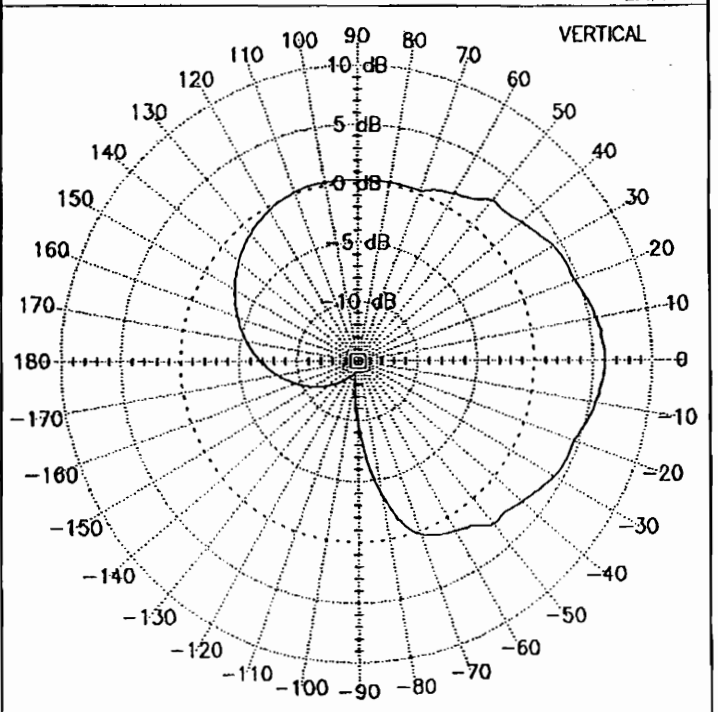


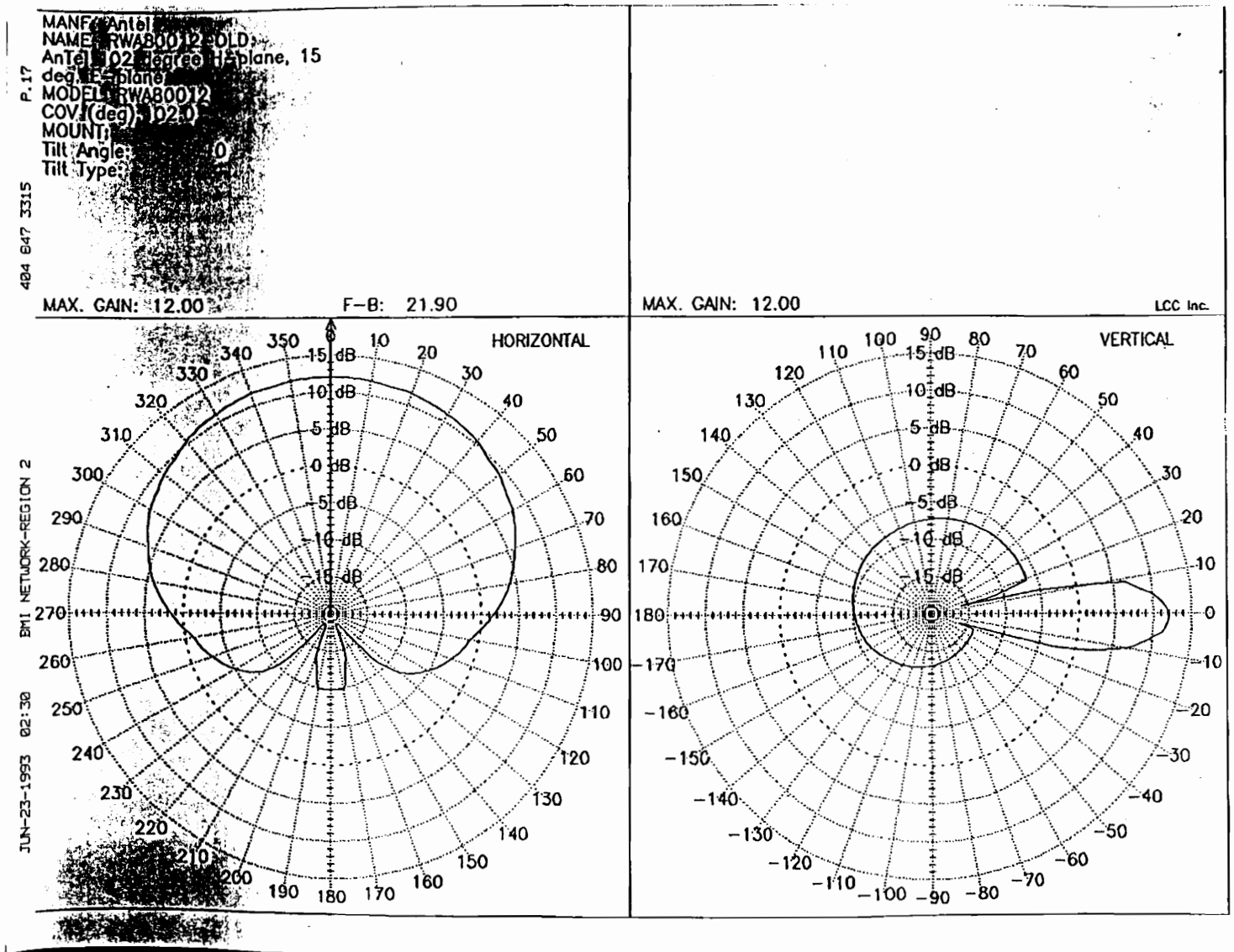
MANF: Antel
NAME: RWA8006-OLD
Antel 6 dB Gain, 102 degree wide
H-plane, 156 degree E-plane.
MODEL:
COV (deg): 102.0
MOUNT:
Tilt Angle: 0
Tilt Type:

MAX. GAIN: 6.00 F-B: 21.90



MAX. GAIN: 6.00 LCC Inc.

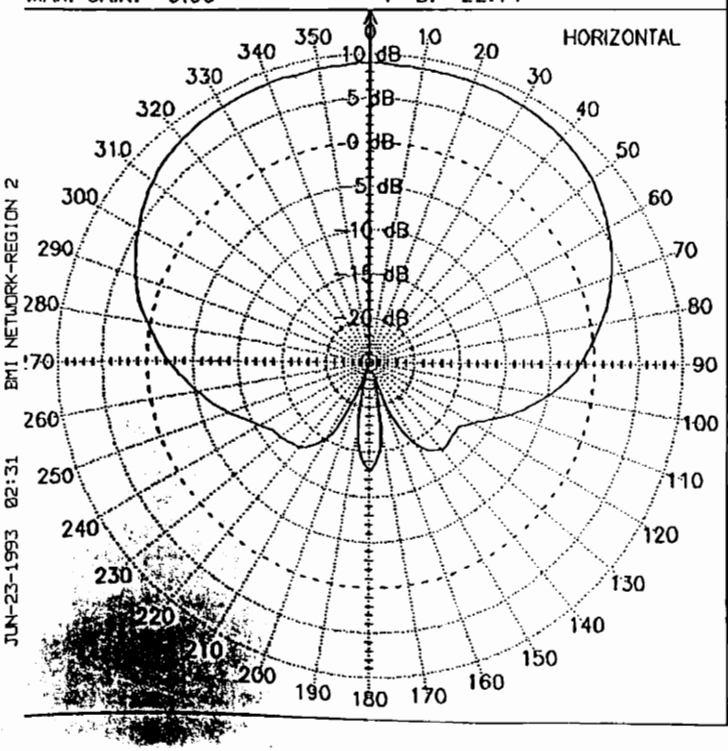



MANF: [redacted]
NAME: RWA80012 OLD
AnTel: 102 degree H-plane, 15
deg. E-plane
MODEL: RWA80012
COV.(deg): 102.0
MOUNT:
Tilt Angle: 0
Tilt Type:
MAX. GAIN: 12.00
F-B: 21.90
HORIZONTAL
MAX. GAIN: 12.00
LCC Inc.
VERTICAL
15 dB
10 dB
5 dB
0 dB
-5 dB
-10 dB
-15 dB
P.17
404 847 3315
BMI NETWORK-REGION 2
JUN-23-1993 02:30

MANF: ANTEL
NAME: RWA8009-OLD

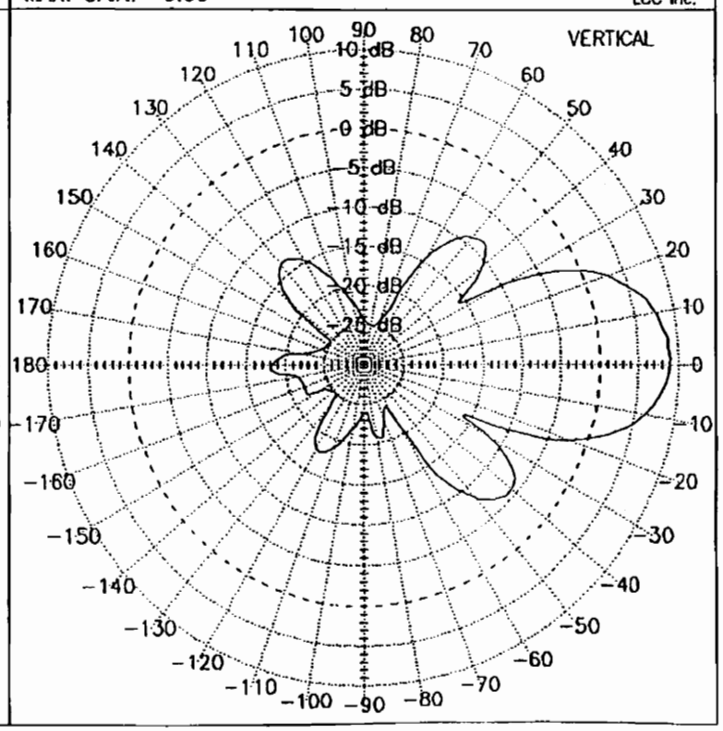
MODEL: RWA8009
COV (deg): 105.0
MOUNT:
Till Angle: 0
Till Type:

MAX. GAIN: 9.00 F-B: 22.14



MAX. GAIN: 9.00

LCC Inc.

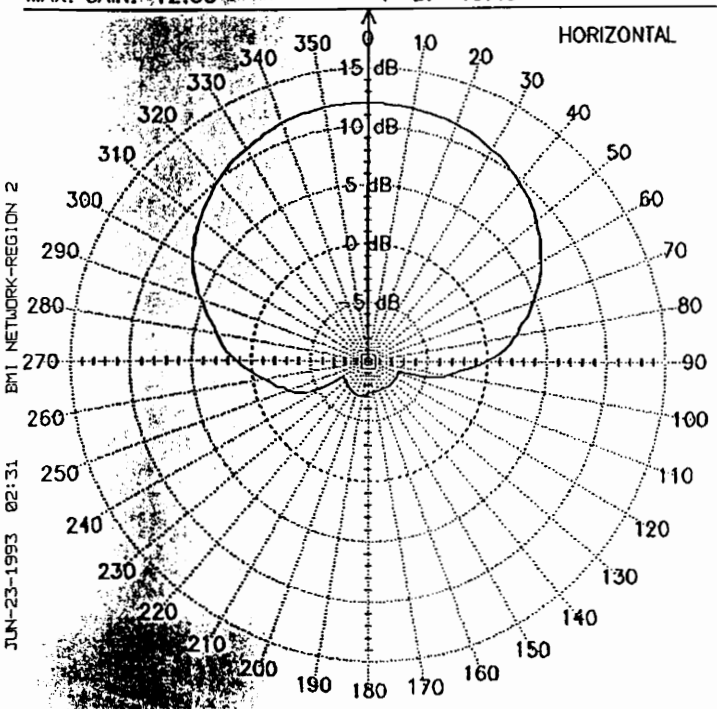


404 847 3315 P.18

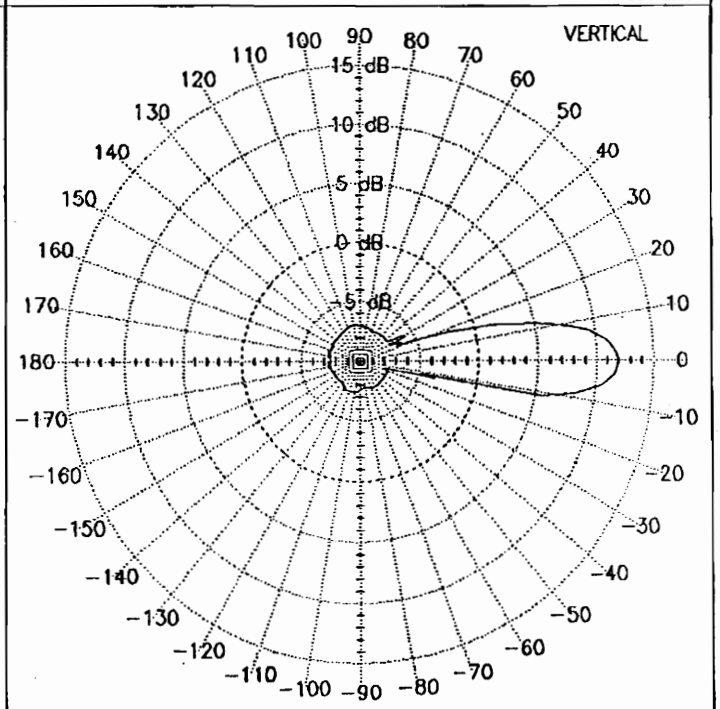
JUN-23-1993 02:31 BMI NETWORK-REGION 2

MANF: SWEDCOM
NAME: ALP 9212 N
MODEL:
COV.(deg): 095.0
MOUNT:
Tilt Angle: 0
Tilt Type:

MAX. GAIN: 12.00 F-B: 19.40



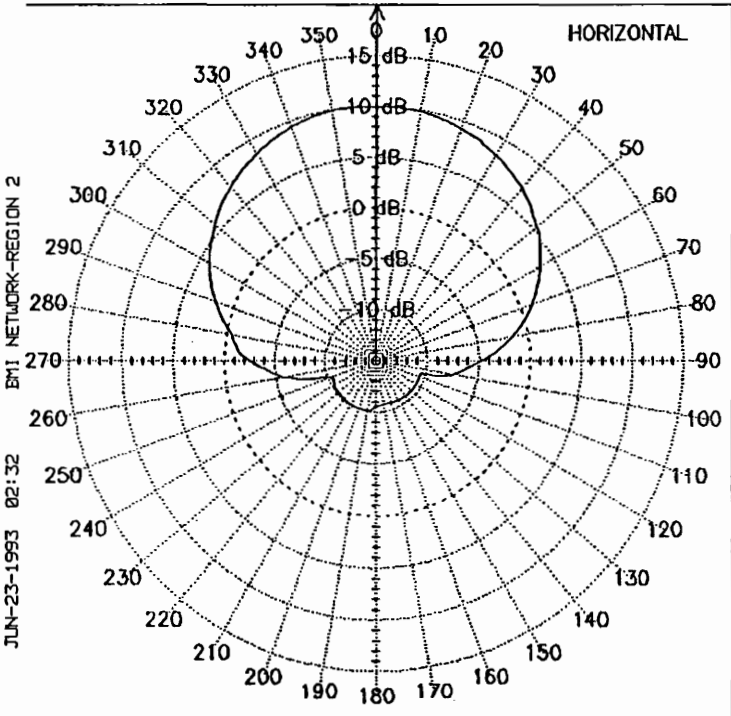
MAX. GAIN: 12.01 LCC Inc.



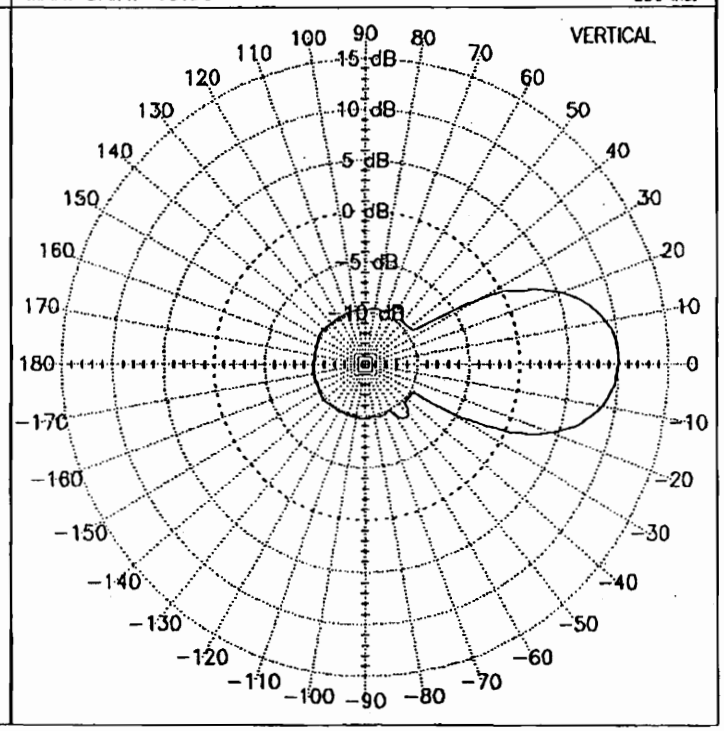
MANF: SWEDCOM
NAME: ALP 8010-N

MODEL:
COV (deg):084.0
MOUNT:
Tilt Angle: 0
Tilt Type:

MAX. GAIN: 10.00 F-B: 20.50



MAX. GAIN: 10.00 LCC Inc.



APPENDIX C The Channel Availability Statistics for the Current Cellular System

Channel Availability Statistics For the Building Under Study Based on a Signal Threshold of -95 dBm

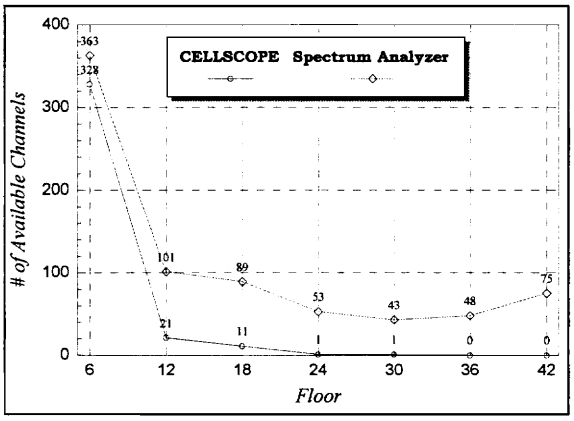


Figure 0-1: Number of Channels Available by Floor On the North Face of the Building Using a Threshold of -95 dBm

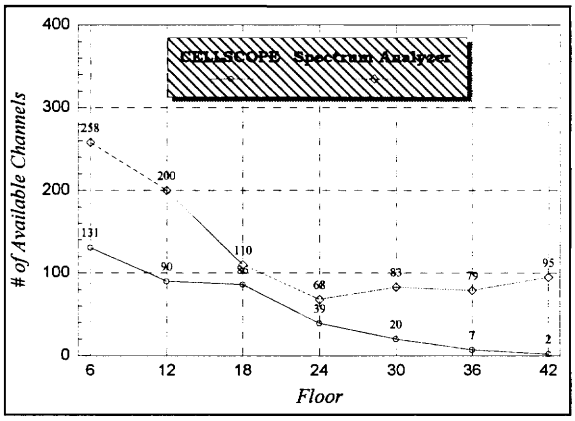


Figure 0-2: Number of Channels Available by Floor On the South Face of the Building Using a Threshold of -95 dBm

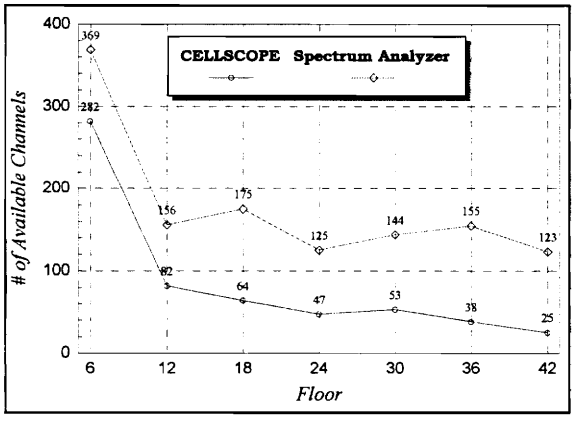


Figure 0-3: Number of Channels Available by Floor On the East Face of the Building Using a Threshold of -95 dBm

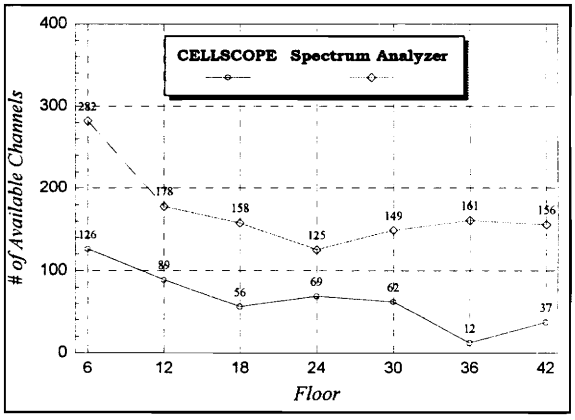


Figure 0-4: Number of Channels Available by Floor On the West Face of the Building Using a Threshold of -95 dBm

Table 0-1: Number of Channels Available By Floor and Location For the Building Under Study Using a Threshold of -95 dBm

	Number of Available Channels (Threshold of -95 dBm)							
	Using CELLSCOPE				Using Spectrum Analyzer			
Floor	North Face	South Face	East Face	West Face	North Face	South Face	East Face	West Face
6	342	157	307	156	371	277	382	299
12	31	111	45	111	127	229	176	199
18	15	100	86	71	111	139	189	178
24	3	51	68	83	70	85	148	145
30	2	30	71	84	68	109	170	182
36	1	12	55	22	66	99	176	179
42	0	6	36	48	102	122	149	182

Channel Availability Statistics For the Building Under Study Based on a Signal Threshold of -90 dBm

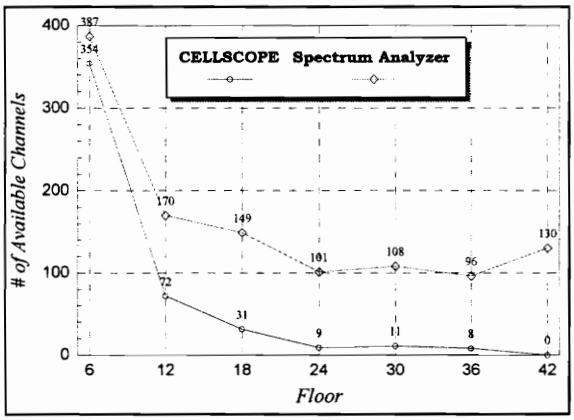


Figure 0-1: Number of Channels Available by Floor On the North Face of the Building Using a Threshold of -90 dBm

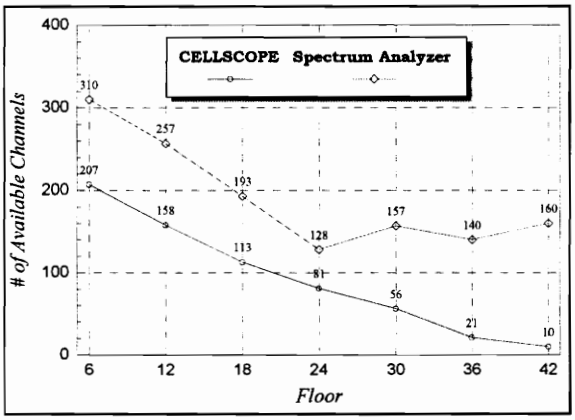


Figure 0-2: Number of Channels Available by Floor On the South Face of the Building Using a Threshold of -90 dBm

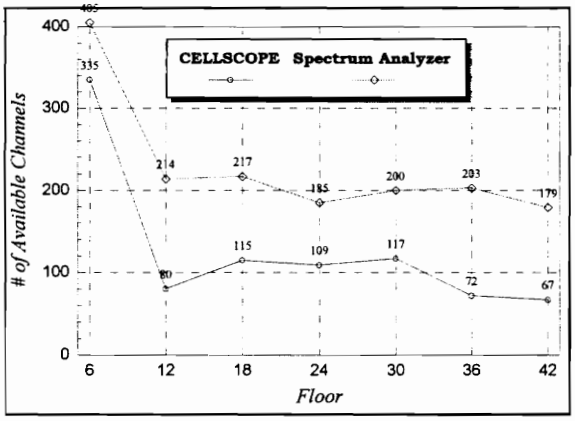


Figure 0-3: Number of Channels Available by Floor On the East Face of the Building Using a Threshold of -90 dBm

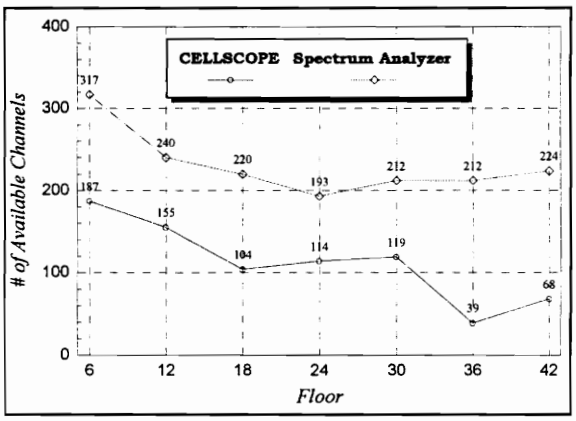


Figure 0-4: Number of Channels Available by Floor On the West Face of the Building Using a Threshold of -90 dBm

Table 0-2: Number of Channels Available By Floor and Location For the Building Under Study Using a Threshold of -90 dBm

	Number of Available Channels (Threshold of -90 dBm)							
	Using CELLSCOPE				Using Spectrum Analyzer			
Floor	North Face	South Face	East Face	West Face	Nort Face	South Face	East Face	West Face
6	354	207	335	187	387	310	405	317
12	72	158	80	155	170	257	214	240
18	31	113	115	104	149	193	217	220
24	9	81	109	114	101	128	185	193
30	11	56	117	119	108	157	200	212
36	8	21	72	39	96	140	203	212
42	0	10	67	68	130	160	179	224

Channel Availability Statistics For the Building Under Study Based on a Signal Threshold of -85 dBm

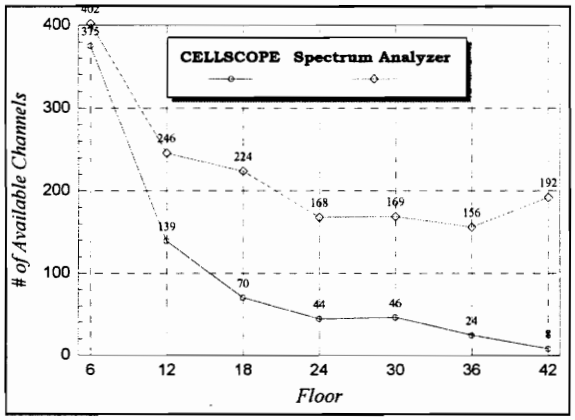


Figure 0-1: Number of Channels Available by Floor On the North Face of the Building Using a Threshold of -85 dBm

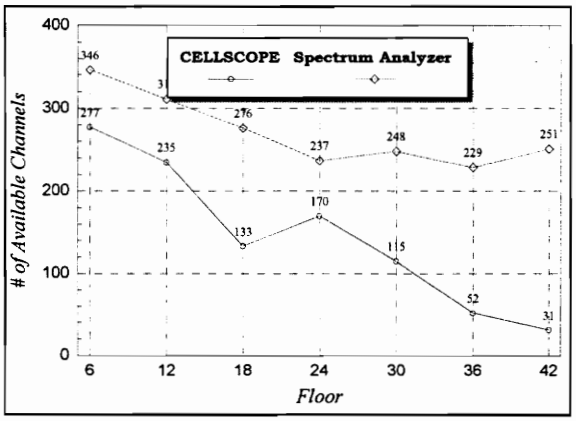


Figure 0-2: Number of Channels Available by Floor On the South Face of the Building Using a Threshold of -85 dBm

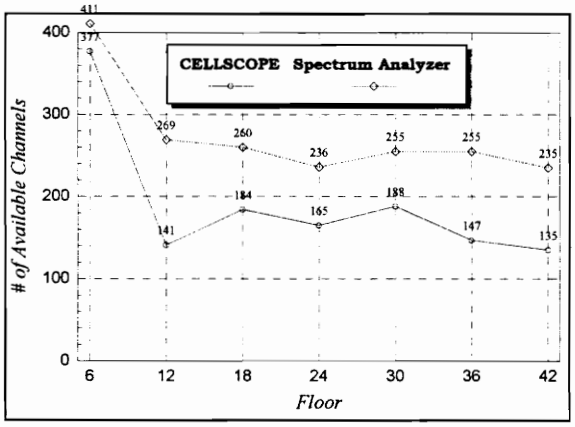


Figure 0-3: Number of Channels Available by Floor On the East Face of the Building Using a Threshold of -85 dBm

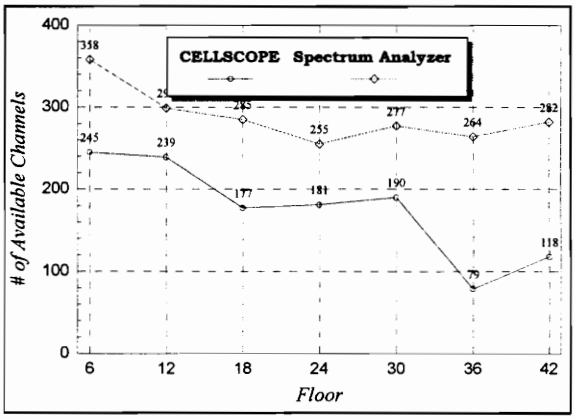


Figure 0-4: Number of Channels Available by Floor On the West Face of the Building Using a Threshold of -85 dBm

Table 0-3: Number of Channels Available By Floor and Location For the Building Under Study Using a Threshold of -85 dBm

	Number of Available Channels (threshold of -85 dBm)							
	Using CELLSCOPE				Using Spectrum Analyzer			
Floor	North Face	South Face	East Face	West Face	Nort Face	South Face	East Face	West Face
6	375	277	377	245	402	346	411	358
12	139	235	141	239	246	311	269	299
18	70	133	184	177	224	276	260	285
24	44	170	165	181	168	237	236	255
30	46	115	188	190	169	248	255	277
36	24	52	147	79	156	229	255	264
42	8	31	135	118	192	251	235	282

Channel Availability Statistics For the Building Under Study Based on a Signal Threshold of -80 dBm

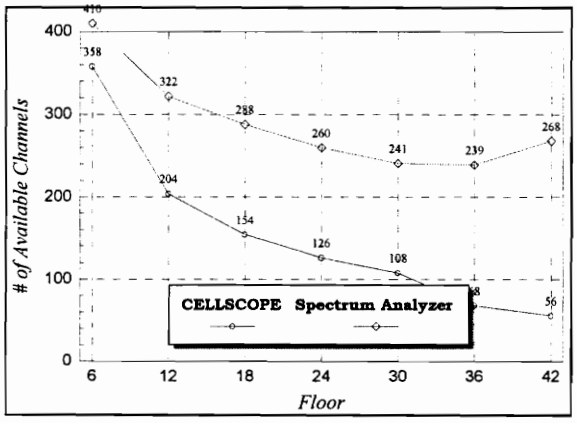


Figure 0-1: Number of Channels Available by Floor On the North Face of the Building Using a Threshold of -80 dBm

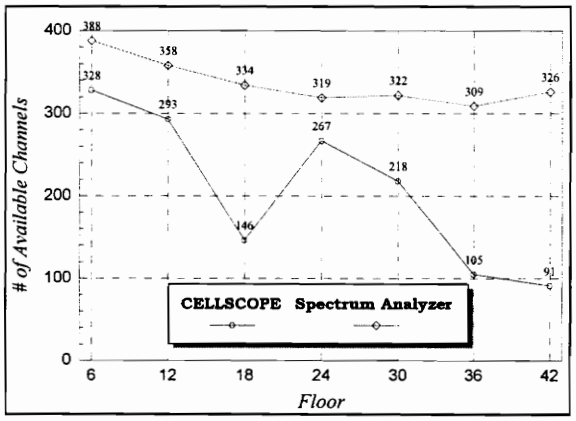


Figure 0-2: Number of Channels Available by Floor On the South Face of the Building Using a Threshold of -80 dBm

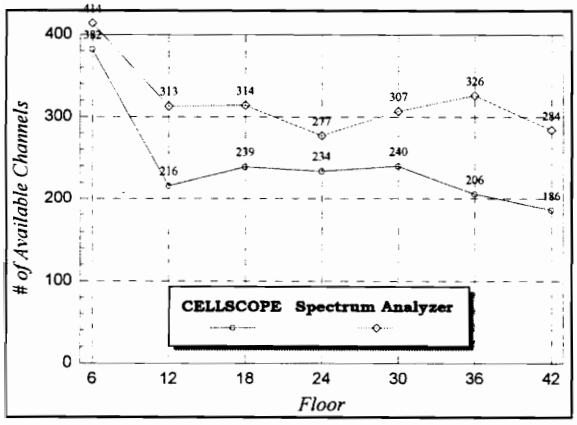


Figure 0-3: Number of Channels Available by Floor On the East Face of the Building Using a Threshold of -80 dBm

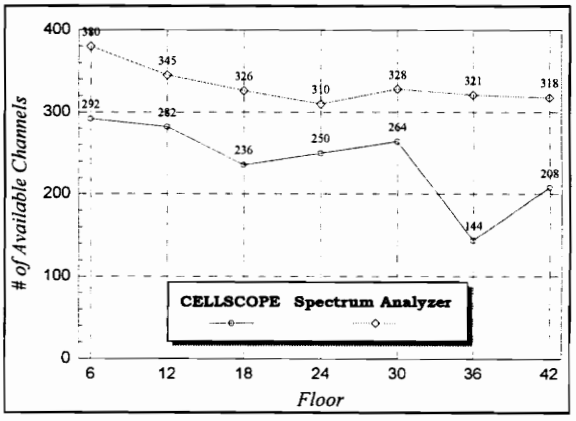


Figure 0-4: Number of Channels Available by Floor On the West Face of the Building Using a Threshold of -80 dBm

Table 0-4: Number of Channels Available By Floor and Location For the Building Under Study Using a Threshold of -80 dBm

	Number of Available Channels (Theshold of -80 dBm)							
	Using CELLSCOPE				Using Spectrum Analyzer			
Floor	North Face	South Face	East Face	West Face	Nort Face	South Face	East Face	West Face
6	388	328	392	292	410	388	414	380
12	204	293	216	282	322	358	313	345
18	154	146	239	236	288	334	314	326
24	126	267	234	250	260	319	277	310
30	108	218	240	264	241	322	307	328
36	68	105	206	144	239	309	326	321
42	56	91	186	208	268	326	284	318

APPENDIX D The Simulation Log File

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page   1)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  0  Month:  3
  Total number of cells       :159
  Total number of subscribers :18145
  Grade of service in all cells  : Mean:  2.59%, Sigma:  0.0029
  Number of subscribers per cell : Mean:    116, Sigma: 69.5569

=>Grade of service calculated for all cells and documented in GOS1_001.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
  No cells need to be split.

=>Grade of service calculated for all cells and documented in GOS2_001.

=>Cellular system snapshot saved in SYS_001.BIN.

=>Cellsite Database saved in CELLS001.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page   2)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  0  Month:  6
  Total number of cells       :159
  Total number of subscribers :19234
  Grade of service in all cells  : Mean:  3.39%, Sigma:  0.0073
  Number of subscribers per cell : Mean:    123, Sigma: 74.2489

=>Grade of service calculated for all cells and documented in GOS1_002.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
Cell #110( 1), Cell #147( 1), Cell #152( 1), Cell #193( 1),

=>All required cell splits completed.

Results of cell splitting:
Cell #110( 1) split into Cell #200( 2), Cell #201( 2), Cell #202( 2), Cell #203( 2)
Cell #147( 1) split into Cell #204( 2), Cell #205( 2), Cell #206( 2), Cell #207( 2)
Cell #152( 1) split into Cell #208( 2), Cell #209( 2), Cell #210( 2), Cell #211( 2)
Cell #193( 1) split into Cell #212( 2), Cell #213( 2), Cell #214( 2), Cell #215( 2)

=>Grade of service calculated for all cells and documented in GOS2_002.

=>Cellular system snapshot saved in SYS_002.BIN.

=>Cellsite Database saved in CELLS002.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page   3)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  0  Month:  9
  Total number of cells       :163
  Total number of subscribers :20371
  Grade of service in all cells  : Mean:  3.72%, Sigma:  0.0153
  Number of subscribers per cell : Mean:    127, Sigma: 69.0240

=>Grade of service calculated for all cells and documented in GOS1_003.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
Cell # 35( 1), Cell #103( 1), Cell #112( 1), Cell #132( 1), Cell #133( 1),
Cell #149( 1), Cell #162( 1), Cell #180( 1), Cell #184( 1), Cell #186( 1),
Cell #187( 1), Cell #188( 1), Cell #189( 1),

=>All required cell splits completed.

Results of cell splitting:
Cell #35( 1) split into Cell #216( 2), Cell #217( 2), Cell #218( 2), Cell #219( 2)
Cell #103( 1) split into Cell #220( 2), Cell #221( 2), Cell #222( 2), Cell #223( 2)
Cell #112( 1) split into Cell #224( 2), Cell #225( 2), Cell #226( 2), Cell #227( 2)
Cell #132( 1) split into Cell #228( 2), Cell #229( 2), Cell #230( 2), Cell #231( 2)
Cell #133( 1) split into Cell #232( 2), Cell #233( 2), Cell #234( 2), Cell #235( 2)
Cell #149( 1) split into Cell #236( 2), Cell #237( 2), Cell #238( 2), Cell #239( 2)
Cell #162( 1) split into Cell #240( 2), Cell #241( 2), Cell #242( 2), Cell #243( 2)

=>Grade of service calculated for all cells and documented in GOS2_003.

=>Cellular system snapshot saved in SYS_003.BIN.

=>Cellsite Database saved in CELLS003.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page   4)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  1  Month:  0
  Total number of cells       :170
  Total number of subscribers :21544
  Grade of service in all cells  : Mean:  3.62%, Sigma:  0.0244
  Number of subscribers per cell : Mean:    129, Sigma: 73.6604

=>Grade of service calculated for all cells and documented in GOS1_004.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
Cell #  3( 1), Cell # 33( 1), Cell # 39( 1), Cell # 50( 1), Cell # 73( 1),
Cell # 84( 1), Cell #126( 1), Cell #138( 1), Cell #144( 1), Cell #146( 1),
Cell #154( 1), Cell #156( 1), Cell #173( 1), Cell #180( 1), Cell #183( 1),
Cell #184( 1), Cell #186( 1), Cell #187( 1), Cell #188( 1), Cell #189( 1),
Cell #199( 1),

=>All required cell splits completed.

Results of cell splitting:
Cell # 3( 1) split into Cell #244( 2), Cell #245( 2), Cell #246( 2), Cell #247( 2)
Cell #33( 1) split into Cell #248( 2), Cell #249( 2), Cell #250( 2), Cell #251( 2)
Cell #39( 1) split into Cell #252( 2), Cell #253( 2), Cell #254( 2), Cell #255( 2)
Cell #50( 1) split into Cell #256( 2), Cell #257( 2), Cell #258( 2), Cell #259( 2)
Cell #73( 1) split into Cell #260( 2), Cell #261( 2), Cell #262( 2), Cell #263( 2)
Cell #84( 1) split into Cell #264( 2), Cell #265( 2), Cell #266( 2), Cell #267( 2)
Cell #126( 1) split into Cell #268( 2), Cell #269( 2), Cell #270( 2), Cell #271( 2)

=>Grade of service calculated for all cells and documented in GOS2_004.

=>Cellular system snapshot saved in SYS_004.BIN.

=>Cellsite Database saved in CELLS004.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page   5)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  1  Month:  3
  Total number of cells       :177
  Total number of subscribers :22802
  Grade of service in all cells  : Mean:  3.60%, Sigma:  0.0344
  Number of subscribers per cell : Mean:    131, Sigma: 71.3107

=>Grade of service calculated for all cells and documented in GOS1_005.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
Cell #  1( 1), Cell #  2( 1), Cell #  4( 1), Cell # 20( 1), Cell # 23( 1),
Cell # 40( 1), Cell # 80( 1), Cell # 85( 1), Cell # 86( 1), Cell # 87( 1),
Cell #101( 1), Cell #105( 1), Cell #109( 1), Cell #117( 1), Cell #138( 1),
Cell #144( 1), Cell #146( 1), Cell #153( 1), Cell #154( 1), Cell #156( 1),
Cell #160( 1), Cell #172( 1), Cell #173( 1), Cell #180( 1), Cell #183( 1),
Cell #184( 1), Cell #186( 1), Cell #187( 1), Cell #188( 1), Cell #189( 1),
Cell #199( 1),

=>All required cell splits completed.

Results of cell splitting:
Cell # 1( 1) split into Cell #272( 2), Cell #273( 2), Cell #274( 2), Cell #275( 2)
Cell # 2( 1) split into Cell #276( 2), Cell #277( 2), Cell #278( 2), Cell #279( 2)
Cell # 4( 1) split into Cell #280( 2), Cell #281( 2), Cell #282( 2), Cell #283( 2)
Cell #20( 1) split into Cell #284( 2), Cell #285( 2), Cell #286( 2), Cell #287( 2)
Cell #23( 1) split into Cell #288( 2), Cell #289( 2), Cell #290( 2), Cell #291( 2)
Cell #40( 1) split into Cell #292( 2), Cell #293( 2), Cell #294( 2), Cell #295( 2)
Cell #80( 1) split into Cell #296( 2), Cell #297( 2), Cell #298( 2), Cell #299( 2)

=>Grade of service calculated for all cells and documented in GOS2_005.

=>Cellular system snapshot saved in SYS_005.BIN.

=>Cellsite Database saved in CELLS005.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page   6)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  1  Month:  6
  Total number of cells       :184
  Total number of subscribers :24139
  Grade of service in all cells  : Mean:  3.54%, Sigma:  0.0450
  Number of subscribers per cell : Mean:    133, Sigma: 75.8769

=>Grade of service calculated for all cells and documented in GOS1_006.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
Cell # 85( 1), Cell # 86( 1), Cell # 87( 1), Cell #101( 1), Cell #105( 1),
Cell #109( 1), Cell #117( 1), Cell #129( 1), Cell #138( 1), Cell #144( 1),
Cell #146( 1), Cell #148( 1), Cell #153( 1), Cell #154( 1), Cell #156( 1),
Cell #160( 1), Cell #163( 1), Cell #172( 1), Cell #173( 1), Cell #180( 1),
Cell #183( 1), Cell #184( 1), Cell #186( 1), Cell #187( 1), Cell #188( 1),
Cell #189( 1), Cell #199( 1),

=>All required cell splits completed.

Results of cell splitting:
Cell #85( 1) split into Cell #300( 2), Cell #301( 2), Cell #302( 2), Cell #303( 2)
Cell #86( 1) split into Cell #304( 2), Cell #305( 2), Cell #306( 2), Cell #307( 2)
Cell #87( 1) split into Cell #308( 2), Cell #309( 2), Cell #310( 2), Cell #311( 2)
Cell #101( 1) split into Cell #312( 2), Cell #313( 2), Cell #314( 2), Cell #315( 2)
Cell #105( 1) split into Cell #316( 2), Cell #317( 2), Cell #318( 2), Cell #319( 2)
Cell #109( 1) split into Cell #320( 2), Cell #321( 2), Cell #322( 2), Cell #323( 2)
Cell #117( 1) split into Cell #324( 2), Cell #325( 2), Cell #326( 2), Cell #327( 2)

=>Grade of service calculated for all cells and documented in GOS2_006.

=>Cellular system snapshot saved in SYS_006.BIN.

=>Cellsite Database saved in CELLS006.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page   7)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  1  Month:  9
  Total number of cells       :191
  Total number of subscribers :25563
  Grade of service in all cells  : Mean:  3.40%, Sigma:  0.0566
  Number of subscribers per cell : Mean:    135, Sigma: 81.1266

=>Grade of service calculated for all cells and documented in GOS1_007.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
Cell #129( 1), Cell #138( 1), Cell #144( 1), Cell #146( 1), Cell #148( 1),
Cell #153( 1), Cell #154( 1), Cell #156( 1), Cell #160( 1), Cell #163( 1),
Cell #172( 1), Cell #173( 1), Cell #180( 1), Cell #183( 1), Cell #184( 1),
Cell #186( 1), Cell #187( 1), Cell #188( 1), Cell #189( 1), Cell #199( 1),


=>All required cell splits completed.

Results of cell splitting:
Cell #129( 1) split into Cell #328( 2), Cell #329( 2), Cell #330( 2), Cell #331( 2)
Cell #138( 1) split into Cell #332( 2), Cell #333( 2), Cell #334( 2), Cell #335( 2)
Cell #144( 1) split into Cell #336( 2), Cell #337( 2), Cell #338( 2), Cell #339( 2)
Cell #146( 1) split into Cell #340( 2), Cell #341( 2), Cell #342( 2), Cell #343( 2)
Cell #148( 1) split into Cell #344( 2), Cell #345( 2), Cell #346( 2), Cell #347( 2)
Cell #153( 1) split into Cell #348( 2), Cell #349( 2), Cell #350( 2), Cell #351( 2)
Cell #154( 1) split into Cell #352( 2), Cell #353( 2), Cell #354( 2), Cell #355( 2)

=>Grade of service calculated for all cells and documented in GOS2_007.

=>Cellular system snapshot saved in SYS_007.BIN.

=>Cellsite Database saved in CELLS007.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page   8)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  2  Month:  0
  Total number of cells       :198
  Total number of subscribers :27074
  Grade of service in all cells  : Mean:  3.00%, Sigma:  0.0675
  Number of subscribers per cell : Mean:    138, Sigma: 81.1030

=>Grade of service calculated for all cells and documented in GOS1_008.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
Cell #156( 1), Cell #160( 1), Cell #163( 1), Cell #172( 1), Cell #173( 1),
Cell #180( 1), Cell #183( 1), Cell #184( 1), Cell #186( 1), Cell #187( 1),
Cell #188( 1), Cell #189( 1), Cell #199( 1),

=>All required cell splits completed.

Results of cell splitting:
Cell #156( 1) split into Cell #356( 2), Cell #357( 2), Cell #358( 2), Cell #359( 2)
Cell #160( 1) split into Cell #360( 2), Cell #361( 2), Cell #362( 2), Cell #363( 2)
Cell #163( 1) split into Cell #364( 2), Cell #365( 2), Cell #366( 2), Cell #367( 2)
Cell #172( 1) split into Cell #368( 2), Cell #369( 2), Cell #370( 2), Cell #371( 2)
Cell #173( 1) split into Cell #372( 2), Cell #373( 2), Cell #374( 2), Cell #375( 2)
Cell #180( 1) split into Cell #376( 2), Cell #377( 2), Cell #378( 2), Cell #379( 2)
Cell #183( 1) split into Cell #380( 2), Cell #381( 2), Cell #382( 2), Cell #383( 2)

=>Grade of service calculated for all cells and documented in GOS2_008.

=>Cellular system snapshot saved in SYS_008.BIN.

=>Cellsite Database saved in CELLS008.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page   9)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  2  Month:  3
  Total number of cells       :205
  Total number of subscribers :28705
  Grade of service in all cells  : Mean:  2.00%, Sigma:  0.0665
  Number of subscribers per cell : Mean:    142, Sigma: 81.8880

=>Grade of service calculated for all cells and documented in GOS1_009.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
Cell #184( 1), Cell #186( 1), Cell #187( 1), Cell #188( 1), Cell #189( 1),
Cell #199( 1),

=>All required cell splits completed.

Results of cell splitting:
Cell #184( 1) split into Cell #384( 2), Cell #385( 2), Cell #386( 2), Cell #387( 2)
Cell #186( 1) split into Cell #388( 2), Cell #389( 2), Cell #390( 2), Cell #391( 2)
Cell #187( 1) split into Cell #392( 2), Cell #393( 2), Cell #394( 2), Cell #395( 2)
Cell #188( 1) split into Cell #396( 2), Cell #397( 2), Cell #398( 2), Cell #399( 2)
Cell #189( 1) split into Cell #400( 2), Cell #401( 2), Cell #402( 2), Cell #403( 2)
Cell #199( 1) split into Cell #404( 2), Cell #405( 2), Cell #406( 2), Cell #407( 2)

=>Grade of service calculated for all cells and documented in GOS2_009.

=>Cellular system snapshot saved in SYS_009.BIN.

=>Cellsite Database saved in CELLS009.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page  10)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  2  Month:  6
  Total number of cells       :211
  Total number of subscribers :30438
  Grade of service in all cells  : Mean:  0.00%, Sigma:  0.0001
  Number of subscribers per cell : Mean:    146, Sigma: 84.9713

=>Grade of service calculated for all cells and documented in GOS1_010.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
  No cells need to be split.

=>Grade of service calculated for all cells and documented in GOS2_010.

=>Cellular system snapshot saved in SYS_010.BIN.

=>Cellsite Database saved in CELLS010.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page  11)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  2  Month:  9
  Total number of cells       :211
  Total number of subscribers :32294
  Grade of service in all cells  : Mean:  0.00%, Sigma:  0.0002
  Number of subscribers per cell : Mean:    155, Sigma: 92.3747

=>Grade of service calculated for all cells and documented in GOS1_011.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
  No cells need to be split.

=>Grade of service calculated for all cells and documented in GOS2_011.

=>Cellular system snapshot saved in SYS_011.BIN.

=>Cellsite Database saved in CELLS011.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page  12)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  3  Month:  0
  Total number of cells       :211
  Total number of subscribers :34274
  Grade of service in all cells  : Mean:  0.01%, Sigma:  0.0006
  Number of subscribers per cell : Mean:    164, Sigma: 100.4566

=>Grade of service calculated for all cells and documented in GOS1_012.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
  No cells need to be split.

=>Grade of service calculated for all cells and documented in GOS2_012.

=>Cellular system snapshot saved in SYS_012.BIN.

=>Cellsite Database saved in CELLS012.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page  13)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  3  Month:  3
  Total number of cells       :211
  Total number of subscribers :36416
  Grade of service in all cells  : Mean:  0.02%, Sigma:  0.0015
  Number of subscribers per cell : Mean:    175, Sigma: 109.3840

=>Grade of service calculated for all cells and documented in GOS1_013.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
  No cells need to be split.

=>Grade of service calculated for all cells and documented in GOS2_013.

=>Cellular system snapshot saved in SYS_013.BIN.

=>Cellsite Database saved in CELLS013.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page  14)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  3  Month:  6
  Total number of cells       :211
  Total number of subscribers :38682
  Grade of service in all cells  : Mean:  0.04%, Sigma:  0.0034
  Number of subscribers per cell : Mean:    185, Sigma: 119.1465

=>Grade of service calculated for all cells and documented in GOS1_014.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
  No cells need to be split.

=>Grade of service calculated for all cells and documented in GOS2_014.

=>Cellular system snapshot saved in SYS_014.BIN.

=>Cellsite Database saved in CELLS014.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page  15)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  3  Month:  9
  Total number of cells       :211
  Total number of subscribers :41126
  Grade of service in all cells  : Mean:  0.09%, Sigma:  0.0067
  Number of subscribers per cell : Mean:    197, Sigma: 129.9275

=>Grade of service calculated for all cells and documented in GOS1_015.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
Cell #201( 2),

=>All required cell splits completed.

Results of cell splitting:
Cell #201( 2) split into Cell #408( 3), Cell #409( 3), Cell #410( 3), Cell #411( 3)

=>Grade of service calculated for all cells and documented in GOS2_015.

=>Cellular system snapshot saved in SYS_015.BIN.

=>Cellsite Database saved in CELLS015.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page  16)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  4  Month:  0
  Total number of cells       :214
  Total number of subscribers :43720
  Grade of service in all cells  : Mean:  0.10%, Sigma:  0.0078
  Number of subscribers per cell : Mean:    207, Sigma: 131.8089

=>Grade of service calculated for all cells and documented in GOS1_016.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
Cell #200( 2), Cell #202( 2), Cell #203( 2),

=>All required cell splits completed.

Results of cell splitting:
Cell #200( 2) split into Cell #412( 3), Cell #413( 3), Cell #414( 3), Cell #415( 3)
Cell #202( 2) split into Cell #416( 3), Cell #417( 3), Cell #418( 3), Cell #419( 3)
Cell #203( 2) split into Cell #420( 3), Cell #421( 3), Cell #422( 3), Cell #423( 3)

=>Grade of service calculated for all cells and documented in GOS2_016.

=>Cellular system snapshot saved in SYS_016.BIN.

=>Cellsite Database saved in CELLS016.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page  17)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  4  Month:  3
  Total number of cells       :223
  Total number of subscribers :46486
  Grade of service in all cells  : Mean:  0.01%, Sigma:  0.0007
  Number of subscribers per cell : Mean:    211, Sigma: 106.3408

=>Grade of service calculated for all cells and documented in GOS1_017.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
  No cells need to be split.

=>Grade of service calculated for all cells and documented in GOS2_017.

=>Cellular system snapshot saved in SYS_017.BIN.

=>Cellsite Database saved in CELLS017.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page  18)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  4  Month:  6
  Total number of cells       :223
  Total number of subscribers :49455
  Grade of service in all cells  : Mean:  0.04%, Sigma:  0.0019
  Number of subscribers per cell : Mean:    224, Sigma: 116.0325

=>Grade of service calculated for all cells and documented in GOS1_018.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
  No cells need to be split.

=>Grade of service calculated for all cells and documented in GOS2_018.

=>Cellular system snapshot saved in SYS_018.BIN.

=>Cellsite Database saved in CELLS018.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page  19)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  4  Month:  9
  Total number of cells       :223
  Total number of subscribers :52642
  Grade of service in all cells  : Mean:  0.09%, Sigma:  0.0043
  Number of subscribers per cell : Mean:    239, Sigma: 126.7766

=>Grade of service calculated for all cells and documented in GOS1_019.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
  No cells need to be split.

=>Grade of service calculated for all cells and documented in GOS2_019.

=>Cellular system snapshot saved in SYS_019.BIN.

=>Cellsite Database saved in CELLS019.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page  20)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  5  Month:  0
  Total number of cells       :223
  Total number of subscribers :56040
  Grade of service in all cells  : Mean:  0.20%, Sigma:  0.0085
  Number of subscribers per cell : Mean:    254, Sigma: 138.6006

=>Grade of service calculated for all cells and documented in GOS1_020.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
Cell #212( 2), Cell #213( 2), Cell #214( 2), Cell #215( 2),

=>All required cell splits completed.

Results of cell splitting:
Cell #212( 2) split into Cell #424( 3), Cell #425( 3), Cell #426( 3), Cell #427( 3)
Cell #213( 2) split into Cell #428( 3), Cell #429( 3), Cell #430( 3), Cell #431( 3)
Cell #214( 2) split into Cell #432( 3), Cell #433( 3), Cell #434( 3), Cell #435( 3)
Cell #215( 2) split into Cell #436( 3), Cell #437( 3), Cell #438( 3), Cell #439( 3)

=>Grade of service calculated for all cells and documented in GOS2_020.

=>Cellular system snapshot saved in SYS_020.BIN.

=>Cellsite Database saved in CELLS020.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page  21)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  5  Month:  3
  Total number of cells       :235
  Total number of subscribers :59618
  Grade of service in all cells  : Mean:  0.18%, Sigma:  0.0053
  Number of subscribers per cell : Mean:    256, Sigma: 115.1815

=>Grade of service calculated for all cells and documented in GOS1_021.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
  No cells need to be split.

=>Grade of service calculated for all cells and documented in GOS2_021.

=>Cellular system snapshot saved in SYS_021.BIN.

=>Cellsite Database saved in CELLS021.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page  22)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  5  Month:  6
  Total number of cells       :235
  Total number of subscribers :63445
  Grade of service in all cells  : Mean:  0.37%, Sigma:  0.0102
  Number of subscribers per cell : Mean:    273, Sigma: 126.0206

=>Grade of service calculated for all cells and documented in GOS1_022.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
Cell #205( 2), Cell #210( 2), Cell #379( 2),

=>All required cell splits completed.

Results of cell splitting:
Cell #205( 2) split into Cell #440( 3), Cell #441( 3), Cell #442( 3), Cell #443( 3)
Cell #210( 2) split into Cell #444( 3), Cell #445( 3), Cell #446( 3), Cell #447( 3)
Cell #379( 2) split into Cell #448( 3), Cell #449( 3), Cell #450( 3), Cell #451( 3)

=>Grade of service calculated for all cells and documented in GOS2_022.

=>Cellular system snapshot saved in SYS_022.BIN.

=>Cellsite Database saved in CELLS022.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page  23)
==============================================================================

Simulation Parameters:
  Time Resolution              :  3 month(s)
  Desired call blockage        :  0.50%
  Cell split criteria          : call blockage>=  5.00%
  Stop time of simulations     :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model              : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  5  Month:  9
  Total number of cells       :244
  Total number of subscribers :67543
  Grade of service in all cells  : Mean:  0.52%, Sigma:  0.0143
  Number of subscribers per cell : Mean:    280, Sigma: 124.8304

=>Grade of service calculated for all cells and documented in GOS1_023.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
Cell #204( 2), Cell #211( 2), Cell #218( 2), Cell #228( 2), Cell #229( 2),
Cell #230( 2), Cell #378( 2), Cell #397( 2), Cell #398( 2), Cell #399( 2),


=>All required cell splits completed.

Results of cell splitting:
Cell #204( 2) split into Cell #452( 3), Cell #453( 3), Cell #454( 3), Cell #455( 3)
Cell #211( 2) split into Cell #456( 3), Cell #457( 3), Cell #458( 3), Cell #459( 3)
Cell #218( 2) split into Cell #460( 3), Cell #461( 3), Cell #462( 3), Cell #463( 3)
Cell #228( 2) split into Cell #464( 3), Cell #465( 3), Cell #466( 3), Cell #467( 3)
Cell #229( 2) split into Cell #468( 3), Cell #469( 3), Cell #470( 3), Cell #471( 3)
Cell #230( 2) split into Cell #472( 3), Cell #473( 3), Cell #474( 3), Cell #475( 3)
Cell #378( 2) split into Cell #476( 3), Cell #477( 3), Cell #478( 3), Cell #479( 3)

=>Grade of service calculated for all cells and documented in GOS2_023.

=>Cellular system snapshot saved in SYS_023.BIN.

=>Cellsite Database saved in CELLS023.TXT.
```

```
USRTC: C$2E905369
                    Capacity Simulations Log File (Page  24)
==============================================================================

Simulation Parameters:
  Time Resolution                :  3 month(s)
  Desired call blockage          :  0.50%
  Cell split criteria            : call blockage>=  5.00%
  Stop time of simulations       :  6 year(s)  0 month(s)
  Interference calculated every: 4000 time step(s)
  Path loss model                : d^n, n=3.46
  Subscriber distribution model:       TWO TIERED
    Subscriber growth rate for tier 1: 20.0%
    Subscriber growth rate for tier 2: 40.0%

Simulation Time:  Year:  6  Month:  0
  Total number of cells       :265
  Total number of subscribers :71928
  Grade of service in all cells  : Mean:  0.54%, Sigma:  0.0162
  Number of subscribers per cell : Mean:    274, Sigma: 119.4253

=>Grade of service calculated for all cells and documented in GOS1_024.

=>The number of subscribers in each cell increased to simulate a  3 month
=>jump in time.

The following cells need to be split to accomodate the increase in the number
of subscribers in each cell:
(NOTE: At most  7 cell splits per 3 months.)
Cell #216( 2), Cell #221( 2), Cell #231( 2), Cell #234( 2), Cell #235( 2),
Cell #376( 2), Cell #384( 2), Cell #386( 2), Cell #390( 2), Cell #397( 2),
Cell #398( 2), Cell #399( 2),

=>All required cell splits completed.

Results of cell splitting:
Cell #216( 2) split into Cell #480( 3), Cell #481( 3), Cell #482( 3), Cell #483( 3)
Cell #221( 2) split into Cell #484( 3), Cell #485( 3), Cell #486( 3), Cell #487( 3)
Cell #231( 2) split into Cell #488( 3), Cell #489( 3), Cell #490( 3), Cell #491( 3)
Cell #234( 2) split into Cell #492( 3), Cell #493( 3), Cell #494( 3), Cell #495( 3)
Cell #235( 2) split into Cell #496( 3), Cell #497( 3), Cell #498( 3), Cell #499( 3)
Cell #376( 2) split into Cell #500( 3), Cell #501( 3), Cell #502( 3), Cell #503( 3)
Cell #384( 2) split into Cell #504( 3), Cell #505( 3), Cell #506( 3), Cell #507( 3)

=>Grade of service calculated for all cells and documented in GOS2_024.

=>Cellular system snapshot saved in SYS_024.BIN.

=>Cellsite Database saved in CELLS024.TXT.
```

APPENDIX E The Derived Channel Sets

1.	355 376 397 418
2.	356 377 398 419 440 461 482 503 524
3.	357 378 399 420 441 462 483
4.	358 379 400 421 442
5.	359 380 401 422
6.	360 381 402 423 444
7.	361 382 403 424
8.	362 383 404 425
9.	363 384 405 426 447 468 489
10.	364 385 406 427 448 469
11.	365 386 407 428 449 470 491
12.	366 387 429
13.	367 388 409 430 451 472 493
14.	368 389 410 431 452
15.	369 390 411 432 453 474 495
16.	370 391 412 433
17.	371 392 413 434 455 476 497
18.	372 393 414 435 456 477 498
19.	373 394 415 436
20.	374 395 416 437 458
21.	375
22.	396 417
23.	408
24.	438 459
25.	439
26.	443
27.	445
28.	446
29.	450
30.	454
31.	457 478 499
32.	460 481
33.	463
34.	464 485
35.	465
36.	466
37.	467
38.	471 492
39.	473
40.	475 496 517 538 559 580
41.	479
42.	480 501
43.	484
44.	486

45.	487
46.	488 509 530
47.	490
48.	494
49.	500 521
50.	502
51.	504
52.	505 526 547 568 589 610 631 652
53.	506
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55.	508 529
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67.	523 544 565
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74.	535 556
75.	536
76.	539 560 581
77.	540 561
78.	542
79.	543
80.	545
81.	546
82.	548 569 590
83.	549 570 591 612 633
84.	550 571
85.	551 572
86.	553 574 595 616
87.	554 575 596
88.	555 576 618
89.	557

90.	558
91.	562
92.	563
93.	564 585
94.	566 587
95.	567 588 609
96.	573
97.	577 598
98.	578
99.	579 600 621 642 663
100.	582
101.	583
102.	584
103.	586
104.	592 613 634 655 718 739 760 781
105.	593 614
106.	594 615 636 657
107.	597
108.	599 620 641 662 725 746 767 788
109.	601
110.	602 623
111.	603 624 645 666
112.	604
113.	605 626 647
114.	606 627 648 732 753 795
115.	607 628 649
116.	608
117.	611 632 653
118.	617 638
119.	619
120.	622 643 664 727 748 769 790
121.	625 646

122.	629 650
123.	630 651 735 756 777 798
124.	635 656 719 740 761 782
125.	637 658 721
126.	639
127.	640 661
128.	644 665 728 749 770 791
129.	654
130.	659 722
131.	660 723 765 786
132.	717 738 759 780
133.	720
134.	724
135.	726 747 768 789
136.	729
137.	730
138.	731 752 773 794
139.	733 754 775 796
140.	734 755 776
141.	736 757 778 799
142.	737 758 779
143.	741 762 783
144.	742 763 784
145.	743 764 785
146.	744
147.	745 766 787
148.	750 771 792
149.	751 772
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VITA

Robert Brickhouse was born in Nashville, Tennessee on November 3, 1969. He received his Bachelor of Science degree in Electrical Engineering from Virginia Tech in 1992. From 1992 to 1994 he worked as a software engineer for TSR Technologies, Inc. in Blacksburg, Virginia. Also in 1992 he enrolled in the masters program in Electrical Engineering at Virginia Tech and joined the Mobile and Portable Radio Research Group, where his graduate research has focused on the modeling of cellular networks. In 1994 when TSR Technologies, Inc. was sold to Grayson Electronics Company, he began working for Grayson Electronics as a design engineer where he worked on designing test equipment for cellular and paging networks.