USWEST COMMUNICATIONS

September 5, 1992

Mr. H. Franklin Wright
Office of Engineering and Technology
Federal Communications Commission
2025 M Street, N.W
Room 7322
Washington, DC 20554

RE: U S WEST COMMUNICATIONS, INC.
SECOND QUARTERLY REPORT
PCS Experimental Licenses:
KK2XCC - Boulder, CO
KK2XCD - Portland, OR

Dear Mr. Wright:

Enclosed please find U S WEST's second quarterly report addressing the above referenced authorization for PCS field trials in Boulder, CO. At this time we have yet to implement experimental trials in Portland, OR.

Should you have any questions or require additional information, please contact Beth Speilicy at (303) 896-7576.

Sincerely,

Sambran Sandoval

Sambran Sandoval
Manager - Network Technology Transport Services

Enclosures

FCC Second Quarterly Report

Experimental License KK2XCC/KK2XCD

U S WEST Advanced Technologies

September 5, 1992

Introduction

U S WEST Advanced Technologies, the research and development division of U S WEST, is submitting this report on tests conducted to further the development of Personal Communications Services. Experimental licenses (call sign KK2XCC/KK2XCD) were granted effective March 5, 1992. Pursuant to F.C.C. regulations, this is our second quarterly report of activities under this authorization. Outdoor reception experiments were conducted in the Pearl Street Mall in Boulder, Colorado. The results of this testing is included in this report.

Purpose and Scope

U S WEST Advanced Technologies' purposes in securing an experimental radio license are as follows.

- To investigate radio propagation (both indoor and outdoor).
- To explore the feasibility and quality of various radio technologies.
- To evaluate patterns of usage and assess customer responses to wireless products.

Limited testing was done in the 866 to 868 MHz in the second quarter of reporting. The testing that was completed during this period was done to compare reception in an urban outdoor environment with the results of earlier line-of-sight and indoor testing that was completed during the first quarter of licensing.

Extensive testing was done in the 2.1 GHz band using a system developed by Bellcore which will be described below.

Equipment

A single Motorola Public Base Station and a single Motorola Silverlink 2000 handset were used for the tests in the 866 to 868 MHz band. For the base station, an omni-directional 3 dB gain antenna was used.

For testing done in the 2.1 GHz band, a Time Division Multiple Access (TDMA) system developed by Bellcore was used. It consisted of a base station with dual spatial diversity antennas; a handset with dual spatial diversity antennas; two phone lines, one for voice, the other for Received Signal Strength (RSS) and Word Error Rate (WER) data; and a remote based PC for data processing.

Methodology

For the 800 MHz band testing, subjective voice quality tests were made from a central base station located at the intersection of Broadway and Pearl Streets in downtown Boulder, Colorado. One antenna was located at the midpoint of traffic pole. A recording of high quality speech was played and sent over the downlink. Test personnel took a single handset and walked over the area notating the received speech quality.A numeric system was used to describe the quality of the speech path and these numbers were applied to a map of the area. Map legends show the speech quality assigned to each of these numbers.

For the tests done in the 2.1 GHz band, the same subjective scoring system was also used. However in these tests, data was collected showing RSS and WER values which provided a more precise record of system performance.

Test Results for CT-2 866-868 MHz:

Please see the first map in the appendix for the results of the tests.

The reception radius for adequate voice quality (a number 3 or 4 on the map) for the north section of Broadway was approximately 750 feet (250 M). For the south section of Broadway, the radius was 600 feet (200 M). For the west section of Pearl Street, the radius of acceptable service measured 500 feet (168 M). For the east section of Pearl Street, the radius was 350 feet (150 M). No attempt was made to correlate actual signal strength measurements with the subjective numerical rating in this particular test. However, earlier measurements done by U S WEST Advanced Technologies characterized line-of-sight fading at 915 MHz, and confirm the perceived voice quality findings. As expected, the subjective voice quality measurements showed variations along certain streets even though the antenna radiation pattern was omni-directional. These voice quality tests confirmed the fading and demonstrated the additional effects of buildings and traffic on reception. It was observed that small offsets in the antenna position (of approximately 0.5 meter) caused large variations in the radius of acceptable service when buildings and traffic intervened. The north section of Broadway represented an almost line-of-sight transmission. However, the Pearl Street axis contained numerous trees, buildings, and moving people. This caused a maximum of 350 feet difference in the radius of adequate coverage. These tests demonstrated the critical effects of antenna placement on reception, a subject of future investigation.

TDMA System Tests in the 2 GHz Bands:

Please see attached report and map in appendix.

Field tests were conducted in a light urban environment in the 2.1 GHz band. The technology test was developed by Bellcore and is known as Wire Access Communications System (WACS), formerly known as Universal Digital Personal Communication System (UDPCS). Detailed results of this testing are contained in a report included with this document.

Future Activities

Plans are being made to get field data on a frequency hopping, multi-diversity system. The system is expected to be ready for testing by December 4, 1992. Data from these tests will be included in future filings.

Tests are also planned with NTIA to determine building penetration losses in the 800 MHz and 1.8 to 2.2 GHz bands, and to determine the percentage of living or working areas with adequate received signal levels. In addition, the impact of base antenna position and height on penetration in the 1.8 to 2.2 GHz band will also be studied.

Another area of future work involves using NTIA to do delay spread measurements in microcells for path lengths not exceeding 400 meters. Trade-offs will be determined involving antenna placement as well as measuring spatial diversity gain and physical separation requirements for microcell antenna

Further studies will also involve measuring the rate of change of the channel impulse response, which will allow the evaluation of the relative merits and performance of various proposed technologies for PCS.

Measured Performance of QPSK in a PCS Environment For a TDMA Portable Radio Link

September 5, 1992

Prepared By
U S WEST Advanced Technologies, Inc.
Product Engineering and Development

Abstract
Field measurements in a light urban environment of a wireless digital portable radio at 2.1 GHz are reported. The experiments were designed to test the radio link, not the network architecture, of a TDMA based system without use of adaptive equalizers. The technology used was proposed and implemented by Bellcore. The tests were conducted for outdoor and mixed (indoor-outdoor) environments in Boulder, CO. The equipment included a radio port, selection diversity, and a portable unit. Subjective voice quality, word error rates, and received signal strength at various locations were measured and recorded during the experiments for non real-time data analysis. For the experimental arrangement used, excellent coverage was obtained within +/- three blocks line-of-sight from the base (outdoor) and +/- one block from the base in a mixed (indoor-to-outdoors) environment. Important sources of system performance degradation, applicable to any technology, are identified.

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Scope of This Document

This document reports field measurements of a portable digital radio link in a light urban environment. The technology used was proposed and implemented by Bellcore. The purpose of the experiments is to test the radio link only and estimate radio link coverage using a low power TDMA system without use of adaptive equalizers. The field data compiled includes subjective voice quality, word error rate, and received signal strength for various test sites.

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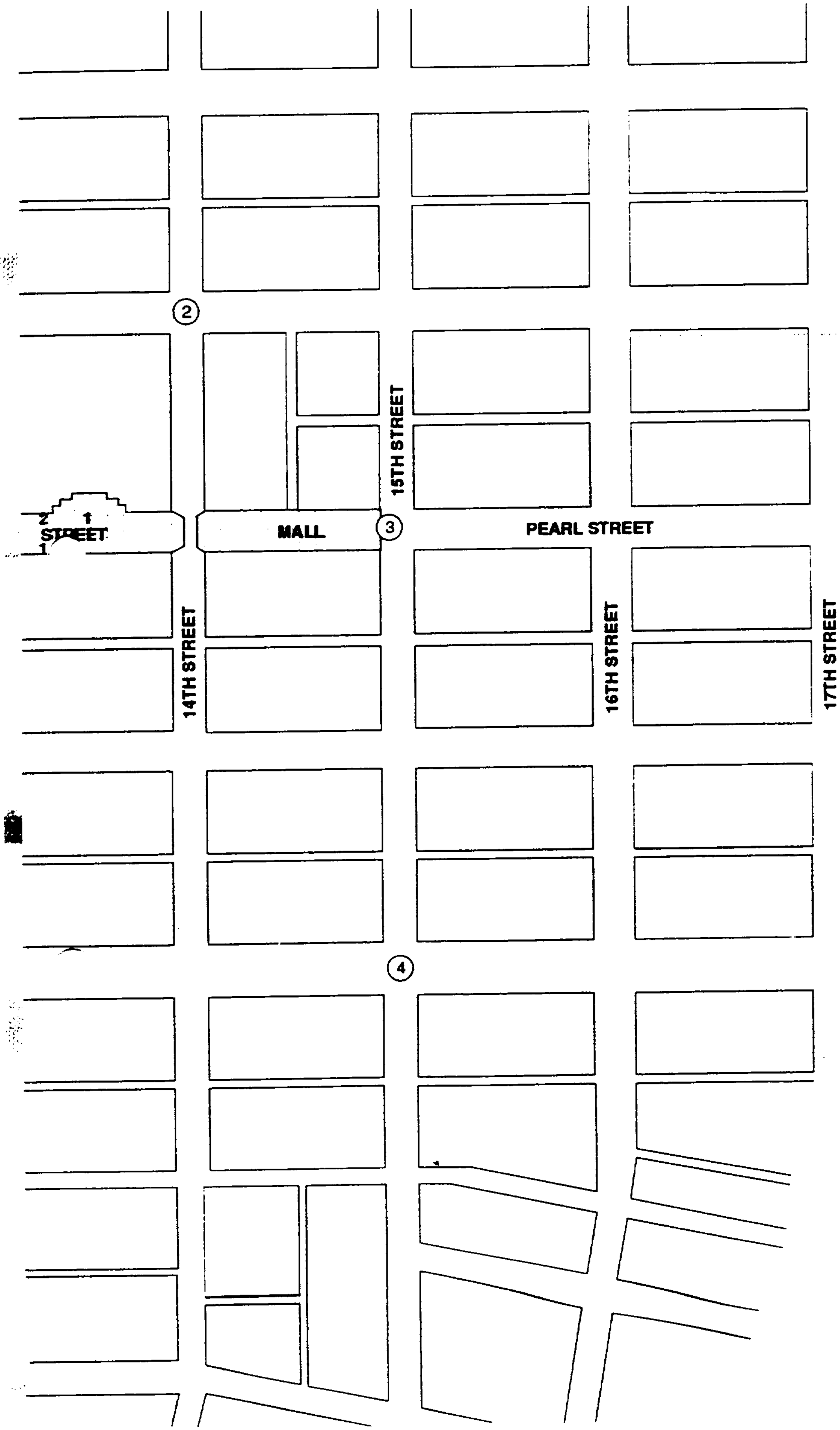

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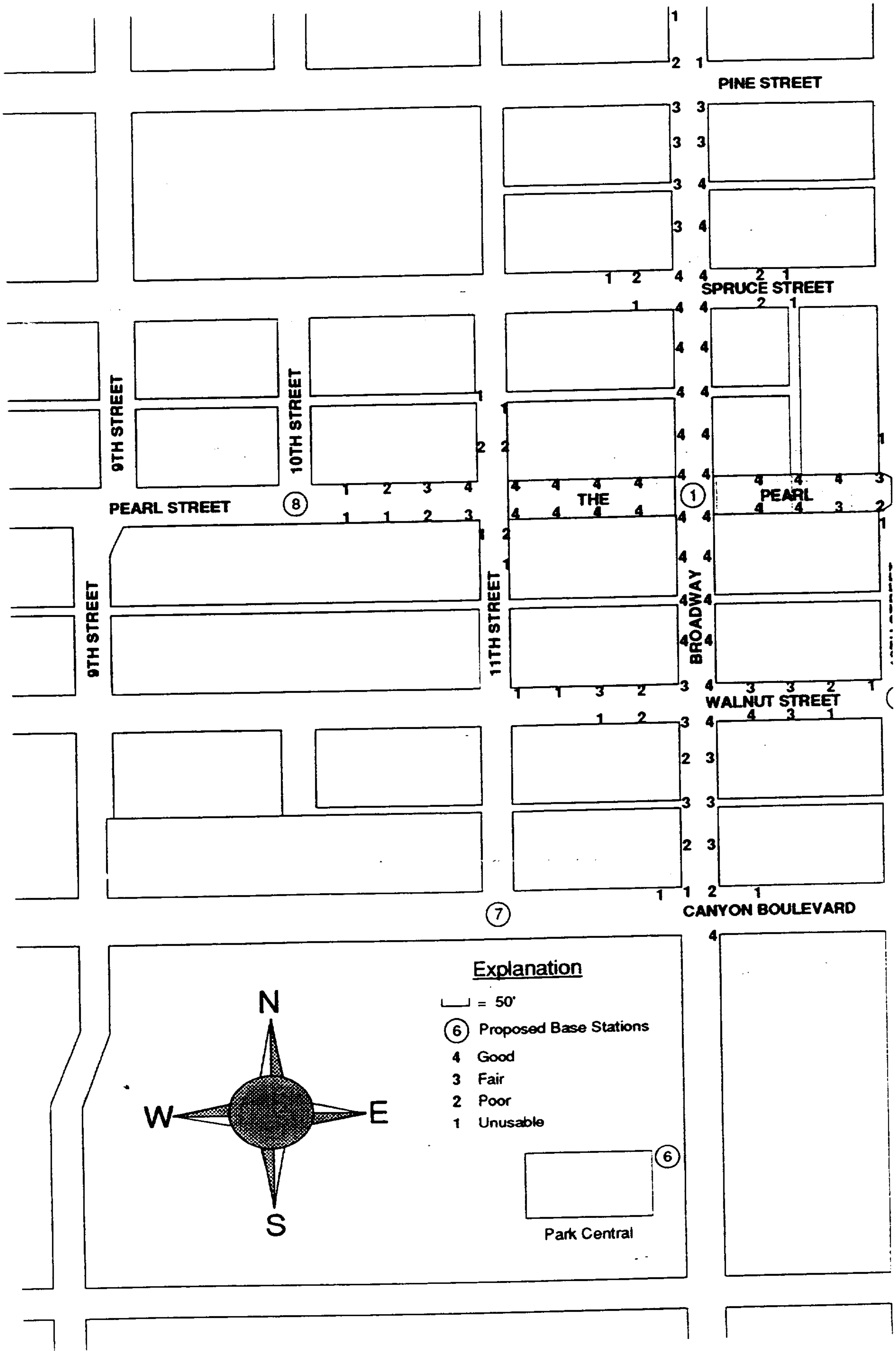

PINE STREET
SPRUCE STREET
9TH STREET
10TH STREET
PEARL STREET
THE
PEARL
11TH STREET
BROADWAY
WALNUT STREET
CANYON BOULEVARD
Explanation
= 50'
6 Proposed Base Stations
4 Good
3 Fair
2 Poor
1 Unusable
N
W
E
S
Park Central

EXECUTIVE SUMMARY

This document reports field measurements in a light urban environment of a wireless portable digital radio operating in the 2.1 GHz band. The experiments were designed to test the radio link, not the network architecture, of a TDMA based system without use of adaptive equalizers.

The experiments were conducted in a light business area in Boulder, CO where building heights did not exceed two floors. Different scenarios were conceived to determine the coverage and quality of the system under test. The test equipment included: A fixed port located on a traffic light, a portable (only one port and one portable were used at all times) moving at pedestrian speeds in line of sight and non-line of sight paths, outdoor, and mixed (indoor-outdoor) environments. Distances between the port and the portable did not exceed 400 m.

The experiments focused primarily on: a) Subjective voice quality b) Word error rates c) Received signal strength.

The technology used, proposed, and implemented by Bellcore, is known as Universal Digital Personal Communication System (UDPCS). This technology employs Time Division Multiple Access (TDMA) with Frequency Division Duplex (FDD) using Quaternary Phase Shift Keying (QPSK) with a bit rate of 500 Kbps and raised cosine Nyquist filtering with a rolloff factor $\alpha = 0.5$. Demodulation is performed by a digital coherent demodulator with two-branch receiver selection diversity and two-branch feedback transmit diversity for the uplink.

Important system uplink parameters were:

+ 6.5 dBi antenna gain at the port
+ 20 dBm of output power at the portable (before the antenna)

<u>Conclusions based on experiments:</u>

1) Excellent voice quality was obtained when the base and the portable were within +/- three blocks from each other in a line of sight path.

2) Excellent voice quality was obtained when the base and the portable were within +/- one block in a mixed (indoor-outdoor) environment.

3) Poor-to-unusable quality was obtained for non-line of sight paths (complete building blockage) when the radial distance between the port and the portable was 140 m or more.

4) Adaptive equalizers were not needed for the distances, data rates, and power levels tested. Received power was the limiting factor, not delay spread.

5) location of the antenna at the port, type of antenna (directional or omni), and gain are critical for adequate coverage. Possible antenna locations include mid-block, side of buildings, street intersections, and street corners. These various alternatives have both technical and economic impacts deserving further study.

6) Significant received power unbalance for the two port antennas was observed in some instances due to partial building blockage and/or tree shadowing. This power unbalance caused an estimated loss in diversity gain ranging from a fraction of a dB to 7 dB.

7) Adequate fading margins must be carefully allocated for vegetation losses (where applicable).

8) For a given average received signal strength per diversity branch at the port, the indoor-outdoor scenario offers the lowest error rate.

9) Shadowing losses modeled by a lognormal random process had standard deviations approximately 3 dB to 5.5 dB.

10) The number of burst errors decreases exponentially with burst duration (i.e. short burst errors are more probable). Estimation of decaying factors allowed the development of Markov chains that model the WER performance for various channel conditions.

I. INTRODUCTION

This document reports field tests measurements of a wireless portable digital radio operating in the 2.1 GHz band. The experiments were designed to test the radio link, not the network architecture, of a TDMA based system without use of adaptive equalizers.

The experiments were conducted in a light business area in Boulder, CO where building heights did not exceed two floors, with no spaces between buildings . Different scenarios were conceived to determine the coverage and quality of the system under test. These included: A fixed port located on a traffic light, a portable moving at pedestrian speeds in line of sight and non-line of sight paths, outdoor and mixed (indoor-outdoor) environments.

The experiments focused primarily on: a) Subjective voice quality b) Word error rates c) Received signal strength.

The technology used, proposed, and implemented by Bellcore, is known as Universal Digital Personal Communication System (UDPCS) [Bellcore, 1991]. This technology employs Time Division Multiple Access (TDMA) with Frequency Division Duplex (FDD) using Quaternary Phase Shift Keying (QPSK) with a bit rate of 500 Kbps and raised cosine Nyquist filtering with a rolloff factor $\alpha = 0.5$. Demodulation is performed by a digital coherent demodulator with two-branch selection diversity.

The document is organized as follows: In section II we describe the experimental arrangement used, specify the hardware technical characteristics, and enclose drawings illustrating the location of the port and port antenna system. Subjective voice quality results are included in section III, which includes a map with voice quality grades throughout the neighbourhood where the measurements were collected. In section IV we report the results of the data analysis using metrics such as: word error rate (WER) and received signal strength (RSS). We quantify also various system degradation factors. The section concludes with a proposed Markov chain that models the WER quality of a link. In section V we summarize the major results and share our conclusions.

II. SYSTEM DESCRIPTION

1. Technical Characteristics

The following list summarizes the most important technical parameters and characteristics associated with UDPCS.

- Frequency Band and Duplexing Technique: Frequency Division Duplex (FDD) with 50 MHz separation between the uplink and the downlink. Uplink frequency was 2.17 GHz and downlink frequency was 2.12 GHz.

- Modulation Technique: Quaternary Phase Shift Keying (QPSK) with raised cosine Nyquist filtering with a rolloff factor $\alpha =$ 0.5.

- Port to Subscriber Unit: Time Division Multiplexing (TDM)

- Subscriber to Unit Port: Time Division Multiple Access (TDMA)

- TDM/TDMA Frame Make-up : 10 time slots of 100 bits each in a 2 ms frame at a rate of 500 Kbps.

- TDMA Burst : Uplink time slot is offset one time slot from the downlink.

- Speech Coding : 32 Kbps ADPCM

- Antenna Type and Gain : Omnidirectional, vertically polarized, port antenna gain was + 6.5 dBi, portable antenna gain was -2 dBi.

- Port Sensitivity (two channels per port):
  Top channel: Pr = -99.5 dBm at WER = 5.7 %
  Top channel: Pr = -97.5 dBm at WER = 0.44%
  Bottom channel: Pr = -99 dBm at WER = 1.04%
  Bottom channel: Pr = -97.5 dBm at WER = 0.14%

- Portable Sensitivity : Pr = -97 dBm at WER = 6.25%

- System Implementation Losses : Back-to-back modem operation with thermal noise only, 3 dB for WER $\leq$ 1E-04

2. Search For Potential Microwave Users in the 2.1 GHZ Band.

Before any measurements were atempted, a data search was conducted to determine the presence of microwave users in the 2.1 GHz band in Boulder, CO. The data bank used is owned and managed by U S WEST Communications. According to the data base, there were users operating in close proximity to the 2.1 GHz band, but these users were located far away from the test area to cause or receive any significant interference, according to our calculations. Our analytical reasoning was later confirmed with a passive test system consisting of an antenna connected to a low noise amplifier (LNA) with a gain of 35 dB, whose output was connected to a spectrum analyzer. Frequency bands adjacent (and including) to 2.1 GHz were searched down to the -120 dBm received power level and no activity was detected.

3. UDPCS Test Procedure

The tests were performed as a collaboration between U S WEST AT and Bellcore personnel. The tests were the first outdoor tests of UDPCS technology in an outdoor pedestrian environment.

The tests used a single base station mounted on a traffic light. Two vertically polarized antennas separated approximately 4 m were used to provide selection diversity. The first antenna was mounted on the vertical post and the second antenna was mounted on the crossarm of the traffic light. A circulator coupled one of the port's receivers with the port's transmitter for a single antenna connection. Thus, only one antenna, the one on the crossarm, was used for transmission at the port, while two antennas were used for reception.

The equipment was powered by 110 VAC available at the traffic light pole. Two Plain Old Telephone (POT) lines were connected to the enclosure containing the equipment. One of the first POT lines was used for voice connectivity and the second POT line was used for modem-based data connectivity to a nearby Central Office (CO). The second line used a 9600 baud modem to transmit Word Error Rate

(WER) and Received Signal Strength (RSS) information from the uplink. The data was stored in a PC located at the CO facility.

The data generation software dumped raw WER and RSS information every 1024 frames or 2.048 sec. The data was dumped in hexadecimal code. A minimum of 16 contiguous (preserving continuity) blocks of 1024 frames were recorded at each test site. The selected numbers allowed anaysis of "instantaneous" WER and RSS, averaged over 2.048 sec, and cumulative WER and RSS values, averaged over 16 x 2.048 = 32.768 sec.

The voice quality tests and data analysis reported here deal exclusively with the uplink. This should not be interpreted as a shortcoming. Since the uplink was the limiting factor for adequate radio coverage.

If the portable moved in the East-West direction away from the port, the path was partially blocked by the edge of the buildings located at the intersection of Broadway and Pearl St., as illustrated in Figure 1. This partial blockage caused an extra signal attenuation on Pearl St. not normally present under more favorable conditions.

The operator of the experimental portable walked at normal speed (about 1 m/s). Data was collected for one minute intervals at each test site to provide meaningful statistical characterization.

III. SUBJECTIVE VOICE QUALITY

Subjective voice quality tests were based on a four point scale, identical to that applied in rating movies. The scoring system is described below.

Score	Meaning
4.0	Good voice quality without noticeable impairments
3.0	Fair link but with noticeable impairments
2.0	Poor with several words or sentences blanked out
1.0	Unusable

The results are illustrated in Figure 2. The results include outdoor and mixed (indoor-to-outdoor) tests. With the base located at the intersection of Pearl St. and Broadway, good voice quality was obtained on Broadway within +/- three blocks line of sight from the base. On Pearl St. good voice quality was obtained within +/- 1.5 blocks from the base. The performance on Pearl St. fell short of the initial expectations because of the partial building blockage at the intersection of Broadway and Pearl St. (see Figure 1) and shadowing due to trees. The indoor to outdoor tests resulted in a good link within +/- one block for the base.

Non line of sight paths suffered tremendous path loses resulting in poor link quality for radial distances between the base and the portable exceeding 140 m. This leads to the conjecture that mid-block base locations may be appropriate for more regular coverage. Preliminary evidence of this is presented in [Persson, 1992,]

IV. DATA ANALYSIS

In this section we present word error rate and received signal strength information for various locations. Scatter plots of WER are presented as a function of average received signal strength for data averaged over time intervals of 2.048 sec and 32.768 sec respectively. The effect of unequal branch diversity gains is also investigated in this section. Shadowing effects are modeled using classical lognormal densities and the standard deviations are calculated. In this section we investigate also the statistics of the error burst durations and propose simple Markov chain models to describe them.

In order to facilitate our discussion, the following nomenclature will be used to identify a particular test site or location.

Outdoor Tests :

SON.E

S = Initial of street name (except Pearl St.) where the measurements were collected.
M = Pearl St.
T = Thirteen St.
B = Broadway
S = Spruce St.
etc.

O = Side of the street where the measurements were collected.
N = North
S = South
W = West
E = East

N = Number of Street (two digits) that Intersects street "S".

E = Number that indicates the location within a block where the data was collected.
0 = corner of streets "S" and "N"
0.5 = mid-block (towards street "N+1")
0.9 = near end-of-block (towards "N+1")

Indoor:

Same as outdoor but append the letter "I" in front, i.e. the nomenclature is: "ISON.E"

1. Word Error Rate and Received Signal Strength as Function of Time for Various Locations

Figures 3 - 10 represent samples of the processed data collected outdoors and Figures 11 -12 are typical samples for indoor-outdoor links. The reader is reminded that, the data analysis deals exclusively with the uplink (portable to base). In these figures, "instantaneous" WER values are plotted for 16 contiguous blocks. One block spans 2.048 sec, contains 1024 words, and each word contains 100 bits. The figures contain also received signal strength information for the two receiving branches measured in dBm. These are the curves with filled circles and triangles and the corresponding values are read with the right y-axis. The numbers in parenthesis next to the RSS curves denote the mean and standard deviation (in dBm) respectively averaged over 16 blocks.

Translation of WER to subjective voice quality is easily done by comparing Figures 3 - 12 against Figure 2. From the curves we can conclude that a minimum average RSS per receiver branch of approximately -94 dBm is needed for fair to good quality. RSS levels in the range -100 dB to -104 dBm led to poor to unusable links. Notice that a mere 6 dB to 10 dB difference can make the difference between a fair link and an unusable link.

By comparing MN13.0 against IMN12.9 and MS13.5 aginst IMS13.5 we can estimate that the building penetration losses for these two locations were approximately 12 - 14 dB. This number may seem a bit low. The explanation is that the front of the businesses where the data was collected had large glass doors and windows, which are less lossy than other typical construction materials.

2. Scatter Plots of Word Error Rate vs. Received Signal Strength

In figures 13-17 we present scatter plots of WER vs. RSS for 2.048 sec and 32.7 sec averaged data points. The x-axis denotes the average received power level per branch from the two receiving branches.

Each of these plots is the compilation of all the test sites belonging to Pearl St., Broadway St., or indoor-to-outdoor. The distinction was necessary because each of these environments had unique characteristics. For example, the links on Pearl St. were partially obstructed by buildings and had tree shadowing. The links on Broadway had just tree shadowing.

The differences in these three scenarios are better displayed by curve fitting the decimal logarithm of WER values vs. RSS. The fitted curves are shown in Figure 18. Notice that lower error rates are obtained for indoor-to-outdoor links. We conjucture that this is due to less delay spread coupled with Rician-like statistics with a stronger direct component for indoor-outdoor links. The performance on Broadway St. suffered from significant unequal branch gains due to tree shadowing affecting one of the antennas. The estimated losses in diversity gain will be quantified in the following section.

3. Effect of Unequal Branch Gains

It is well known that a system employing diversity suffers a diversity gain degradation if the branches have unequal received power levels [Halpern, 1977]. From figures 3-12 we can verify that unequal power levels were measured for the two receiving branches in most instances. The most dramatic example is shown in Figure 10 where a 14 dB differential RSS was observed. This differential is attributed to tree shadowing affecting one of the antennas. Following the previous reference and assuming a Rayleigh field, the degradation in diversity gain was estimated for three different scenarios. The results are shown in Figure 19. Notice that for Broadway St. the degradation in diversity gain due to power unbalance is greater than that of Pearl St. or indoors. This explains (at least partially) why Broadway St. in Figure 18 has the worst performance.

4. Shadowing Effects

The received signal strength information presented in the previous sections was obtained using a 2.048 sec time averaging window. Assuming a pedestrian speed of approximately 1 m/s, this time window corresponds to approximately 14 wavelengths. The 2.048 s window basically removes the "fast" variations of the fading signal, leaving the "slow" or long term variations, which are typically modeled by a lognormal density function [Lee, 1989, Parsons, 1992]

Figure 20 shows the probability distribution function of the "slow" processes for two scenarios. Notice that 90% of the time the attenuation due to shadowing is 5.5 dB or smaller.

5. Statistical Characterization of Error Burst Durations

It is illustrative to investigate the characteristics of the error burst durations. This information may be useful for selecting combined ARQ and forward error correction (FEC) schemes for data transmission. Typical samples of the number of error bursts and their burst duration, measured in words, is illustrated in Figure 21 for four different test sites. A total of 16,384 words per site were used. As expected, the number of bursts in error decreases exponentially with burst duration. The corresponding probability distribution functions for the four previous samples are illustrated in Figure 22. The subjective voice quality for the four selected samples range from "fair" to "good" using the scoring system of section III. For the sample rated "fair", with a score of 3.0, the median burst duration was 4 words, and 90% of the time the burst duration was 20 words or less. The sample rated "good", with a score of 4.0, only single and double word bursts were observed.

6.0 Markov Chain Model For Communication Link.

This section proposes a Markov chain that models the WER performance, incorporating burst durations, of a communications link. The model is depicted in Figure 23. The markov chain contains N+1 states, where N is the maximum burst duration (in words).

Given:

$$\sum_{i=1}^{N} P_{oi} = \text{averaged WER} \tag{1}$$

then

$$P_{i0} = 1 \qquad , i = 1,...N \tag{2}$$

$$P_{oo} = 1 - \sum_{i=1}^{N} P_{oi} \tag{3a}$$

$$P_{o1}/P_{oL} = e^{b(L-1)} \qquad 1 \leq L \leq N \tag{3b}$$

examples:

"Good" channel, WER = 1E-03, b=1, N=2

"Fair-Good" channel, WER = 3E-03, b=0.6, N=5

"Fair" channel, WER = 1E-02, b =0.20, N=20

Once WER, b, and N are known, the transition probabilities can be calculated using equations 2 and 3 above.

V. CONCLUSIONS AND SUGGESTIONS

Field tests of a digital portable radio at 2.1 GHz were presented in this document. The technology, relying on TDMA, was proposed and implemented by Bellcore. Only the radio link was tested during the experiments, which included a radio port, selection diversity and a portable. The measurements were conducted in Boulder, CO in a light business area for outdoors and indoor-outdoors surroundings. It was concluded that adaptive equalizers were not needed for the data rates, power levels and distances tested.

For line-of-sight paths between the base and the portable, excellent voice quality was obtained within +/- three blocks (approximately 300 m). Excellent voice quality was obtained also when the base and the portable were within +/- one block in a mixed (indoor-to-outdoor) environment. Poor-to-unusable quality was obtained for non line-of-sight paths (complete building blockage occured) when the radial distance between the port and the portable exceeded 140 m.

Significant tree shadowing losses were observed. This is a reminder that adequate fading margins must be allocated for vegetation losses, whenever they are applicable.

The experiments used only one base and one portable. The tests were adequate to determine coverage range. Other factors present in a multi-cell, multi-user environment such as: cochannel interference, reuse factors, hand-off mechanisms, channel allocation, networking, data transmission, etc. need to be addressed in the future.

The experiments were conducted with a bulky laboratory prototype, with approximately 3 dB implementation losses and noise figures in the neighborhood of 8-10 dB. It is expected that the radio sensitivity can be lowered by several dB (TBD) if the same technology is built by a respected vendor. This translates directly into smaller transmitted power levels for the same coverage area estimated here, or greater coverage areas with the same transmitted power levels used here.

The impact of cochannel interference, reuse factors, and overall system capacity needs to be addressed.

The relative merits of this technology must be weighted side-by-side, on a fair basis, with other proposed technologies, specially with those using spread spectrum concepts.

VI. REFERENCES

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6. Hakan Persson, "Microcellular Structures and Their Performance, VTC '92, pp. 413-418.

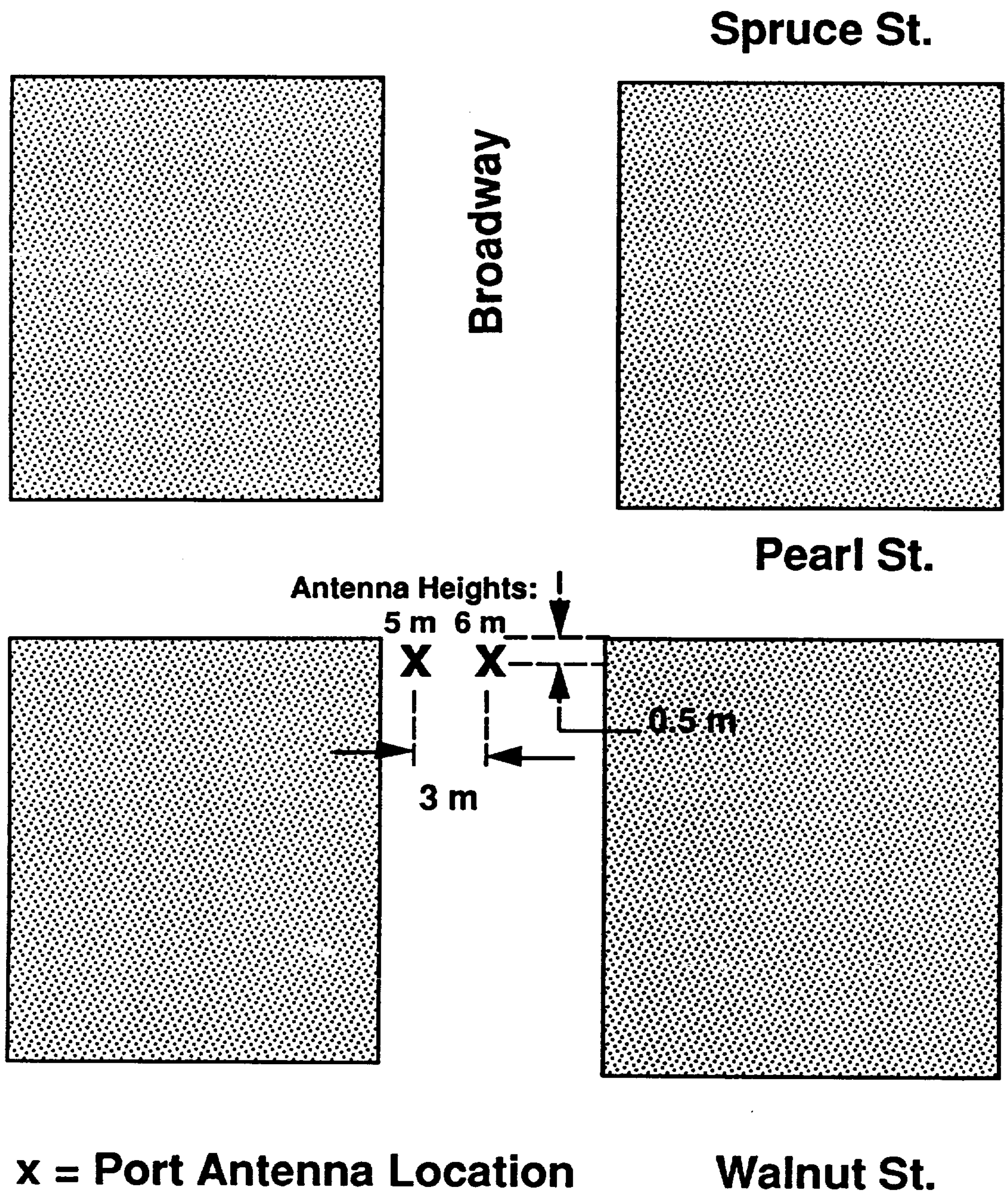

Spruce St.
Broadway
Pearl St.
Antenna Heights:
5 m 6 m
X X
0.5 m
3 m
x = Port Antenna Location
Walnut St.

Figure 1

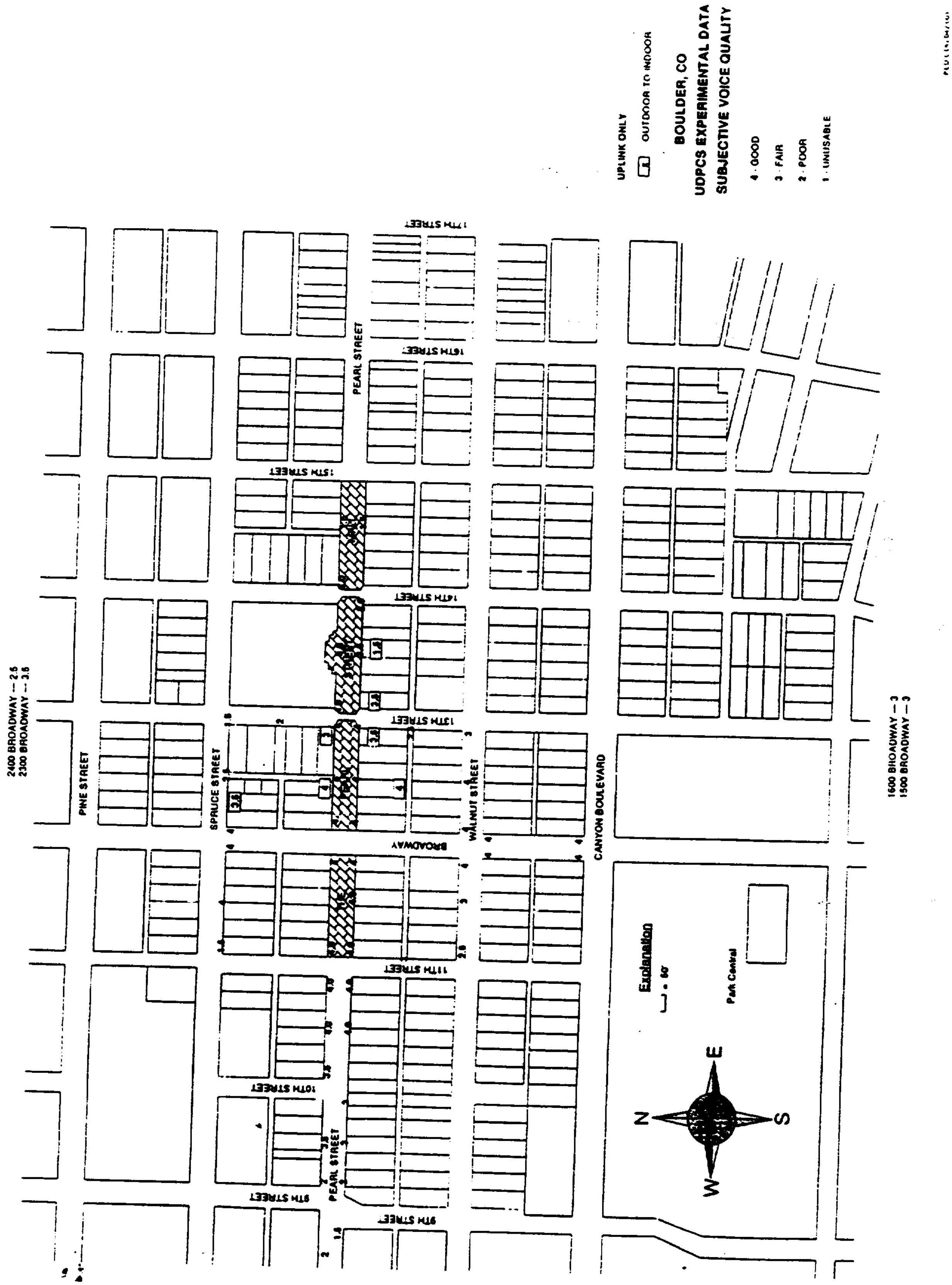

UPLINK ONLY
OUTDOOR TO INDOOR
BOULDER, CO
UDPCS EXPERIMENTAL DATA
SUBJECTIVE VOICE QUALITY
4 - GOOD
3 - FAIR
2 - POOR
1 - UNUSABLE
17TH STREET
16TH STREET
15TH STREET
14TH STREET
13TH STREET
11TH STREET
10TH STREET
9TH STREET
PEARL STREET
PINE STREET
SPRUCE STREET
BROADWAY
WALNUT STREET
CANYON BOULEVARD
2400 BROADWAY – 2.5
2300 BROADWAY – 3.5
1600 BROADWAY – 3
1500 BROADWAY – 3
Explanation
Park Central
N
S
E
W

Figure 2

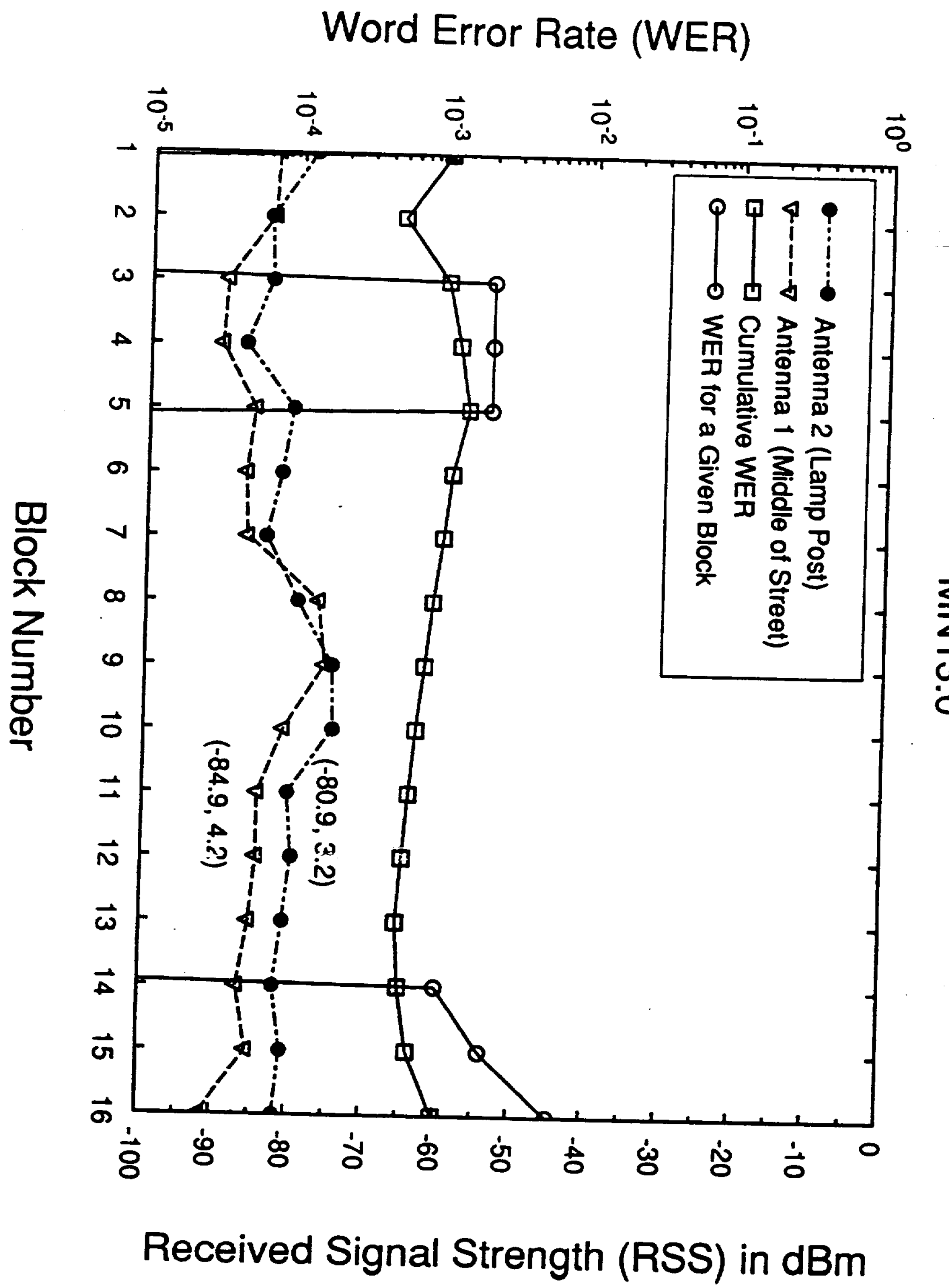

MN13.0
Word Error Rate (WER)
Received Signal Strength (RSS) in dBm
Block Number
Antenna 2 (Lamp Post)
Antenna 1 (Middle of Street)
Cumulative WER
WER for a Given Block
(-80.9, 3.2)
(-84.9, 4.2)

Figure 3

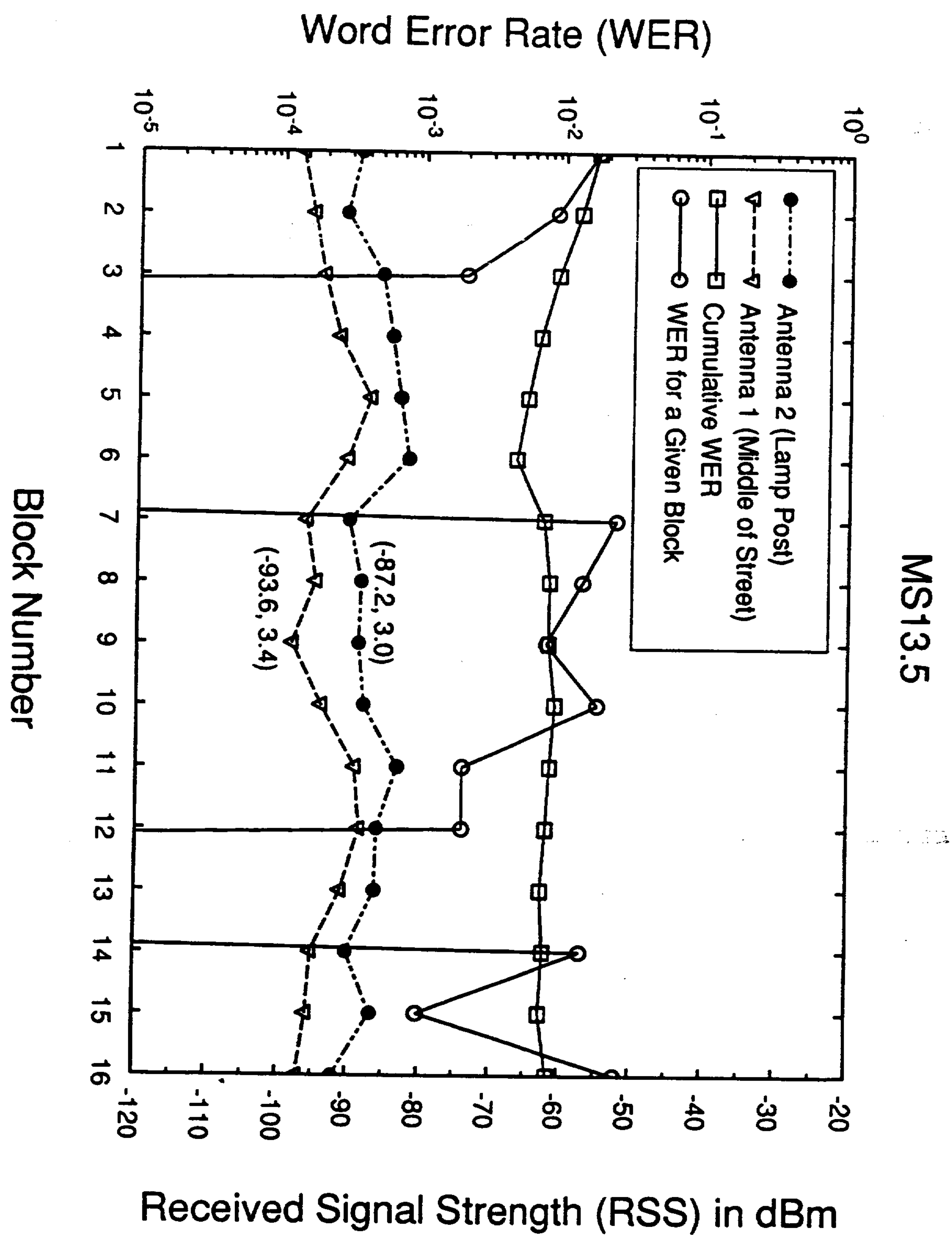
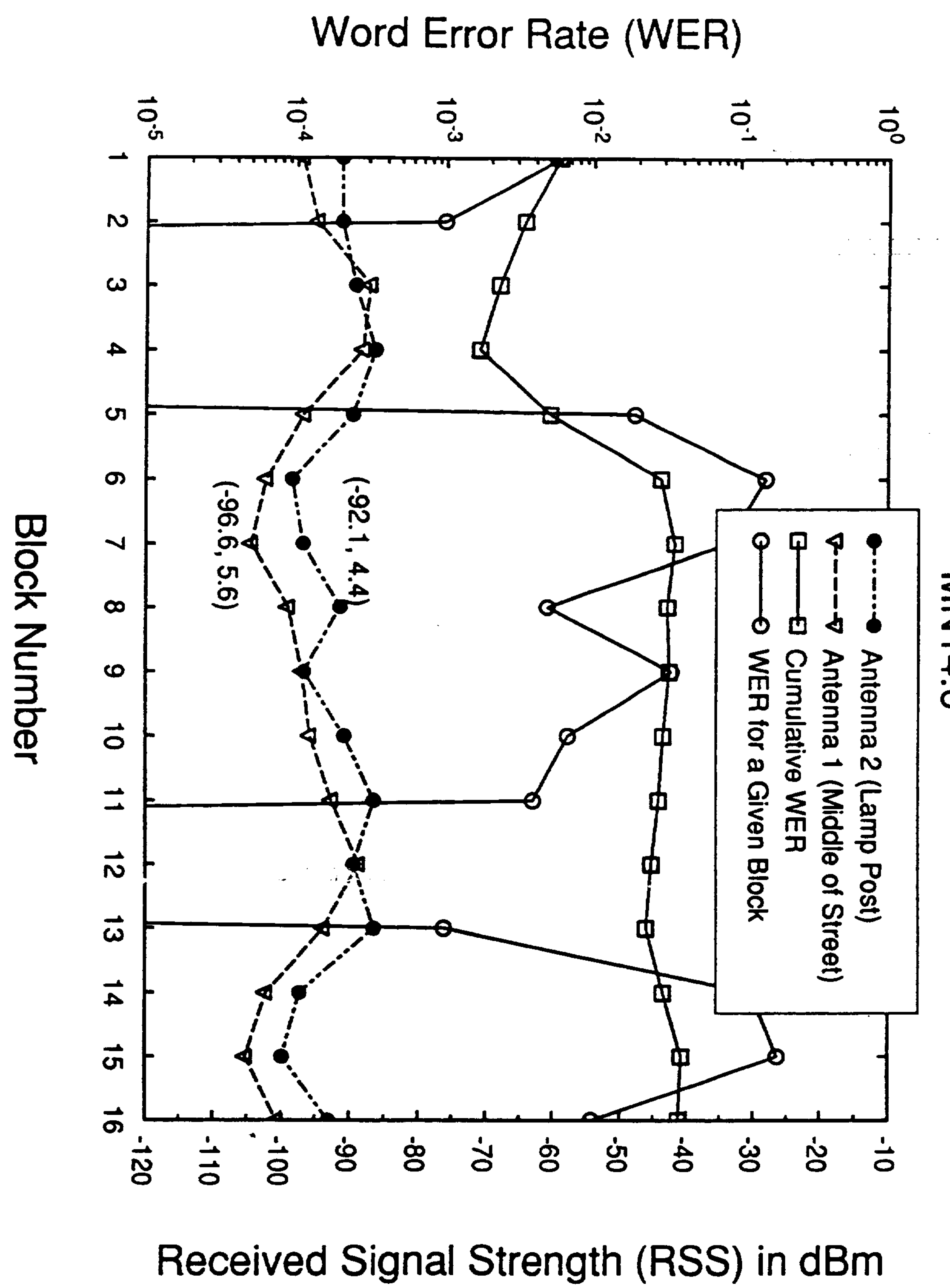

MS13.5
Word Error Rate (WER)
Received Signal Strength (RSS) in dBm
Block Number
Antenna 2 (Lamp Post)
Antenna 1 (Middle of Street)
Cumulative WER
WER for a Given Block
(-87.2, 3.0)
(-93.6, 3.4)

Figure 4



Word Error Rate (WER)
MN14.0
Antenna 2 (Lamp Post)
Antenna 1 (Middle of Street)
Cumulative WER
WER for a Given Block
(-92.1, 4.4)
(-96.6, 5.6)
Block Number
Received Signal Strength (RSS) in dBm

Figure 5

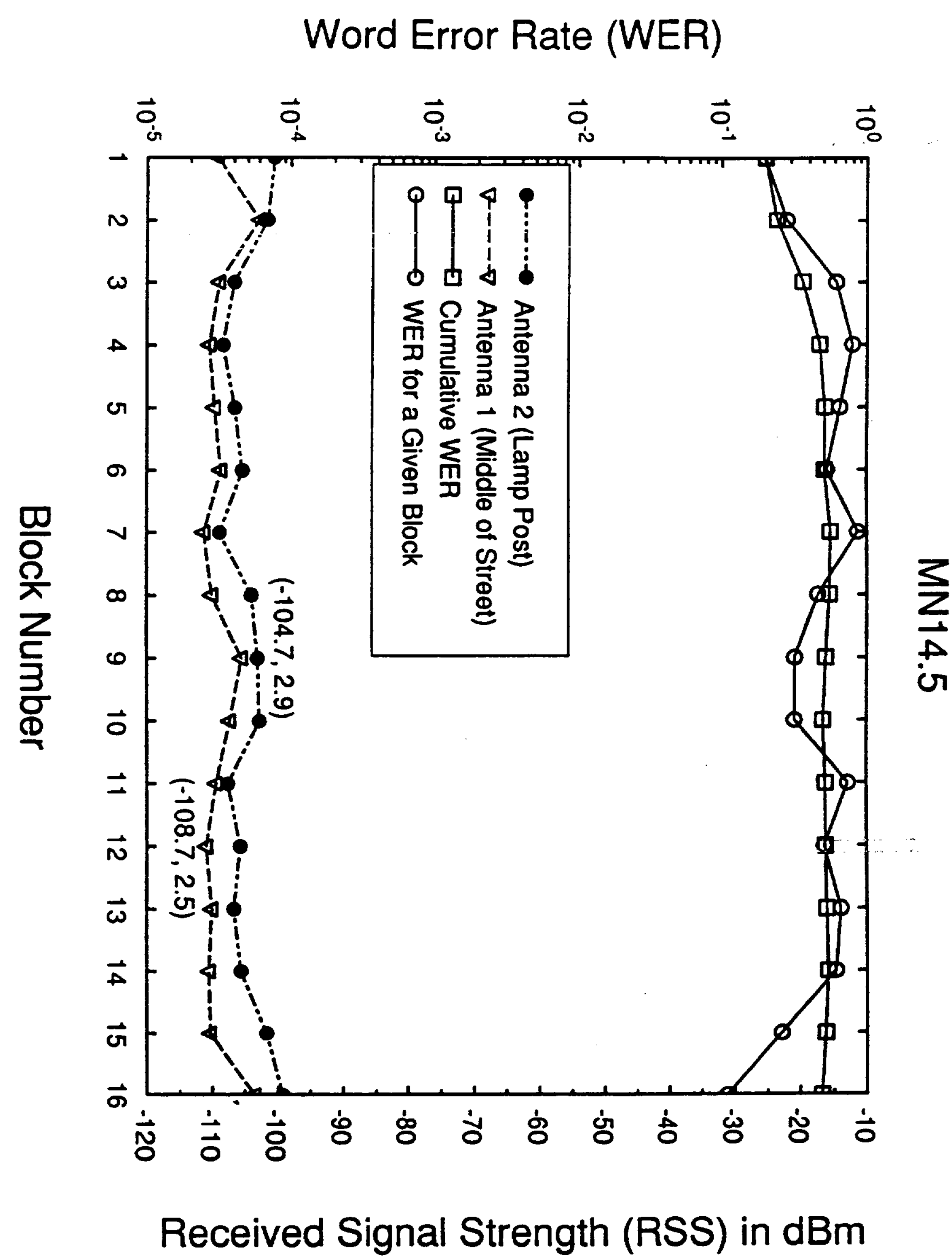

Word Error Rate (WER)
MN14.5
Antenna 2 (Lamp Post)
Antenna 1 (Middle of Street)
Cumulative WER
WER for a Given Block
(-104.7, 2.9)
(-108.7, 2.5)
Block Number
Received Signal Strength (RSS) in dBm

Figure 6

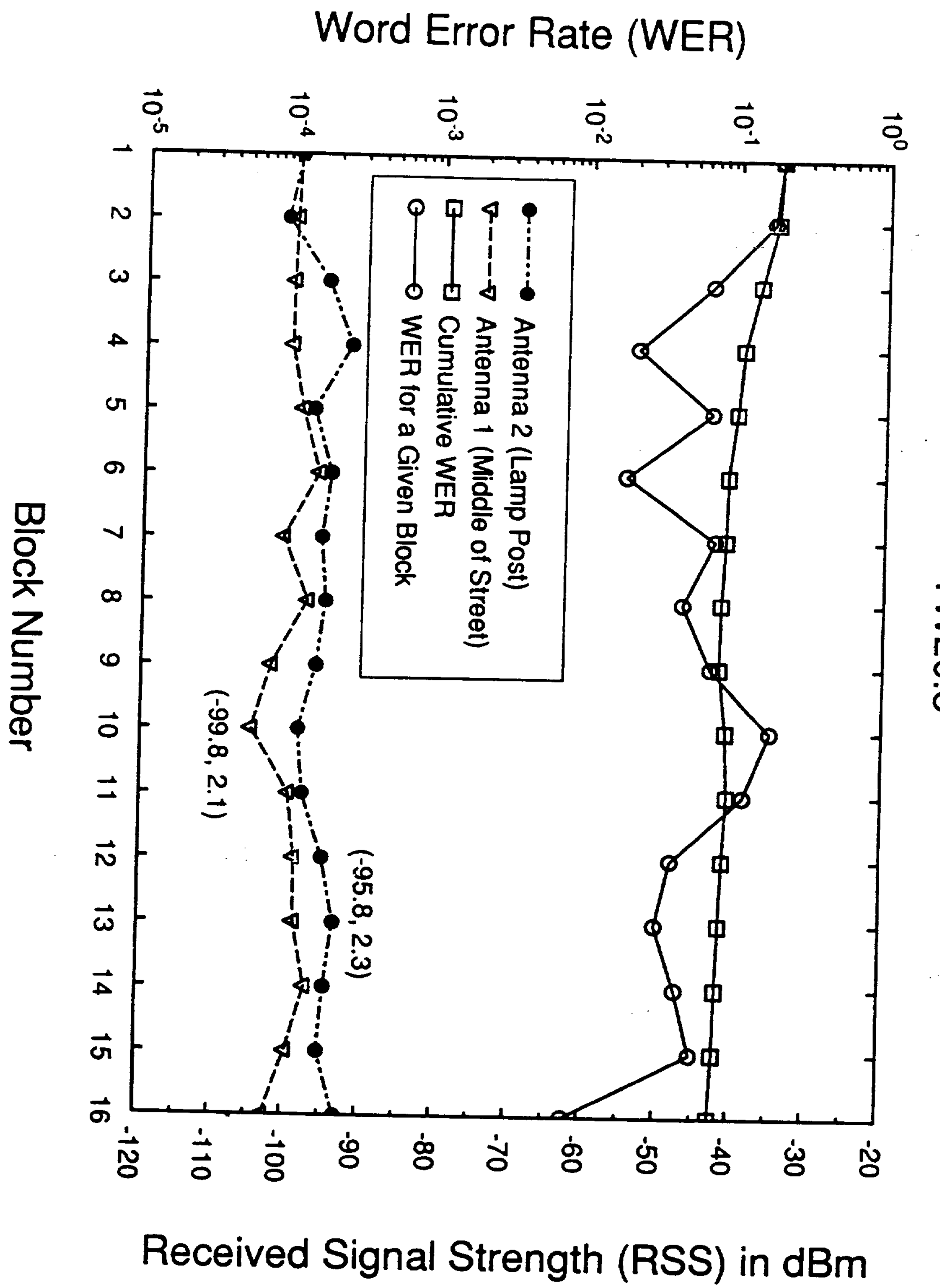

TW20.5
Word Error Rate (WER)
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
Antenna 2 (Lamp Post)
Antenna 1 (Middle of Street)
Cumulative WER
WER for a Given Block
(-99.8, 2.1)
(-95.8, 2.3)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Block Number
-20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120
Received Signal Strength (RSS) in dBm

Figure 7

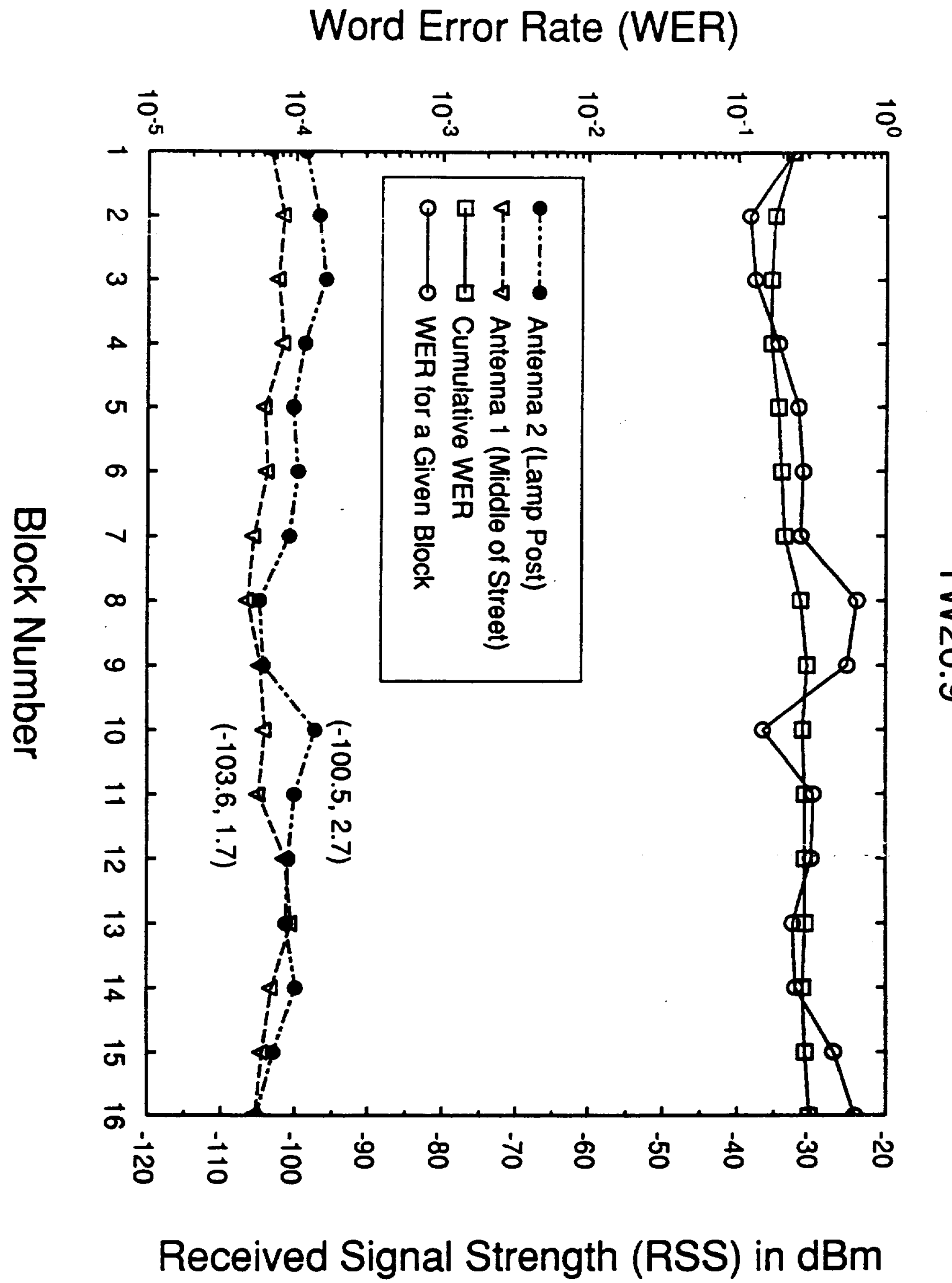

Word Error Rate (WER)
TW20.9
Antenna 2 (Lamp Post)
Antenna 1 (Middle of Street)
Cumulative WER
WER for a Given Block
(-100.5, 2.7)
(-103.6, 1.7)
Block Number
Received Signal Strength (RSS) in dBm

Figure 8

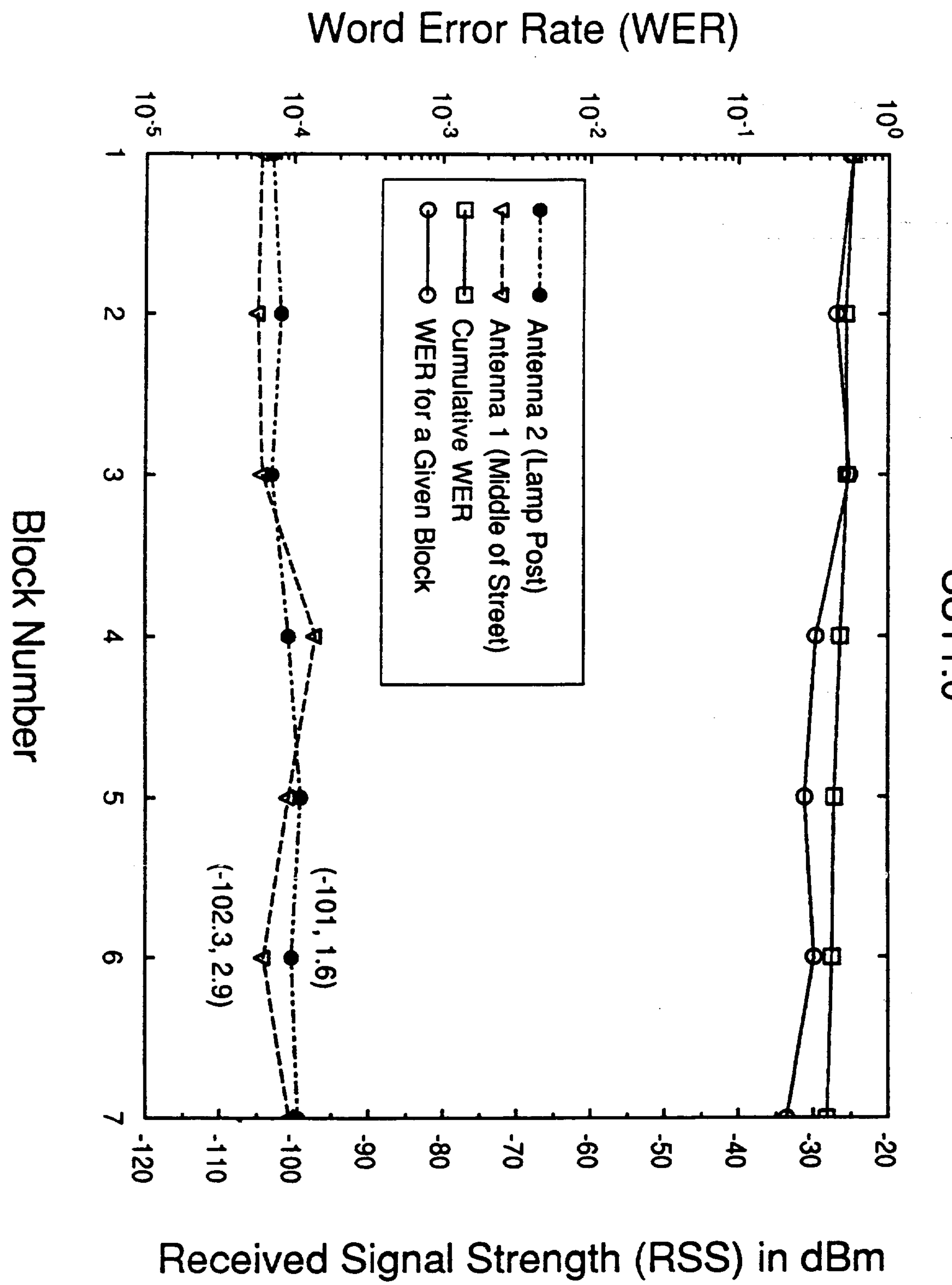

SS11.0
Word Error Rate (WER)
Received Signal Strength (RSS) in dBm
Block Number
Antenna 2 (Lamp Post)
Antenna 1 (Middle of Street)
Cumulative WER
WER for a Given Block
(-101, 1.6)
(-102.3, 2.9)

Figure 9

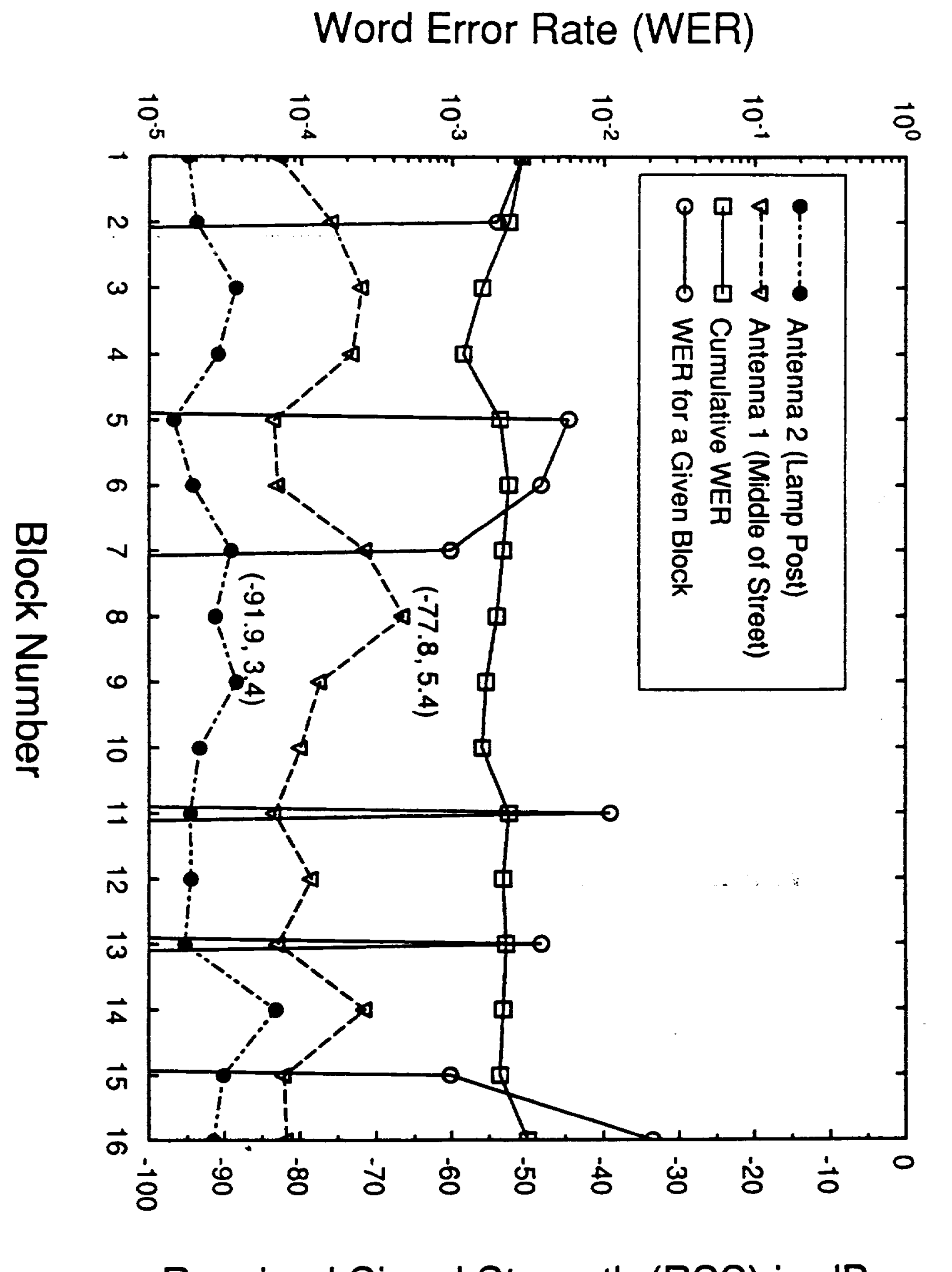

Word Error Rate (WER)
BW18.0
Antenna 2 (Lamp Post)
Antenna 1 (Middle of Street)
Cumulative WER
WER for a Given Block
(-77.8, 5.4)
(-91.9, 3.4)
Block Number
Received Signal Strength (RSS) in dBm

Figure 10

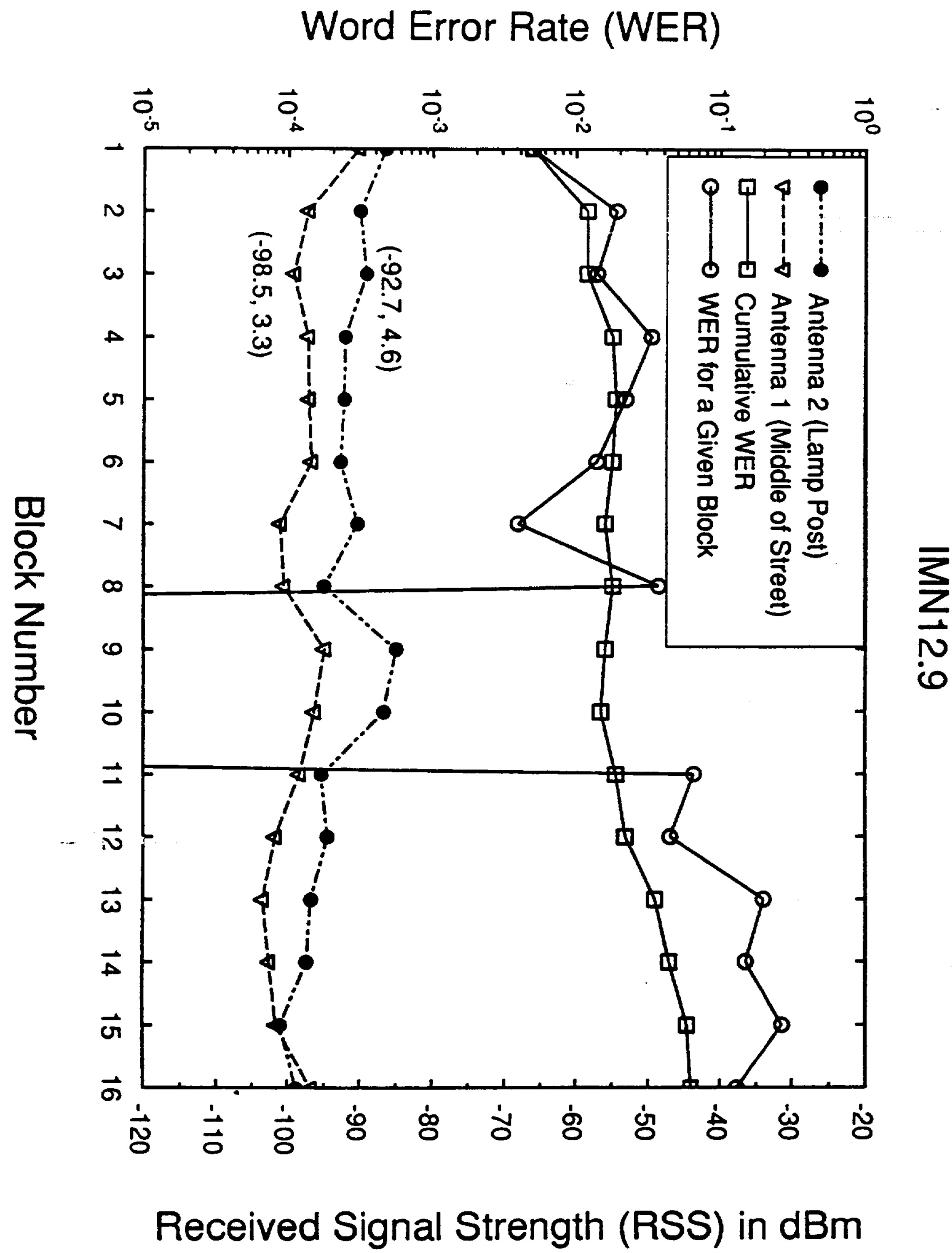

Word Error Rate (WER)
IMN12.9
Antenna 2 (Lamp Post)
Antenna 1 (Middle of Street)
Cumulative WER
WER for a Given Block
(-92.7, 4.6)
(-98.5, 3.3)
Block Number
Received Signal Strength (RSS) in dBm

Figure 11

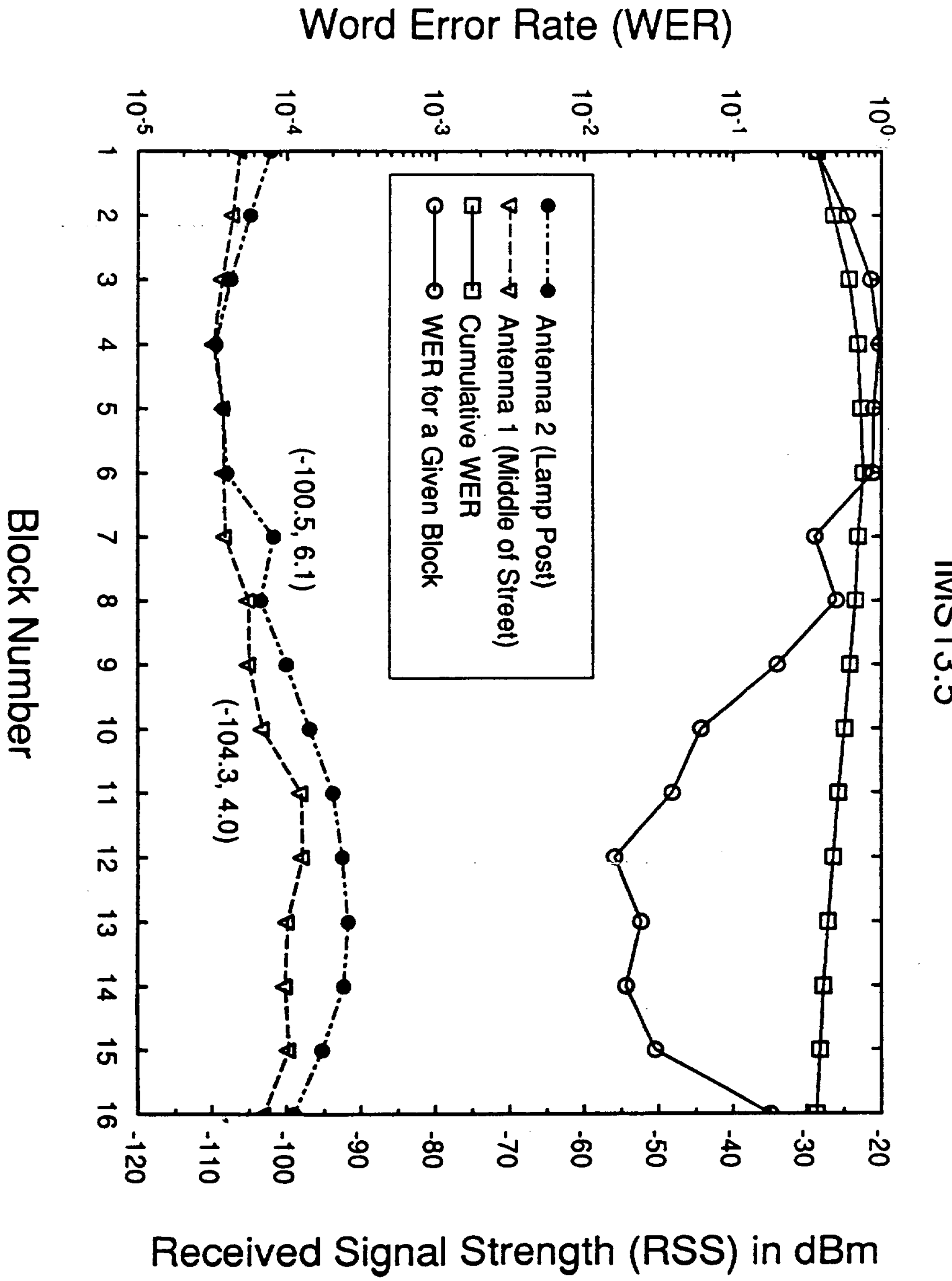
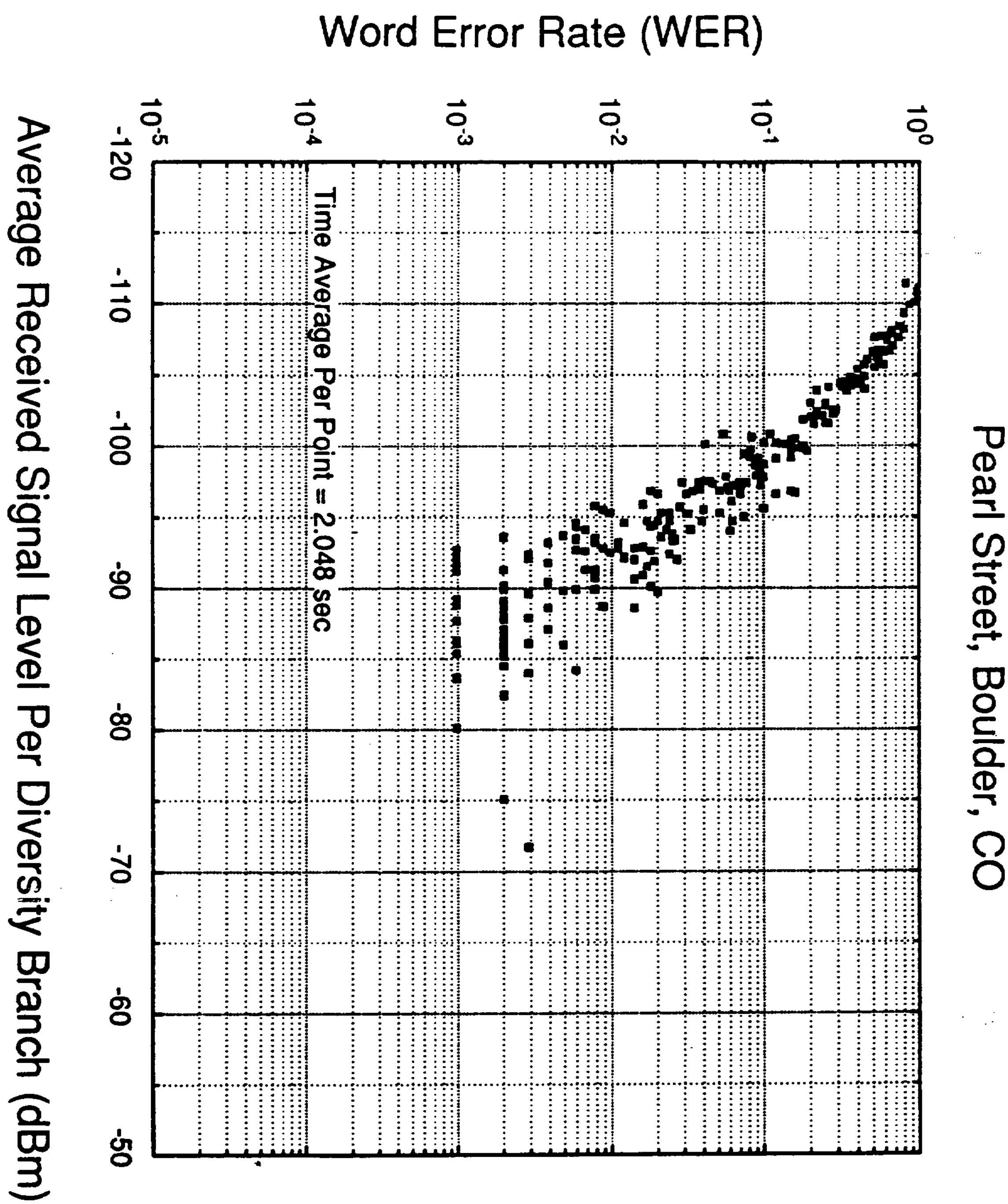
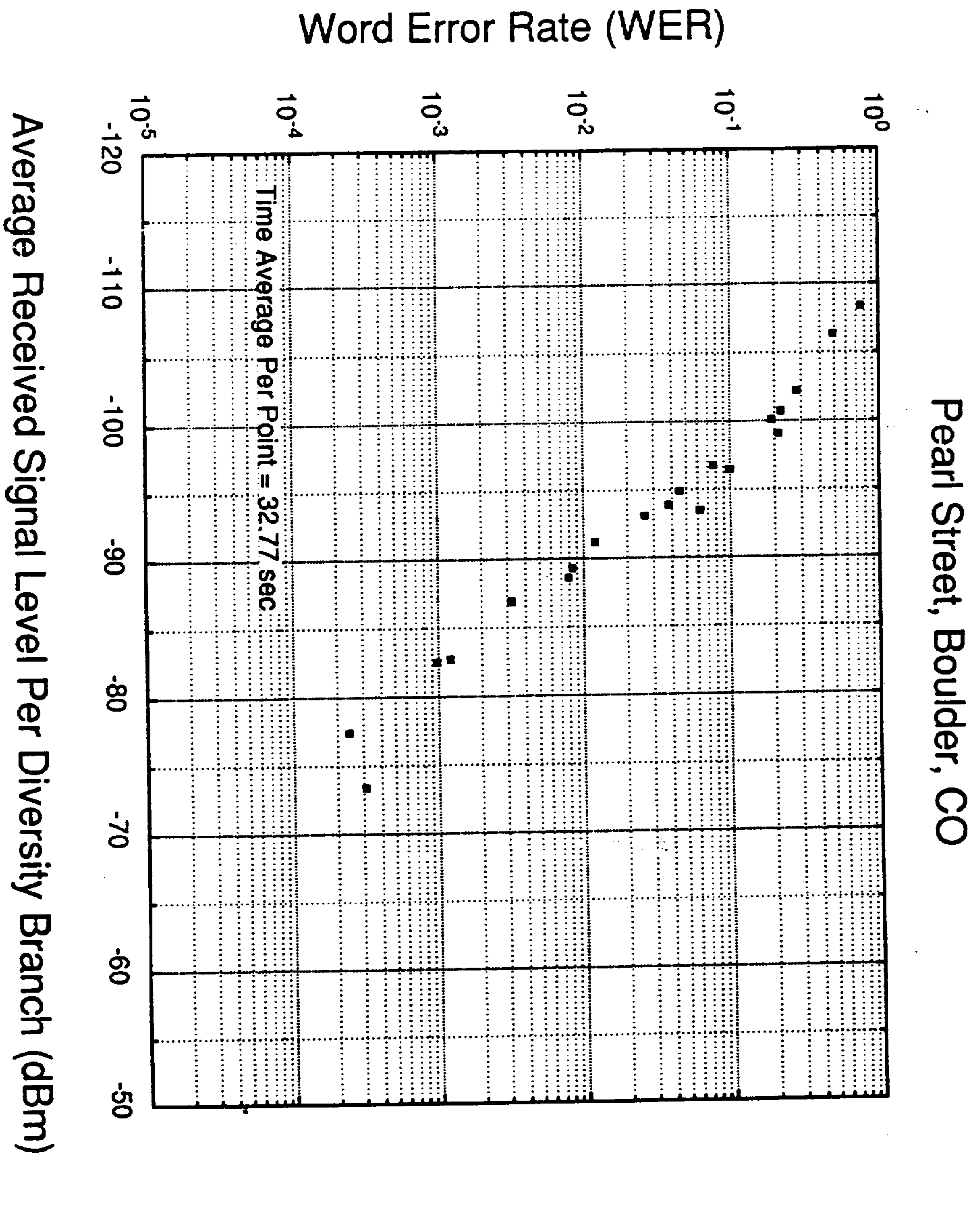

IMS13.5
Word Error Rate (WER)
Received Signal Strength (RSS) in dBm
Block Number
Antenna 2 (Lamp Post)
Antenna 1 (Middle of Street)
Cumulative WER
WER for a Given Block
(-100.5, 6.1)
(-104.3, 4.0)

Figure 12



Word Error Rate (WER)
Pearl Street, Boulder, CO
Average Received Signal Level Per Diversity Branch (dBm)
Time Average Per Point = 2.048 sec
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
-120
-110
-100
-90
-80
-70
-60
-50

Figure 13



Pearl Street, Boulder, CO
Word Error Rate (WER)
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
-120
-110
-100
-90
-80
-70
-60
-50
Time Average Per Point = 32.77 sec
Average Received Signal Level Per Diversity Branch (dBm)

Figure 14

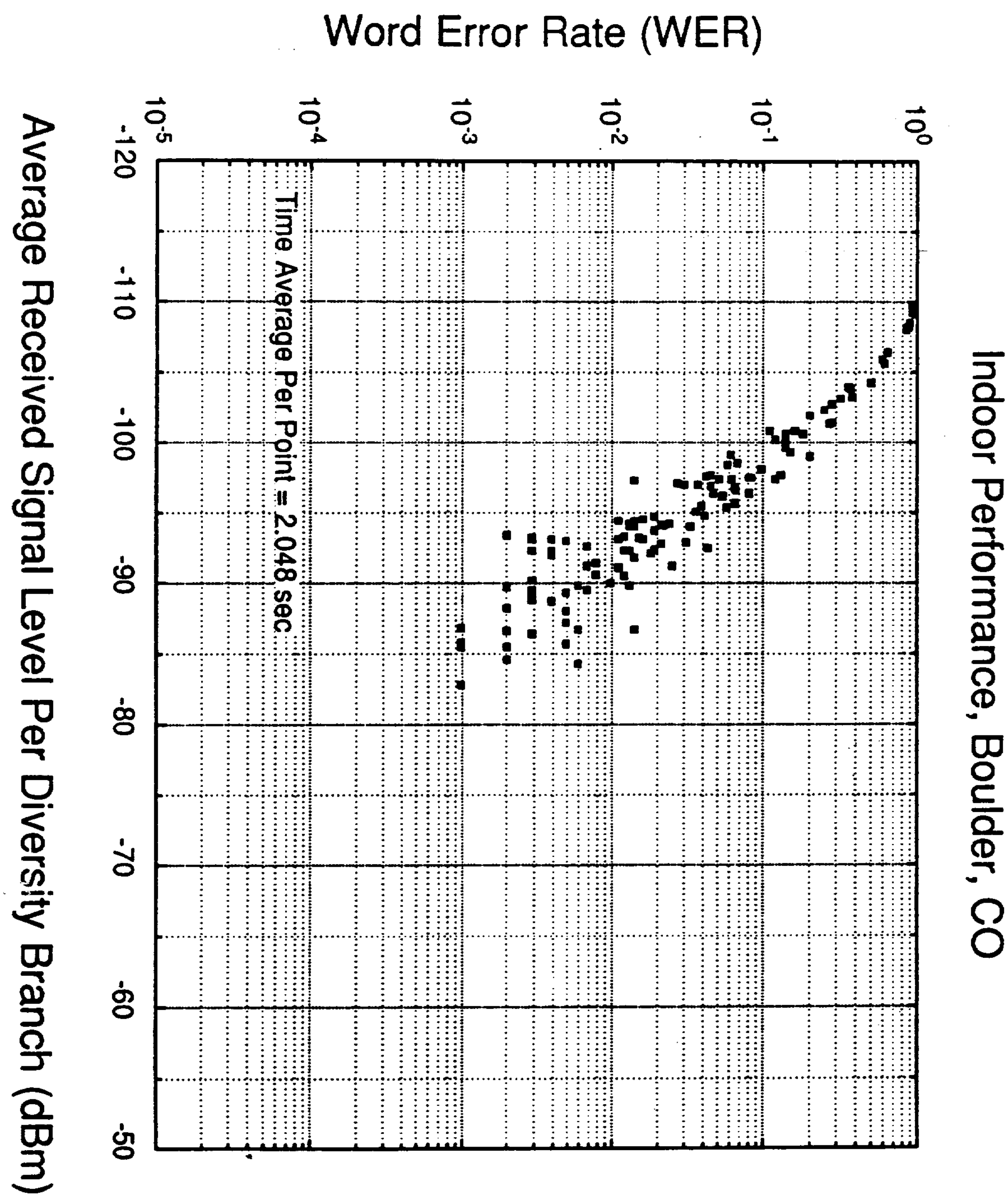

Indoor Performance, Boulder, CO
Word Error Rate (WER)
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
-120
-110
-100
-90
-80
-70
-60
-50
Time Average Per Point = 2.048 sec
Average Received Signal Level Per Diversity Branch (dBm)

Figure 15

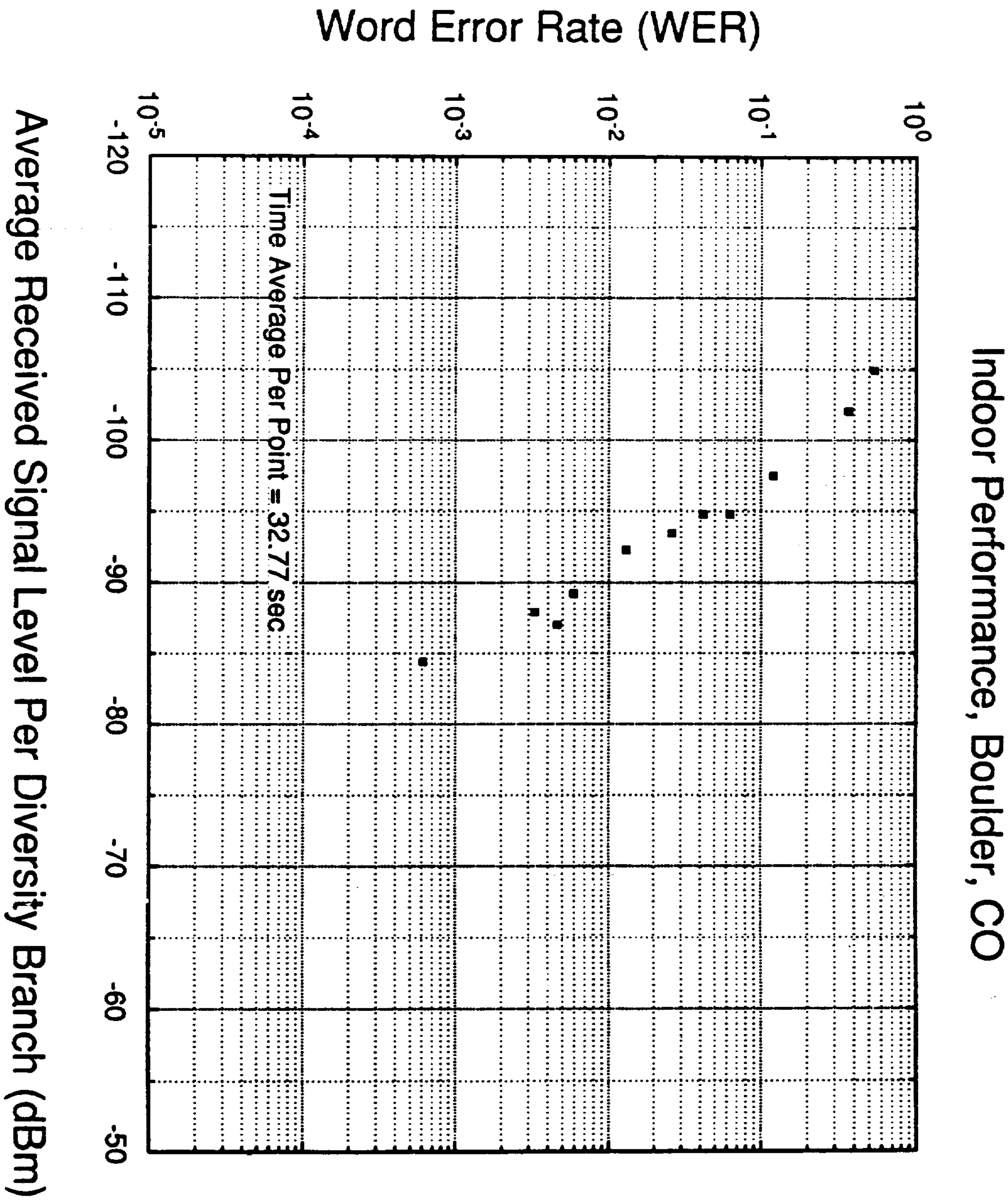

Indoor Performance, Boulder, CO
Word Error Rate (WER)
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
-120
-110
-100
-90
-80
-70
-60
-50
Time Average Per Point = 32.77 sec
Average Received Signal Level Per Diversity Branch (dBm)

Figure 16

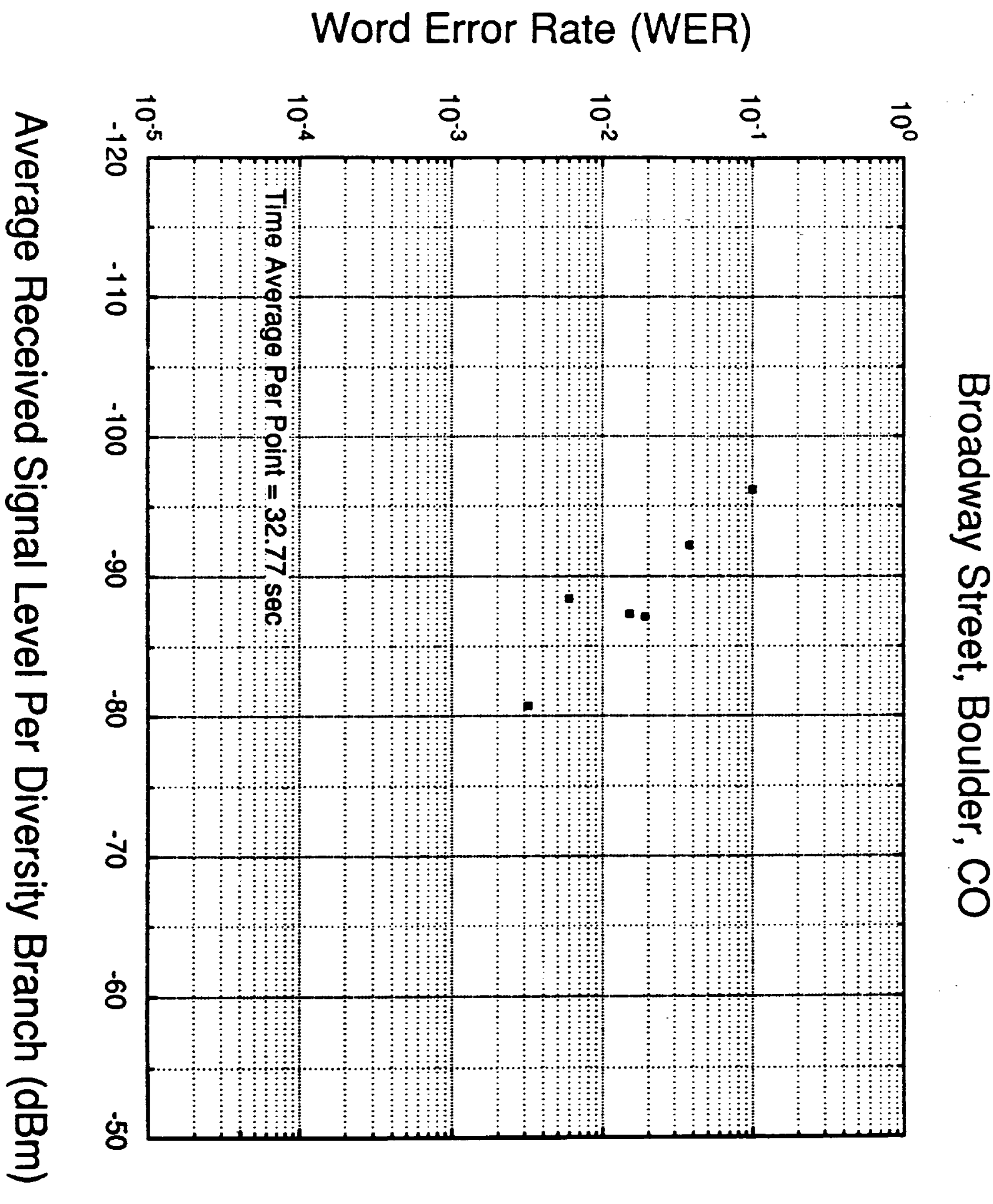

Broadway Street, Boulder, CO
Word Error Rate (WER)
Average Received Signal Level Per Diversity Branch (dBm)
Time Average Per Point = 32.77 sec
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
-120
-110
-100
-90
-80
-70
-60
-50

Figure 17

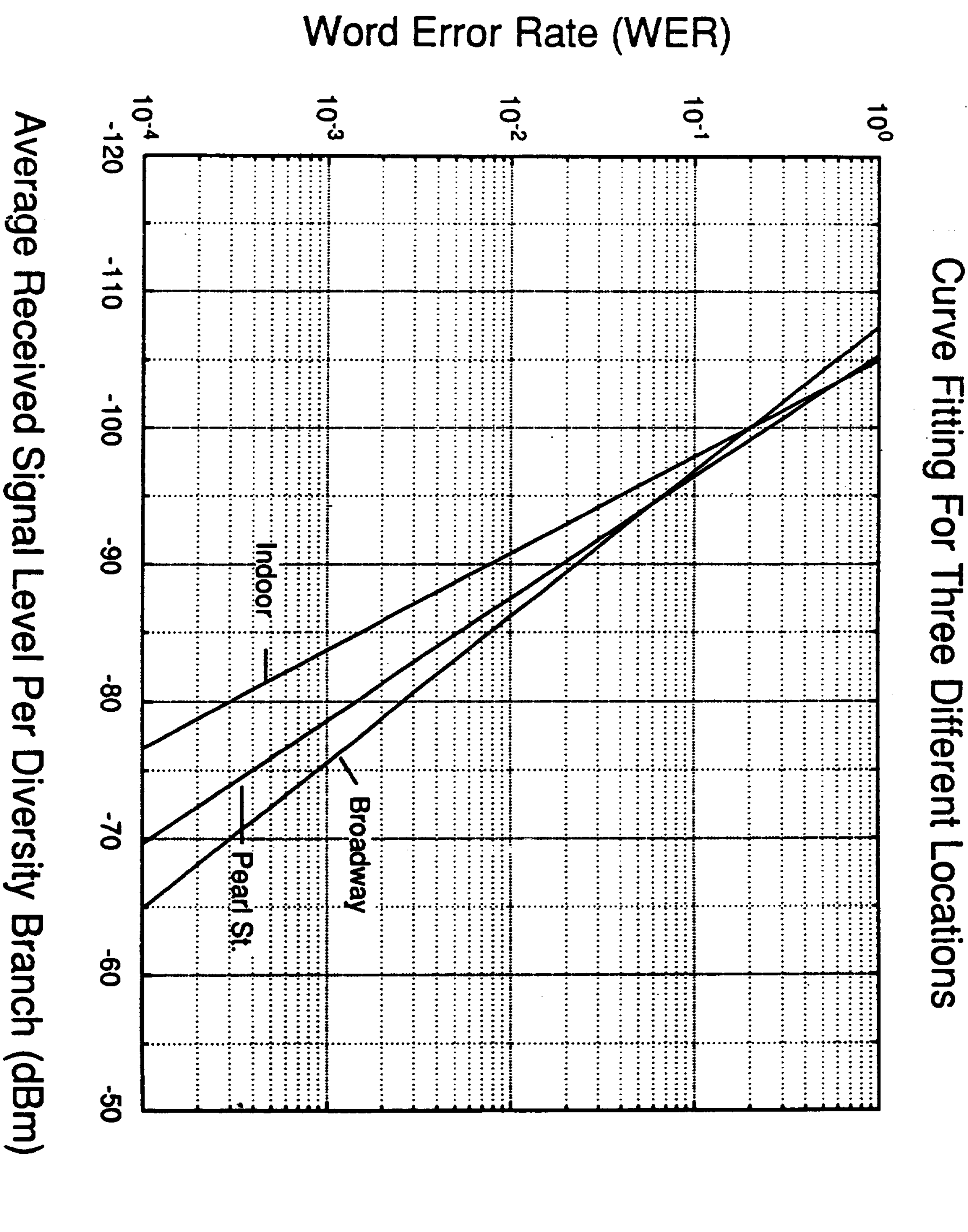

Curve Fitting For Three Different Locations
Word Error Rate (WER)
10^0
10^-1
10^-2
10^-3
10^-4
Average Received Signal Level Per Diversity Branch (dBm)
-120
-110
-100
-90
-80
-70
-60
-50
Indoor
Broadway
Pearl St.

Figure 18

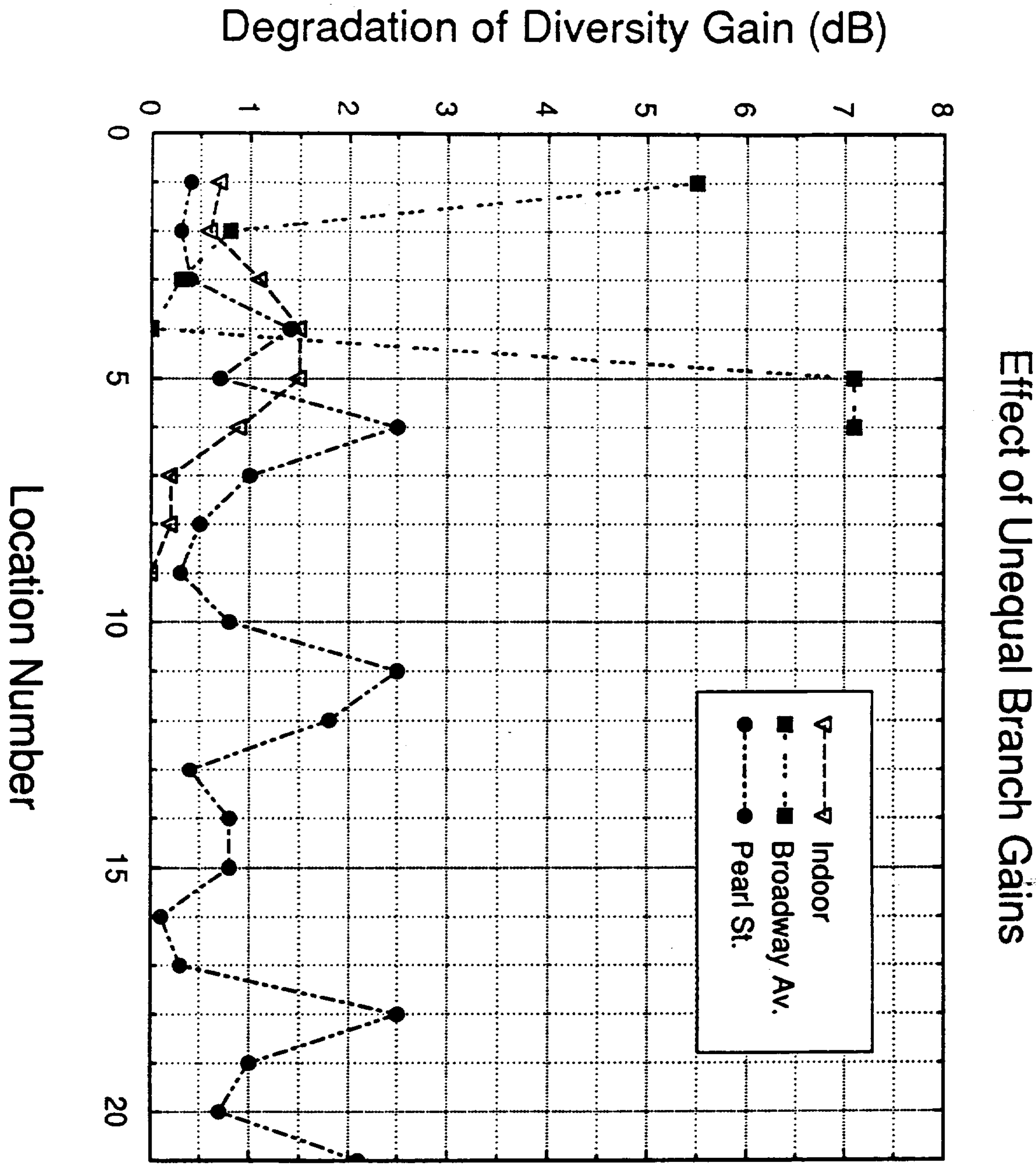

Effect of Unequal Branch Gains
Degradation of Diversity Gain (dB)
Location Number
Indoor
Broadway Av.
Pearl St.
0
1
2
3
4
5
6
7
8
0
5
10
15
20

Figure 19

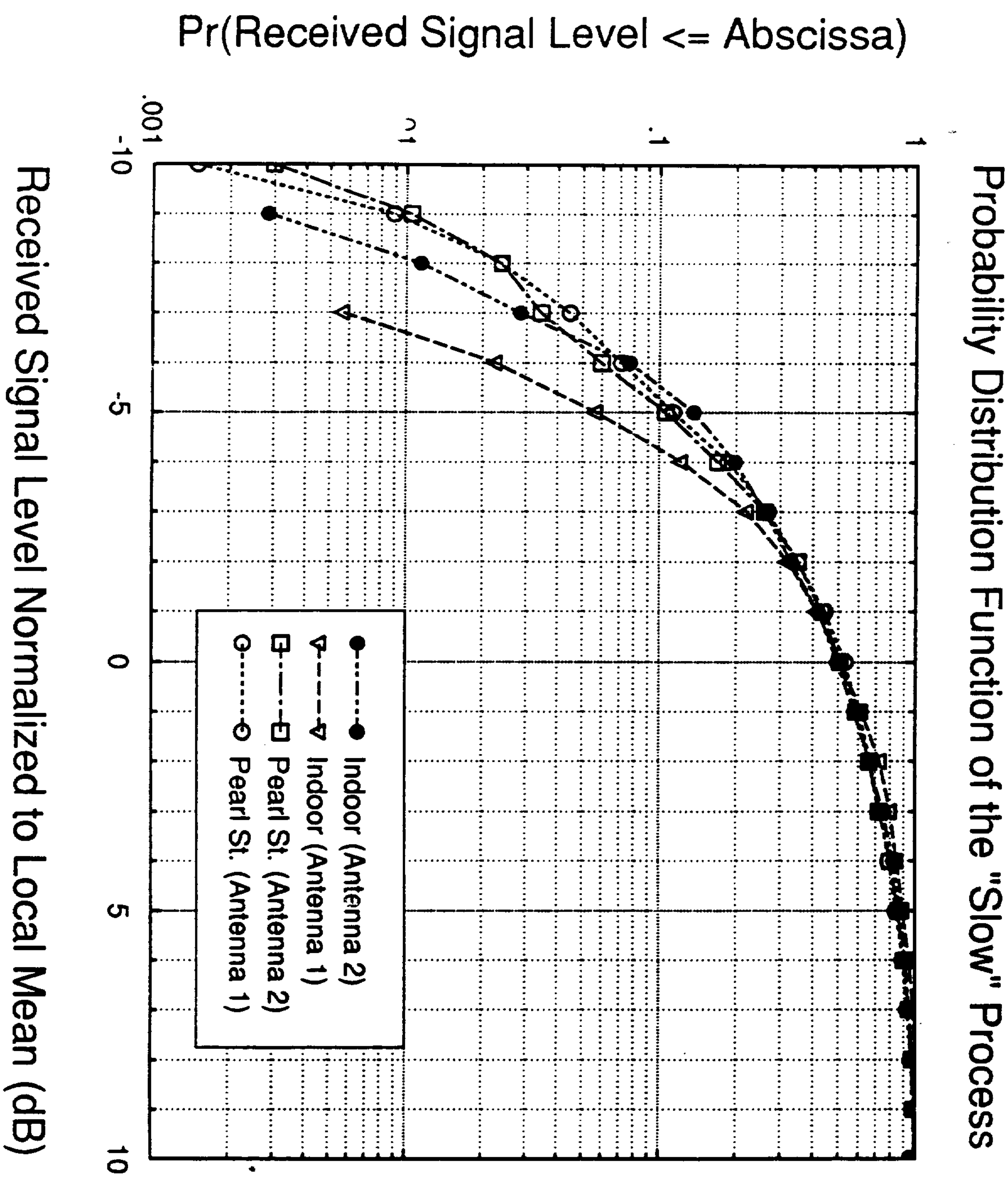

Probability Distribution Function of the "Slow" Process
Pr(Received Signal Level <= Abscissa)
Received Signal Level Normalized to Local Mean (dB)
Indoor (Antenna 2)
Indoor (Antenna 1)
Pearl St. (Antenna 2)
Pearl St. (Antenna 1)
1
.1
.01
.001
-10
-5
0
5
10

Figure 20

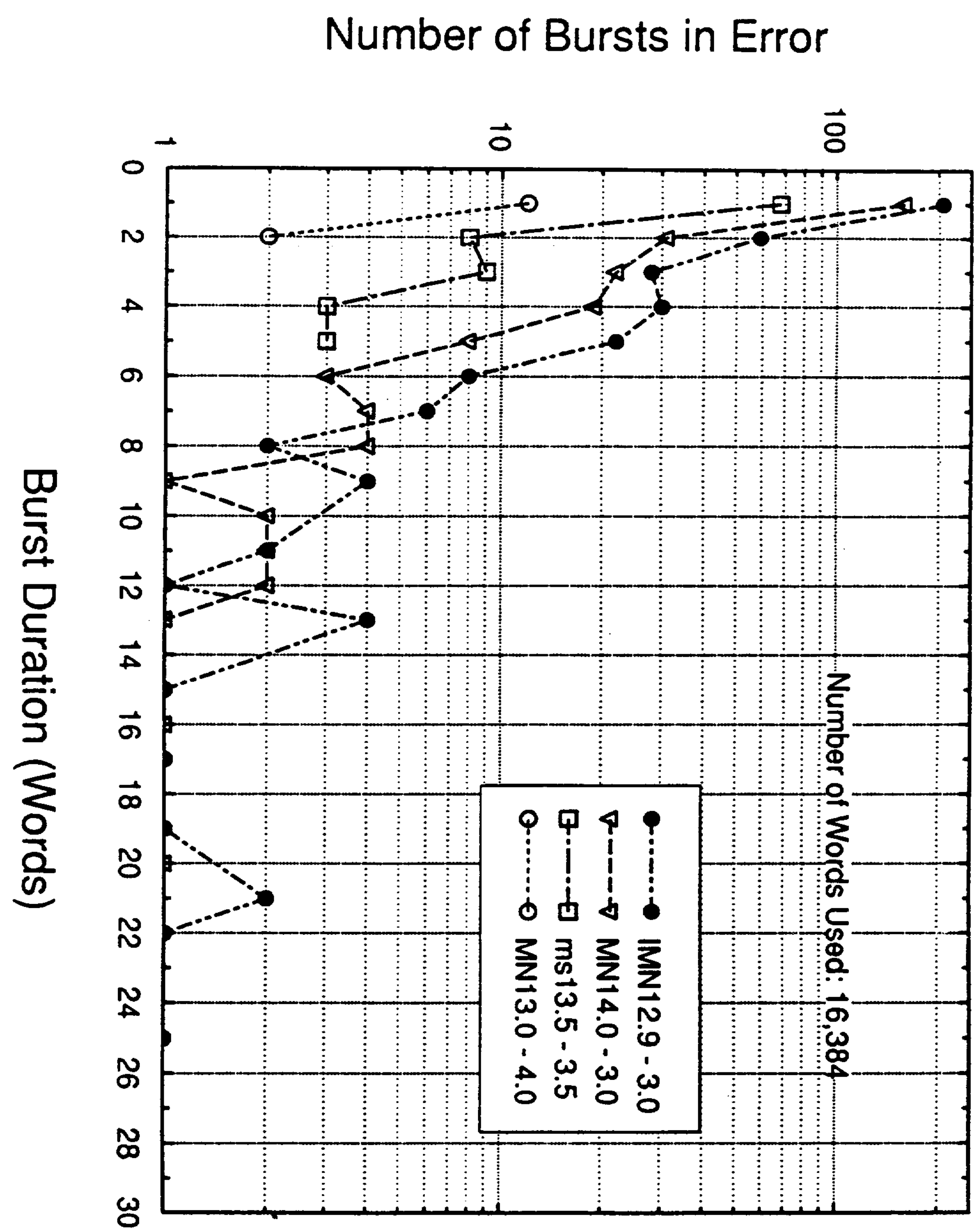

Number of Bursts in Error
Burst Duration (Words)
Number of Words Used: 16,384
IMN12.9 - 3.0
MN14.0 - 3.0
ms13.5 - 3.5
MN13.0 - 4.0
1
10
100
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

Figure 21

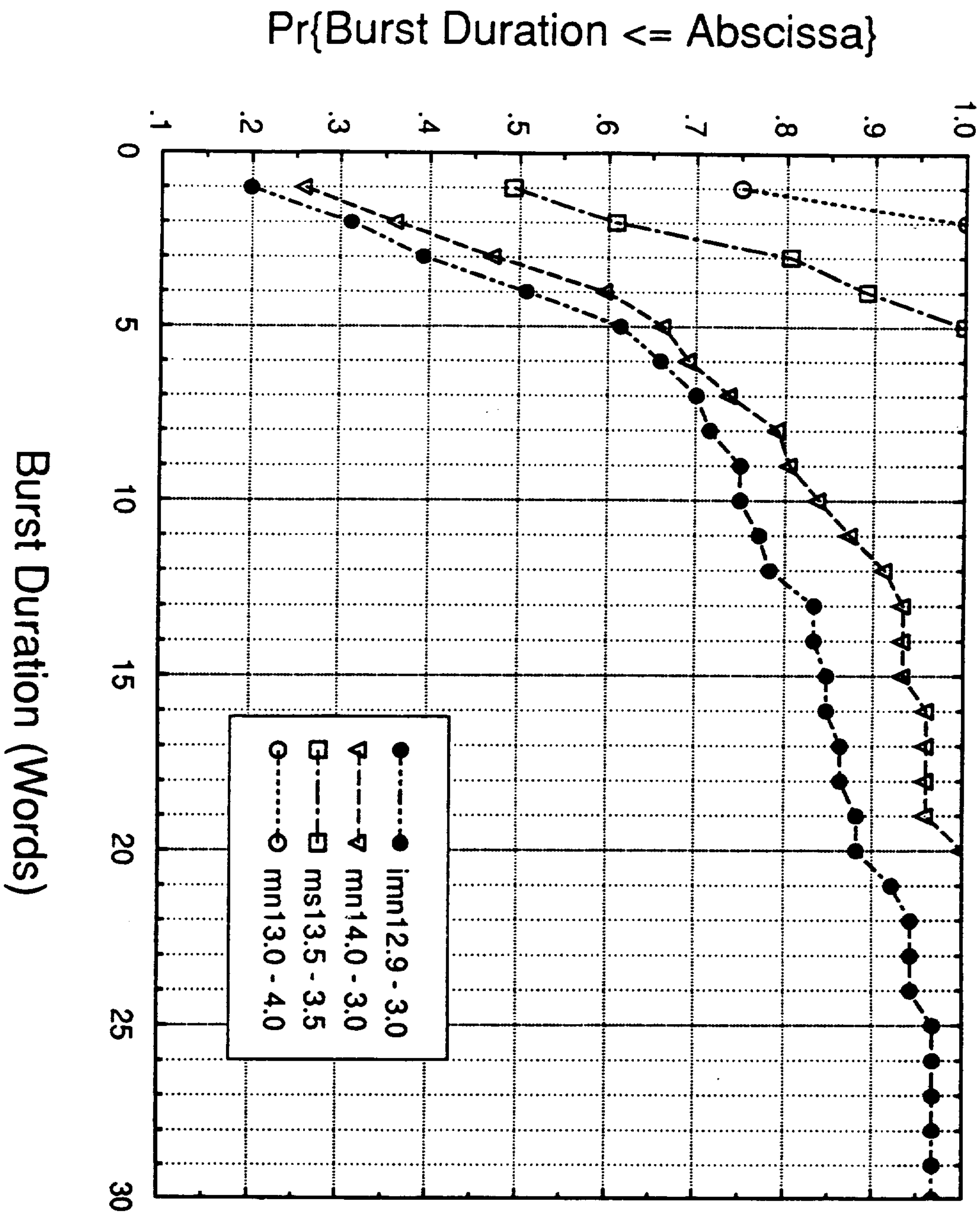
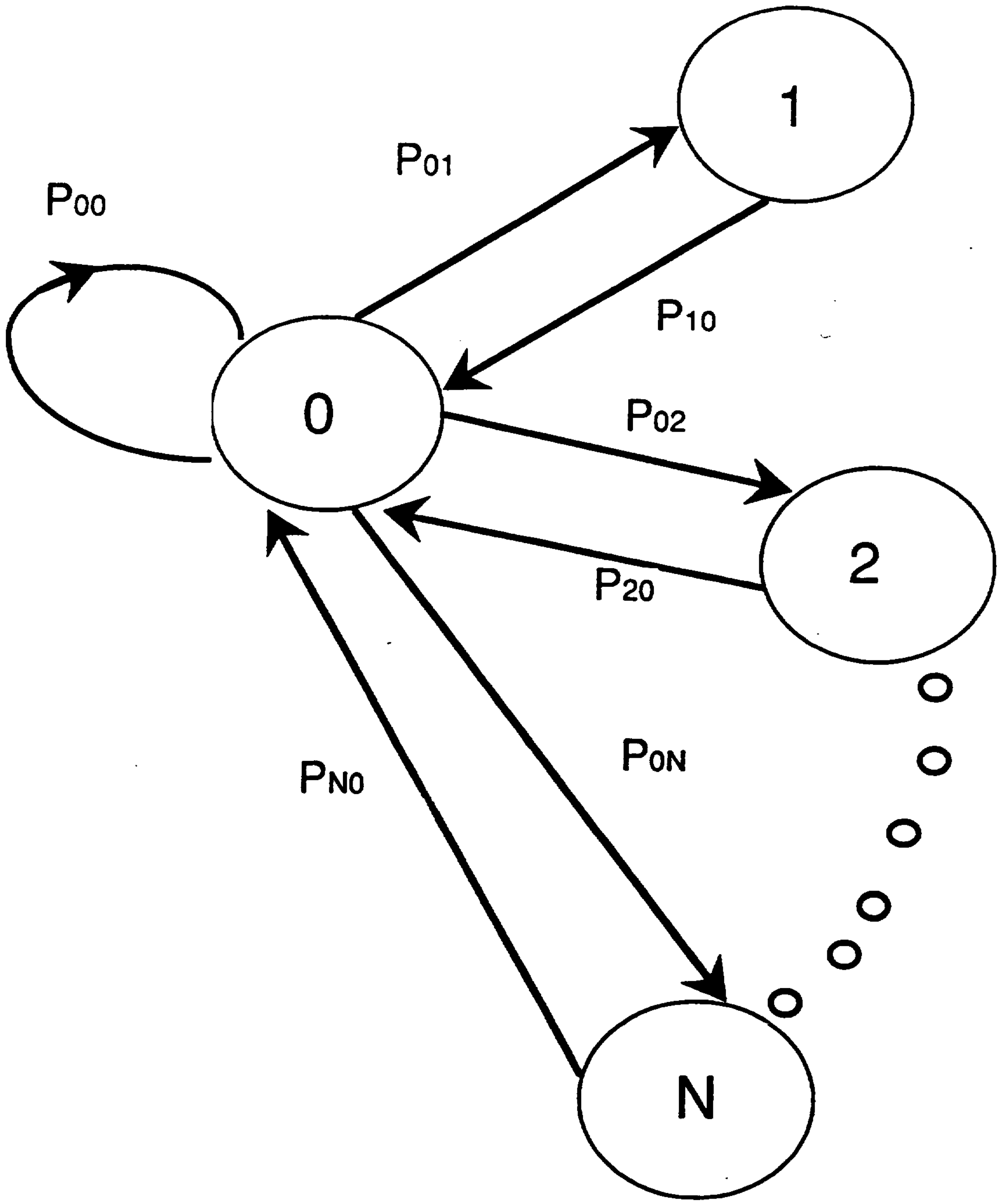

Pr{Burst Duration <= Abscissa}
Burst Duration (Words)
imn12.9 - 3.0
mn14.0 - 3.0
ms13.5 - 3.5
mn13.0 - 4.0

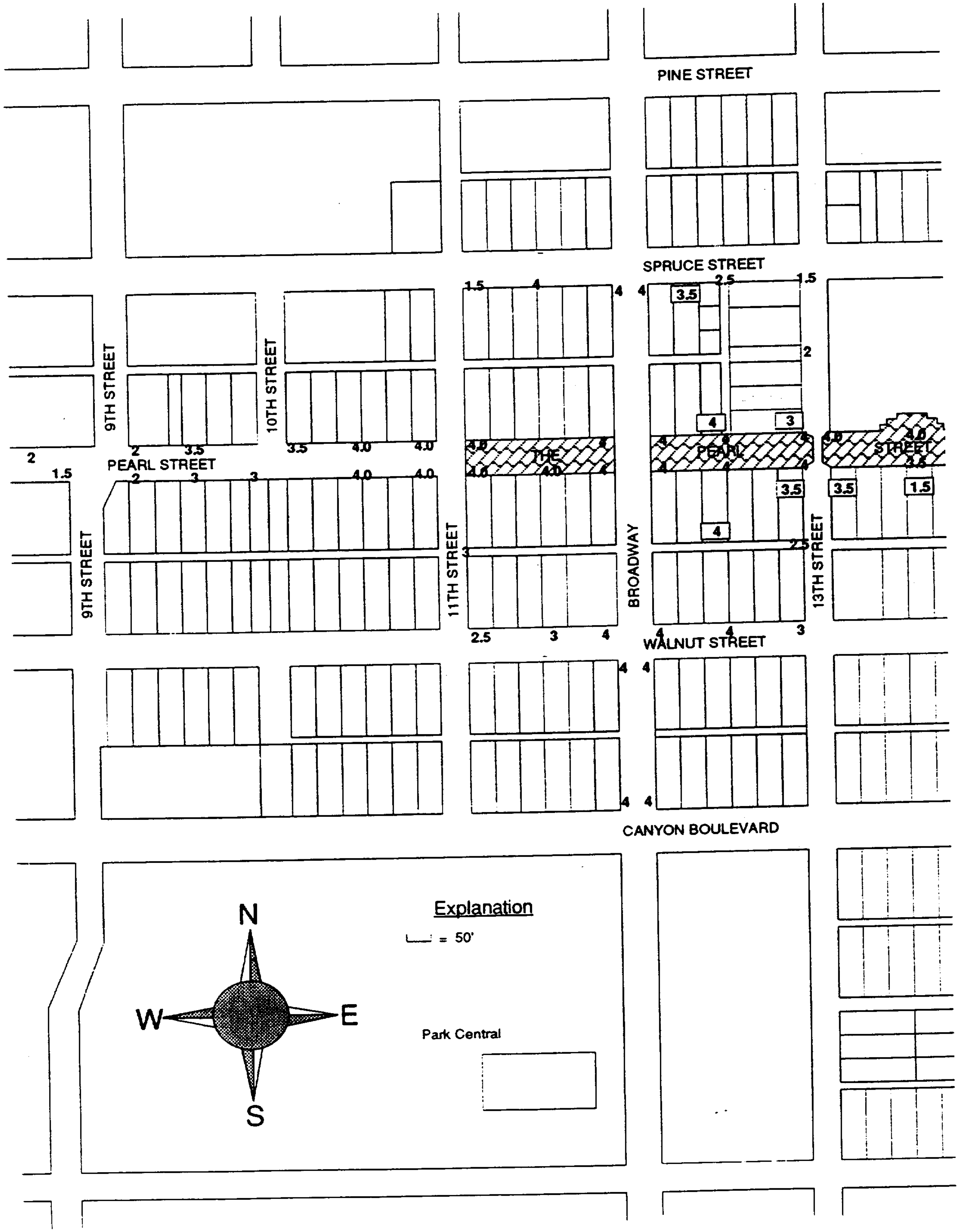
Figure 22



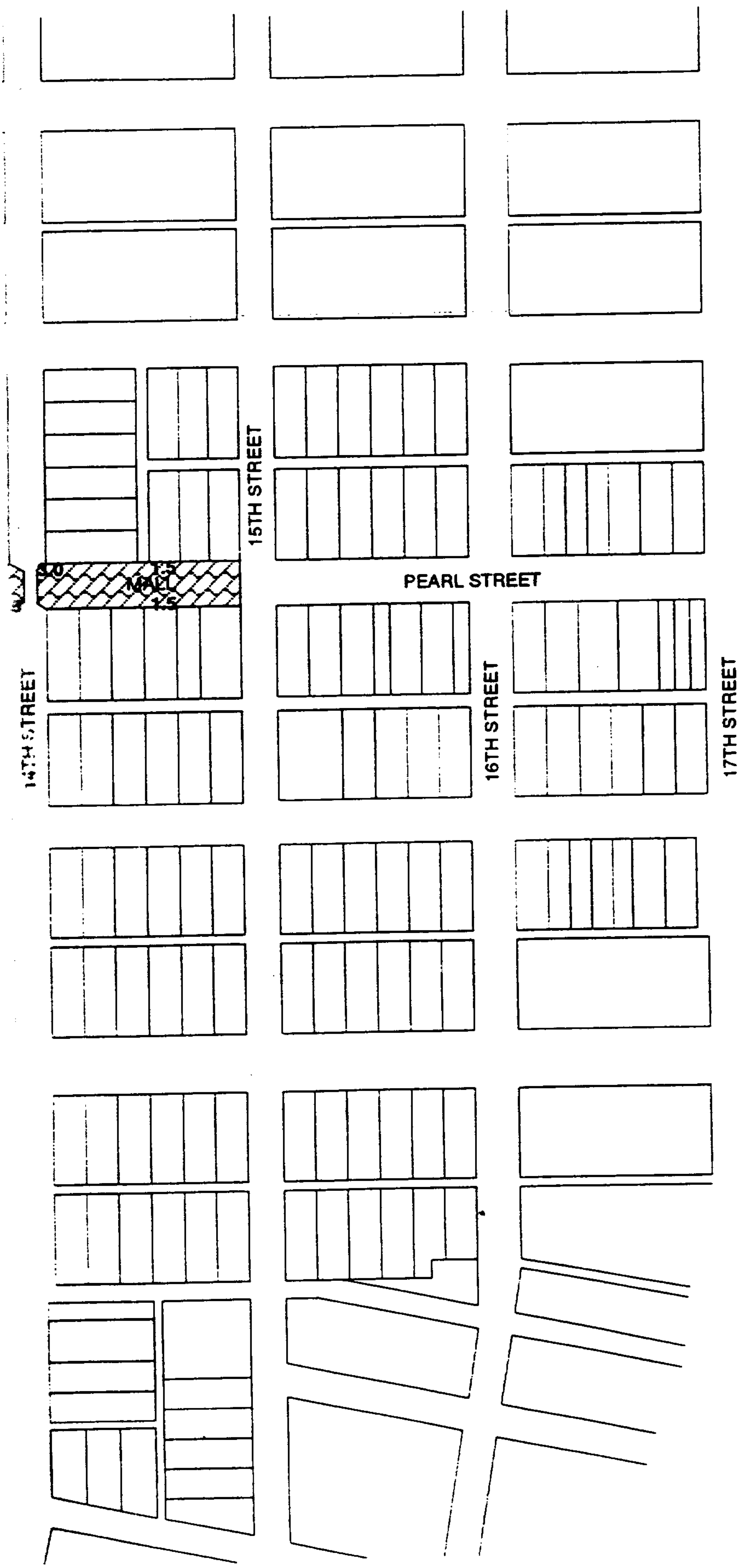
N = Burst Duration

Figure 23

2400 BROADWAY — 2.5
2300 BROADWAY — 3.5



1600 BROADWAY — 3
1500 BROADWAY — 3



UPLINK ONLY

[x] OUTDOOR-TO-INDOOR

BOULDER, CO
UDPCS EXPERIMENTAL DATA
SUBJECTIVE VOICE QUALITY

4 - GOOD

3 - FAIR

2 - POOR

1 - UNUSABLE