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Analysis of Spectrum Utilization and Message Length Statistics for the Railroad Land Mobile Radio Service

Michael Terada

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In support of the Federal Railroad Administration (FRA) of the United States Department of Transportation, the Institute for Telecommunication Sciences (ITS) has completed a field spectrum usage survey designed to examine individual channel utilization and message length distributions. The measurement system was developed by ITS staff members to measure signal strength in each of the 91 channels used by the railroad industry in the frequency band from 160.215 MHz to 161.565 MHz. The measurement system surveyed three different sites selected for varying conditions such as the different types of traffic over the channels, propagation environments, line-of-sight conditions, and electromagnetic interference.

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U.S. DEPARTMENT OF COMMERCE
William M. Daley, Secretary

Larry Irving, Assistant Secretary
for Communications and Information

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ANALYSIS OF SPECTRUM UTILIZATION AND MESSAGE LENGTH STATISTICS FOR THE RAILROAD LAND MOBILE RADIO SERVICE

Michael Terada[1]

In support of the Federal Railroad Administration of the United States Department of Transportation, the Institute for Telecommunication Sciences (ITS) has completed a field spectrum utilization survey designed to examine individual channel utilization and message length distributions. The measurement system was developed by ITS staff members to measure signal strength in each of the 91 channels used by the railroad industry in the frequency band from 160.215-161.565 MHz. The measurement system surveyed three different sites selected for varying conditions such as the different types of traffic over the channels, propagation environments, line-of-sight conditions, and electromagnetic interference.

Key words: spectrum usage; spectrum utilization; message characteristics; message length distributions

1. INTRODUCTION

The Institute for Telecommunication Sciences (ITS) has been involved in a railroad telecommunications study for the Federal Railroad Administration (FRA). This study has examined and reviewed a telecommunications system to be used by the Union Pacific and the Burlington Northern Railroads (UP/BN RRs) in their development of a positive train control (PTC) system. As part of that study, ITS was asked to provide support to the FRA on understanding telecommunications policy developments and utilizing telecommunications technology that affects PTC and high-speed rail (HSR) telecommunications system.

This report describes ITS' examination of the railroad industry's current spectrum utilization. In particular, we report on the frequencies from 160.215-161.565 MHz, which are exclusively assigned to the railroad land mobile radio service. Each of the channels is 15 kHz wide and is frequency modulated (FM). Each user may use the channels in one of two ways to transmit voice or data. The channels can be used as mobile-to-base station (or mobile) using a single frequency or as mobile-to-repeater-to-base station (or mobile) using two frequencies. The channels assigned in other bands are shared with other services and the 800/900-MHz assignments currently have limited use for data communications. Using the measurement system, we surveyed three different sites that would allow for varying conditions, such as the different types of traffic over the channels, propagation environments, line-of-sight conditions, and

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electromagnetic interference. The spectrum utilization surveys were conducted from June 11, 1996, through August 20, 1996, at three different sites spanning two states and three cities. Throughout this report, the term utilization and usage are used interchangeably.

2. SPECTRUM UTILIZATION SURVEY

We examined spectrum utilization of the radio channels in order to determine (1) current spectrum utilization and (2) any diurnal variations for selected sites. The spectrum utilization was analyzed by recording individual channel usage and message characteristics to determine message length distributions for particular measurement sites, voice channels, and data channels.

2.1 Survey Site Selection

Three cities were selected for the spectrum usage measurements: Kansas City, Missouri; Saint Louis, Missouri; and Chicago, Illinois. Figures 1, 2, and 3 show the location of the measurements for Kansas City, Saint Louis, and Chicago, respectively. Figures 4, 5, and 6 show the surrounding area and site locations for Kansas City, Saint Louis, and Chicago, respectively. These cities were chosen because they are important railroad centers, and the radio traffic at these locations was expected to be some of the busiest in the country. The measurements were made in railroad yards with site selection assistance from Union Pacific.
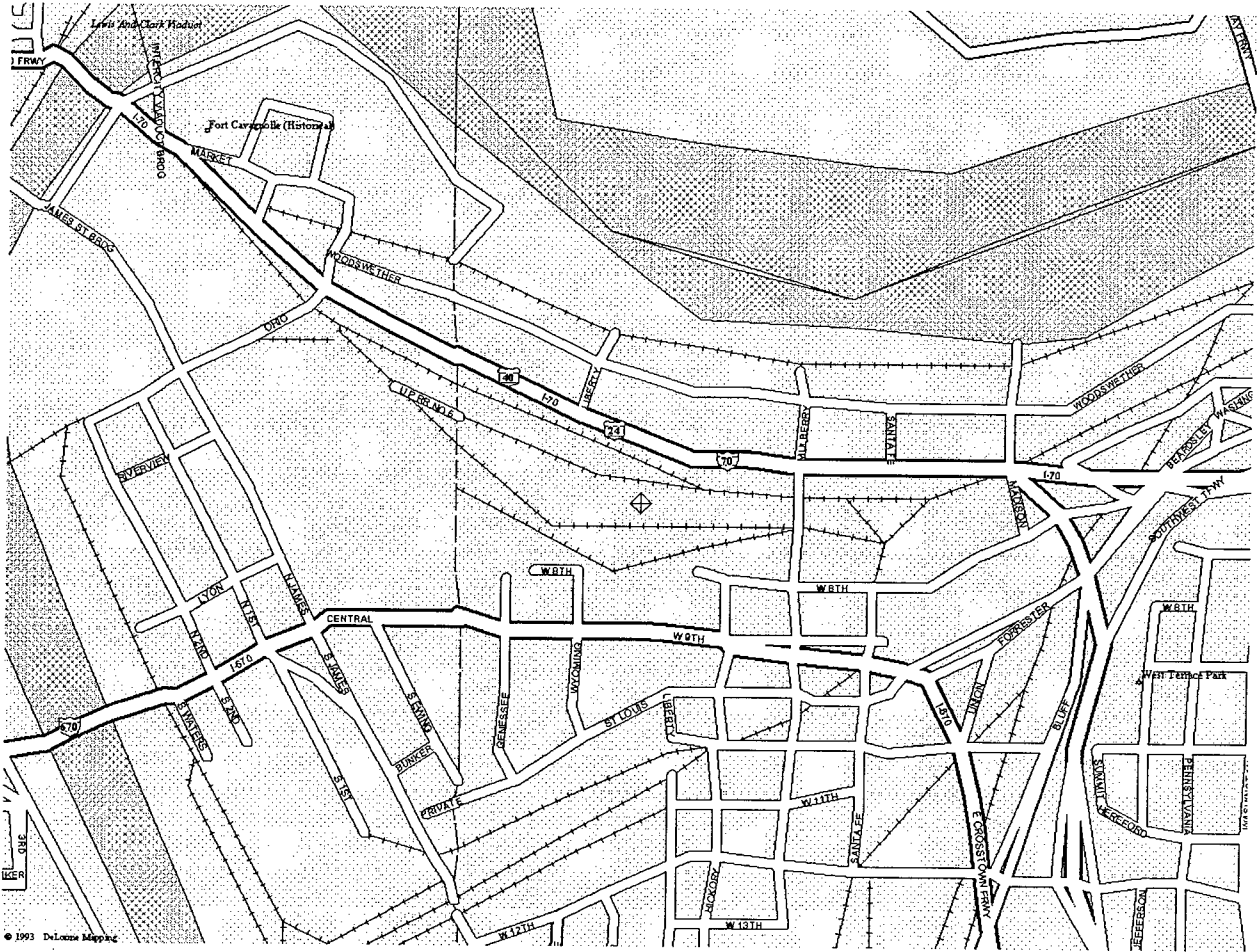
Figure 1. Detailed map of the site location in Kansas City, Missouri; the diamond with the cross in the middle marks the measurement site. Map from DeLorme's MapExpert, Freeport, Maine © 1993 DeLorme Mapping.
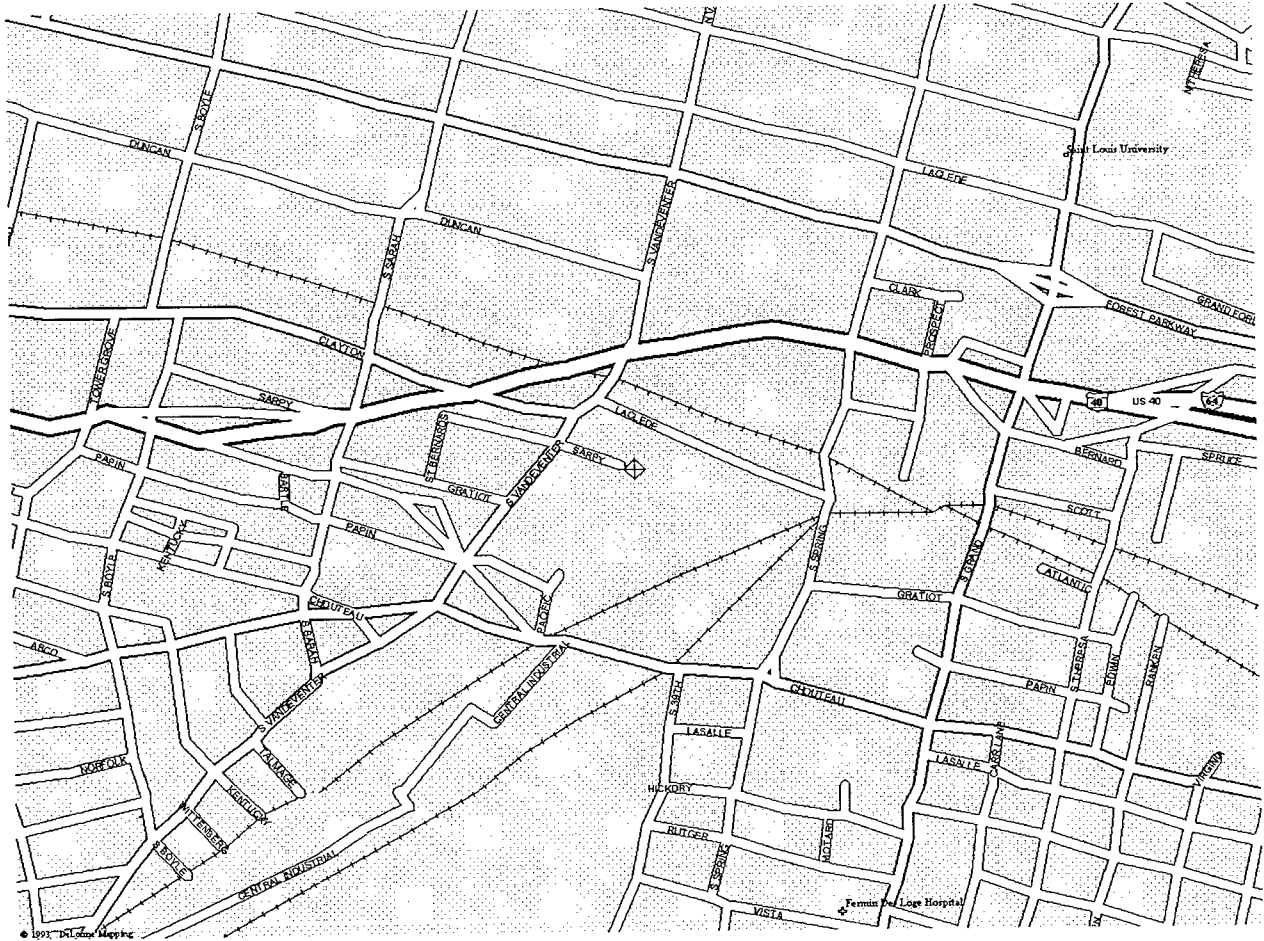
Figure 2. Detailed map of the site location in Saint Louis, Missouri; the diamond with the cross in the middle marks the measurement site. Map from DeLorme's MapExpert, Freeport, Maine © 1993 DeLorme Mapping.
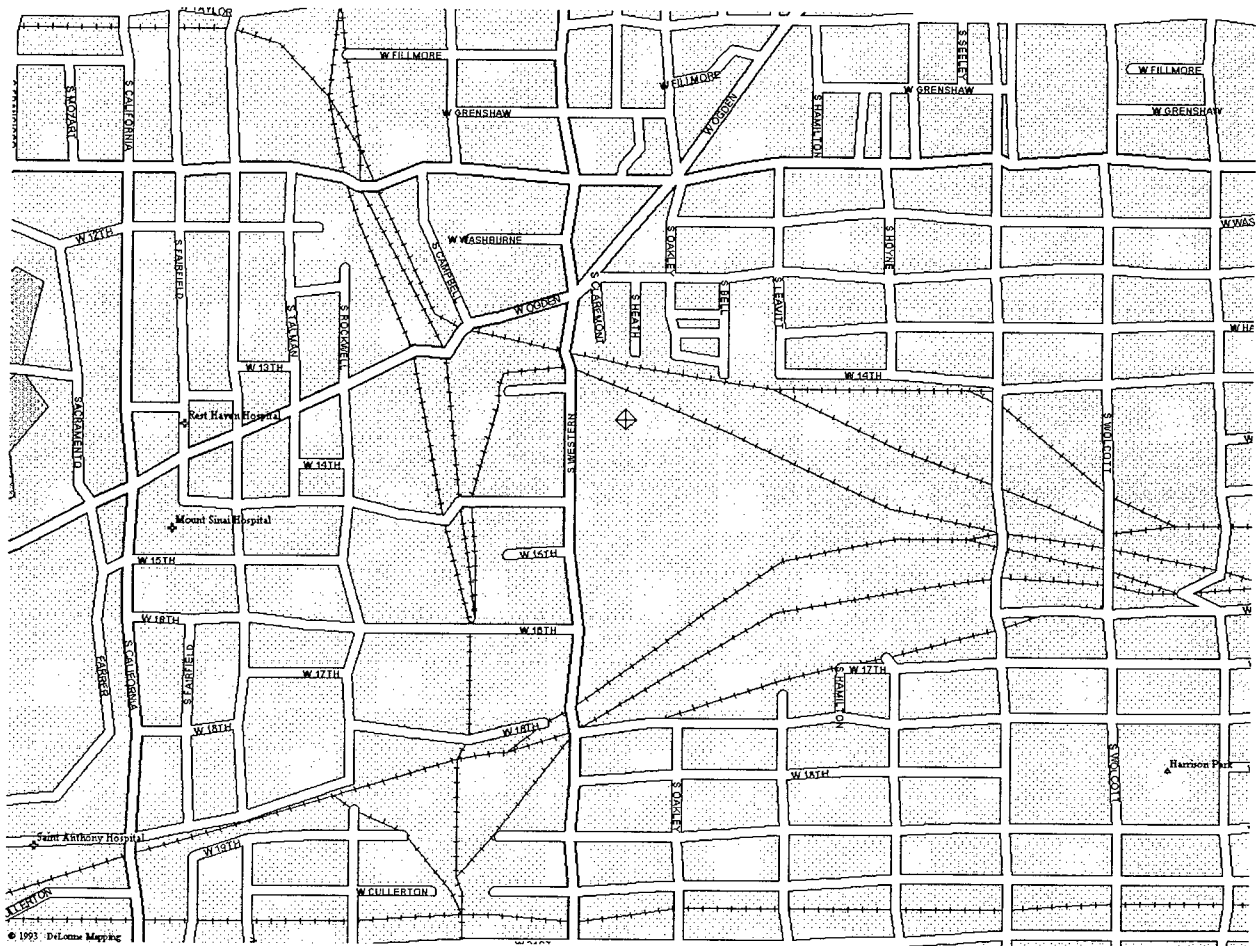
Figure 3. Detailed map of the site location in Chicago, Illinois; the diamond with the cross in the middle marks the measurement site. Map from DeLorme's MapExpert, Freeport, Maine © 1993 DeLorme Mapping.
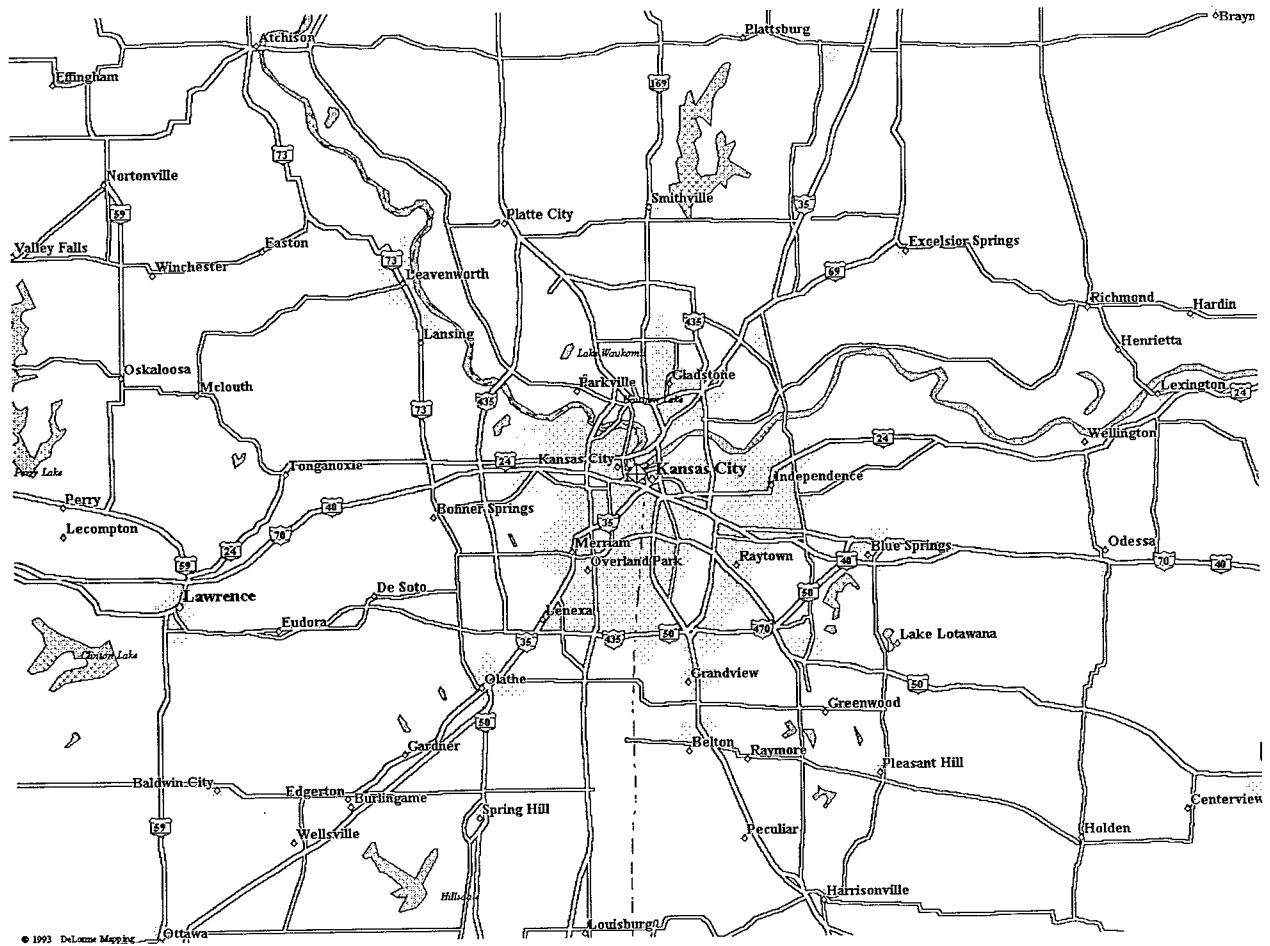
Figure 4. Map of the surrounding area of the Kansas City, Missouri site; the diamond with the cross in the middle marks the measurement site. Map from DeLorme's MapExpert, Freeport, Maine © 1993 DeLorme Mapping.

Figure 5. Map of the surrounding area of the Saint Louis, Missouri site; the diamond with the cross in the middle marks the measurement site. Map from DeLorme's MapExpert, Freeport, Maine © 1993 DeLorme Mapping.

Figure 6. Map of the surrounding area of the Chicago, Illinois site; the diamond with the cross in the middle marks the measurement site. Map from DeLorme's MapExpert, Freeport, Maine © 1993 DeLorme Mapping.
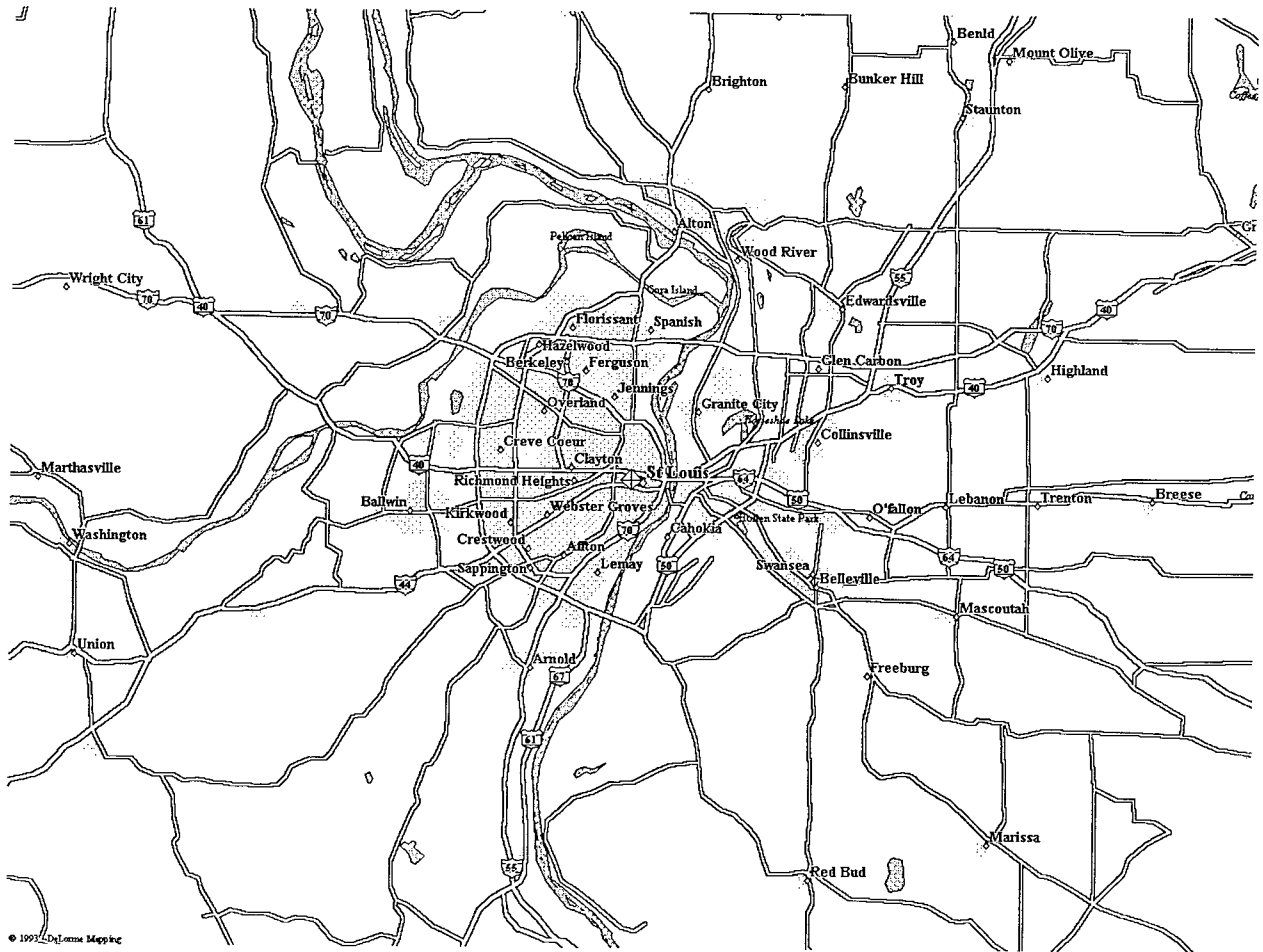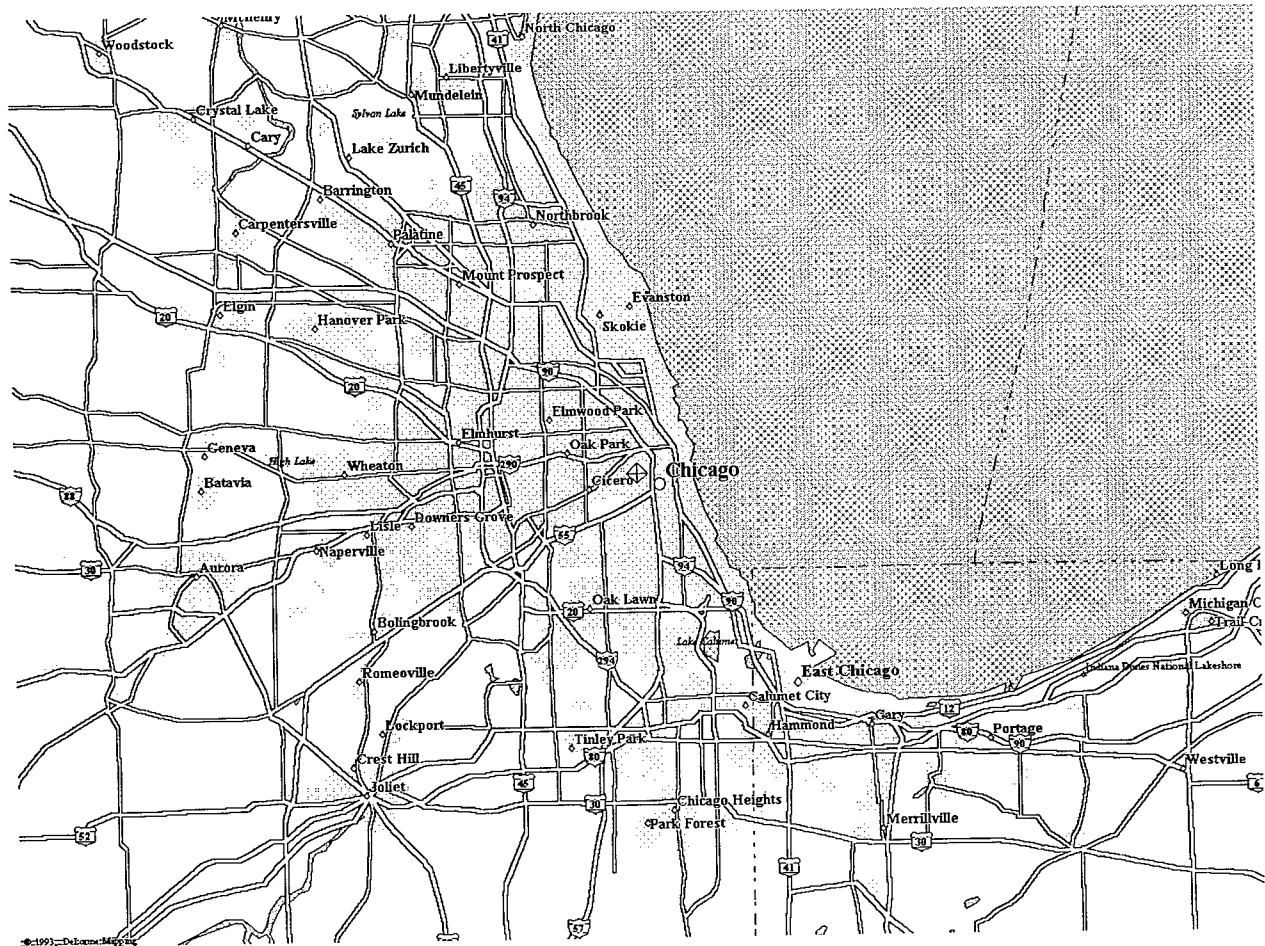
To enhance signal intercept probability, line-of-sight coverage was considered to increase the probability of weak signal reception, such as transmissions from mobile and distant transmitters. The measurement antenna was mounted on a 9-m mast to increase the line-of-sight area. To prevent measurement system overload due to high input signals, the sites needed to be distant (at least 1 km) from base stations and repeaters used by railroads, or if there were transmitters nearby, they had to be low-power transmitters. The sites were selected because there was a high probability that the receiver would be able to receive signals from multiple rail yards. Finally, the sites had to have limited man-made noise such as impulsive noise from automobile ignition systems and electrical machinery (other than what could be expected from locomotives). Logistical factors that had to be considered included (1) commercial power, since these measurements needed to be conducted continuously for one week; and (2) the security of personnel, vehicle, and electronic equipment.

Plots showing the line-of-sight and nonline-of-sight regions from the measurement system's raised antenna are shown in Figures 7, 8, and 9 for Kansas City, Saint Louis, and Chicago,

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respectively. On the plots, line-of-sight regions mean that the top and bottom of the antenna can be seen and receiver-line-of-sight regions mean that the top of the antenna can be seen. Shadow program plot overlays are provided by Telecommunications Analysis Services, Institute for Telecommunication Sciences, U.S. Department of Commerce, Boulder, CO 80303-3328.
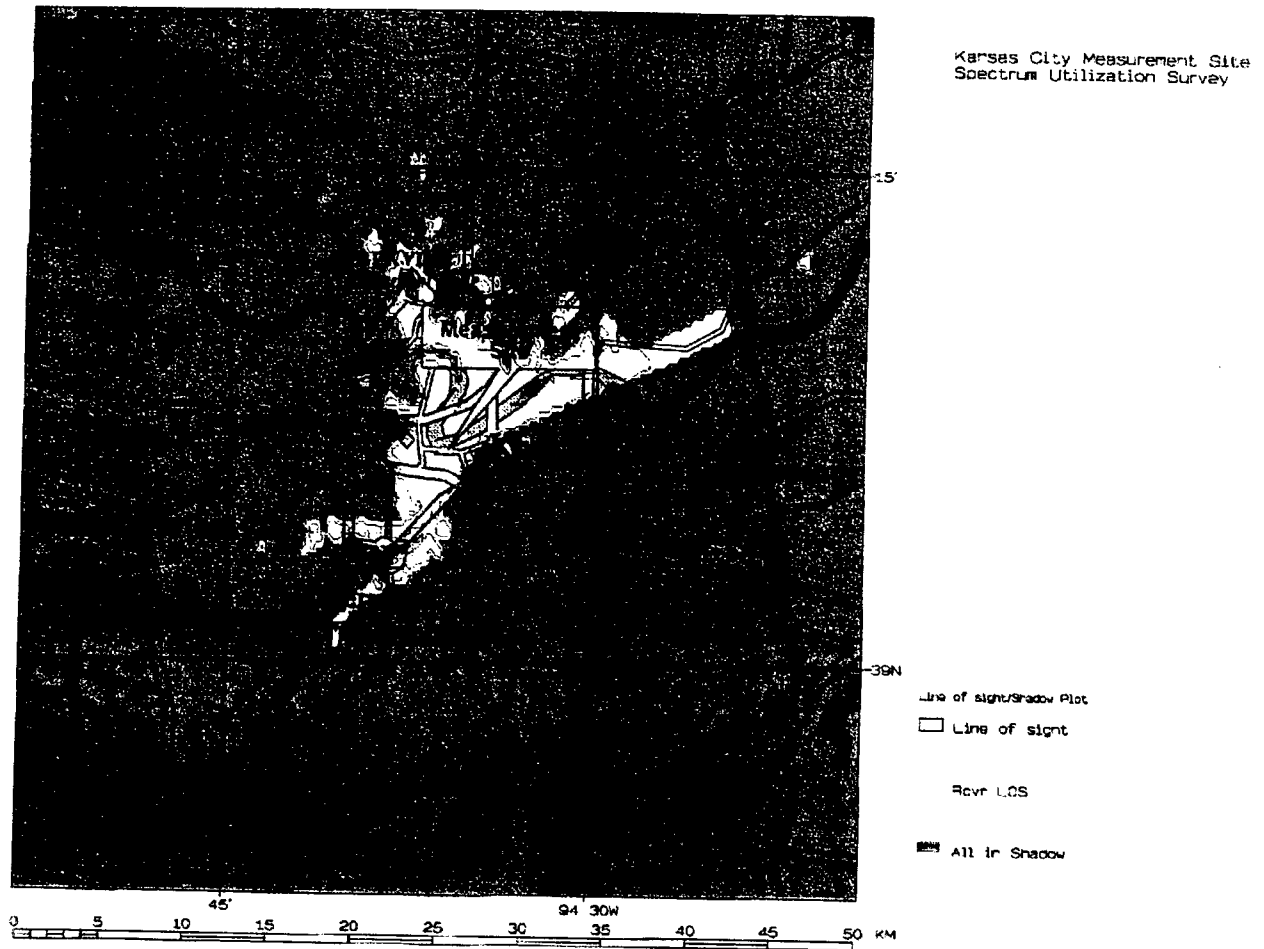

Figure 7. Line-of-sight and nonline-of-sight regions from the measurement system's raised antenna in Kansas City, Missouri. Map from DeLorme's MapExpert, Freeport, Maine © 1993 DeLorme Mapping.
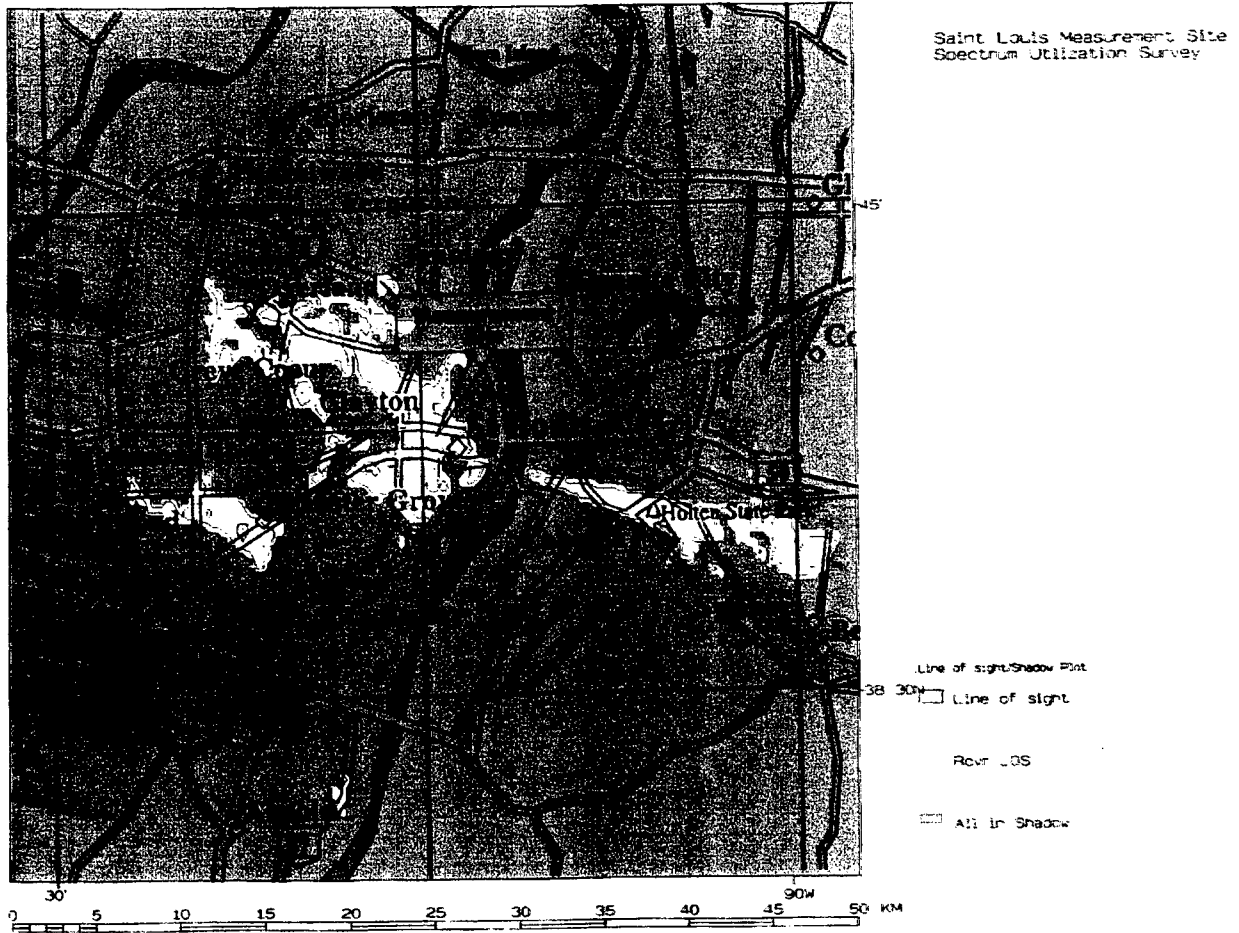
Figure 8. Line-of-sight and nonline-of-sight regions from the measurement system's raised antenna in Saint Louis, Missouri. Map from DeLorme's MapExpert, Freeport, Maine © 1993 DeLorme Mapping.
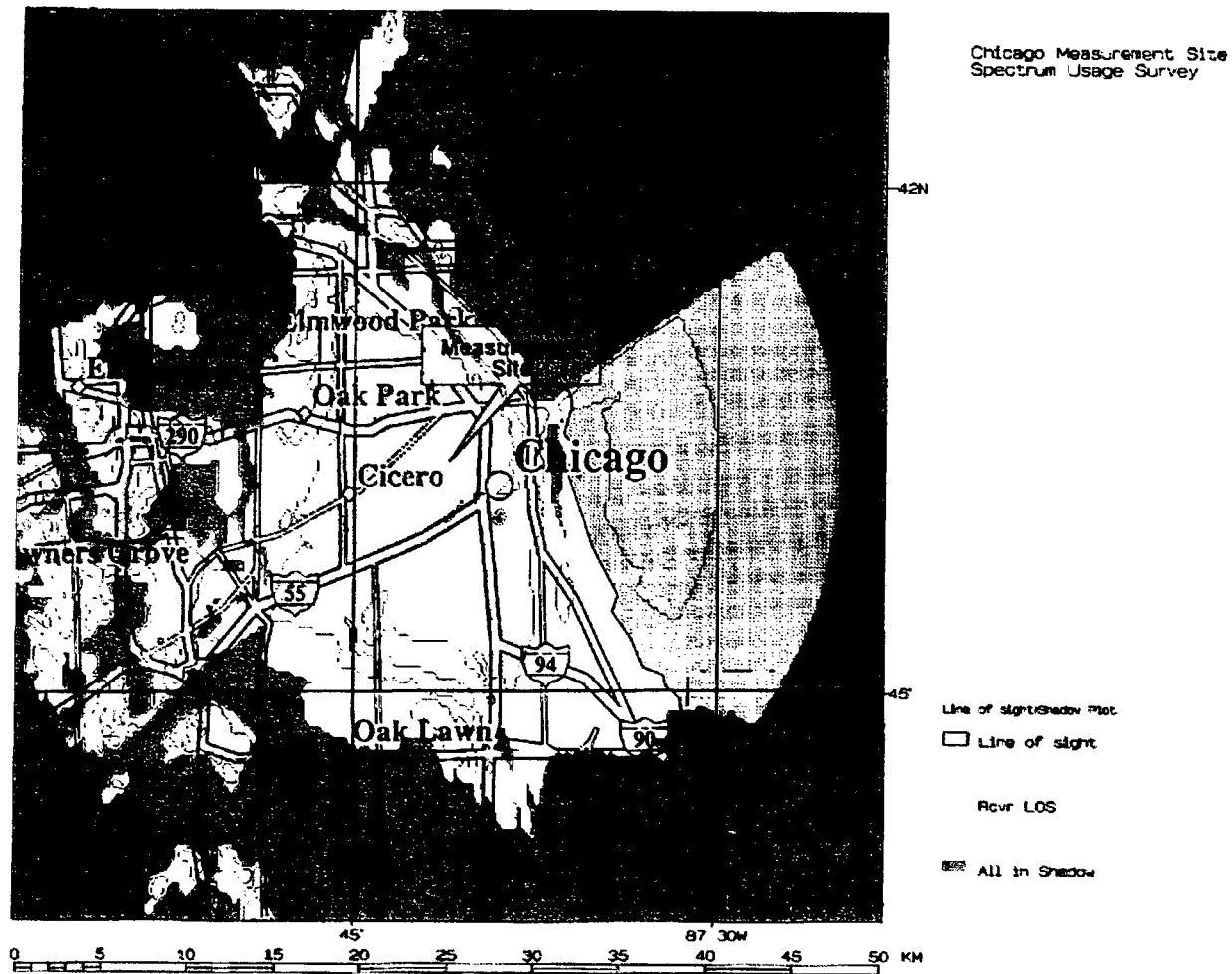
Figure 9. Line-of-site and nonline-of-sight regions from the measurement system's raised antenna in Chicago, Illinois. Map from DeLorme's Map Expert, Freeport, Maine © 1993 DeLorme Mapping.

2.2 Measurement System

To obtain a good sampling of the railroad service frequency band spectrum usage from 160.215-161.565 MHz, measurements were made 24 hours per day for approximately a one-week period at each site. The system was operated automatically using the data acquisition (DA) software described in the Appendix. The measurement software provides instructions to configure the receiver system, execute measurement routines, record measured data, and maintain a real-time log of the measurements and key parameters.

The measurement system provides a "snapshot" of the spectrum occupancy at the time of measurement for a given location and antenna height. This "snapshot" can change by adjusting

such factors as sampling rate; time of day, month, or year of measurement; measurement location; or antenna height.

The channel occupancy surveys were conducted using a discone antenna connected to an RF preselector and preamplifier. The signals were then passed through a spectrum analyzer with a 15-kHz wide IF filter (centered at 21.4 MHz) used in place of the spectrum analyzer's built-in IF (resolution bandwidth) filter. This was required because the spectrum analyzer's filter would not reject energy from adjacent channels well enough to give an accurate representation of the energy in each channel. The preselector and spectrum analyzer were both controlled by a Pentium-based computer via an IEEE-488 bus. Figure 10 shows a block diagram of the measurement system. The measurement equipment was installed in a van to facilitate taking the measurements at the three different locations. The antenna was attached to a 9-m mast to increase reception of the radio signals.

Discone antenna

Preselector and
Preamplifier 0-2 GHz
(HP-85685A)

Spectrum Analyzer
0-22 GHz (HP-8566B)
and 15 kHz IF Filter

Pentium-based Computer
with GPIB interface

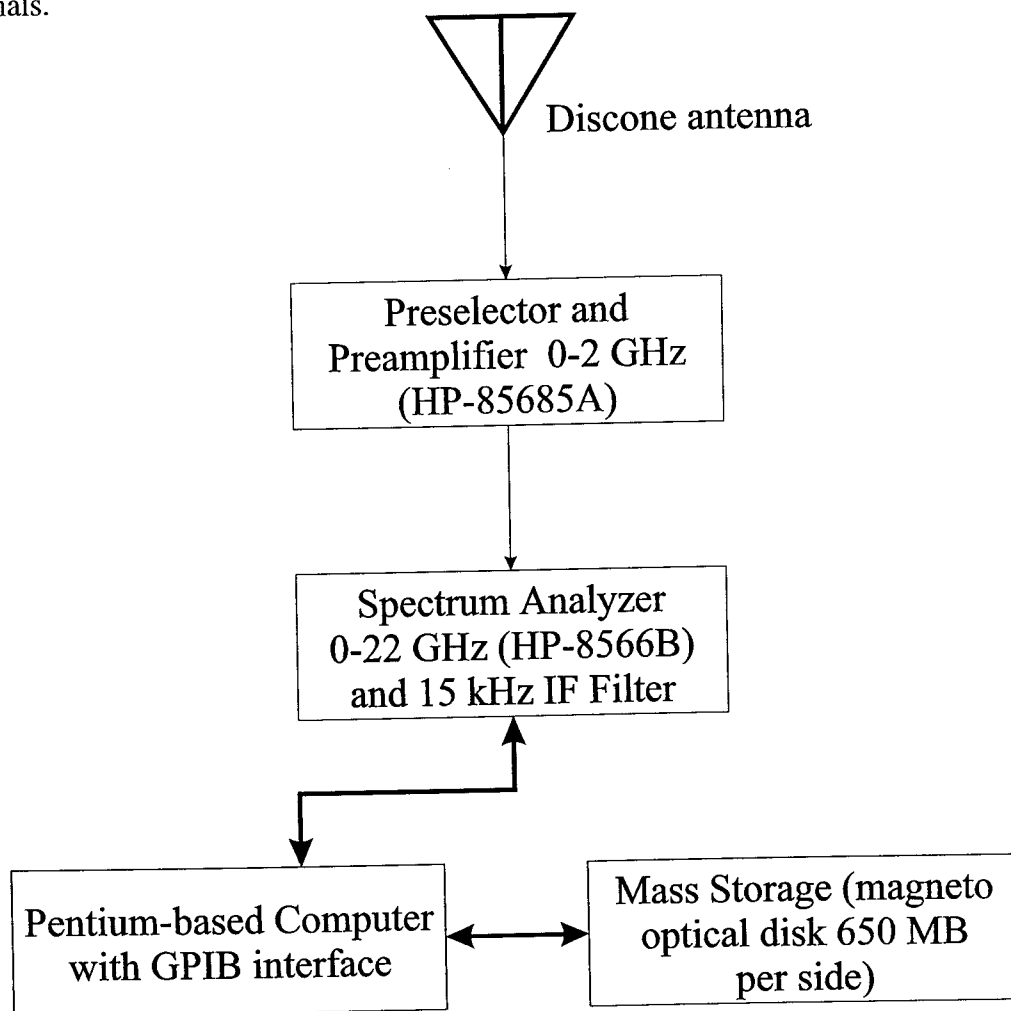Mass Storage (magneto
optical disk 650 MB
per side)

Figure 10. Block diagram of the measurement system.

3. ANALYSIS ALGORITHM

Channel occupancy was determined by making a sweep of the railroad land mobile radio service band with a spectrum analyzer. The measurement system sampled the frequency band from 160.208-161.572 MHz at approximately 1-s intervals. The sweep time over the frequency band was 620 ms with 1001 points or bins recorded per sweep. When a signal that exceeded a certain threshold was measured in a channel, a channel was considered occupied during that time. The channel usage was then determined by the total number of times that the channel was occupied divided by the total number of sweeps.

The message lengths were determined by detecting a signal in a channel on successive sweeps. For example, if there was no signal in a given channel on a sweep, but if a signal was detected in that channel during the next sweep, then it was determined that a message had started. If this signal was also present for six subsequent sweeps and then was not there on the seventh sweep, this was considered a single message of seven sweeps long (the first sweep plus the six subsequent sweeps). Since each sweep is approximately 1 s in length, this message would be approximately 7 s long.

An example of a spectrum analyzer trace is shown in Figure 11. This figure shows the noise and signals from several channels.
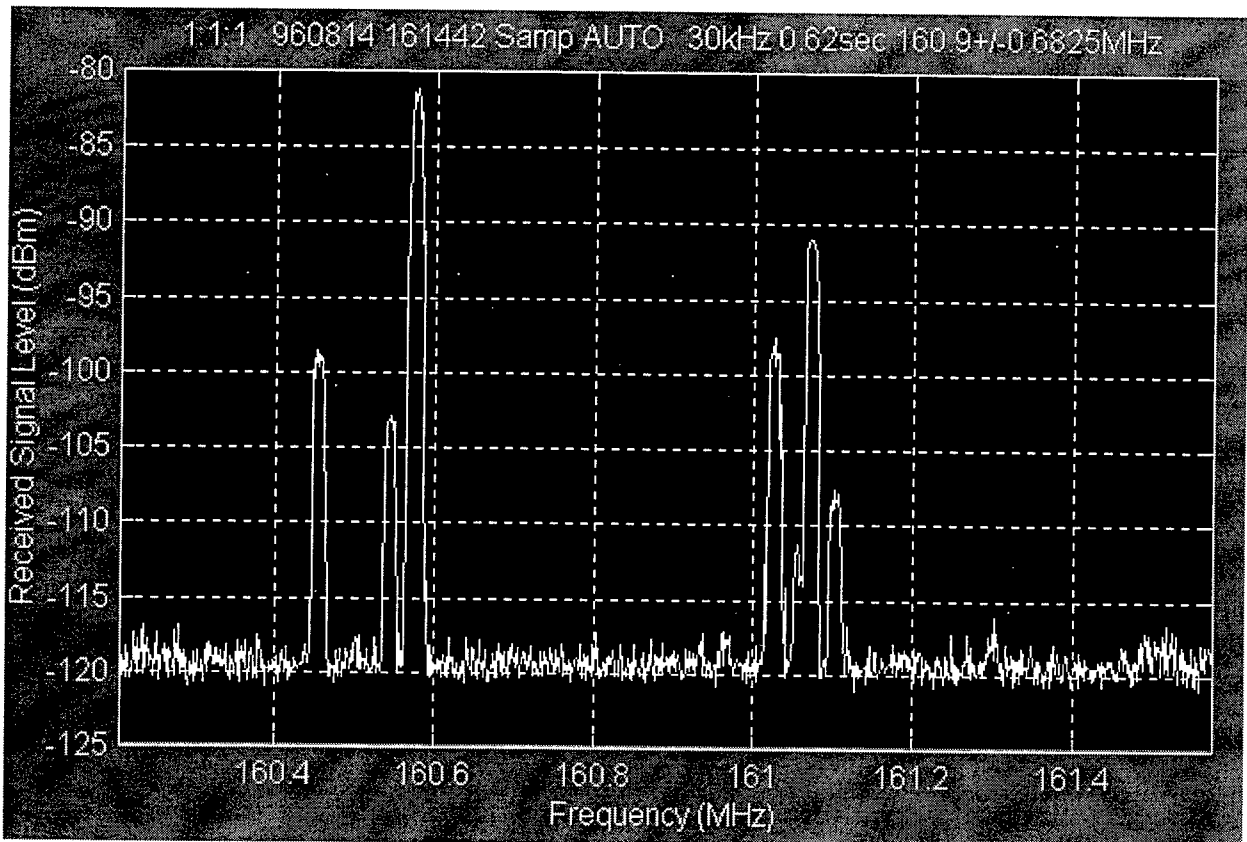

Figure 11. A typical spectrum analyzer trace from a site.

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3.1 Noise Reduction Algorithm

To reduce the chances of noise giving a false indication that the channel was being used, the following issues were addressed:

1. To be considered a real signal, the measured level must exceed a signal threshold. The signal threshold was determined by measuring the mean noise power over a 24-hour period and selecting a threshold approximately 6 dB above the mean noise level.

2. In our analysis, the threshold appeared to eliminate most false signals due to noise when the mean value of the noise floor remains constant. Signals from transmitters weaker than the threshold were not counted in the analysis.

3. To ensure that the channel was occupied by a real signal and not impulsive noise, several measurement bins of the channel were evaluated. Each channel is 15-kHz wide and each channel occupies about eleven bins of the 1001 measurement bins swept by the spectrum analyzer. If the center bin contained a signal above the threshold, the two bins on either side of the center were also checked to ensure that their levels were above the threshold as well. If not, the channel was determined to contain noise, and not a signal.

3.2 Data Analysis

The raw data that were collected at the three different sites were processed to obtain message length statistics, channel utilization, band usage, median message length, and mean message length. These statistics can be calculated for any part of the day for an arbitrary time period.

On all of the figures that show the processed data from the different sites, there is a nominal value of one added to the number of messages for each message length. This was done because a log-log scale was used to show more information. This value however, was added just prior to plotting the results, so it does not affect any of the other statistics shown. Each of the figures have a time factor and band usage. The time factor is a correction to the value of the message lengths to obtain the actual times of each message. Because it was not possible to have the measurement system sweep at precisely 1-s intervals, this time factor is the average time of each sweep in seconds. The band usage is the cumulative utilization of each channel divided by the number of channels in the band. That is, it is the average channel utilization for the band.

Figure 12 shows a 1-hour time period for Chicago, Illinois. All 91 channels were scanned for signals, yet this figure shows that there were some channels that were not used during this particular 1-hour period. Because of that, there is a high confidence that the signals detected are real and that they are not false indications generated by noise or other artifacts.

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One of the objectives was to evaluate diurnal variations. Obtaining diurnal statistics on the traffic was difficult because of the continuous way the data was collected, stored, and processed. However, 1-hr blocks could be evaluated during different parts of the day. The data taken at the Chicago site were examined closely for any diurnal effects. Based on the small sample size, it appeared that there was a diurnal effect caused mainly by extra traffic being generated during the normal work day. This radio traffic could be attributed to commuter train traffic and "8 to 5" track force workers. Traffic roughly doubles during the normal work hours. Figure 13 shows an hour when the traffic is noticeably lower during the day and Figure 14 shows an hour when the traffic is noticeably higher during the day. These two figures show roughly a 300% difference in traffic since Figure 13 shows the least busy hour for a 24-hour period and Figure 14 shows the busiest hour for that 24-hour period.

Besides evaluating diurnal effects, another objective was to investigate message length characteristics to determine whether they are indicative of the type of traffic being sent on a particular channel. Certain channels primarily carry either voice or data traffic. When these channels are analyzed individually, they show characteristics that would indicate that these channels are indeed carrying a specific type of traffic. For the data channels, we did not expect the traffic to contain any messages that are very long because packet sizes should be relatively small. For the voice channels, we did expect the traffic to contain some messages that are substantially longer than the average. Figure 15 shows analysis results for a channel used for data transmission, and Figure 16 shows analysis results for a channel used for voice transmission.

In Figure 15, the messages are all under 10 s in duration. The reason for some of the longer messages is probably due to the resolution of the measuring system. The measuring system can only sample a channel approximately once per second. It is, therefore, possible for a message to be transmitted and terminated and another message started before the measurement system looks at that channel again. To the measurement system, that signal would be counted as the same message. In Figure 16, there are some messages that are very long—on the order of 100 s. We know from voice traffic over the telephone that there can be some very long conversation times, much longer than the average.

The three different sites had some subtle differences between them. One of the differences that is not seen in the analysis is the average noise floor. The average noise floor varied slightly from site-to-site and affects the minimum threshold selected. Other variations are the channels that are used and the percent utilization of a given channel. The message length statistics, however, had a tendency to follow a straight line when the number of messages of a given message length were plotted on a log-log scale. Figures 17, 18, and 19 show measurement results over a typical day's worth of activities for Kansas City, Saint Louis, and Chicago, respectively.
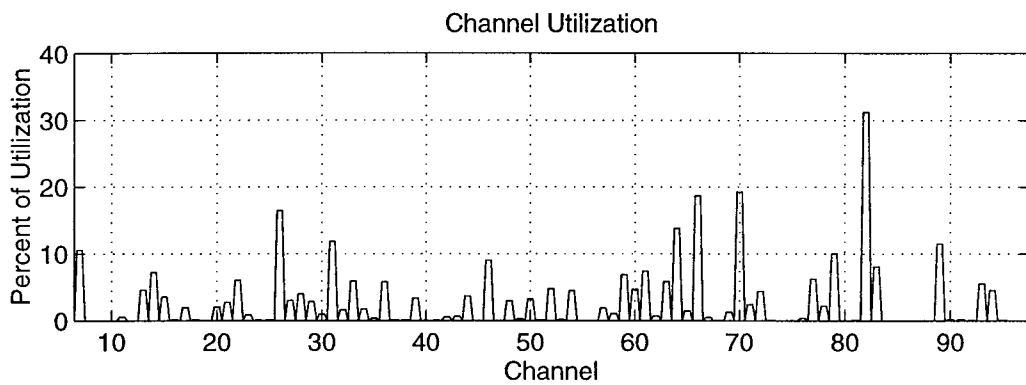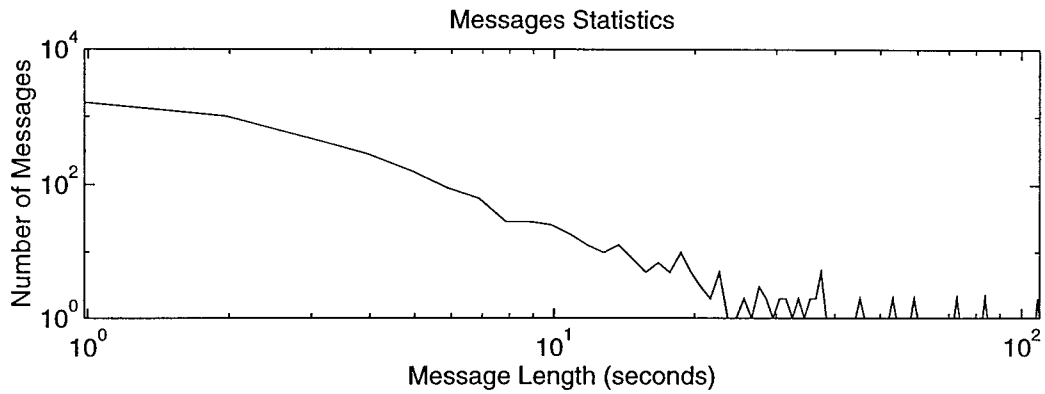
Messages Statistics

Channel Utilization

Measurement Location: Chicago   Channels 7 – 97

Measurement type: Swept Spectrum

Beg. Freq.: 160.208 MHz   End Freq.: 161.572 MHz

RBW: 30kHz   Detector: Sample   Sweep time: 0.62 Sec.   Points: 1001

Data Directory: F:\DATA\

First record: F:22 R:78   Number of records: 3660

Measurement Start: 960814 (YYMMDD) 170000 (HHMMSS)

Measurement End: 960814 (YYMMDD) 180000 (HHMMSS)

Time factor: 0.9836   Band usage: 3.304%   Threshold: –111dBm

Median Message Length: 1.967   Mean Message Length: 2.772   Total Number of Messages: 3904

Figure 12. Measurement results for a 1-hr time period at the Chicago, Illinois site.
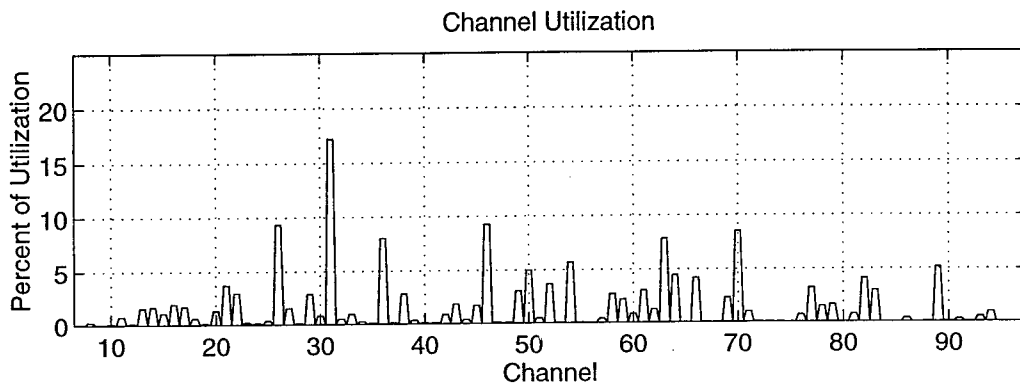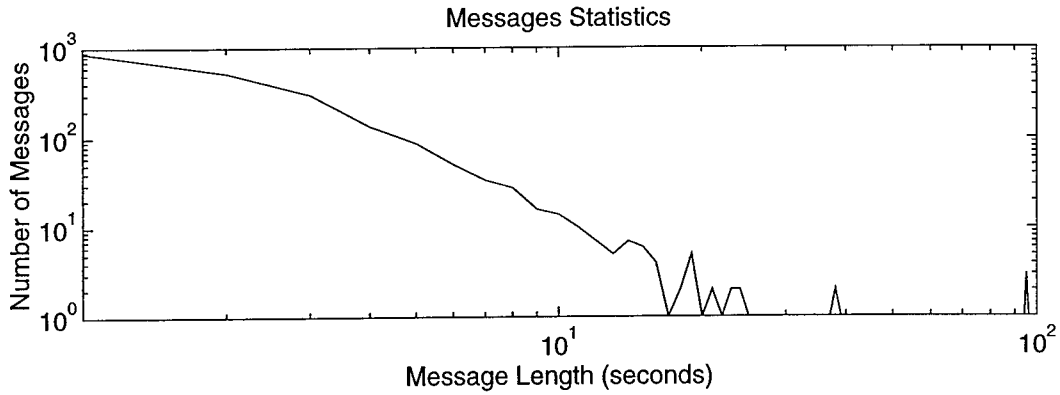
Messages Statistics

Channel Utilization

Measurement Location: Chicago   Channels 7 – 97

Measurement type: Swept Spectrum

Beg. Freq.: 160.208 MHz   End Freq.: 161.572 MHz

RBW: 30kHz   Detector: Sample   Sweep time: 0.62 Sec.   Points: 1001

Data Directory: F:\DATA\

First record: F:427 R:98   Number of records: 3594

Measurement Start: 960816 (YYMMDD) 60000 (HHMMSS)

Measurement End: 960816 (YYMMDD) 70000 (HHMMSS)

Time factor: 1.002   Band usage: 1.726%   Threshold: –112dBm

Median Message Length: 2.003   Mean Message Length: 2.679   Total Number of Messages: 2111

Figure 13.   Measurement results for a 1-hr time period when the traffic is noticeably lower during the day (Chicago, Illinois site).

Messages Statistics

Number of Messages

10^4

10^2

10^0

10^1 10^2

Message Length (seconds)

Channel Utilization

Percent of Utilization

20

15

10

5

0

10   20   30   40   50   60   70   80   90
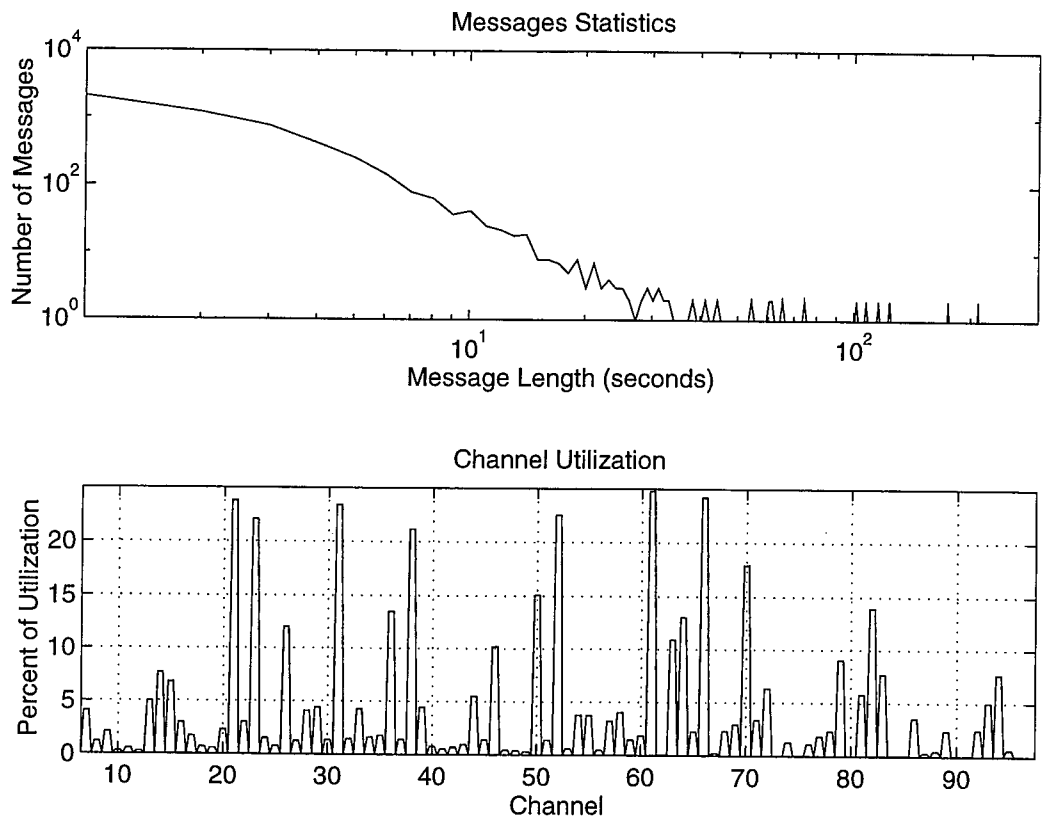
Channel

Measurement Location: Chicago   Channels 7 – 97

Measurement type: Swept Spectrum

Beg. Freq.: 160.208 MHz   End Freq.: 161.572 MHz

RBW: 30kHz   Detector: Sample   Sweep time: 0.62 Sec.   Points: 1001

Data Directory: F:\DATA\

First record: F:511 R:110   Number of records: 3581

Measurement Start: 960816 (YYMMDD) 90000 (HHMMSS)

Measurement End: 960816 (YYMMDD) 100000 (HHMMSS)

Time factor: 1.005   Band usage: 4.797%   Threshold: –112dBm

Median Message Length: 2.011   Mean Message Length: 3.05   Total Number of Messages: 5152

Figure 14.   Measurement results for a 1-hr time period when the traffic is noticeably higher during the day (Chicago, Illinois site).

Messages Statistics

Number of Messages vs Message Length (seconds)

Channel Utilization

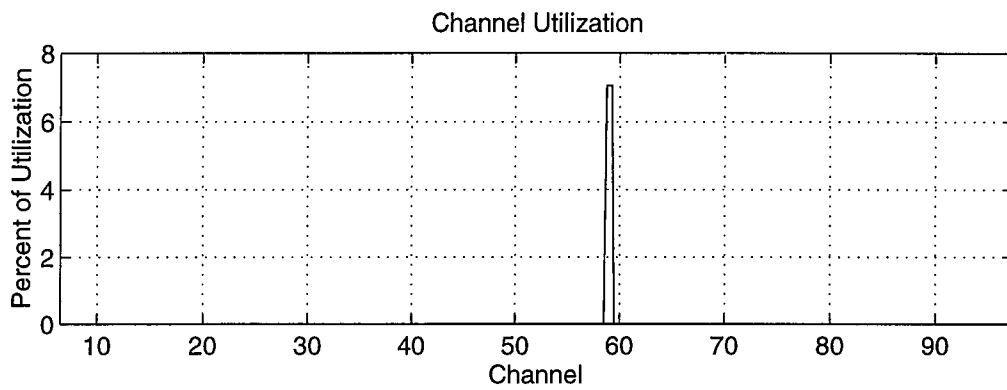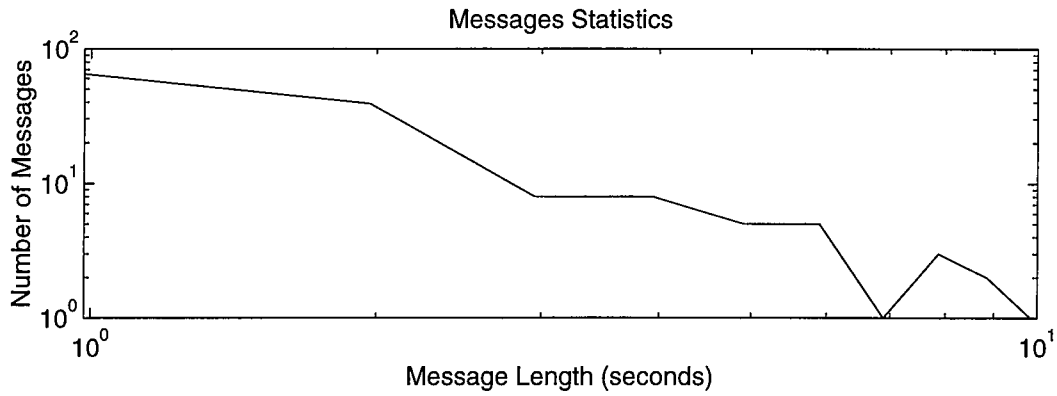Percent of Utilization vs Channel

Measurement Location: Chicago   Channel: 59 161.0100 MHz

Measurement type: Swept Spectrum

Beg. Freq.: 160.208 MHz   End Freq.: 161.572 MHz

RBW: 30kHz   Detector: Sample   Sweep time: 0.62 Sec.   Points: 1001

Data Directory: F:\DATA\

First record: F:22 R:78   Number of records: 3660

Measurement Start: 960814 (YYMMDD) 170000 (HHMMSS)

Measurement End: 960814 (YYMMDD) 180000 (HHMMSS)

Time factor: 0.9836   Band usage: 7.049%   Threshold: –112dBm

Median Message Length: 0.9836   Mean Message Length: 1.998   Total Number of Messages: 127

Figure 15. Measurement results showing an example of a channel carrying data traffic.

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Messages Statistics

Number of Messages vs Message Length (seconds)

Channel Utilization

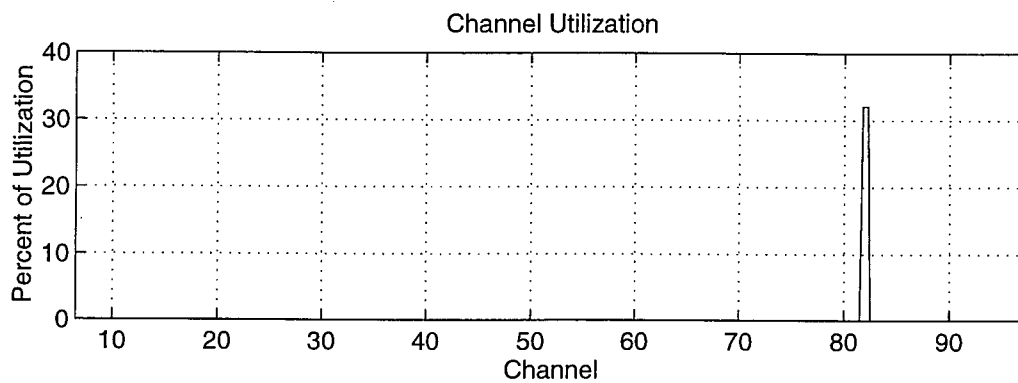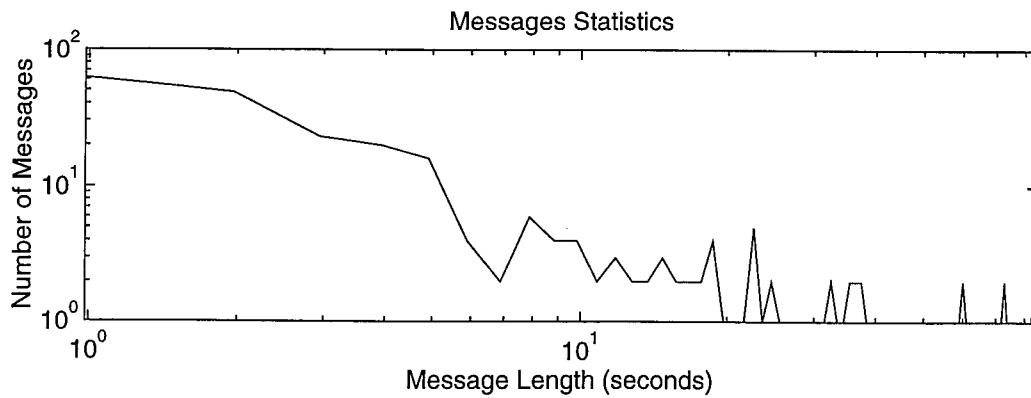Percent of Utilization vs Channel

Measurement Location: Chicago   Channel: 82 161.3550 MHz

Measurement type: Swept Spectrum

Beg. Freq.: 160.208 MHz   End Freq.: 161.572 MHz

RBW: 30kHz   Detector: Sample   Sweep time: 0.62 Sec.   Points: 1001

Data Directory: F:\DATA\

First record: F:22 R:78   Number of records: 3660

Measurement Start: 960814 (YYMMDD) 170000 (HHMMSS)

Measurement End: 960814 (YYMMDD) 180000 (HHMMSS)

Time factor: 0.9836   Band usage: 32.1%   Threshold: –112dBm

Median Message Length: 1.967   Mean Message Length: 5.665   Total Number of Messages: 204

Figure 16.   Measurement results showing an example of a channel carrying voice traffic.

Messages Statistics

Number of Messages vs Message Length (seconds)

Channel Utilization
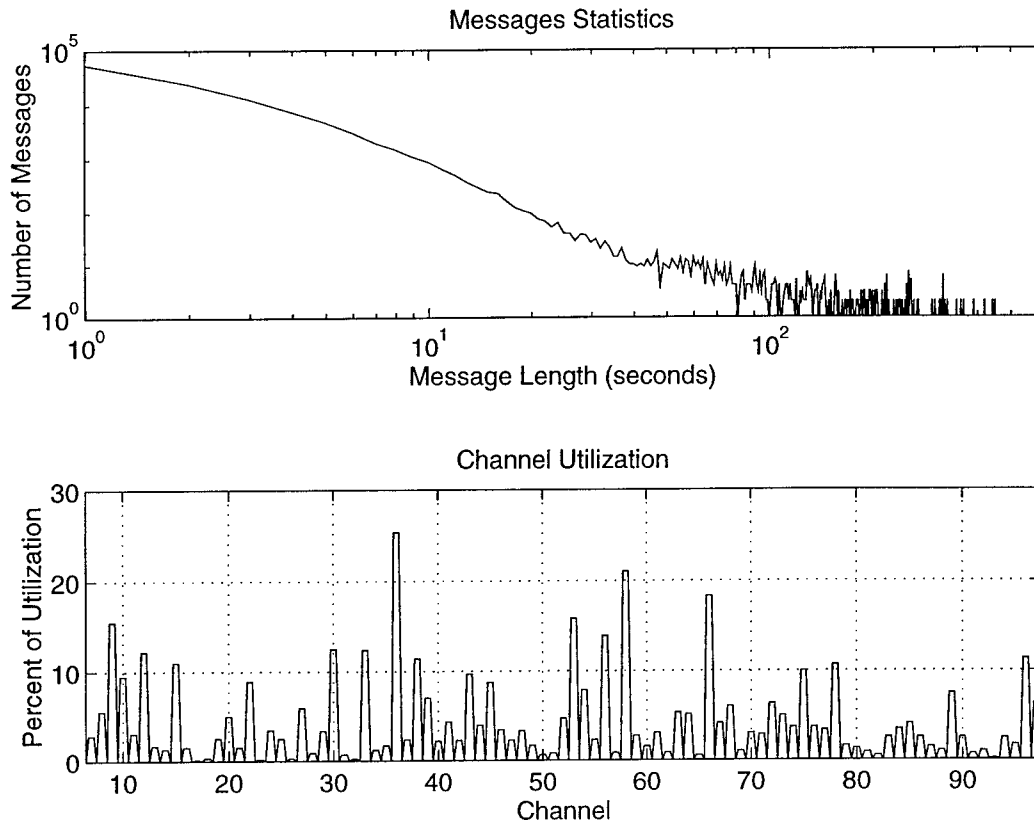
Percent of Utilization vs Channel

Measurement Location: Kansas City   Channels 7 – 97

Measurement type: Swept Spectrum

Beg. Freq.: 160.208 MHz   End Freq.: 161.572 MHz

RBW: 30kHz   Detector: Sample   Sweep time: 0.62 Sec.   Points: 1001

Data Directory: F:\DATA\

First record: F:1 R:1   Number of records: 8.64e+004

Measurement Start: 960612 (YYMMDD) 113343 (HHMMSS)

Measurement End: 960613 (YYMMDD) 112604 (HHMMSS)

Time factor: 0.9947   Band usage: 4.766%   Threshold: –114dBm

Median Message Length: 1.989   Mean Message Length: 3.17   Total Number of Messages: 1.176e+005

Figure 17.   Measurement results over a typical day's worth of activity at the Kansas City, Missouri site.

Messages Statistics

Channel Utilization

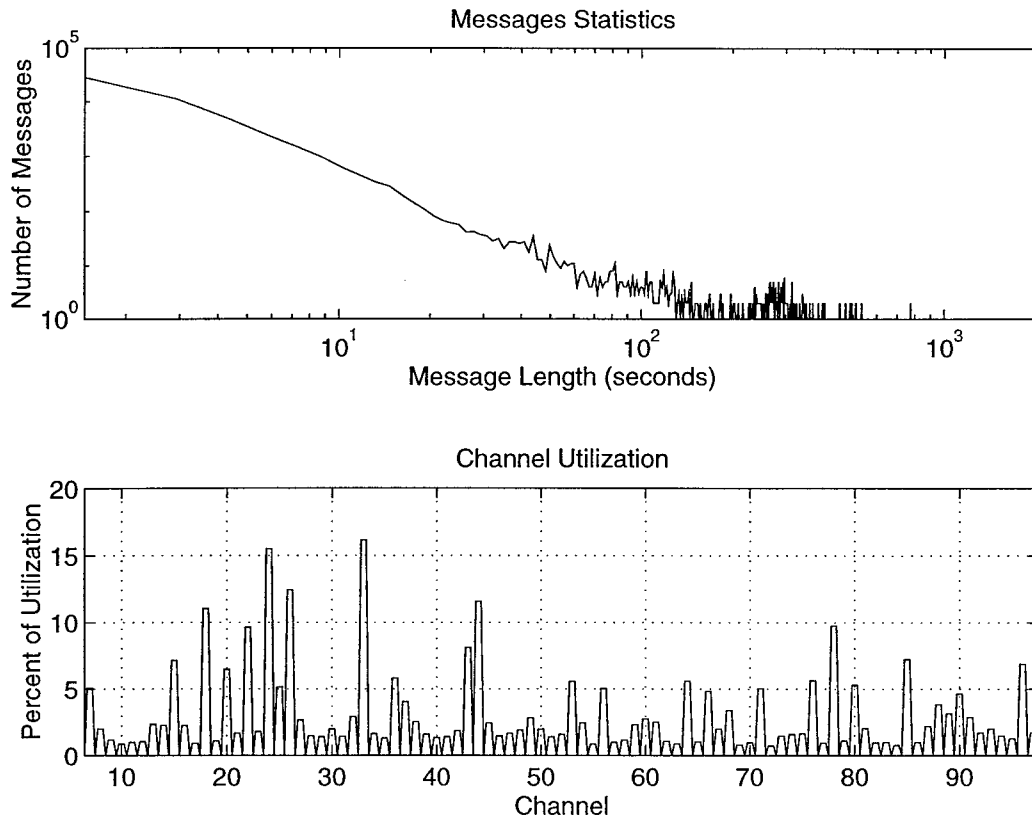
Measurement Location: Saint Louis   Channels 7 – 97

Measurement type: Swept Spectrum

Beg. Freq.: 160.208 MHz   End Freq.: 161.572 MHz

RBW: 30kHz   Detector: Sample   Sweep time: 0.62 Sec.   Points: 1001

Data Directory: F:\DATA\

First record: F:1 R:1   Number of records: 5.474e+004

Measurement Start: 960723 (YYMMDD) 125837 (HHMMSS)

Measurement End: 960724 (YYMMDD) 111341 (HHMMSS)

Time factor: 1.463   Band usage: 3.274%   Threshold: –111dBm

Median Message Length: 1.463   Mean Message Length: 4.578   Total Number of Messages: 5.213e+004

Figure 18.   Measurement results over a typical day's worth of activity at the Saint Louis, Missouri site.

Messages Statistics

Channel Utilization

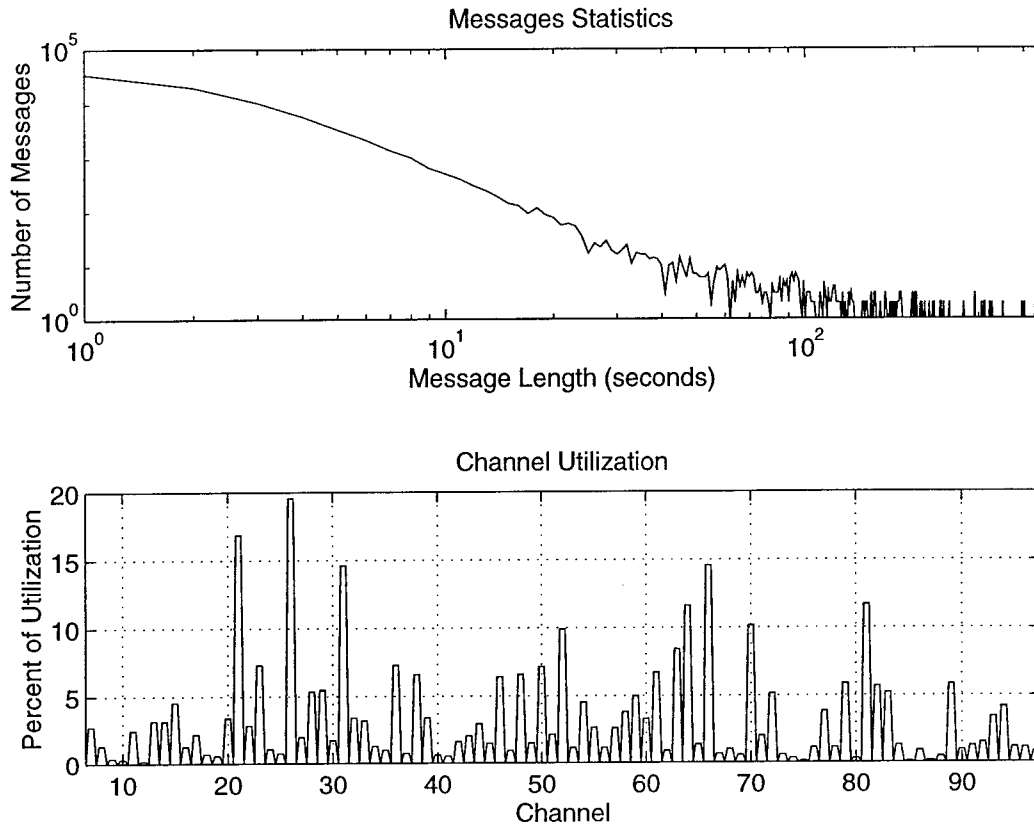
Measurement Location: Chicago   Channels 7 – 97

Measurement type: Swept Spectrum

Beg. Freq.: 160.208 MHz   End Freq.: 161.572 MHz

RBW: 30kHz   Detector: Sample   Sweep time: 0.62 Sec.   Points: 1001

Data Directory: F:\DATA\

First record: F:1 R:1   Number of records: 8.178e+004

Measurement Start: 960814 (YYMMDD) 161442 (HHMMSS)

Measurement End: 960815 (YYMMDD) 145720 (HHMMSS)

Time factor: 0.9997   Band usage: 3.52%   Threshold: –112dBm

Median Message Length: 1.999   Mean Message Length: 3.132   Total Number of Messages: 8.362e+004

Figure 19. Measurement results over a typical day's worth of activity at the Chicago, Illinois site.

3.3 Spectrum Usage Comparison

Although there have been several Federal Communications Commission (FCC) studies [1-4] that have investigated land mobile spectrum utilization, none of them have surveyed and characterized the traffic in the 160.215- to 161.565-MHz band as in-depth as this survey has done. The way in which the data were measured in the earlier studies and the emphasis of the studies was much different than the survey done for this report. However, we did compare data taken during the previous studies with those taken during this study (Table 1 and Table 2).

There are differences in the ways the data were obtained and analyzed in the previous studies versus this study. In the previous studies, channels were monitored as a block of frequencies continuously for a 5-min period then not monitored while two other blocks of frequencies were monitored. Thus, a group of channels would be monitored for 5 min during a 15-min period. The frequencies were monitored for two days per site and only between the hours of 8:00 A.M. and 6:00 P.M. The peak hour transmission occupancy for the FCC was determined by the 90th percentile occupancy[2] of the 5-min occupancies for each channel and is shown in Tables 1 and 3 below. By contrast, the peak hour transmission occupancy for this study was determined by the peak band usage for a 1-hr period and is shown in Tables 2 and 4 below. All the tables show the number of channels that have a certain percent usage.

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[2]"90th Percentile Occupancy: This occupancy statistic characterizes peak usage on a channel defined as the five-minute occupancy value exceeded by only 10% of all five-minute values... [The 90th Percentile Occupancy was used because] it requires fewer samples per hour for comparable accuracy... [and] peak usage period[s] occurred during different hours each day... [The 90th Percentile Occupancy was found to have] excellent statistical correlation between Peak Hour and 90th Percentile Occupancies. The parameters are roughly equivalent in characterizing peak usage."[2]

Table 1. Survey Comparisons Showing the Number of Channels Having a Given Percent Usage (90th percentile occupancy) [1-4]

Site Location	Percent Usage									
	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100
Detroit Belle Island	75	10	4	2	-	-	-	-	-	-
Detroit Galinee Park	83	5	3	-	-	-	-	-	-	-
Detroit Oakland Community College	79	6	2	4	-	-	-	-	-	-
LA Griffith Park	36	17	18	7	1	3	3	3	1	2
LA Rose Hill Memorial Park	60	10	11	1	3	2	2	1	1	-
LA Orange Hill Restaurant	72	5	5	3	2	1	2	1	-	-
LA Torrance Airport	68	8	5	2	2	2	1	-	2	1
San Diego Grosmont College	86	2	-	1	-	1	-	-	1	-
San Diego Montgomery Field	84	4	-	-	2	-	1	-	-	-
San Diego Point Loma	83	3	1	1	1	1	1	-	-	-
Washington D.C. University of Maryland, Fort Myer	75	12	3	1	-	-	-	-	-	-

Table 2. Survey Comparisons Showing the Number of Channels Having a Given Percent Usage (busy hour).

Site Location	Percent Usage									
	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100
Saint Louis	57(24)*	9	1	-	-	-	-	-	-	-
Kansas City	67(0)*	14	4	4	1	1	-	-	-	-
Chicago	65(15)*	7	-	3	-	1	-	-	-	-

*The numbers in the parenthesis are channels with exactly zero usage during the busy hour.

In the FCC reports, several usage groups were categorized to subjectively quantify the measured channel usage. They defined a mobile channel with measured usage of 40-100% (or 60-100%) during the 90th percentile 5-min period to have "Very High Usage," 16-39% (or 24-59%) to have "Substantial Usage," and 0-15% (or 0-23%) to have "Low Usage." Those with exactly 0% usage are noted as "Zero." The results of the groupings for the FCC surveys and the present survey are given in Table 3 and 4, respectively.

The tables show that in the 20 years since the FCC surveys, the most change has been an increase in traffic that resulted in reduction of channels with zero usage and an increase of channels with low usage. The majority of the channels still do not fall into the "Very High" or "Substantial Usage" groupings.

Table 3. Survey Comparisons Showing the Number of Channels Within Various Usage Groups (90th percentile occupancy) [1-4]

Site Location	Zero	Low (0-15%)	Substantial (16-39%)	Very High (40-100%)
Detroit	-	79	12	-
	Zero	Low (0-23%)	Substantial (24-59%)	Very High (60-100%)
LA	27	19	33	12
San Diego	57	27	3	4
Washington D.C.	53	30	8	-

Table 4. Survey Comparisons Showing the Number of Channels Within Various Usage Groups (busy hour)

Site Location	Zero	Low (0-15%)	Substantial (16-39%)	Very High (40-100%)
Saint Louis	24	64	3	-
Kansas City	0	74	15	2
Chicago	15	68	7	1
	Zero	Low (0-23%)	Substantial (24-59%)	Very High (60-100%)
Saint Louis	24	66	1	-
Kansas City	0	85	5	1
Chicago	15	72	4	-

4. CONCLUSION

Spectrum utilization measurements were made in the frequency range from 160.215- to 161.565 MHz; this band is exclusively assigned to the railroad land mobile radio service. Each of the channels is 15-kHz wide. Three different sites were surveyed; these sites were expected to have high radio traffic and to allow for varying conditions such as the different types of traffic over the channels, propagation environments, line-of-sight conditions, and electromagnetic interference. The spectrum usage surveys spanned two states and three cities. The measurements were made to determine the usage of each channel over 24-hour periods, to evaluate diurnal variations, and to determine message length statistics.

Significant findings are:

1. From observations made at the measurement sites, there appear to be four categories of usage:
    *   Voice—dispatch channels had high measured usage (about 40% on some channels during a busy hour).
    *   Voice—telephone interconnect channels also had high measured usage (about 40% on some channels during a busy hour).
    *   Voice—point-to-point communication channels had moderate measured usage (usually between a few percent to 20% over a 24-hour period).
    *   Data channels had low measured usage (around 5% during the busy hour).

2. Typical results at three railroad measurements sites for 91 channels in the 160.215- to 161.565-MHz railroad-land-mobile-radio-service band include:

- 60,000-130,000 messages per 24-hour period.
- 2,000-7,000 messages per hour.
- Diurnal variation of three to four fold increase between least and most busy hour.
- Median message length of 2 s.

At all three measurement locations, characteristics of the message length statistics were similar. The message lengths of different channels (voice, data, or mixed) all had a large number of short messages (1 to 2 s long) such that the median message length was usually around 2 s long. At all three sites, the message length statistics could be approximated by a straight line when plotted on a log-log scale. The fraction of messages versus message length could be approximated by the following probability density function:

$$y = A / (C + x^B)$$

where: x is the message length in seconds (discrete),
y is the fraction of messages with length X; and
$A = 1.46, B = 2.31, C = 1.99.$

Voice channels with dispatch and telephone interconnect traffic seem to have the most usage. For these channels, one person may be the primary communicator on the channel, and that person is the one that is controlling the traffic. For dispatch or telephone interconnect cases, it seems reasonable that the channel would show relatively high usage. The data channels do not appear to be used as much as the voice channels. Since data channels are expected to be able to carry up to about 40-50% loads without major performance problems, these channels have much room for growth.

Typical results over all 91 channels varied from between about 2000-7000 messages per hour and between about 60,000-130,000 messages per day. Diurnal variations show approximately a three to four fold difference between the busy hour and the least busy hour. Many of the channels show usage above 1% over a 24-hour period, with some channels showing over 50% usage during a 1-hr period. In the telephone industry, a maximum blockage of 1% is engineered for their systems during the busiest time of year. Blockage means that a person who tries to make a call cannot complete the call because the communication network is busy and cannot handle another call. For the radio system used by the railroad industry, blockage by 50% or more may be somewhat acceptable since the person trying to use the channel may be able to wait for the channel to clear, or use another channel.

5. REFERENCES

[1]   Larry D. Reed, Keith A. Larson, and William V. Tranavitch, *"Land mobile spectrum utilization Chicago, Illinois—Categorization of long-term data,"* Federal Communications Commission, Washington, D.C., 1977

[2]   Larry D. Reed, Keith A. Larson, and William V. Tranavitch, *"Land mobile spectrum utilization Detroit, Michigan,"* Federal Communications Commission, Washington, D.C., 1978.

[3]   Larry D. Reed, *"Land mobile spectrum utilization Los Angeles and San Diego, CA,"* Federal Communications Commission, Washington, D.C., 1979.

[4]   Larry D. Reed, *"Land mobile spectrum utilization Washington, D.C.,"* Federal Communications Commission, Washington, D.C., 1981.

APPENDIX: DATA ACQUISITION SOFTWARE

The measurement system uses software developed by the Institute for Telecommunication Sciences (ITS) to control all measurement system functions via computer. This control program, called Data Acquisition (DA), runs on any DOS-based computer with sufficient memory. It interfaces with the measurement system via general-an IEEE-488 bus at rates limited only by the computer's operating speed and functional speed of the managed hardware (interfaces, switches, components, etc.). DA will support any available combination of RF front-ends, spectrum analyzers, and auxiliary analysis equipment.

The DA program is basically four control subroutines that direct operation of multiple subroutine kernels that in turn control every function of the measurement system. This appendix includes descriptions of the three control subroutines used for the railroad land mobile radio measurements (receiver algorithm, spectrum analyzer, and RF front-end) and the resultant system functions. As DA program development continues to meet new measurement demands, these functional descriptions may change with time.

1. RECEIVER ALGORITHM SUBROUTINE

The DA receiver algorithm subroutine provides software management for up to 32 measurement algorithms (called program kernels in DA or band events). Any one of these algorithms, when coupled with spectrum analyzer and front-end selections (described later in this appendix), becomes a customized measurement system for receiving certain signals or signal types. Because the characteristics of emitters and the requirements for data on those emitters vary considerably, many different algorithms have been developed. However, all of the algorithms are based upon either a frequency sweep across the spectrum of interest, or a series of discrete steps across that spectrum. Since the railroad land mobile radio measurements used only the swept mode, the stepped mode is not discussed below.

> **Swept**: This algorithm controls a conventional spectrum analyzer[1] sweep across a selected portion of spectrum. Any type of detection available in the analyzer (i.e., positive peak, sample, etc.) can be used. Repeated sweeps may be programmed, and multiple sweeps incorporating the maximum-hold spectrum analyzer mode may also be performed. This algorithm also allows for sweeping a spectral band in several sub-bands (scans). This feature is important if a narrow bandwidth (e.g., 10 kHz) must be used to measure a spectral band that is more than 1000 times the width of the measurement bandwidth, e.g., measuring 900-930 MHz with a 10-kHz bandwidth requires at least three scans to ensure no loss of data.

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[1]For spectrum surveys and most operations with DA software control, any IEEE-488 interfaced spectrum analyzer that processes at least 1000 points (frequencies) per display sweep may be used.

1.1 Receiver Parameters

The following are brief descriptions of the DA program input parameters needed to run the above subroutines (algorithms).

Start and Stop Frequencies: The value in MHz of the first and last frequency point to be measured. These numbers must be equal to or fall outside the event frequency band range.

Sweeps: The number of sweeps in each scan. DA processes each sweep so increasing this number can add greatly to measurement time; however, increasing this value also increases the probability of intercept for intermittent signals.

2. SPECTRUM ANALYZER SUBROUTINE

The DA spectrum analyzer subroutine manages configuration control strings (via the IEEE-488 bus) for the spectrum analyzer. The operator selects spectrum analyzer parameters (listed in the following subsection) from menus in the DA program. Generally, parameters are selected that will configure the analyzer to run with a receiver algorithm for a desired measurement scenario. DA protects against out-of-range and nonlinear configurations but the operator can control the analyzer manually for unusual situations.

2.1 Spectrum Analyzer Parameters

When the DA program sends command strings to the analyzer, all signal path parameters are reset according to the operator selections for the measurement scenario. The following are brief descriptions of the analyzer parameter choices controlled by DA.

Attenuation: May be adjusted from 0-70 dB in 10-dB increments. The spectrum analyzer subroutine determines whether or not measurement system front-end attenuators are available and if so will set them to the selected value. Spectrum analyzer attenuation is set to zero when measurement system attenuation is active, if however, measurement system attenuators are not available the spectrum analyzer attenuation will be set to the selected value.

IF Bandwidth: May be selected from 0.01-3000 kHz in a 1, 3, 10 progression.

Detector: Normal, positive peak, negative peak, sample, maximum hold, and video average modes are available.

Video Bandwidth: May be selected from 0.01-3000 kHz in a 1, 3, 10 progression.

Display: Amplitude graticule choices in dB/division are: 1, 2, 5, and 10. This parameter selection applies to both the analyzer and the system console displays.

Reference Level: May be adjusted from -10 to -70 dBm in 10-dB increments.

Sweeps: Number of analyzer processed sweeps per scan. This parameter is only used with maximum hold or video averaged detection.

Sweep Time: This parameter (entered in seconds) specifies sweep (trace) time if used with swept algorithms, or specifies step-time (dwell) if used with a stepped algorithm.

3. RF FRONT-END SUBROUTINE

The DA software handles the RF front-end path selection differently than other routines. Most of the RF-path parameters are predetermined by the measurement algorithm so operators need only select an antenna and choose whether preamplifiers are turned on or off. Preselection is also controlled by the antenna selection.

The antenna selection is made from a list of antenna choices that is stored in a separately maintained library file called by the RF Front-end Subroutine. Antenna information stored in the file includes:

- antenna type (omni, cavity-backed, etc.);

- manufacturer (may include identification or model number);

- port (tells the computer where signals enter the measurement system and includes particulars on any external signal conditioning such as special mounting, additional amplifiers, or extra path gain or loss);

- frequency range;

- vertical and horizontal beam widths;

- dB gain;

- front to back ratio; and

- side lobe levels.