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Spectrum Usage Measurements in Potential PCS Frequency Bands

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SPECTRUM USAGE MEASUREMENTS IN POTENTIAL PCS FREQUENCY BANDS

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Spectrum usage measurements were made in several potential Personal Communication Services (PCS) frequency bands in the 600 to 2600 MHz range in five U.S. cities. Geographic dependence (within a city) of spectrum usage was determined for all of the cities. Measurements were made using a mobile, computer-controlled, automated radio frequency measurement system that was installed in a mini-van. The raw data taken at each site consisted of received signal levels for each frequency measured. These were processed to provide signal level, measured frequency usage, and measured band usage graphs. The heaviest usage for all cities was seen in the 869-894 MHz (cellular base station-to-mobile) band and the 864-868 MHz (SMR) band. The frequency bands showing the least usage in all cities were the 901-902 MHz (GPMRS), 1850-1990 MHz (Private Fixed Microwave), and the 2400-2483.5 MHz (ISM and Part 15) bands.

Key words: measured band usage; measured frequency usage; PCS; Personal Communication Services; received signal level; spectrum usage

1. INTRODUCTION

The Institute for Telecommunication Sciences (ITS) and Telesis Technology Laboratory, Inc. (TTL), a subsidiary of Pacific Telesis Group, have entered into a cooperative research agreement under the provisions of the Federal Technology Transfer Act (FTTA) of 1986. As part of this agreement, ITS is assisting TTL in accomplishing the channel characterization portion of the TTL Personal Communications Services (PCS) Experimental License Project. The channel characterization work over radio paths anticipated for PCS use is currently under way and includes measurements of spectrum usage, noise, signal strength, and delay spread. This report discusses the ITS field experiment to measure spectrum usage in several potential PCS frequency bands in the 600 to 2600 MHz range in five cities in the United States**. The spectrum usage measurements over this frequency range will provide information to assist the FCC in determining what frequency bands are suitable for PCS and whether PCS can share spectrum with current users.

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** Funding for the spectrum usage measurements was provided by TTL.

Section 2 of this report outlines the reasons for making the spectrum usage measurements and discusses the measurement strategy. In Section 3, the software and hardware used in the measurement system are detailed. A system block diagram is shown as well as photographs of the measurement van and the equipment. The measurement procedure is described in Section 4. In this section, the calibration method, antenna system test, and typical steps followed to make a measurement at a site are presented. Section 5 shows how the data were analyzed and discusses the three types of graphs used to present and summarize the data. The signal level graph shows minimum, maximum, and mean received signal levels (RSLs) at each measured frequency. The measured frequency usage and measured band usage graphs provide information on the geographic variations of RSL in a given city. Section 6 describes how to interpret the data. This includes a discussion of receiver detector types and resolution bandwidths as well as other factors that affect the measured data. In sections 7 through 11, the processed data from each city is presented via the signal level, measured frequency usage, and measured band usage graphs. A comparison of the data between all of the cities is given in Section 12. Section 13 provides a summary and some conclusions.

2. OBJECTIVES AND MEASUREMENT STRATEGY

The basic objective in the spectrum usage measurements is to determine the relative degree of current spectrum usage for all frequency bands listed in the TTL PCS Experimental License. These frequency bands, which are grouped according to service, are shown in Table 2.1. The results of these measurements should assist in determining which frequency bands show potential for PCS and which frequency bands show no potential.

Table 2.1 Individual Frequency Bands Grouped According to Service

Frequency Range	Type of Service
614-806 MHz	UHF-TV
824-849 MHz 869-894 MHz	Cellular
849-851 MHz 894-896 MHz	Air-to-ground
864-868 MHz	Specialized Mobile Radio (SMR)
901-902 MHz 930-931 MHz 940-941 MHz	General Purpose Mobile Radio Service (GPMRS)
902-928 MHz	Industrial, Scientific, and Medical (ISM), Part 15, Automatic Vehicle Location, Amateur Radio
1850-1990 MHz	Private Fixed Microwave
2110-2130 MHz 2160-2180 MHz	Common Carrier Fixed Microwave
2400-2483.5 MHz	ISM, Part 15

A complete characterization of spectrum usage would require a measurement program sufficiently extensive to provide significant information on time and location statistics. Ideally, this would have included measurements at many sites, each lasting long enough to get information on diurnal and other temporal patterns. Because of the need to constrain the size of the measurement effort, the measurement program was designed to get the information that seemed to be most important.

Point-to-point microwave bands seem attractive to some PCS proponents for sharing with PCS. Prior to making the measurements it was assumed that the usage in the microwave bands would change only slowly with time, but that the highly directional antennas would cause usage to change rapidly as a function of geographic location. Similarly, the low power and low antenna height used by proposed PCS systems would cause PCS usage to be localized--therefore also a strong function of geographic location. It was expected that the UHF-TV bands would be quite constant with time. The cellular telephone and mobile bands were expected to be a strong function of time and location, but it was also expected that most of these bands would be very busy (and, therefore, less likely to be suitable for sharing with PCS).

The preceding assumptions led to the conclusion that geographic factors would be more important than temporal factors. Therefore, these measurements were designed to provide an extensive sampling of various geographic locations, using a measurement system that would encounter radio signals in about the same way that future PCS users would.

Measurements were taken in five cities: Dallas, Chicago, New York, Los Angeles, and San Francisco. To select sites within a city, a grid was placed about the center of the city. A 5×5 square grid with five mile spacing between grid lines was used. Sites were selected at the intersection points and center point of the grid. This yielded a total of 37 measurement sites per city. The actual measurements were made at locations within a one mile radius of the grid intersection points and center point. For some cities it was not practical to adhere to this square grid (e.g., some of the Chicago sites were located in Lake Michigan). In these cases the grid was extended in appropriate directions to generate new sites. In general, the new sites were selected to be spaced five miles apart just like the sites selected from the original square grid.

The measurements were made with a small van, using an omnidirectional vertically polarized rooftop antenna. Due to the large number of sites per city, it was only possible to make measurements at each site for about 30 minutes. This, while not allowing enough time to develop good temporal statistics on the received signals at each site, still accomplished the objective of providing good statistics of the geographic variability. The measurements were generally taken between 7 AM and 9 PM. The 14 individual frequency bands listed in Table 2.1 were grouped into five measurement frequency bands in order to be measured in a uniform and efficient manner. The five measurement frequency bands were: 614-806 MHz, 824-944 MHz, 1850-1994 MHz, 2110-2182 MHz, and 2400-2600 MHz.

The measurements were made with a spectrum analyzer system (described in more detail in the next sections), using three sets of measurement parameters. These parameters are described as follows:

narrowband:	10 kHz bandwidth, 3 kHz video filter, sampling detector
wideband:	300 kHz bandwidth, 10 kHz video filter, sampling detector
peak:	300 kHz bandwidth, 3000 kHz video filter, peak detector.

All frequencies were measured with each set of parameters. Table 2.2 summarizes the measurement system parameters used along with the measured frequencies.

Table 2.2 Measurement System Parameters and Frequencies

Measurement Number	Frequency Band (MHz)	Frequency Span per Scan (MHz)	Resolution BW (kHz)	Video BW (kHz)	Number of Scans per Band	Detector	Sweep Time (msec)
1	614-806	6	10	3	32	Sampling	500
2	1850-1994	6	10	3	24	Sampling	500
3	2110-2182	6	10	3	12	Sampling	500
4	824-944	6	10	3	20	Sampling	500
5	2300-2600	6	10	3	50	Sampling	500
6	614-806	192	300	10	1	Sampling	200
7	824-944	120	300	10	1	Sampling	100
8	1850-2182	166	300	10	2	Sampling	200
9	2300-2600	150	300	10	2	Sampling	200
10	614-806	192	300	3000	1	Peak	50
11	824-944	120	300	3000	1	Peak	50
12	1850-2182	166	300	3000	2	Peak	50
13	2300-2600	150	300	3000	2	Peak	50

Ideally, one would like to make measurements with a bandwidth as close as possible to the bandwidth of the PCS system. Since that bandwidth was not known, the selection of measurement parameters was made to cover the range of likely bandwidths and to show as much as possible about the actual use of the spectrum. The narrowband data was expected to give the most detailed information and the best measurement sensitivity for weak signals. It is closest to the bandwidth of the actual audio channel of a PCS system. However, the narrowband measurements also required the most time to complete. The wideband measurements were closer in bandwidth to proposed time-division multiple access (TDMA) systems. They required much less time to measure, but they were 15 dB less sensitive to weak signal levels. The peak measurements were included to detect impulsive signals (e.g., radars and automobile ignition noise) which might bother PCS systems without sufficient error correction. Also, the possibility of interference from PCS to radar systems might prevent sharing in a given band. The peak measurements were about 25 dB less sensitive to weak signals than the narrowband measurements.

Examples of measurements made with narrowband, wideband, and peak parameters are shown and discussed in the Data Interpretation section (Section 6). Most of the data analysis was performed using the narrowband data. This gives the best information on weak signals, but tends to indicate less spectrum usage than the wideband or peak data. This effect is further discussed in Section 6.

Referring to Table 2.2, at each site measurements 1 to 13 were taken initially and then measurements 4 to 13 were repeated 4 more times. This scheme achieved the objective of measuring frequency bands that were believed to have constant signals only once (for each of the three sets of measurement parameters) while providing relatively independent time samples of data (approximately five minutes apart) in the bands in which signals were expected to be keyed on and off.

3. MEASUREMENT SYSTEM

The Spectrum Usage Measurement System is one of a family of computer-controlled rf measurement systems at ITS whose software allows the user to configure the receiver from a user interface (set of menus). The minimum required hardware for these measurement systems includes a programmable spectrum analyzer, personal computer, and computer interface (GPIB) card. The Spectrum Usage Measurement System measures rf signals in the 600 to 2600 MHz frequency range. It is installed in a mini-van and uses a portable generator to supply power to the equipment. An omnidirectional receive antenna is mounted on standoffs approximately one foot above the roof of the vehicle. A photograph of the measurement van is shown in Figure 3.1.

3.1 Software

The measurement system software is configured so that custom, automated measurements can be set up and performed in either an unattended or attended mode. The software runs under the DOS operating system and has a user interface with real-time graphics capability. This software provides the capability of performing noise diode calibrations of the system, automated and manual mode measurements, data archiving, and analysis. The software can be used to make a wide variety of rf measurements. Some of the measurements that have been made with this software include wide dynamic range (140 dB) radar measurements, ISM and Part 15 device emission measurements, pulse shape and modulation measurements, spectrum usage measurements, and delay spread propagation measurements.

3.2 Hardware

A block diagram of the system hardware used in the Spectrum Usage Measurement System is shown in Figure 3.2. A wideband vertically polarized biconical omnidirectional antenna with an average gain of 0 dBi (measured) is used. The received signal travels to a four-port coaxial switch which is used to select the bandpass filter and amplifier path or the straight-through path. The four-port coaxial switch and the switches inside the rf preselector are coordinated by the software to switch according to the frequency range in which the measurements are being made. When measurements are being taken between 1500 and 2600 MHz, the discrete bandpass filter/amplifier path (controlled by the four-port coaxial switch) is selected and the YIG tracking filter/amplifier path in the rf preselector is bypassed. When measurements are being taken between 600 and 1500 MHz, the discrete bandpass filter/amplifier path is bypassed and the YIG filter/amplifier path in the rf preselector is selected.

The discrete bandpass filter is a 21-pole filter and has a passband from 1500 to 2600 MHz. This filter has a sharp rolloff on both the high and low frequency ends and gives greater than 45 dB of attenuation between dc and 1350 MHz and between 2700 and 4000 MHz. This filter is included to minimize potential intermodulation distortion from strong signals outside the 1500 to 2600 MHz frequency band (especially L-Band and S-Band radars). The discrete amplifier following the bandpass filter has a gain of approximately 20 dB with a

Figure 3.1 Photograph of the Spectrum Usage Measurement Van.

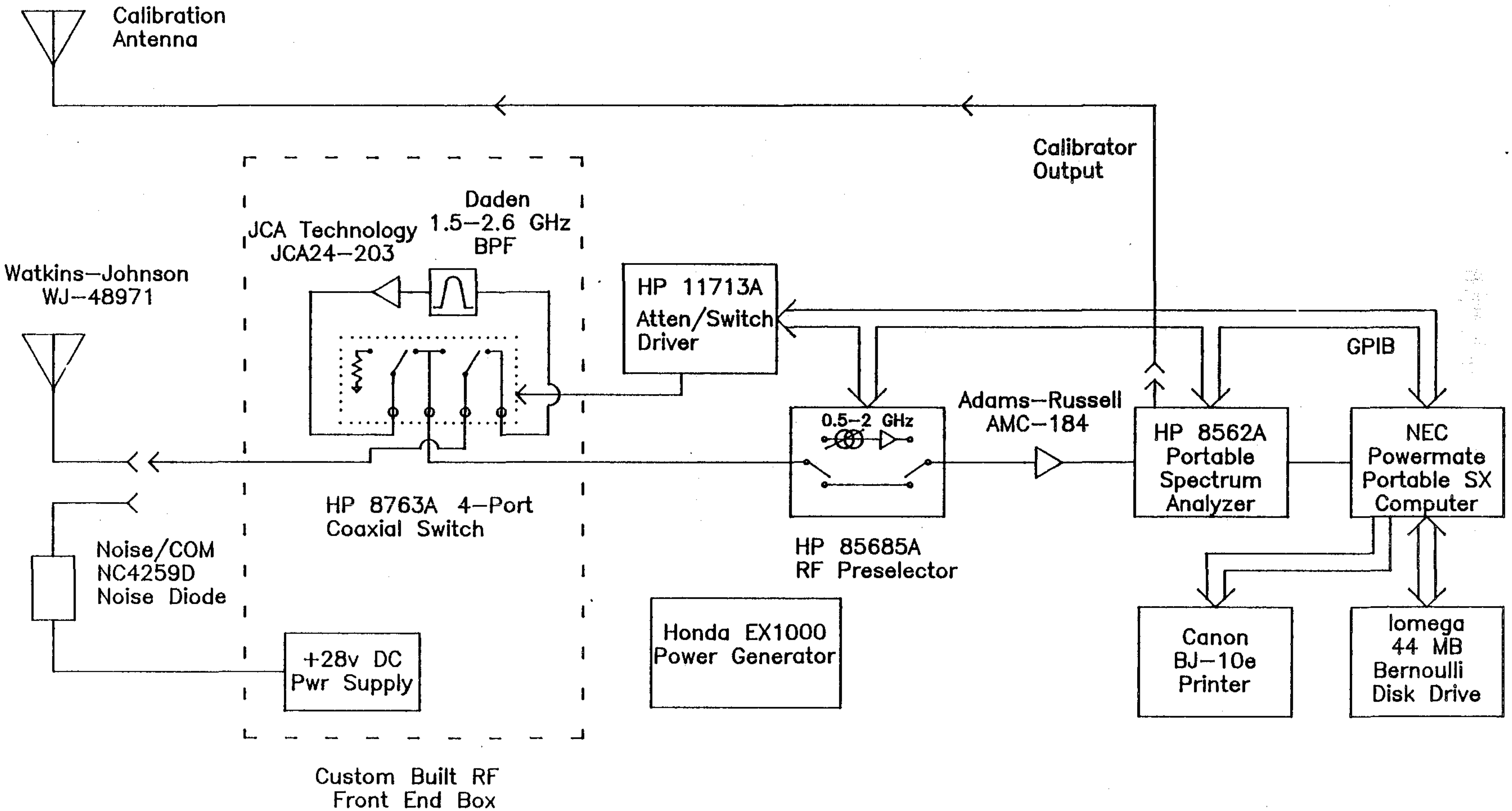

Figure 3.2 Block diagram of the Spectrum Usage Measurement System.

maximum noise figure of 4 dB. The YIG filter in the rf preselector has a 3 dB bandwidth of approximately 20 MHz. The gain through the YIG filter and amplifier in the rf preselector is approximately 20 dB.

After the rf preselector, the signal passes through another amplifier. This amplifier provides 20 dB gain for signals in the whole measurement frequency range (i.e., 600 to 2600 MHz). The purpose of this second amplifier is to improve the overall system noise figure by adding enough gain to overdrive the noise of the spectrum analyzer. The signal, after passing through this last amplifier, is measured by a programmable spectrum analyzer.

The measurement system is controlled by a portable computer via the GPIB bus. The attenuator/switch driver, the spectrum analyzer, and the rf preselector are all under GPIB control. The attenuator/switch driver controls the four-port coaxial switch. A 44MB Bernoulli disk drive is used to store each data record taken (one data record corresponds to one scan on the spectrum analyzer). A printer is included in the system to provide hard copies of noise diode calibrations and sample measurements.

The +28v dc power supply is required to power the noise diode. The noise diode used has an excess noise ratio (ENR) of 25 dB which allows the noise figure measurement to be performed on the system. A photograph of the measurement system installed in the van is shown in Figure 3.3.

Figure 3.3 Photograph of the Spectrum Usage Measurement System.

4. MEASUREMENT PROCEDURE

The measurement procedure section is divided into subsections on the noise diode calibration, the antenna system test, and the measurement and data collection process at each measurement site.

4.1 Noise Diode Calibration

A noise diode calibration procedure was performed twice a day while the system was in the field making measurements. The procedure consisted of manually disconnecting the antenna feed cable at the antenna output connector and manually connecting a 25 dB ENR noise diode to the end of the antenna feed cable. The measurement system software allowed for a semi-automated noise diode calibration. By selecting spectrum analyzer calibration from the set of menus in the measurement system software, the Y-factor method (using on and off noise diode power) of calculating system noise figure was implemented. Along with system noise figure, the system gain was also determined. The system noise figure was computed at the antenna output terminals while the overall system gain was computed from the antenna output terminals through the spectrum analyzer. The system noise figure, system amplitude correction (inverse of system gain), and system noise level (in a 1 Hz bandwidth) vs frequency were displayed on the computer screen. The system operator compared these calibration curves to the initial calibration curves of the measurement system to determine whether the system was operating properly. If the system was operating properly, the calibration curves were saved to disk and the system noise figure and the system amplitude correction plots were printed out. The calibration curves were used in two different ways. For each frequency measured, the amplitude correction values were added to the RSL obtained from the spectrum analyzer to get the actual RSL at the antenna output terminals. Additionally, for every record of data stored (i.e., for every frequency scan of the spectrum analyzer) the average noise figure, system noise level in a 1 Hz bandwidth, and amplitude correction were recorded. These parameters were used to provide an additional check of the data integrity.

Figure 4.1 shows a typical system noise figure vs frequency plot from a noise diode calibration. Note that the system noise figure from 600 to 1000 MHz is always below 13 dB while the system noise figure from 1850 to 2600 MHz is always below 11 dB and is around 8 dB on the average. The transition at 1500 MHz occurs because the front end of the measurement system changes at this frequency. Figure 4.2 shows a typical system amplitude correction vs frequency plot from a noise diode calibration. From this plot, the gain of the system from 600 to 1000 MHz is approximately 36 dB while the gain from 1850 to 2600 MHz varies from about 26 to 36 dB.

4.2 Antenna System Test

The antenna system test was performed once a day before measurements commenced. This procedure entailed mounting a short monopole calibration antenna on the roof of the mini-van a fixed distance away from the omnidirectional receive antenna. The calibration antenna was connected to the Calibrator Output port of the HP 8562A Spectrum Analyzer. The

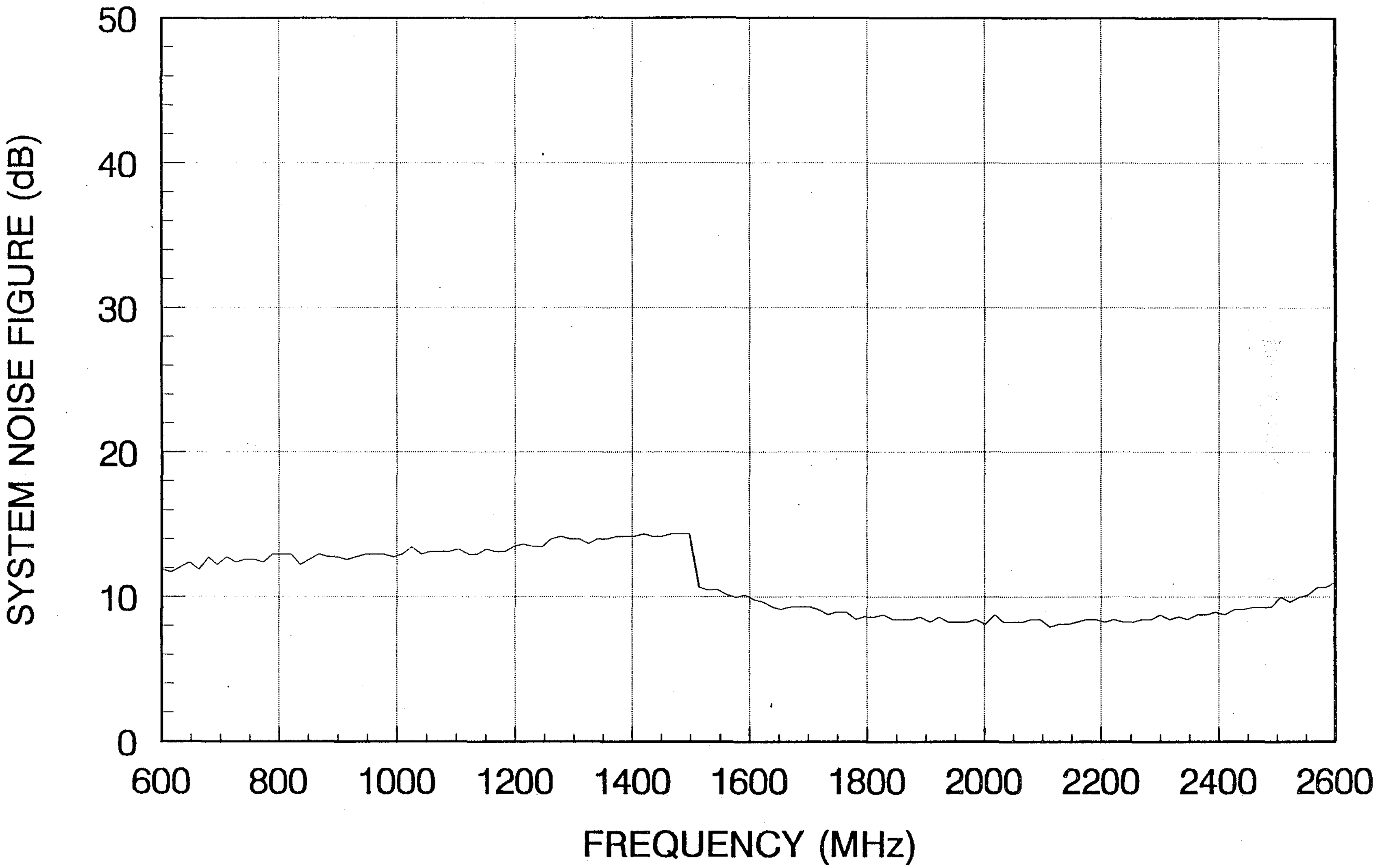

Figure 4.1 Typical system noise figure vs frequency.

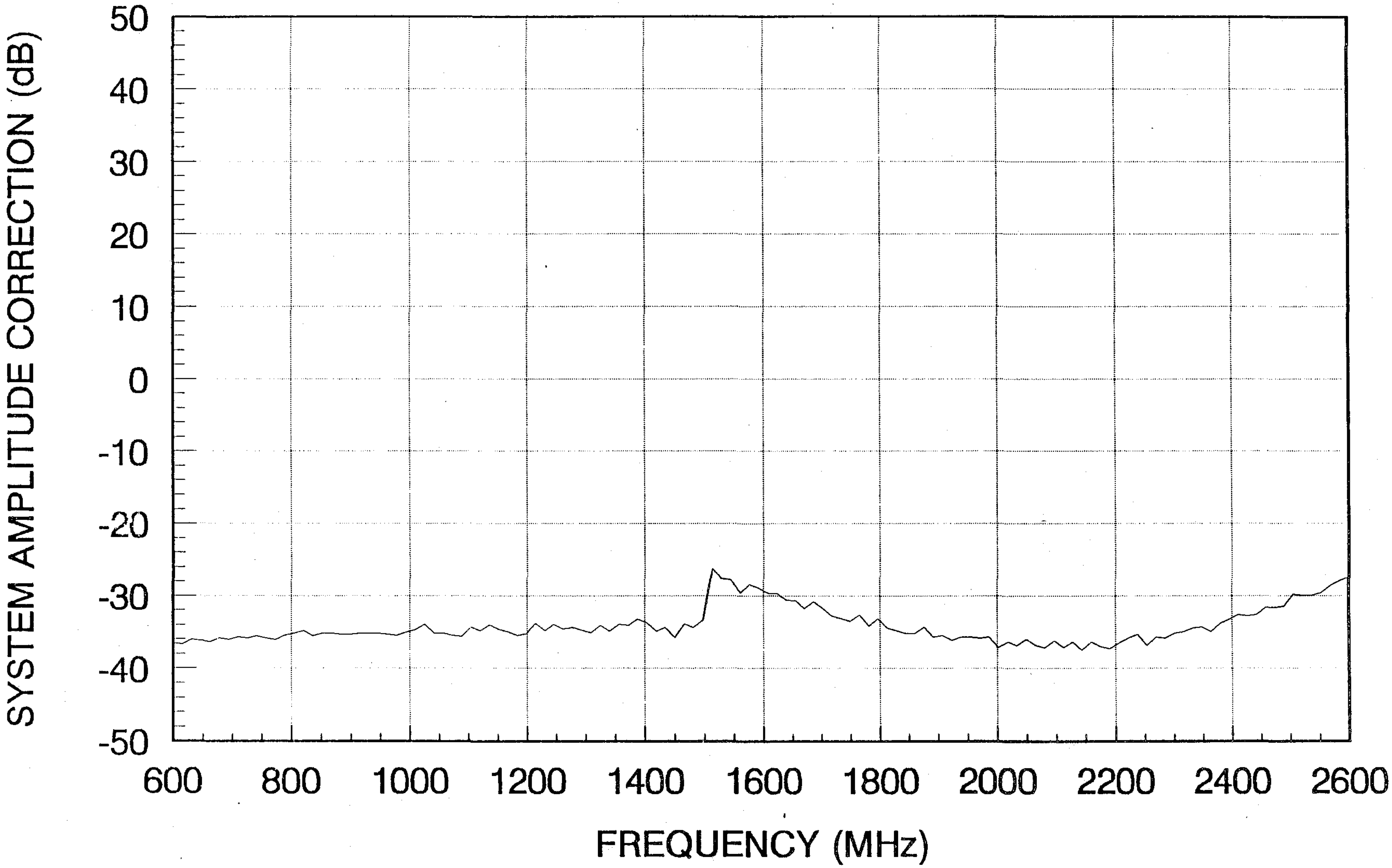

Figure 4.2 Typical system amplitude correction vs frequency.

Calibrator Output was a comb generator output producing a 300 MHz calibration signal and its harmonics. The RSL was measured with the measurement system at the harmonics between 600 and 2400 MHz. The RSL vs frequency plot (antenna system test plot) was then compared to a baseline antenna system test plot that was made during system development testing. This test was used exclusively to verify that the antenna and bulkhead connector cabling were working properly and was primarily qualitative in nature. Large differences in RSL seen between the present and baseline antenna system test plots would point to a malfunction or degradation in the antenna itself or the bulkhead connector cabling. When using this test, care was taken to ensure that ambient interfering signals were not present. By disconnecting the calibration antenna from the Calibrator Output and repeating the same measurement, the ambient signal environment was measured. The results of the antenna system test were not printed, saved, or used in system gain calibration. Before actually starting to make the spectrum usage measurements, the calibration antenna was removed from the roof of the mini-van.

4.3 Measurement and Data Collection Process at Each Location

The same procedure was followed at each location to make the measurements. Upon first starting out in the morning, the power generator was started and all of the equipment was turned on to allow sufficient time for the equipment to warm up. The rf preselector was the most sensitive piece of equipment with respect to warm up time and required at least 30 minutes to warm up. The equipment was kept running continuously throughout the day to ensure that the equipment was always warmed up during a measurement. The equipment was turned off only to refuel the generator.

After arriving at a location, the measurement software was initiated and the logistics information was entered. Specifically, the latitude and longitude, name of the city, location zoning classification (i.e., urban, suburban, and rural), test location number, and street address were entered. Additional information entered was the test type (spectrum usage), the test number (usually "1" unless the measurement was repeated at the same site), and any comments. All of this information was recorded with each data record. Each data record corresponds to one scan of the spectrum analyzer.

Following the logistics information, the beginning file number was incremented and the record number was re-initialized. The Bernoulli disk drive was then checked to ensure that the correct formatted disk was in the drive. At this time, the automated measurements were started via the measurement system software. The current date and time were displayed on the computer screen along with information specific to the measurement (such as whether or not unattended hard copy or recording was on). This information was checked for accuracy while the data began to be recorded. As the data were being taken, the spectrum analyzer screen showed the data that were being recorded. The data being taken were observed to be sure that valid signals were being measured and to check for system saturation. After all measurements had been taken at a location, the recorded data were checked for validity by looking at a few of the first and last data records that were taken at that location.

Location zone classification

The location zone classification was determined according to the following rules: If surrounding buildings in a location were spaced more closely than one building per 1/4 mile then the location was classified as either suburban or urban. The urban classification required the surrounding buildings to be at least four stories in height. If surrounding buildings were less than four stories in height then the location was classified as suburban. The rural classification was used when buildings were spaced at least 1/4 mile apart. These rules for choosing location zones were established to be easily implemented by field personnel in a consistent manner and to distinguish zones that would exhibit significant differences in propagation effects.

5. DATA ANALYSIS

The raw data taken at each site within a city consists of RSLs (in dBm) for each frequency measured. The data analysis entails processing these raw data to develop three different types of statistics. These statistics are then presented in graphical form. The three types of graphs that are generated are listed below:

1. Signal level: This graph shows the minimum, maximum, and mean RSL vs frequency.

2. Measured frequency usage: This graph displays the percentage of sites where the RSL at a frequency never exceeded a threshold during the measurements.

3. Measured band usage: This graph shows the percentage of sites for which a given percentage (or more) of the frequencies in the band have RSLs that never exceeded the selected threshold during the measurements.

The narrowband raw data (10 kHz resolution bandwidth) are used in generating these graphs. The narrowband data were selected chiefly to take advantage of the lower noise floor, which allowed the reliable measurement of weaker signals. The signal level and measured frequency usage graphs are presented for each of the five measurement frequency bands: 614-806 MHz, 824-944 MHz, 1850-1994 MHz, 2110-2182 MHz, and 2400-2600 MHz. The measured band usage graphs are presented for each of the 14 individual frequency bands listed in Table 2.1.

Signal level

The signal level graphs show RSLs across an entire measurement frequency band. These plots show minimum, maximum, and mean signal levels at each frequency as measured at all sites in the city. The frequency scale on these graphs is highly compressed, since some of these graphs contain as many as 20,000 measured frequency points. Even though much of the detail is not observable, the intended function of the signal level graphs is to provide a qualitative view of signals, not a quantitative one. Therefore, it is not important that the data are too compressed to clearly show the details. However, the graph gives a strong impression as to how the signals are grouped in the band and whether the usage is heavy, random, etc.

The top graph in Figure 5.1 shows an example signal level graph for the 824-944 MHz frequency band using the narrowband data. The maximum RSL curve shows much activity and strong signals (up to -45 dBm) for the 824-849 MHz, 851-866 MHz, 869-894 MHz, 929-932 MHz, and 935-940 MHz frequency ranges. The mean RSL curve suggests that the signals in the 824-849 MHz band were detected at only a few of the sites while the signals in the 851-866 MHz, 869-894 MHz, 929-932 MHz, and 935-940 MHz frequency ranges were detected at a considerable number of sites.

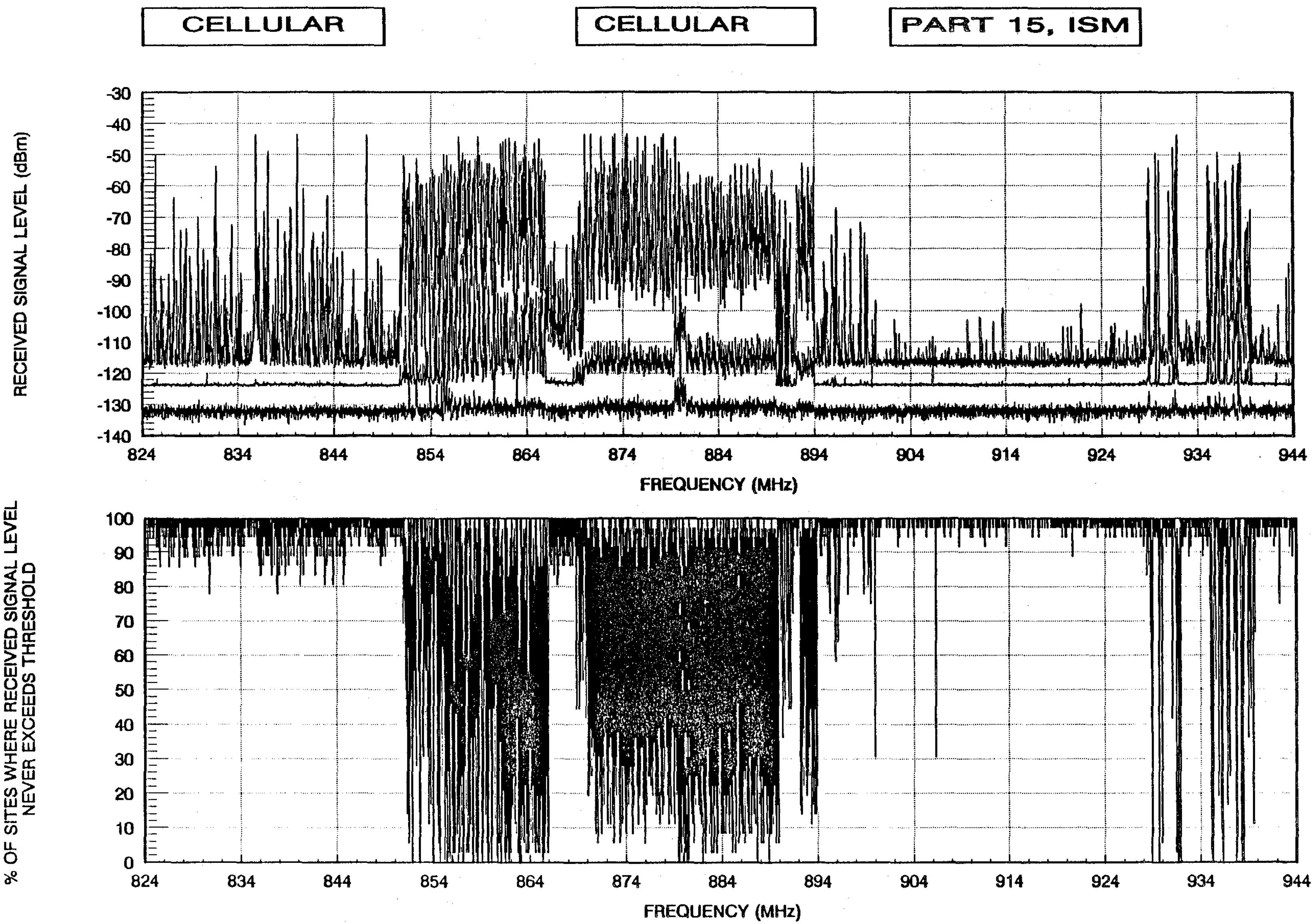

Figure 5.1 Example signal level (top) and measured frequency usage (bottom) plots for 824-944 MHz.

Measured frequency usage

The measured frequency usage graphs show the percentage of sites where a frequency was unused[1] during the measurement periods. These graphs are produced for six thresholds (-115 dBm to -90 dBm in 5 dB steps) and contain data from all sites in the city. Note that the lowest curve on each graph corresponds to the -115 dBm threshold while the highest curve corresponds to the -90 dBm threshold. As the threshold is raised, more sites will have RSLs that never exceed the threshold. The curves corresponding to each threshold may overlap but can never cross each other. In other words, a curve corresponding to a lower threshold can never exceed a curve corresponding to a higher threshold.

The frequency scale here, as in the signal level graph, is over the entire measurement frequency band. The large number of data points obscures many of the details but the graph is only intended to give a qualitative view of the data. The measured frequency usage graph is placed on the same page with the corresponding signal level graph, which allows an easier comparison between the two.

An example of a measured frequency usage plot using the narrowband data is given in the bottom graph of Figure 5.1. At 80% to 90% of the sites, most of the frequencies in the 824-849 MHz band were apparently unused. Conversely, at less than 10% of the sites, most of the frequencies in the 851-866 MHz, 929-932 MHz, and 935-940 MHz frequency ranges were apparently unused. Note that for this example and most of the measured frequency usage plots using the narrowband data, the curves corresponding to the different thresholds cannot be distinguished. The curve corresponding to the -115 dBm threshold does show up as the lowest curve though.

Measured band usage

The measured band usage graphs show the percentage of sites that had a certain percentage or more of the frequency band unused[2] during the measurement periods. These graphs show the distribution of the percentage of each band that is unused over the various sites and are intended as the major quantitative output for this measurement experiment. For the

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[1] For the purposes of this report, a frequency is considered unused if the RSLs at that frequency never exceeded a given threshold during the measurements. Note that this connotation only applies to the time at which the measurements were made, thus at other times the frequency could have been in use. Note also that a frequency considered to be unused in this report does not indicate that any system deployed at that frequency will not experience or cause interference. This would require a detailed Electromagnetic Compatibility (EMC) analysis which is beyond the scope of this report.

[2] For the purposes of this report, the percentage of frequency band (or band) unused means the percentage of frequencies in the band whose RSLs never exceeded the selected threshold during the measurements. A high percentage of the band unused is not an indication of the likelihood of a regulatory allocation change.

measured band usage graphs, the five measurement bands used in the signal level and measured frequency usage graphs are divided into the 14 individual frequency bands listed in Table 2.1.

For each of the 14 individual frequency bands, there are 4 graphs--one for each of the site zoning categories: urban, suburban, rural, and all sites combined. Each of the graphs contain data on the percentage of sites (for all sites in the particular zoning category) that have more than a particular percentage of frequencies unused in the band. Six thresholds (-115 dBm to -90 dBm in 5 dB steps) are used in generating the measured band usage graphs.

As in the measured frequency usage graphs, note that the lowest curve on each graph corresponds to the -115 dBm threshold while the highest curve corresponds to the -90 dBm threshold. As the threshold is raised, more frequencies in the band will have RSLs that never exceed the threshold. The curves corresponding to each threshold may overlap but can never cross each other (even though they may appear to cross on some graphs). In other words, a curve corresponding to a lower threshold can never exceed a curve corresponding to a higher threshold. The curves in the measured band usage graphs may be relatively coarse, since the individual zoning categories may contain only a few sites. If there are only four urban sites, for example, the site percentage can only change in 25% increments. The data were processed for band usage using 1% steps of the percentage of the band unused. Therefore, when it is stated in this report that none of the band was unused, it really means that less than 1% of the band was unused.

An example of these plots using the narrowband data for the 869-894 MHz frequency band is shown in Figure 5.2. Referring to the plot for urban sites in Figure 5.2, note that for the -110 dBm threshold 50% of the urban sites in the 869-894 MHz frequency band had at least 37% of the band unused. For the -115 dBm threshold, 50% of the urban sites had at least 21% of the band unused. Considering the -105 dBm threshold, 75% of all sites had at least 57% of the band unused. Conversely, 25% of all sites had less than 57% of the band unused. As expected, when the threshold is increased, more of the band appears unused. Another intuitive observation is that as a smaller percentage of the sites is considered more of the band appears unused.

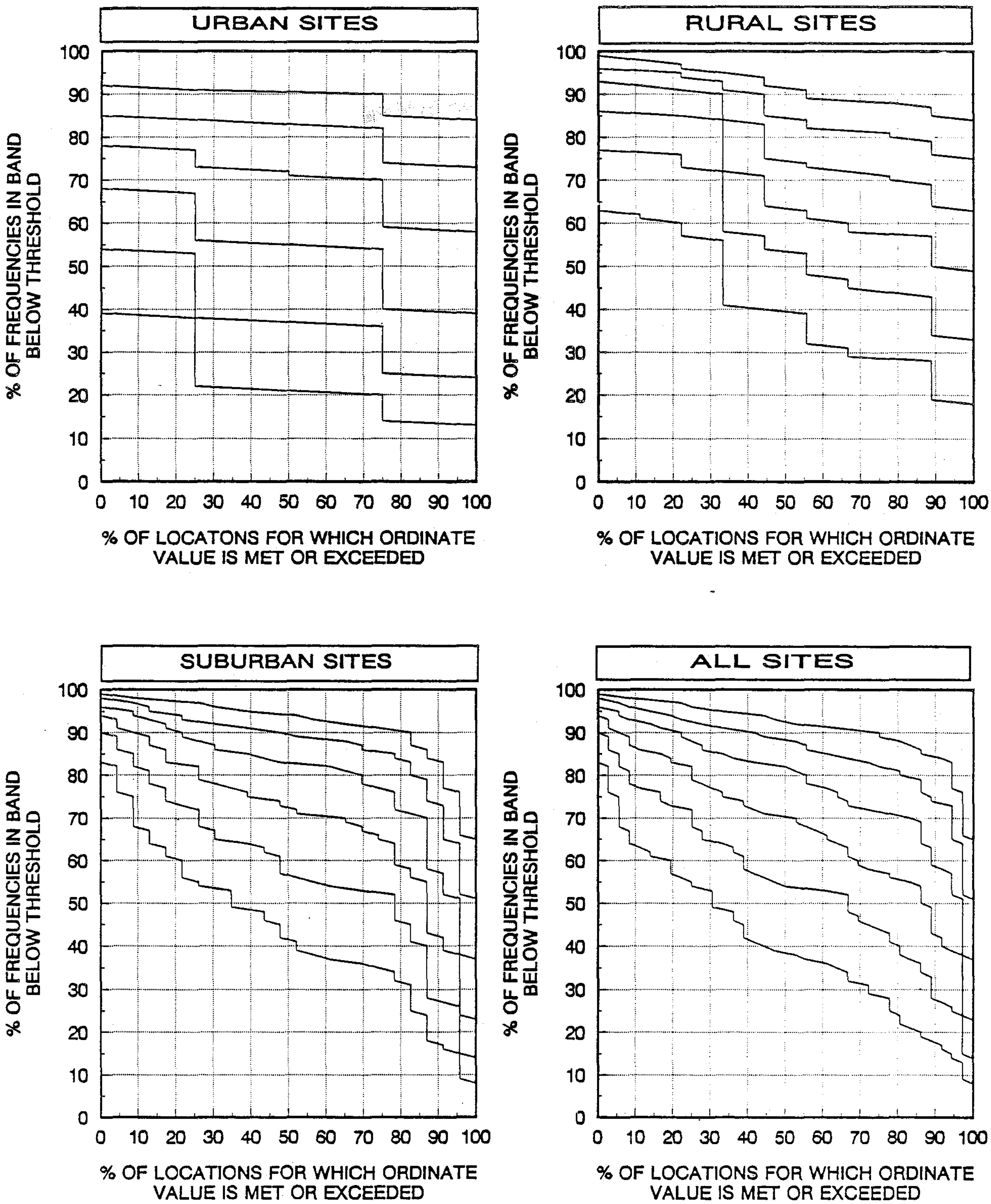

Figure 5.2 Example measured band usage plots for urban, suburban, rural, and all site types for 869-894 MHz.

6. DATA INTERPRETATION

The previous section discussed how the analysis graphs are to be understood in terms of the input data and the analysis process. The discussion of data analysis in Section 5 and the data presented in Sections 7-12 of this report are restricted to the narrowband data; the broadband and peak data described in Section 2 show a different picture. This section discusses adjustments to the narrowband analysis data that may be needed to make it apply more accurately to the problem of describing the PCS radio environment, especially if the PCS system uses bandwidths larger than 10 kHz.

As an example of the different analysis results that can be obtained with the use of different measurement parameters, consider the measurements obtained in Dallas in the 614-806 MHz (UHF-TV) band. Comparable data exist for the other cities as well, and they show similar results. Figure 6.1 shows the signal level graphs using the narrowband, wideband, and peak measurement parameters for the UHF-TV band. As presented in Section 2, the narrowband, wideband, and peak measurement parameters are described as follows:

narrowband:	10 kHz bandwidth, 3 kHz video filter, sampling detector
wideband:	300 kHz bandwidth, 10 kHz video filter, sampling detector
peak:	300 kHz bandwidth, 3000 kHz video filter, peak detector.

Each of the three signal level graphs in Figure 6.1 show measurement results which appear different, even though all of them are accurate representations of the data. The middle line (mean signal) on each graph shows system noise at frequencies where there is no signal. A comparison of these graphs shows that the average narrowband noise is near -124 dBm, the average broadband noise is about -110 dBm, and the average peak noise is about -100 dBm (note the different RSL scale on the narrowband graph). The 14 dB difference between the narrowband and the wideband measurements is due to the difference in bandwidths, and is very close to the 10 log bandwidth ratio for a 30:1 change in bandwidth (10 log 30 = 14.7 dB). The 10 dB change between the wideband and peak measurements is due to the peak weighting of the random system noise characteristics.

Although the different levels of system noise are easily explained by theory, they do affect the weakest signal that the system can measure. Signals that are smaller than the system noise are masked by it and cannot be seen. The better sensitivity of the narrowband measurements to detect weak signals was the main reason that the narrowband measurements were used as the basis for most of the analyses in this report.

The narrowband measurement shows less usage than the wideband measurement; the wideband measurement shows less usage than the peak measurement. This is caused by two effects. The "bandwidth convolution" effect makes any signal appear at least as wide as the bandwidth used to measure it. For example, the video and audio carriers in the TV signals (the pair of strong signals 4.5 MHz apart in the TV bands) appear to be very narrow in the narrowband graphs and much wider in the wideband and peak graphs. The increase in apparent system noise level for the wideband and peak graphs (discussed two paragraphs earlier) also increases the level of usage. Since the thresholds used in the measured frequency usage and measured band usage graphs ranged from -115 to -90 dBm in 5 dB steps, the average system

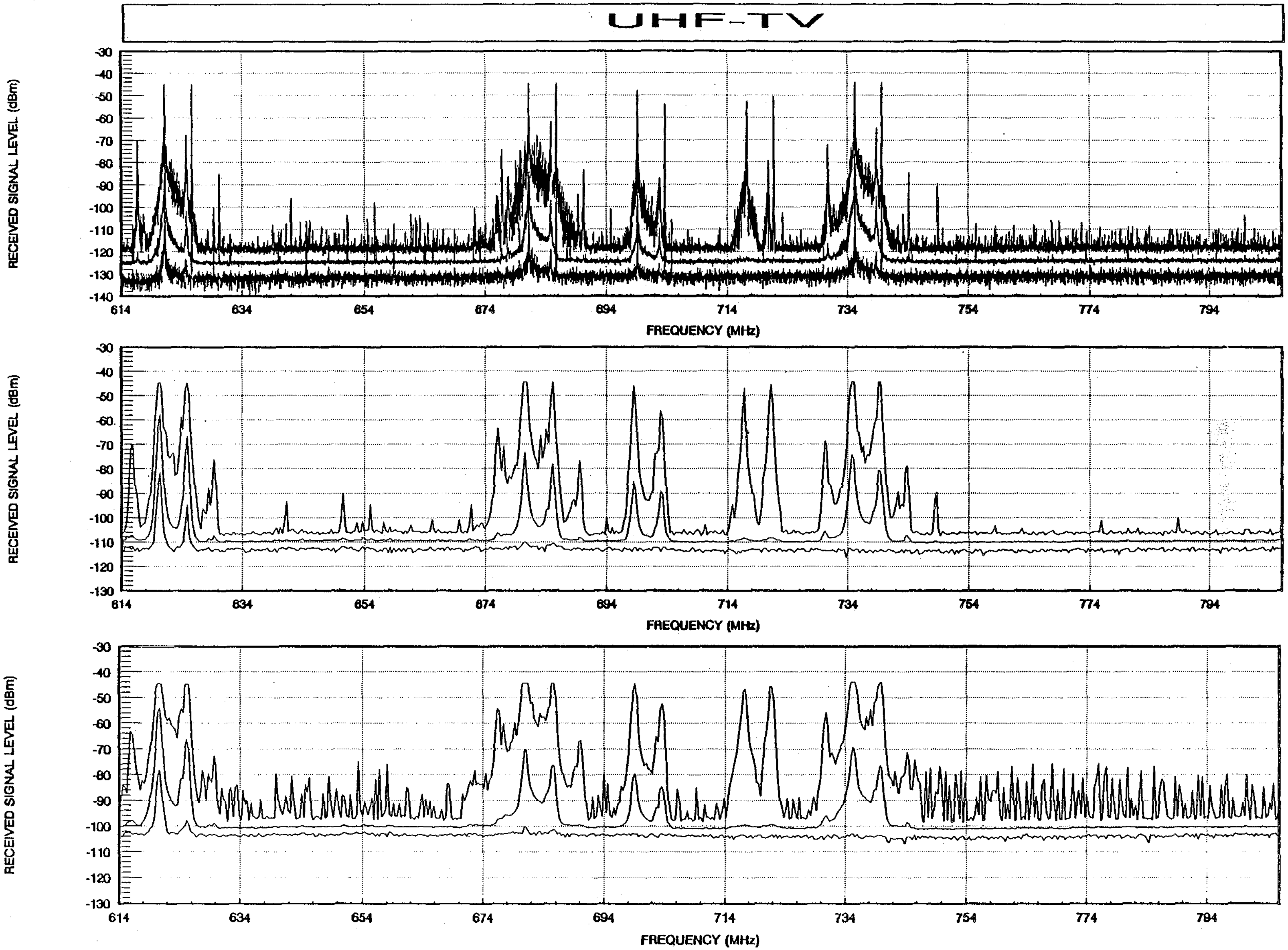

Figure 6.1 Comparison of signal level graphs using narrowband (top), wideband (middle), and peak (bottom) measurement parameters.

noise for wideband (-110 dBm) and peak measurements (-100 dBm) is actually larger than some of the thresholds. In these cases, system noise alone will cause the frequency to indicate high usage a high percentage of the time.

It is evident from the signal level graphs in Figure 6.1 that some intermodulation distortion from the video and audio carriers of the UHF-TV signals has occurred. The tracking YIG filter in the rf preselector was used to minimize the potential for intermodulation distortion. The YIG had a bandwidth of about 20 MHz so two strong signals (like the video and audio carriers of the UHF-TV signal) could still produce this undesirable effect. The only band in the measured data where intermodulation distortion was apparent was in the UHF-TV band.

The narrowband, wideband, and peak measured frequency usage graphs for the UHF-TV band are shown in Figure 6.2. Although these graphs look superficially similar, a closer inspection will reveal differences. It is known that the lowest curve will be for the -115 dBm threshold while the highest curve will be for the -90 dBm threshold, a total of six curves. Therefore, looking at the wideband measured frequency usage graph, one notes that the trace near the "0% of sites" line is actually the -110 dBm line. The -115 dBm line is invisible lying along the bottom edge of the graph. By looking at the wideband signal level graph in Figure 6.1, note that the minimum RSL is always greater than -115 dBm. Hence, it makes sense that 0% of the sites had RSLs that never exceeded -115 dBm. With the peak measured frequency usage graph, the -115 dBm, -110 dBm, and -105 dBm lines are all invisible lying along the bottom edge of the graph. Also, by looking at the peak signal level graph in Figure 6.1, note that the minimum RSL was always greater than -105 dBm. Therefore, it makes sense that 0% of the sites had RSLs that never exceeded -105 dBm.

Figure 6.3 contains the narrowband, wideband, and peak measurement versions of the measured band usage graphs for the UHF-TV band at all Dallas sites. These graphs clearly show the effect of the higher receiver noise levels for the wideband and peak graphs. Note that the graph for the narrowband case shows six curves corresponding to the six different thresholds. The graphs for the wideband and peak cases show only five and three curves respectively. The higher system noise causes all frequencies at the lower thresholds (-115 dBm for the wideband case and -115, -110, and -105 dBm for the peak case) to be completely used at all of the sites. Additionally, the higher system noise causes an unrealistically high percentage of band usage for the -110 dBm threshold in the wideband case and the -100 dBm threshold in the peak case. The bandwidth convolution effect causes more usage to be indicated at the higher thresholds for the wideband and peak measurements. This phenomenon is illustrated by considering the -90 dBm threshold curves on the measured band usage graphs. 50% of the sites have at least 99%, at least 94%, and at least 87% of the band unused for the narrowband, wideband, and peak cases, respectively.

A proper use of this data suggests that the influence of system noise on usage should be ignored as much as possible. The bandwidth convolution effect, on the other hand, could be used to scale usage to the actual bandwidth used in a proposed PCS system.

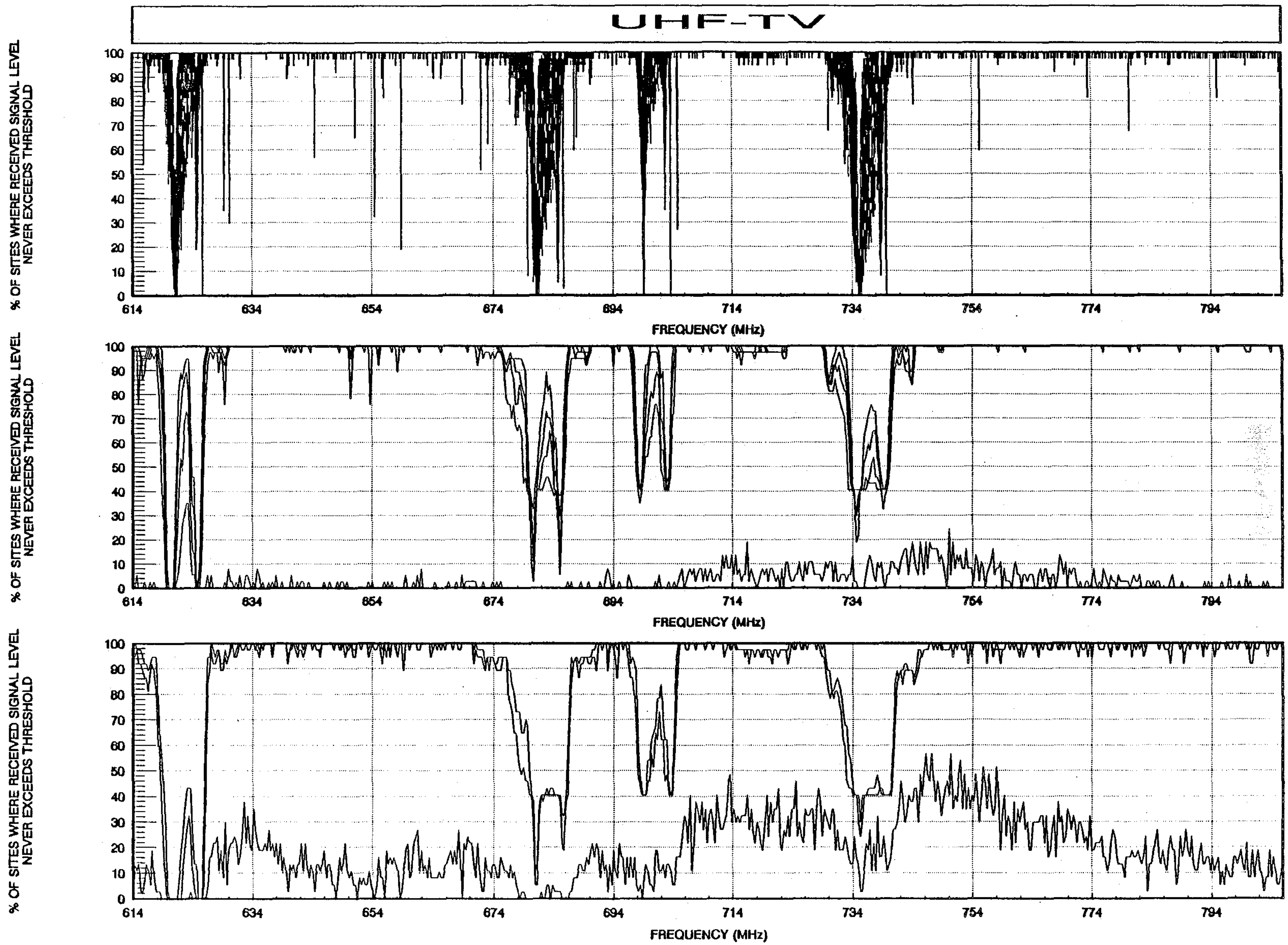

Figure 6.2 Comparison of measured frequency usage graphs using narrowband (top), wideband (middle), and peak (bottom) measurement parameters.

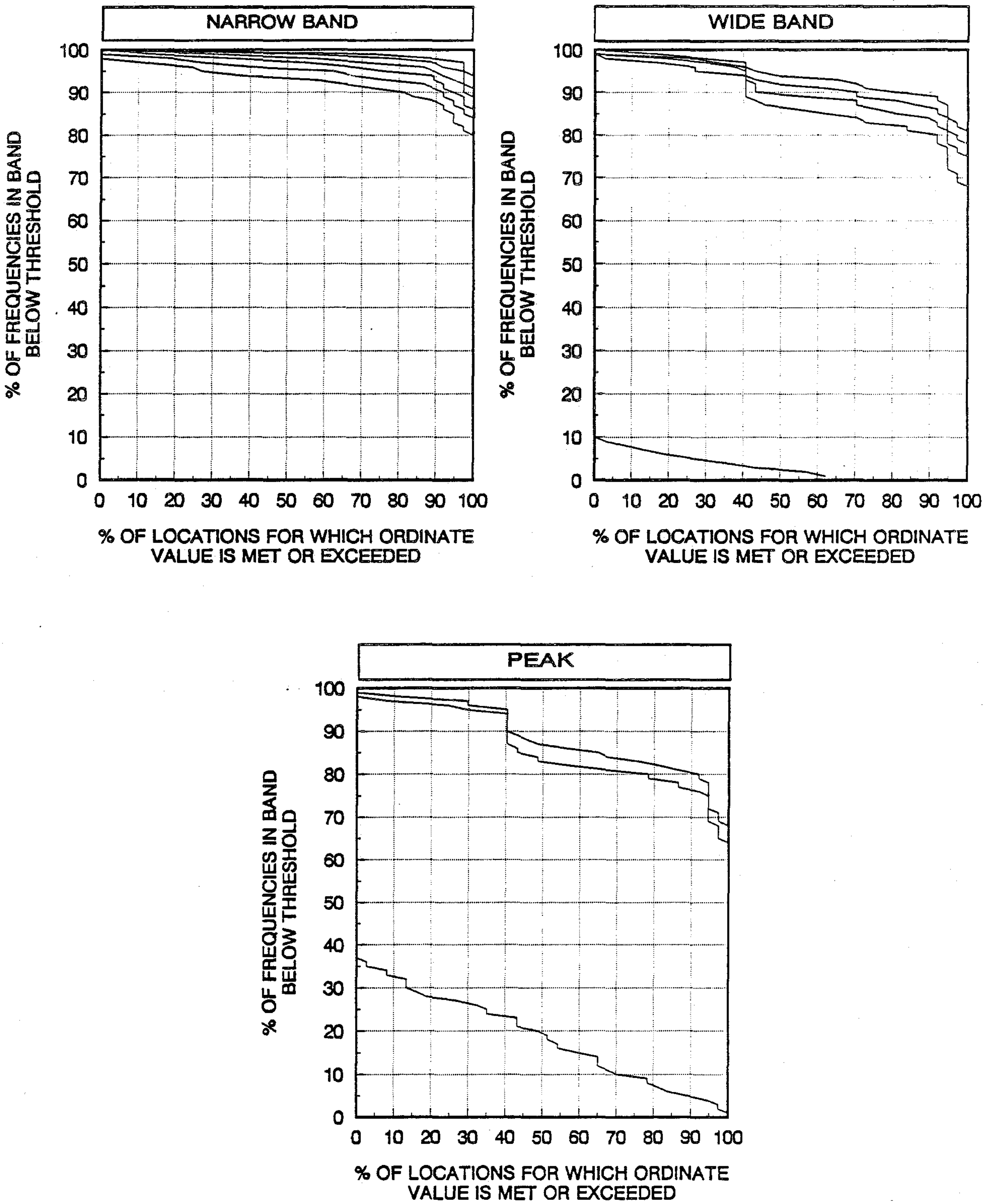

Figure 6.3 Comparison of measured band usage graphs using narrowband, wideband, and peak measurement parameters.

Receivers and transmitters

When trying to discover the amount of radio spectrum unused, a measurement of existing signals indicates what local transmitters are operating that could interfere with a PCS signal. However, additional frequency use can also be prohibited because of local receivers that might receive interference from a PCS signal. In a band where equal numbers of transmitters and receivers are tuned to different frequencies, for example, one might claim that the frequencies shown as used should be doubled. This is because the measurements recorded only transmitter usage and the frequencies denied by receivers need to be accounted for also. This effect is now discussed for point-to-point microwave links.

In point-to-point microwave links, the receiver uses the same frequency as the corresponding transmitter. If the transmitter signals are actually received by the measurement system, no additional spectrum is used by the receivers. There is a case, however, where additional spectrum usage due to the receivers would not show up in the measurements made in this experiment. This case occurs when measurements were made in a location where the transmitted signal was not received by the measurement system but the point-to-point microwave receiver could be interfered with by a PCS system. If this phenomenon were occurring during the measurements, more spectrum would be used than that implied by the measured data. The degree to which more spectrum would be used is strictly a function of how often this phenomenon occurred.

Antenna characteristics

A vertically polarized omnidirectional antenna was used for these measurements. Many signals, however, are horizontally polarized, and they could have been missed because of the different polarization. In the point-to-point microwave bands, about half of the frequencies are transmitted with horizontal polarization; the other half are transmitted with vertical polarization. The UHF-TV bands contain predominately horizontally polarized signals, but the LMR and cellular bands contain predominately vertically polarized signals.

Reception of a signal with the "wrong" polarization will result in a lower effective antenna gain. In the case of a direct path between the main beam of a microwave antenna and the measurement antenna, this could cause as much as a 20 dB decrease in effective antenna gain. This would cause the signals to appear weaker in the measurements than they actually were for as many as half of the signals measured.

On the other hand, most of the measurement sites were not line-of-sight to the microwave antenna main beam. The signal path to the receiving antenna may have been via reflections or diffraction paths or may have been line-of-sight to a sidelobe or backlobe of the microwave antenna. In these cases, the polarization will tend to be scrambled, and there should be little systematic effect on the levels of signals received. Overall, it is estimated that 10% to 40% of the horizontally polarized signals might have been missed because of antenna polarization. The polarization of antennas to be used in PCS is uncertain although the existing land mobile systems use vertically polarized antennas.

Impulsive signals

The peak measurements were made especially to detect impulsive signals, such as radars and automobile ignition systems. Such signals have the capability to interfere with digital systems, but the low duty cycle of impulsive signals would generally let them escape detection with the narrowband and wideband systems. The signal level graphs of Figure 6.1 show a pervasive noise background that was captured with the peak measurement but does not show up in either the narrowband or wideband measurements. Because of the nature of the peak measurement system it was not possible to give any quantitative description of the impulsive noise. It is, however, probably important to include some additional error correction for digital communication systems operating below 1 GHz.

Indoor transmitters

The measurements in this experiment were made exclusively outdoors. Hence, signals from transmitters operating indoors (such as some ISM and Part 15 devices) appeared weaker than if the measurements had been made indoors. Therefore, PCS systems operating indoors would see higher usage in the bands with indoor transmitters (such as the ISM and Part 15 bands) than indicated from the measurements taken in this experiment.

Detailed time and frequency usage distributions

The measured usage data reported on here has been analyzed to give a single number representing a sum of usage at all frequencies in a band, for all locations (and times). A more detailed knowledge of how that usage is distributed in time, amplitude, frequency, and location would be needed to complete an EMC analysis of a proposed system or to design a system which might be the most compatible with the actual usage in a given frequency band. Depending on a detailed knowledge of frequency usage, various techniques of error correction, modulation, real-time frequency selection, or geographical frequency coordination might be selected to give adequate performance in an operational PCS system.

Summary

This section has presented a discussion of modifications which might be desirable to apply to the narrowband measurement results presented in the remainder of the report. The exact nature and extent of these modifications will be dependent on the specifications of the PCS system that is being considered. For purposes of brevity and simplicity, only the narrowband data is presented in the remainder of this report.

7. DALLAS DATA

A map showing the measurement sites in Dallas is shown in Figure 7.1. The map shows the measurement sites as a one mile radius about each intersection and center point of the site selection grid. Table 7.1 lists the measurement sites according to their zoning classifications (i.e., urban, suburban, and rural). The definition of these zoning classifications is given in Section 4.3 of this report.

Table 7.1 Categorization of Numbered Measurement Sites in Dallas

Urban				Suburban				Rural			
15	16	18	19	1	2	3	4	5	6	7	10
				8	9	11	12	25	31	32	33
				13	14	17	20	35			
				21	22	23	24				
				26	27	28	29				
				30	34	36	37				

Table 7.1 shows that approximately 11% of the sites are urban, 65% of the sites are suburban, and 24% of the sites are rural. The statistics generated for all site types combined is therefore weighted most heavily by the suburban sites. While extracting information from the data that are presented here, the distribution of site zoning types must be kept in mind. Due to the size of the sample set, the statistics generated for suburban sites provide a fairly accurate representation of suburban sites in this city. The statistics generated for the other site types do not provide as good a representation of their site types in this city, due to the more limited sample size.

For the narrowband measurements, the signal level, measured frequency usage, and measured band usage graphs are presented for the five measurement frequency bands: 614-806 MHz, 824-944 MHz, 1850-1994 MHz, 2110-2182 MHz, and 2400-2600 MHz. For brevity, the detailed discussion of the data will consider just the -115 dBm threshold, although occasionally the results obtained by using different thresholds will be pointed out. In examining the graphs, note that the curves corresponding to the six threshold levels in the measured frequency and band usage graphs can never cross but they can overlap. The data from all other cities is presented in later sections and will not be discussed in detail. In the Comparison of Data Between Cities section, the salient similarities and differences in the data seen from the different cities will be discussed. Hence, the discussion of the data from Dallas will serve as the basis for comparison between all of the cities.

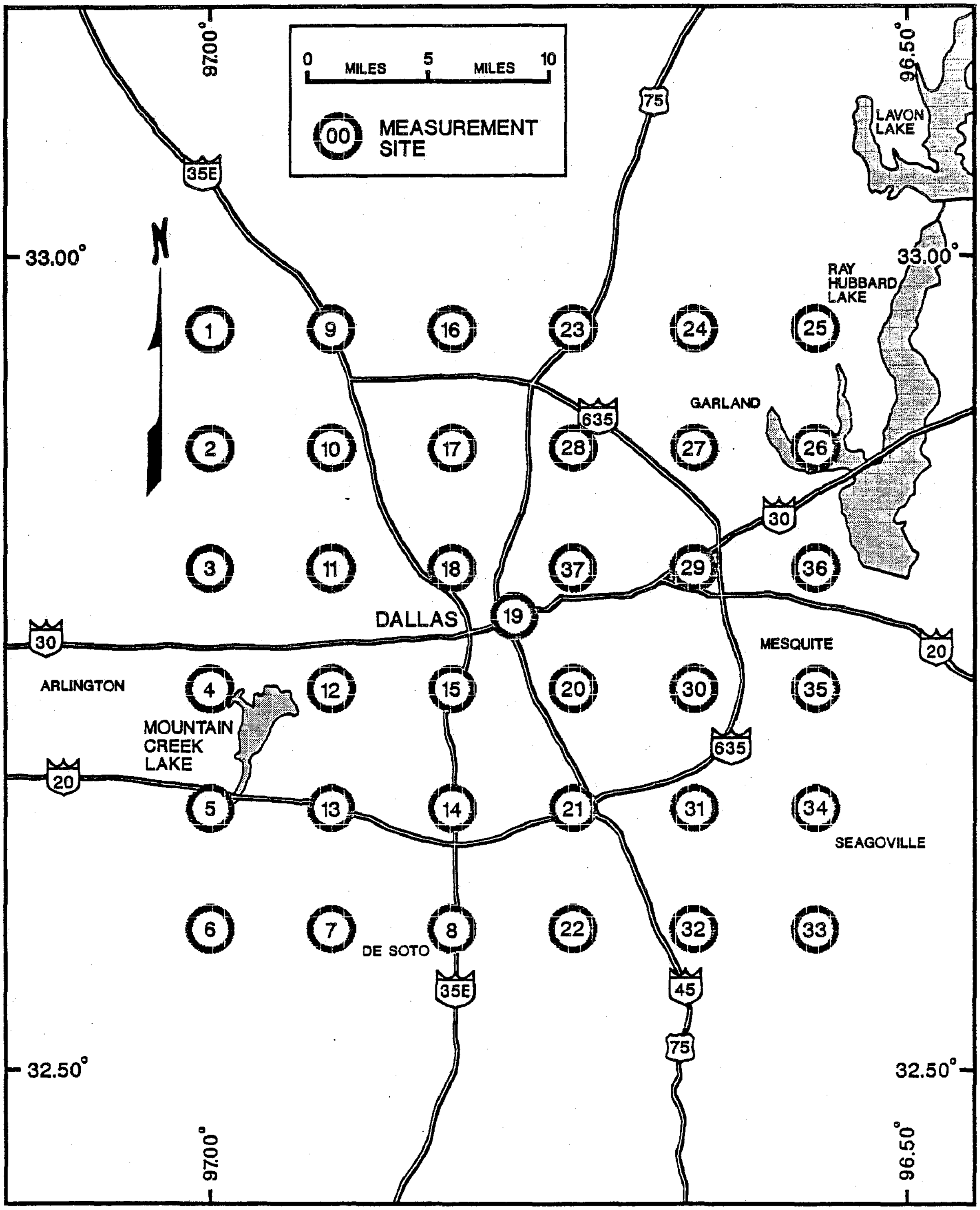

Figure 7.1 Measurement sites in Dallas.

7.1 The 614-806 MHz Measurement Frequency Band

Figure 7.2 shows the signal level and measured frequency usage graphs for the 614-806 MHz (UHF-TV) band. First consider the signal level (top) graph in Figure 7.2. Looking at the maximum RSL, it is clear that five strong UHF-TV transmitters were observed in the Dallas measurements. The mean RSL provides some additional interesting information. Namely, only four strong UHF-TV transmitters are detectable from the mean RSL curve; channel 55 (716-722 MHz) does not show up on the mean RSL curve. This suggests that channel 55 was received at only a few of the sites probably because it operates only a few hours a day. Examining the measured frequency usage (bottom) graph in Figure 7.2 for the frequencies occupied by channel 55, approximately 95% of the sites have those frequencies unused[3]. The six thresholds shown on this plot are obscured but the intent of this graph is strictly to get a qualitative picture of spectrum usage. As expected, the frequencies occupied by the four other strong UHF-TV transmitters show that few of the sites have those frequencies unused.

Figure 7.3 shows the measured band usage graphs for the 614-806 MHz band. Here all six thresholds are distinguishable. Considering only the -115 dBm threshold, all urban sites have at least 91% of the band unused[4], all suburban sites have at least 85% of the band unused, all rural sites have at least 80% of the band unused, and all sites combined have at least 80% of the band unused. As expected, when the threshold is increased, more of the band appears unused. Another observation is that as a smaller percentage of the sites is considered more of the band appears unused.

7.2 The 824-944 MHz Measurement Frequency Band

Investigating the signal level graph in Figure 7.4, several interesting facts are noticed. First of all, the maximum RSL curve shows much activity and strong signals for the 824-849 MHz, 851-866 MHz, 869-894 MHz, 929-932 MHz, and 935-940 MHz frequency ranges. The mean RSL curve suggests that the signals in the 824-849 MHz band were received at only a few of the sites. By observing the corresponding measured frequency usage graph in Figure 7.4 for the 824-849 MHz band, the busiest frequency is unused at approximately 80% of the sites. Conversely, in the 851-866 MHz, 869-894 MHz, 929-932 MHz, and 935-940 MHz frequency ranges, the busiest frequency is unused at 0% of the sites.

Cellular bands

Figure 7.5 shows the measured band usage graphs for the 824-849 MHz band (cellular mobile-to-base station). All of the urban sites have at least 93% of the frequencies unused while all rural sites have at least 89% of the frequencies unused. From Figure 7.5, it is seen that all sites and all of the suburban sites have at least 88% of the band unused.

3,4 For definitions of unused frequency and the percentage of band unused see page 19.

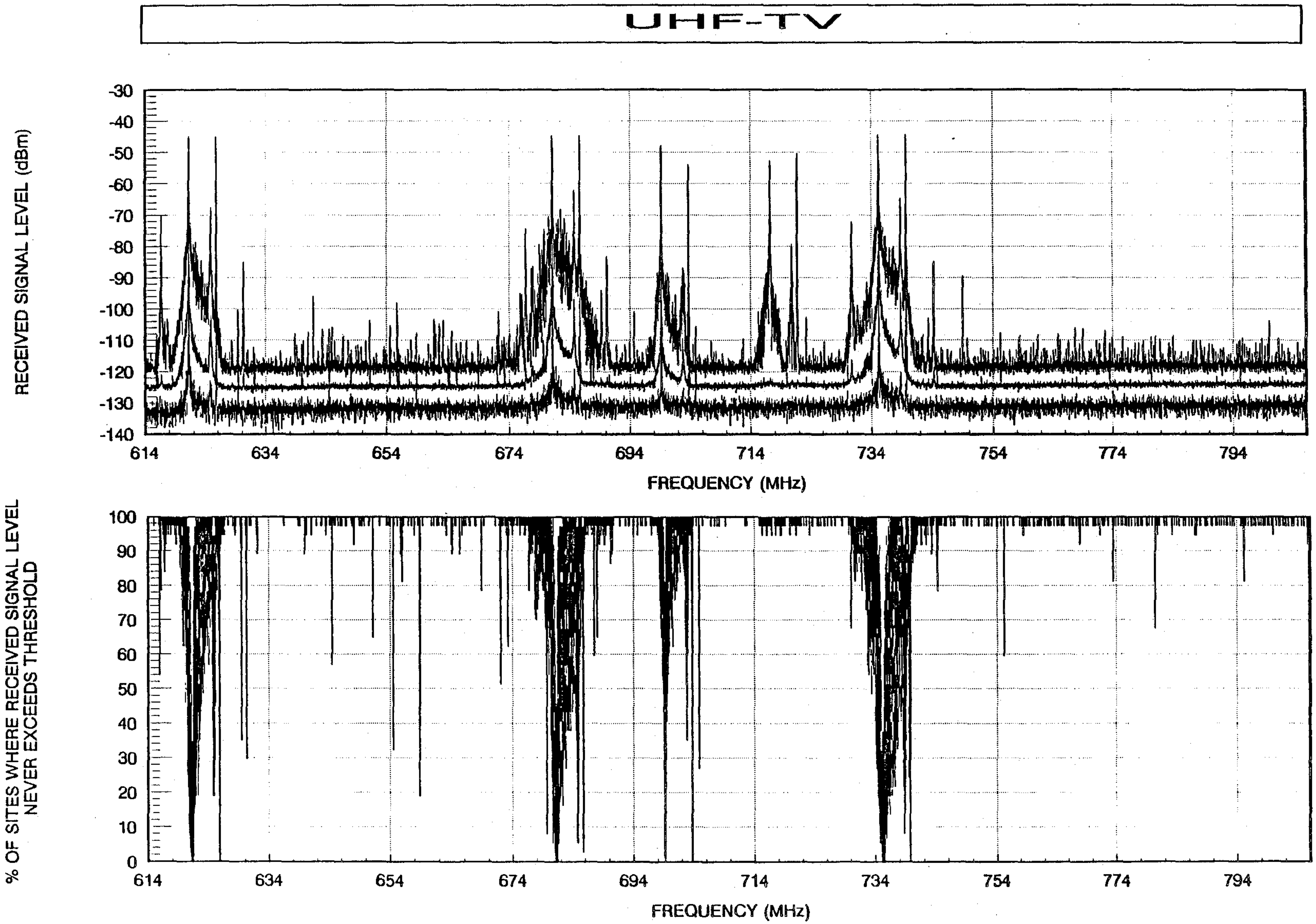

Figure 7.2 Signal level (top) and measured frequency usage (bottom) plots for Dallas 614-806 MHz.

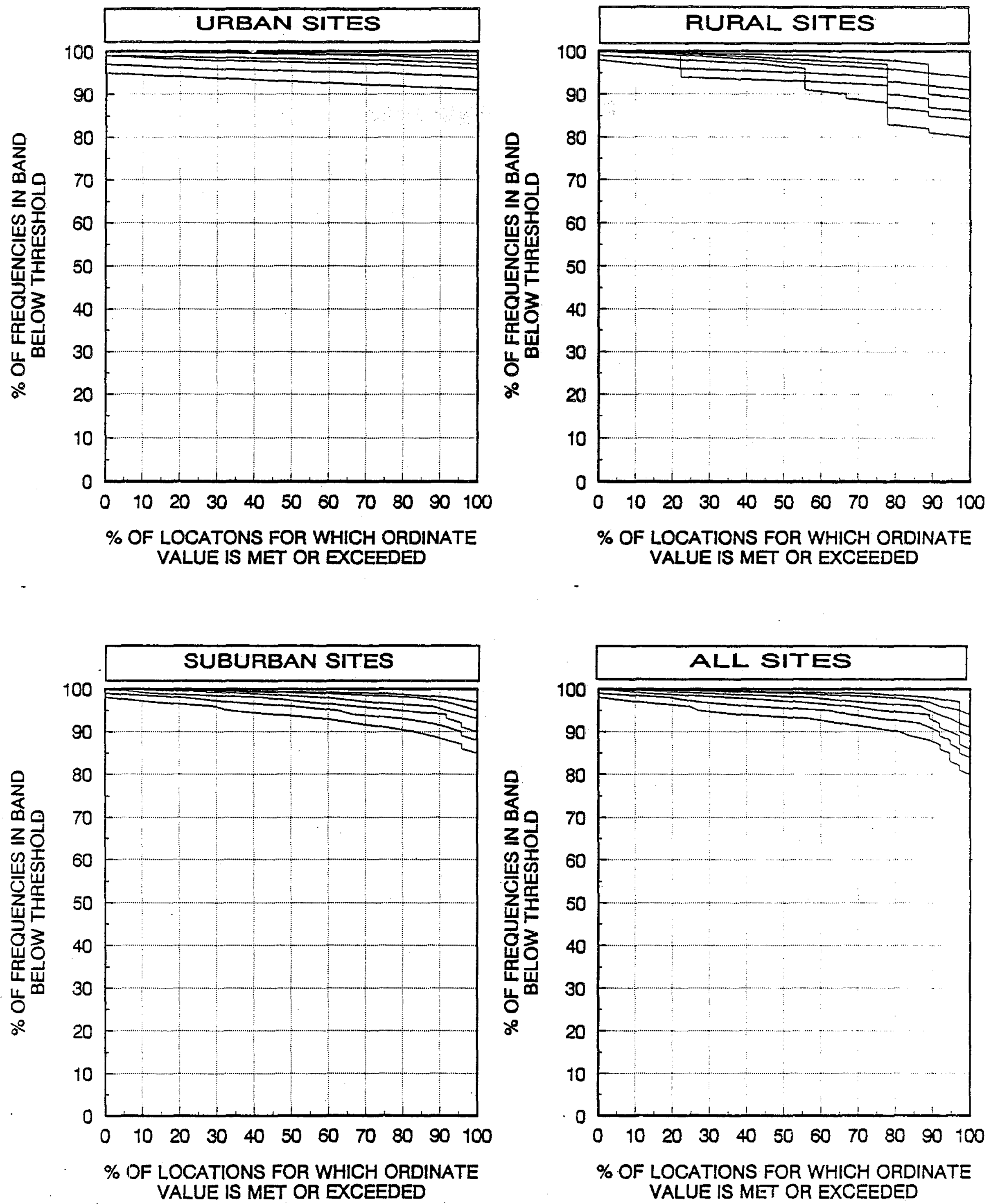

Figure 7.3 Measured band usage plots for urban, suburban, rural, and all site types for Dallas 614 - 806 MHz.

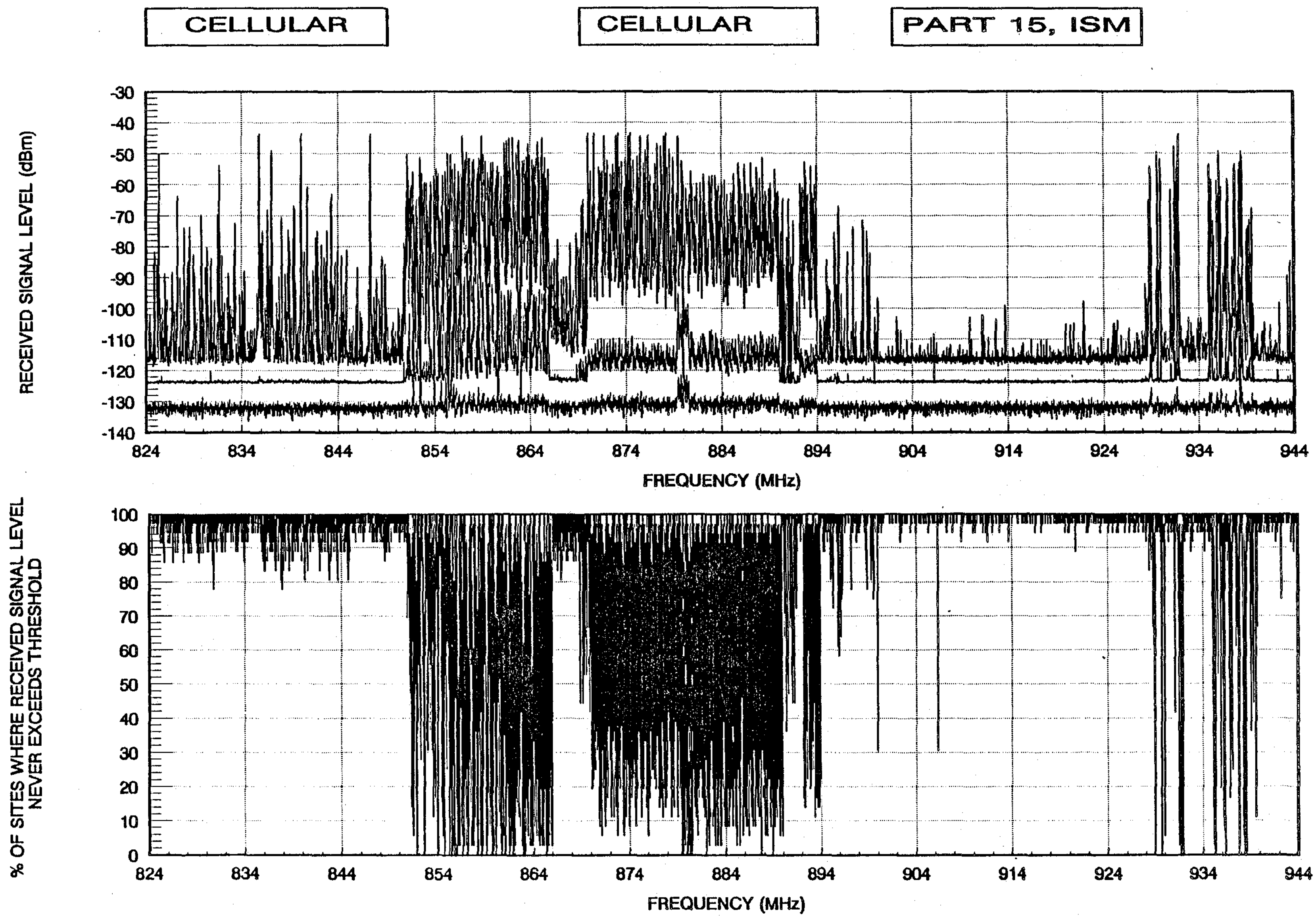

Figure 7.4 Signal level (top) and measured frequency usage (bottom) plots for Dallas 824 - 944 MHz.

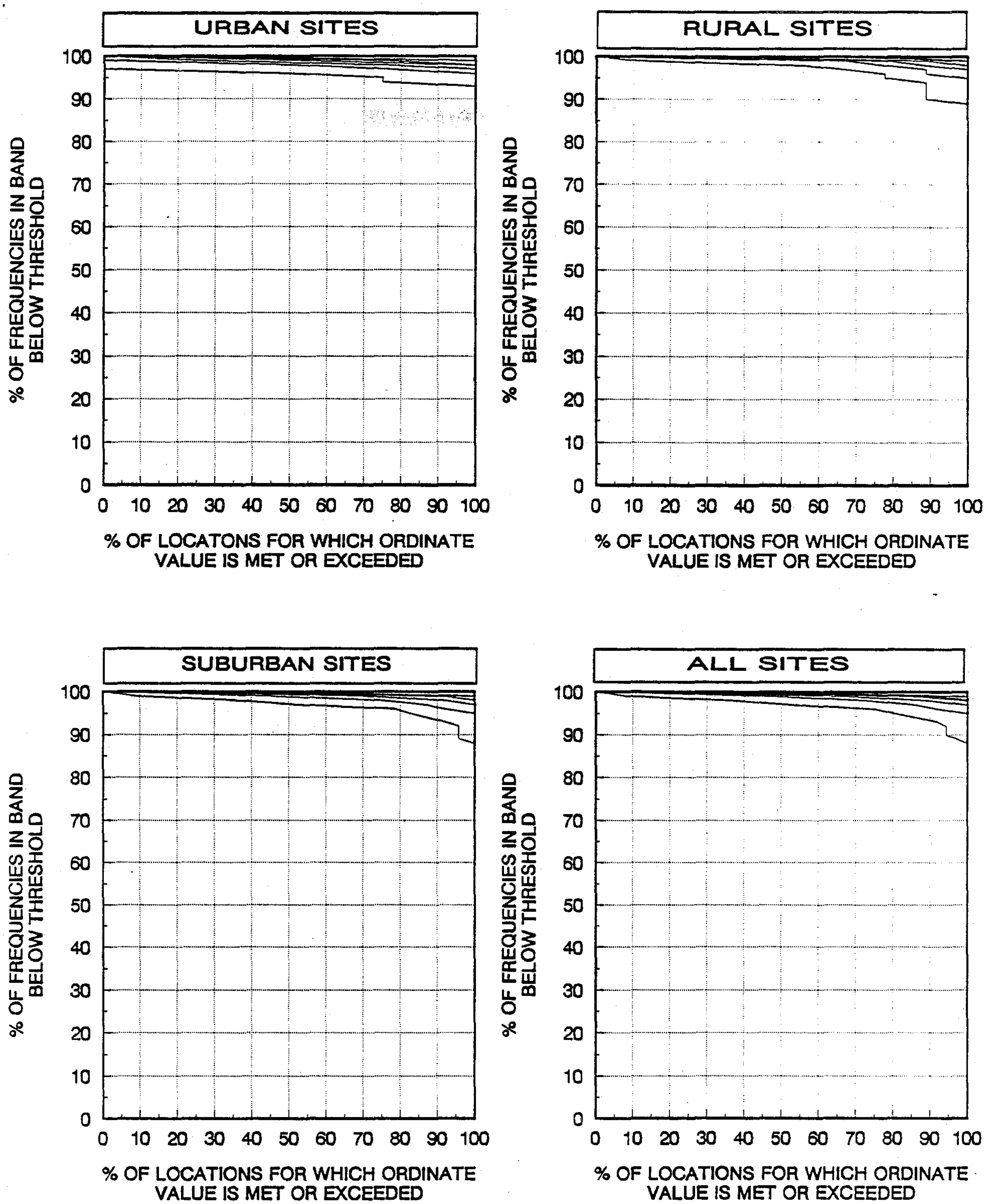

Figure 7.5 Measured band usage plots for urban, suburban, rural, and all site types for Dallas 824 - 849 MHz.

Figure 7.6, the measured band usage graphs for the 869-894 MHz (cellular base-station-to-mobile) band, shows heavy usage. All rural sites have at least 18% of the band unused while all suburban sites have at least 8% of the band unused. All urban sites have at least 13% of the band unused while all sites have at least 8% of the band unused. Note that 50% of all sites have at least 38% of the frequencies unused.

Clearly, the cellular mobile-to-base station band shows much less usage than the cellular base station-to-mobile band. This may seem strange because intuition would suggest that the mobile-to-base station band would be used as much as the base station-to-mobile band. Cellular is indeed a duplex operation where both channels are used for the duration of the call. The important factor here is that the propagation losses are higher from the typical cellular mobile unit (with a low antenna) to the measurement receiver than from the cellular base station (with a higher antenna) to the measurement receiver. Therefore, the base station signals are seen much better than the mobile signals.

Air-to-ground bands

The measured band usage graphs for the 849-851 MHz band are displayed in Figure 7.7. All rural sites show at least 78% of the band unused. At least 89% of the band is unused for all suburban sites while at least 58% of the band is unused for all sites and all urban sites. Inspecting the measured band usage graphs for the 894-896 MHz band shown in Figure 7.8, one finds most of the frequencies (at least 85%) unused for all of the sites.

SMR band

For the 864-868 MHz band, the measured band usage graphs are presented in Figure 7.9. These graphs show quite a bit more band usage than in the air-to-ground bands. For all rural sites at least 20% of the band is unused, for all of the suburban sites at least 53% of the band is unused, for all of the urban sites at least 1% of the band is unused, and for all sites at least 1% of the band is unused. It can be deduced from these graphs that one urban site has very few of the frequencies unused in the band (less than 1%). Examining the maximum RSL curve on the signal level graph in Figure 7.4, notice a downward sloping set of signals/noise from 866-868 MHz. These signals/noise are above the -115 dBm threshold at one urban site thus causing most of the band to be used at that site. It is possible that these signals/noise are noise sidebands from a strong transmitter at the urban site.

GPMRS bands

The 901-902 MHz band, whose measured band usage graphs are shown in Figure 7.10, shows low usage. For this band, almost all of the frequencies are unused for all of the sites.

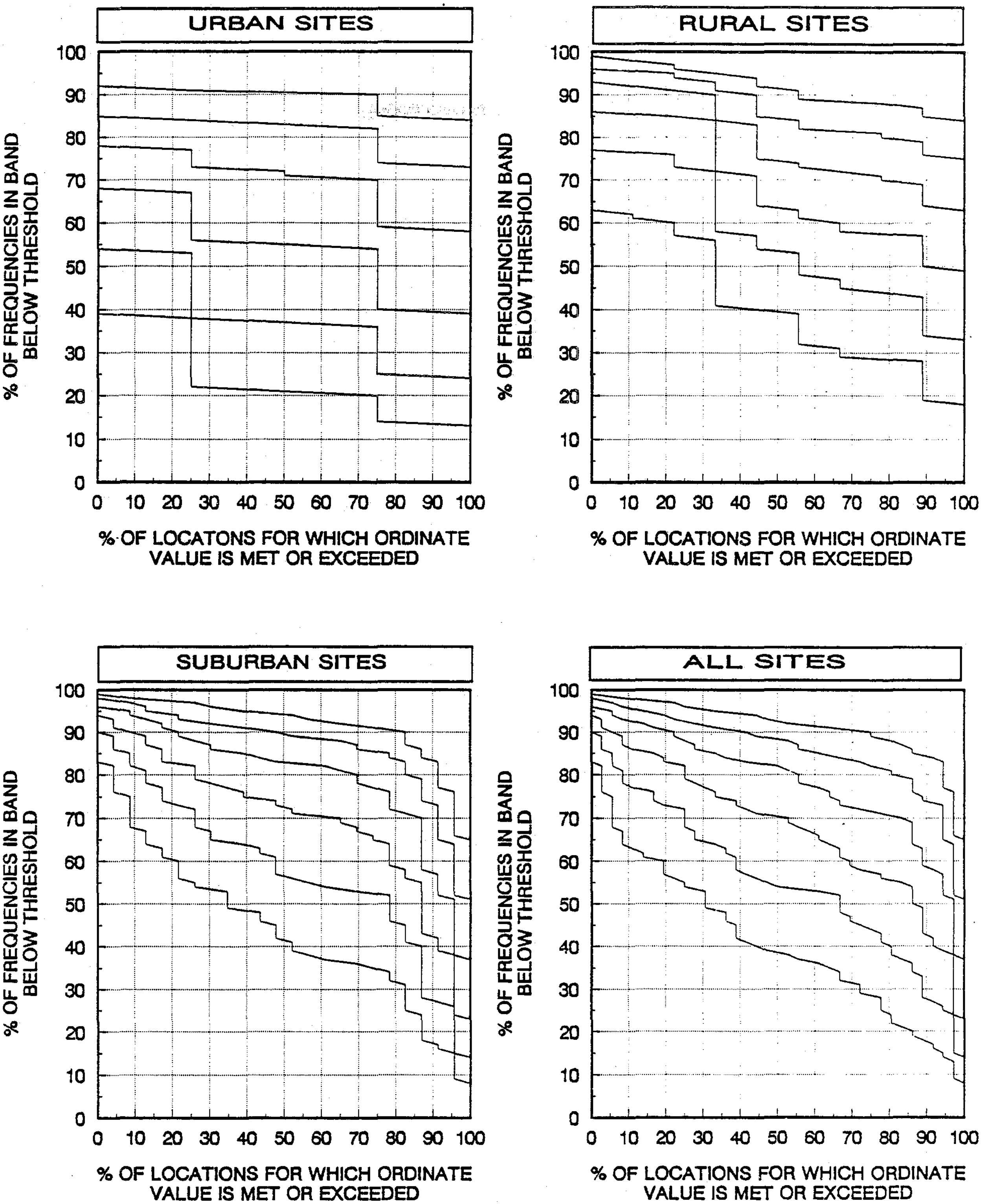

Figure 7.6 Measured band usage plots for urban, suburban, rural, and all site types for Dallas 869 - 894 MHz.

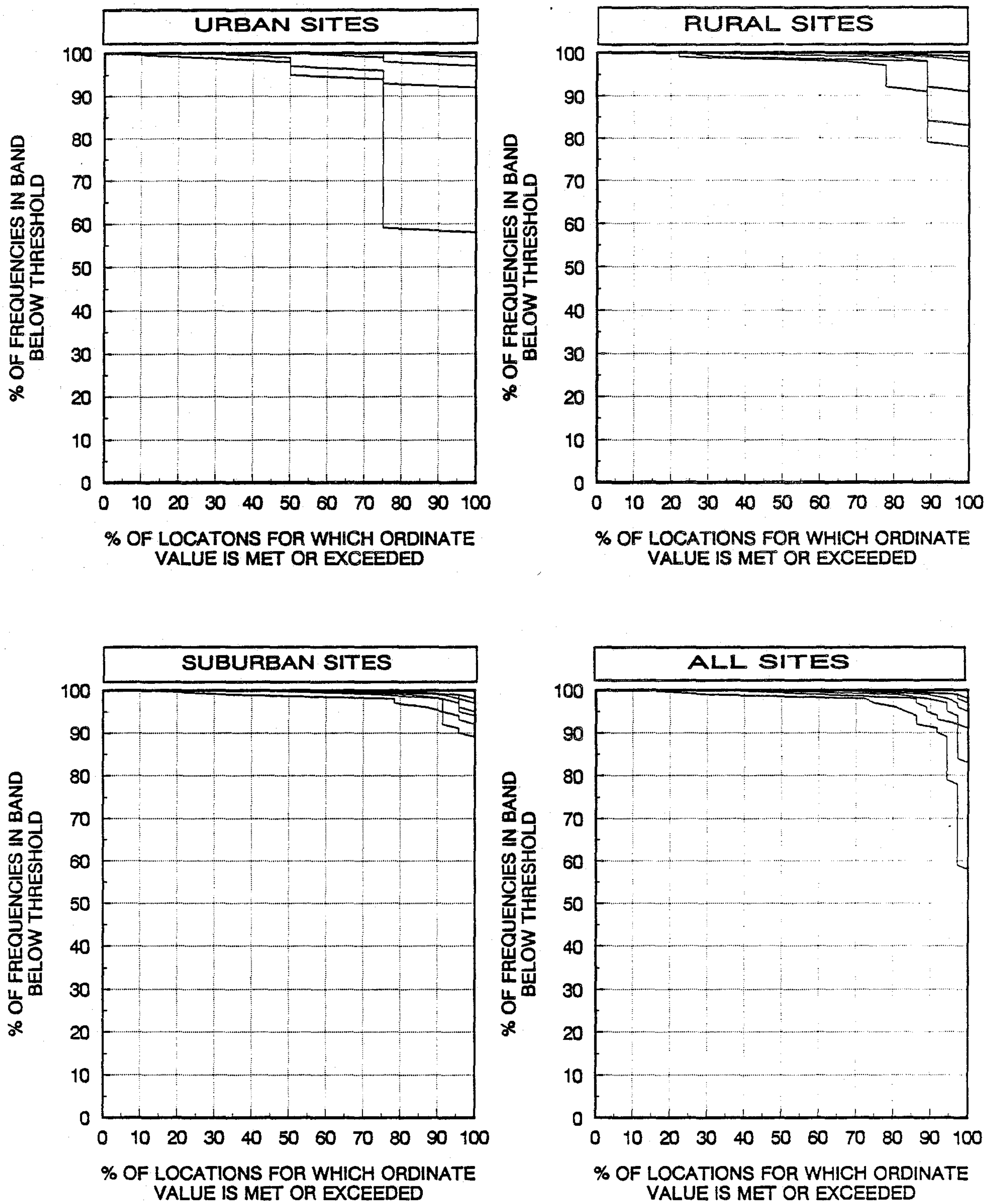

Figure 7.7 Measured band usage plots for urban, suburban, rural, and all site types for Dallas 849 - 851 MHz.

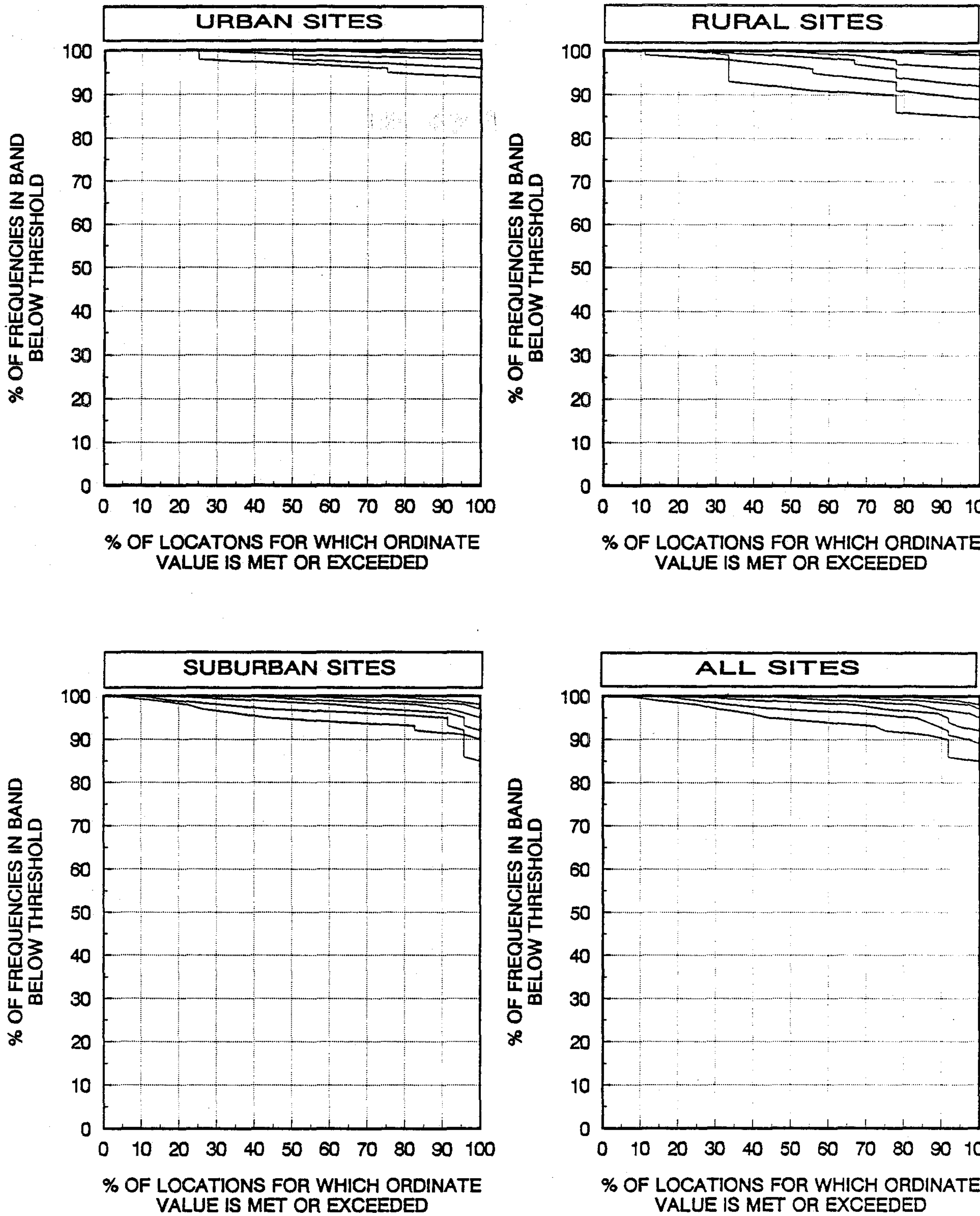

Figure 7.8 Measured band usage plots for urban, suburban, rural, and all site types for Dallas 894 - 896 MHz.

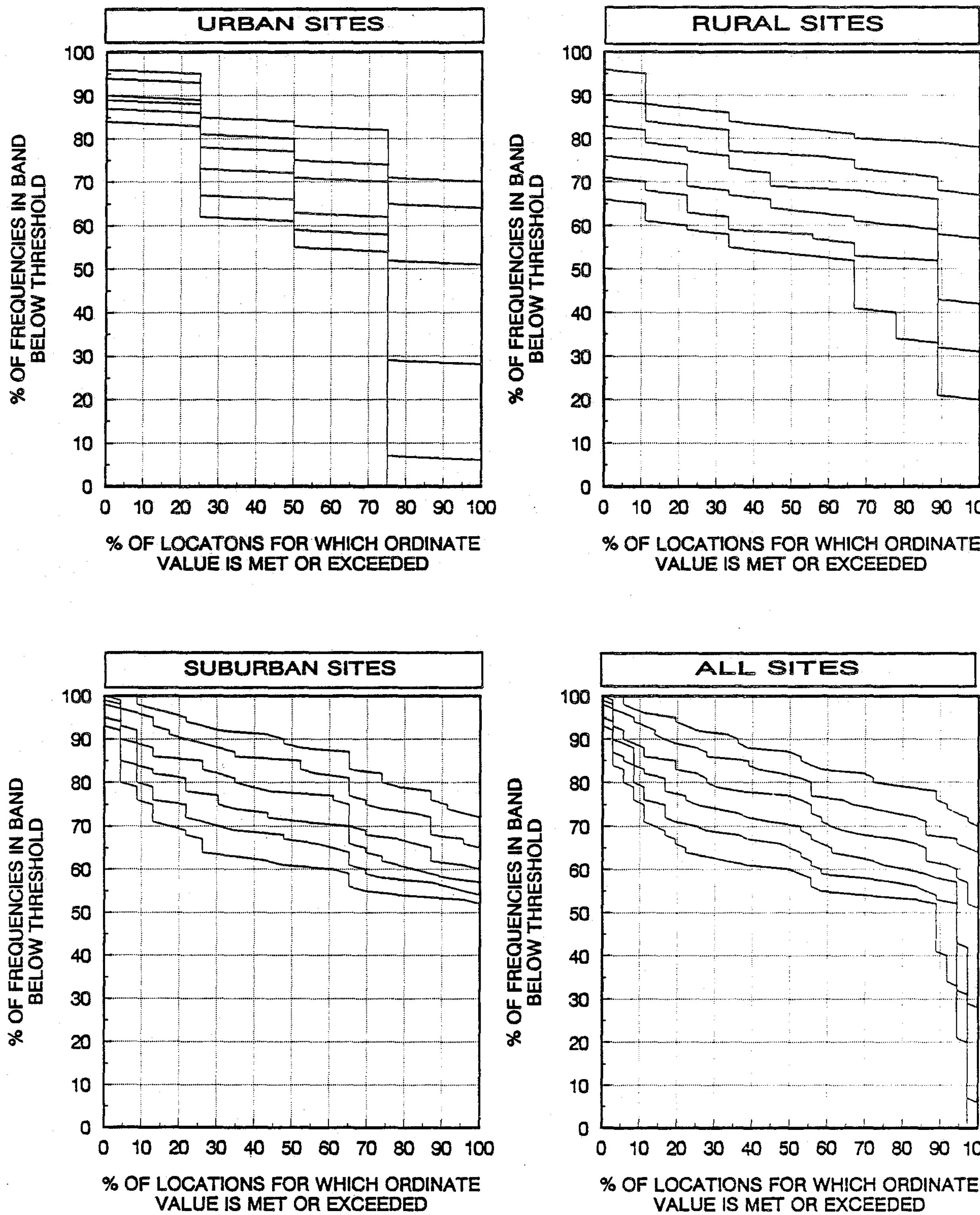

Figure 7.9 Measured band usage plots for urban, suburban, rural, and all site types for Dallas 864 - 868 MHz.

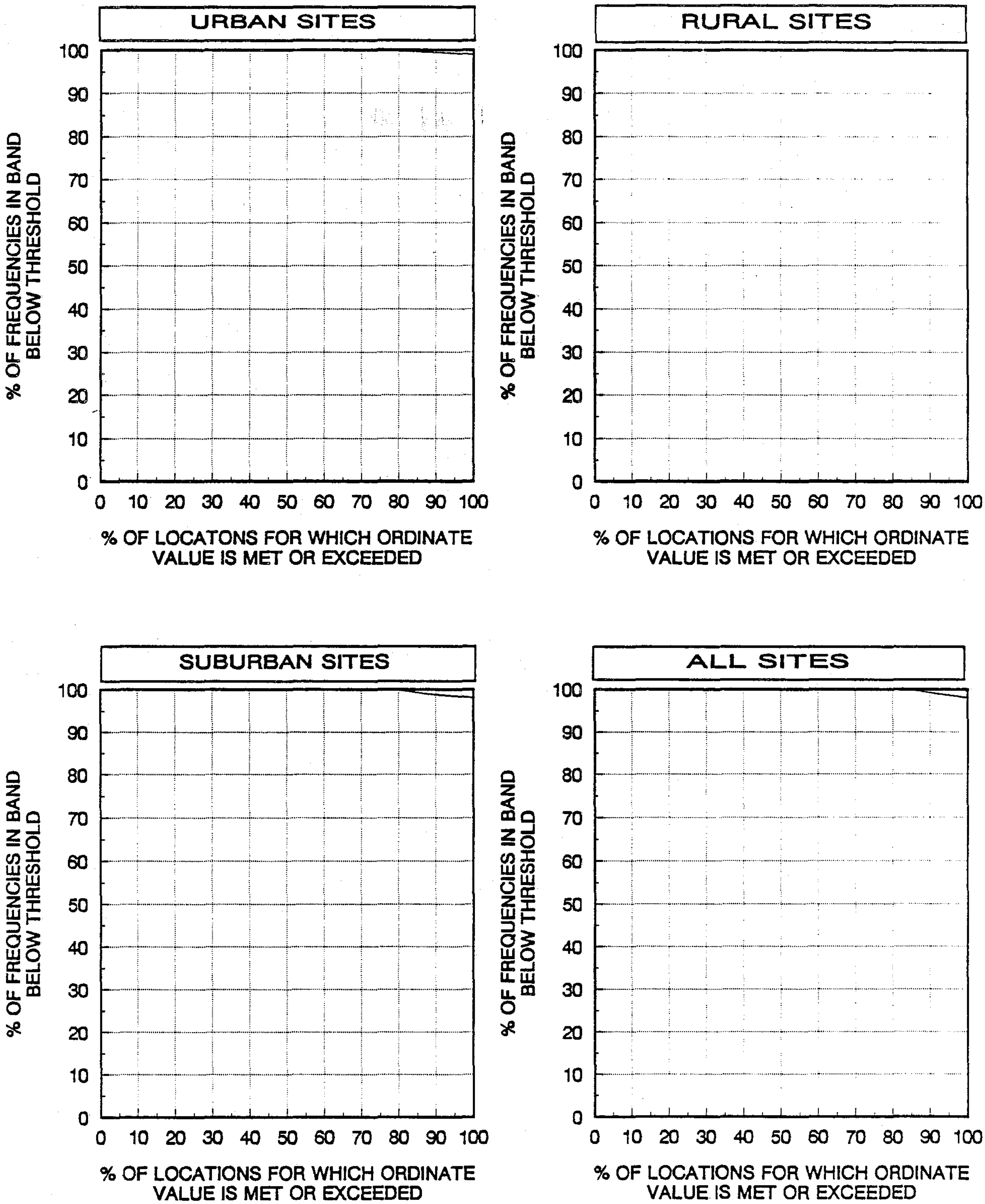

Figure 7.10 Measured band usage plots for urban, suburban, rural, and all site types for Dallas 901 - 902 MHz.

The measured band usage graphs of the 930-931 MHz band (Figure 7.11) and 940-941 MHz band (Figure 7.12) show very similar usage. For all urban sites and all sites, at least 49% of the 930-931 MHz band is unused while at least 41% of the 940-941 MHz band is unused. For all rural and suburban sites almost all of the frequencies in both bands are unused.

ISM and Part 15 band

The 902-928 MHz band, whose measured band usage graphs are shown in Figure 7.13, shows very similar usage to the 901-902 MHz band (Figure 7.10). For the 902-928 MHz band, almost all of the frequencies are unused for all of the sites.

7.3 The 1850-1994 MHz Measurement Frequency Band

Figure 7.14 shows the signal level and measured frequency usage graphs for the 1850-1994 MHz band. First consider the signal level graph. Looking at the maximum RSL, it appears that a few broadband and several narrowband signals were detected. The highest amplitude signal received in this band was -90 dBm. Since the mean RSL curve shows much lower amplitude signals than the maximum RSL curve, it suggests that these signals were present at most at a few sites. The measured frequency usage graph in Figure 7.14 supports this suggestion. This graph shows that the busiest frequency is unused at approximately 80% of the sites. In other words, the signals detected in the signal level graph are in general only detected at a few sites.

Private fixed microwave band

The measured band usage graphs for the 1850-1990 MHz band, shown in Figure 7.15, display low usage. Almost all the frequencies in the band are unused at all sites.

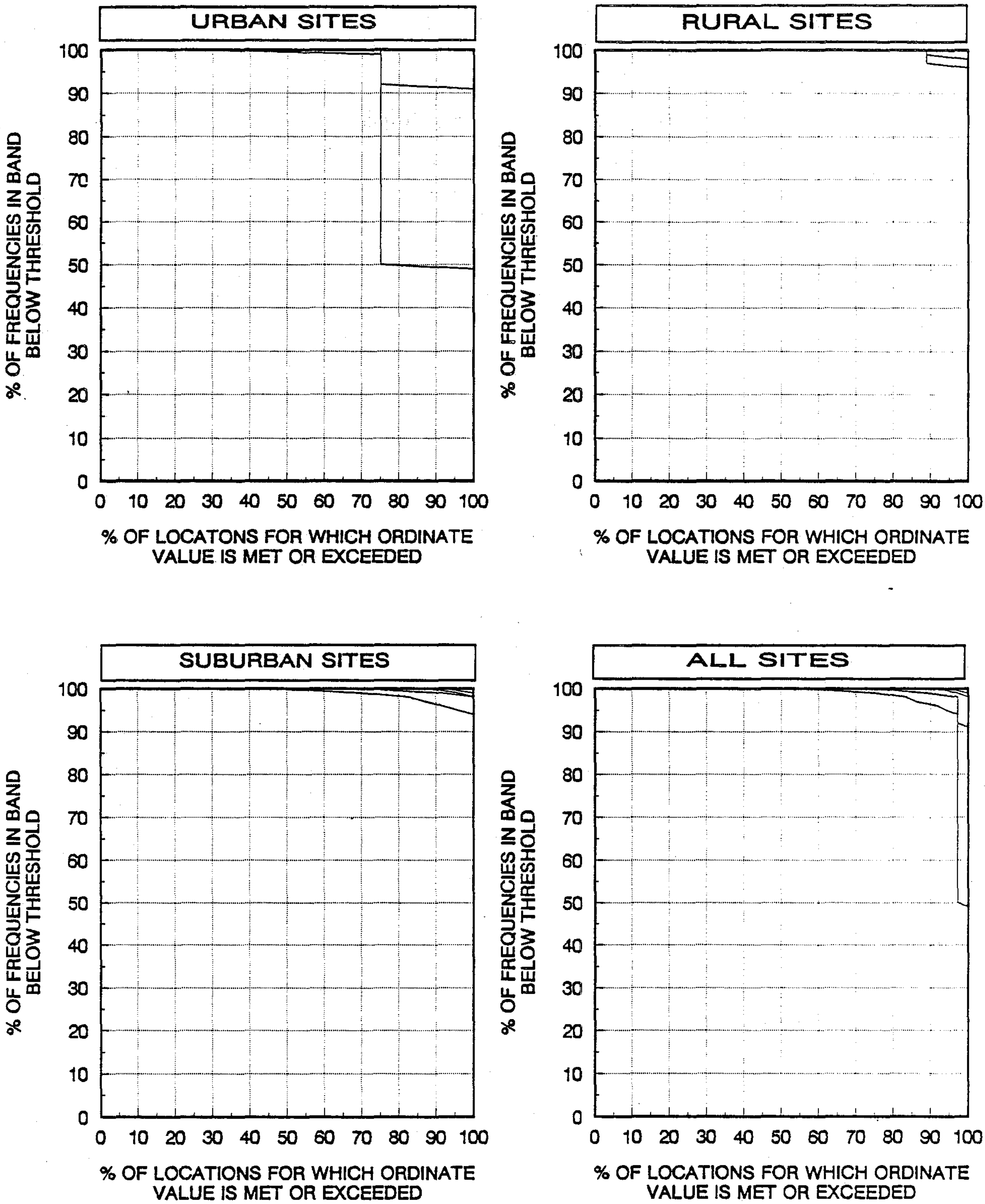

Figure 7.11 Measured band usage plots for urban, suburban, rural, and all site types for Dallas 930 - 931 MHz.

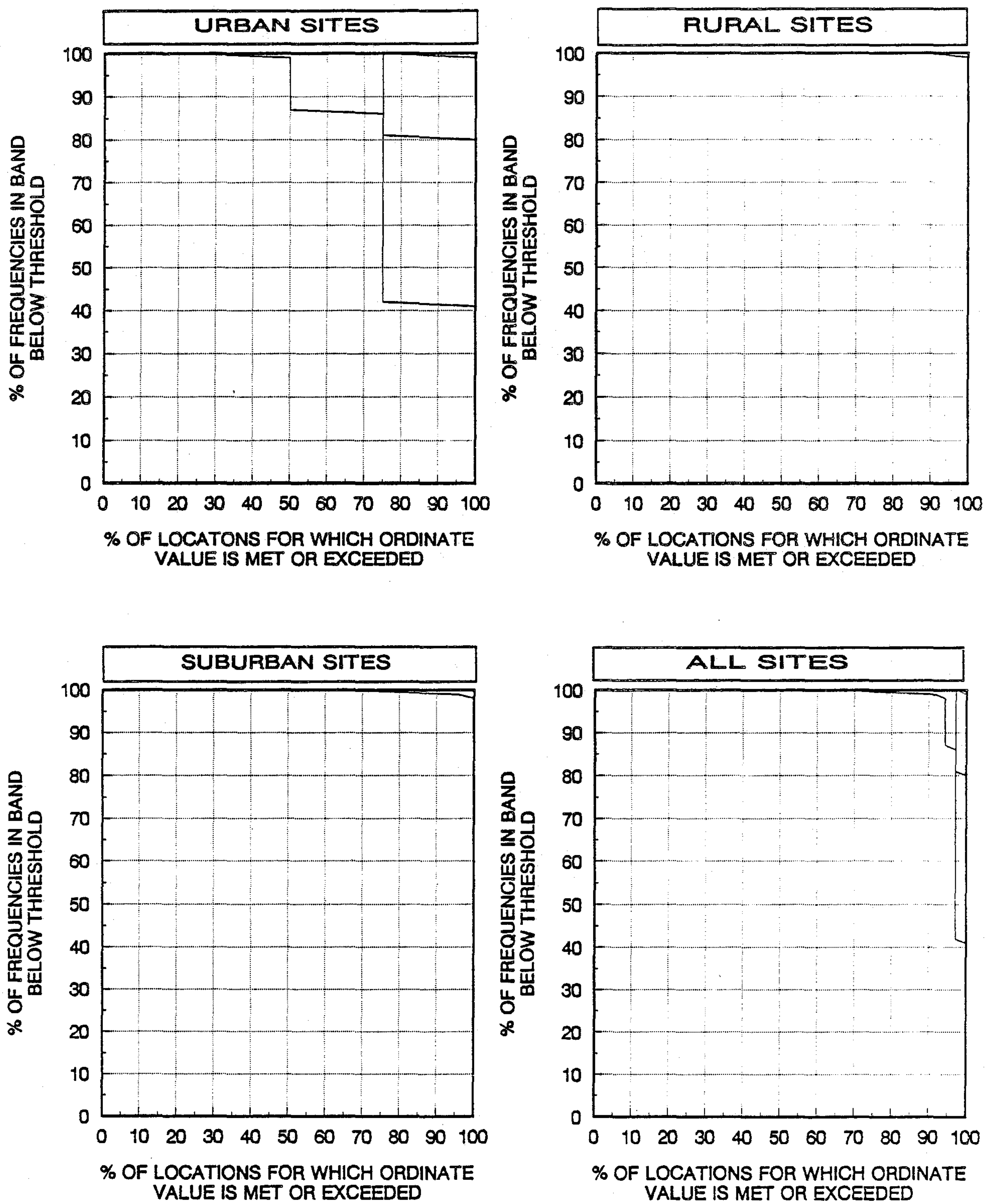

Figure 7.12 Measured band usage plots for urban, suburban, rural, and all site types for Dallas 940 - 941 MHz.

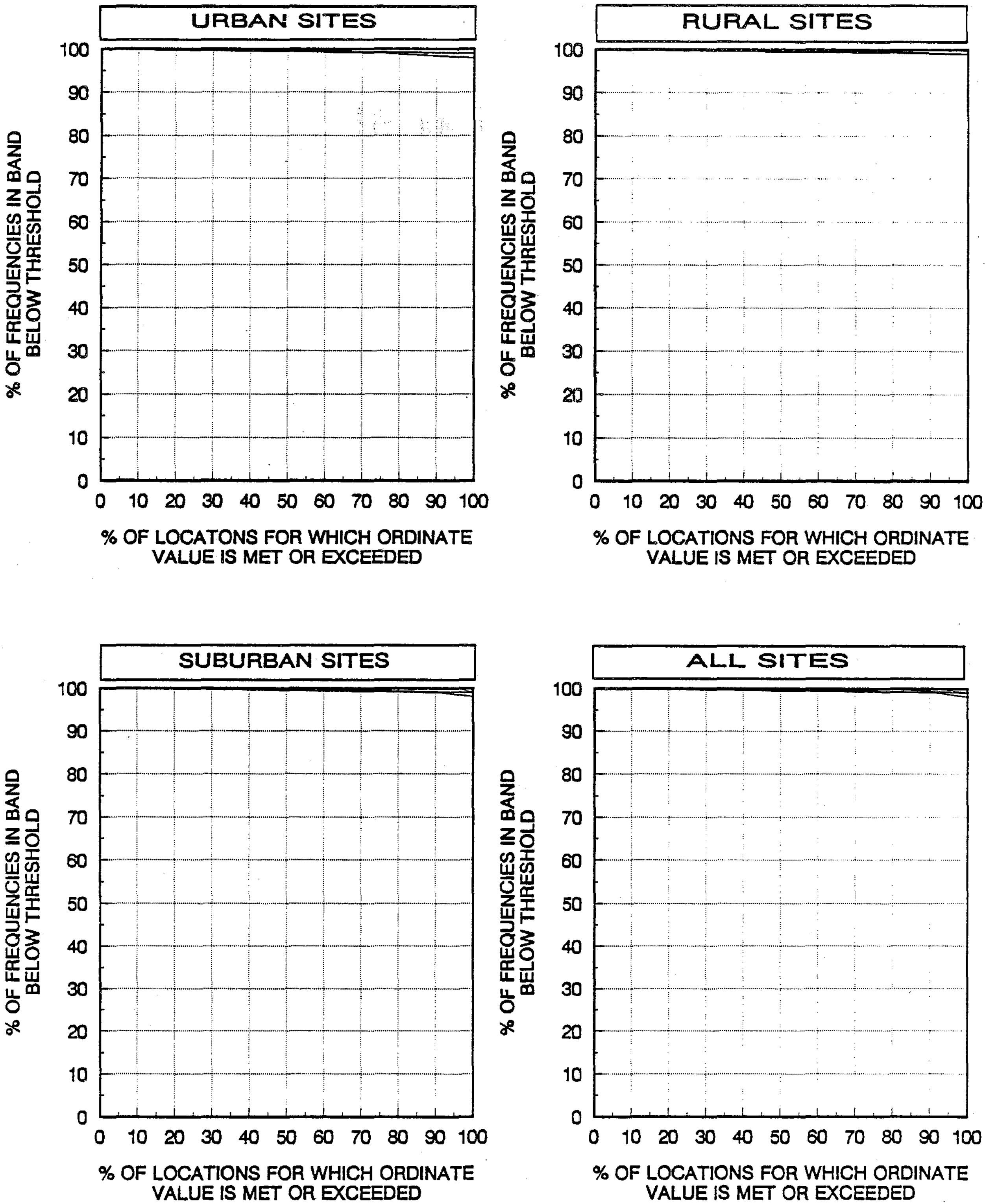

Figure 7.13 Measured band usage plots for urban, suburban, rural, and all site types for Dallas 902 - 928 MHz.

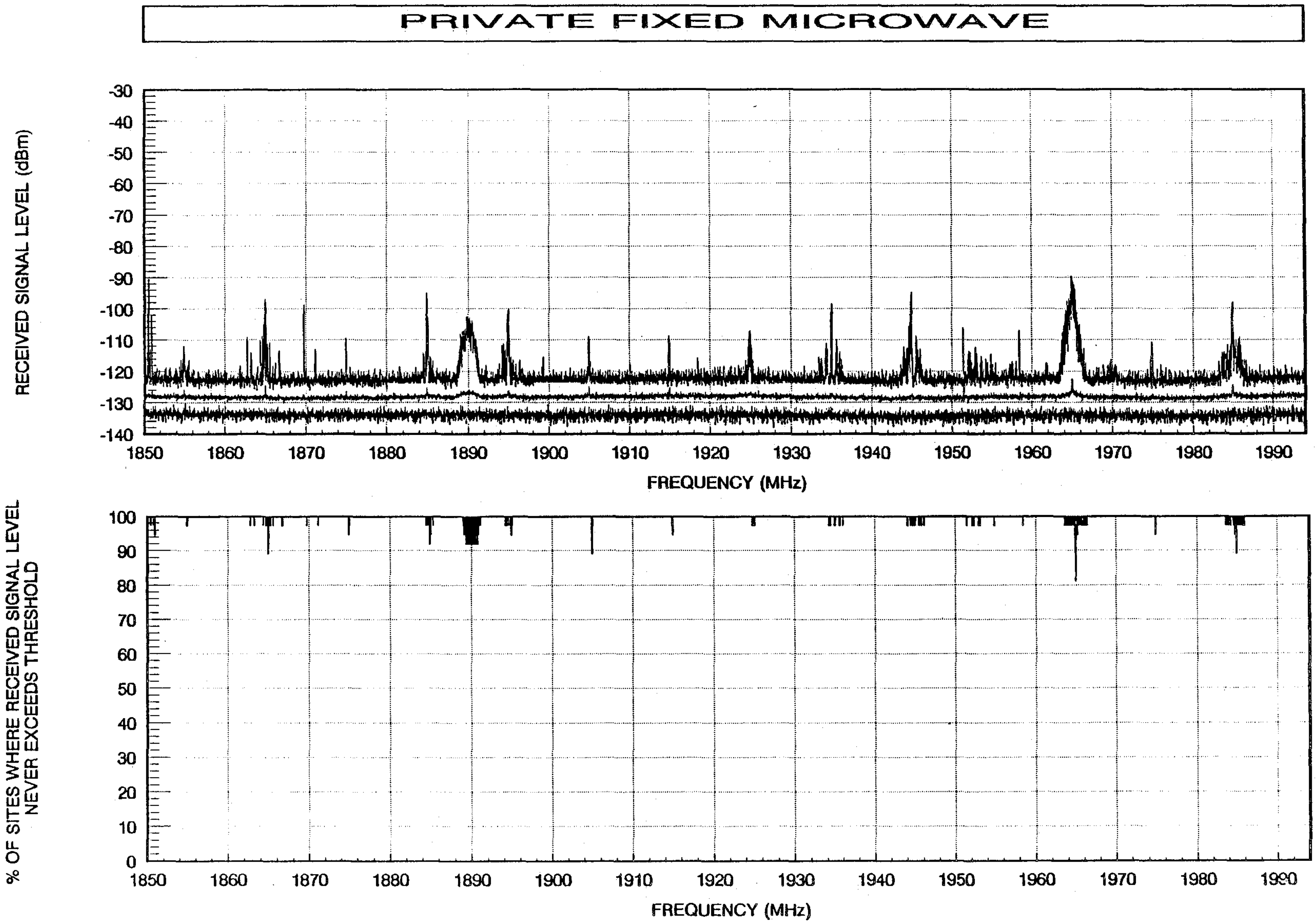

Figure 7.14 Signal level (top) and measured frequency usage (bottom) plots for Dallas 1850 - 1994 MHz.

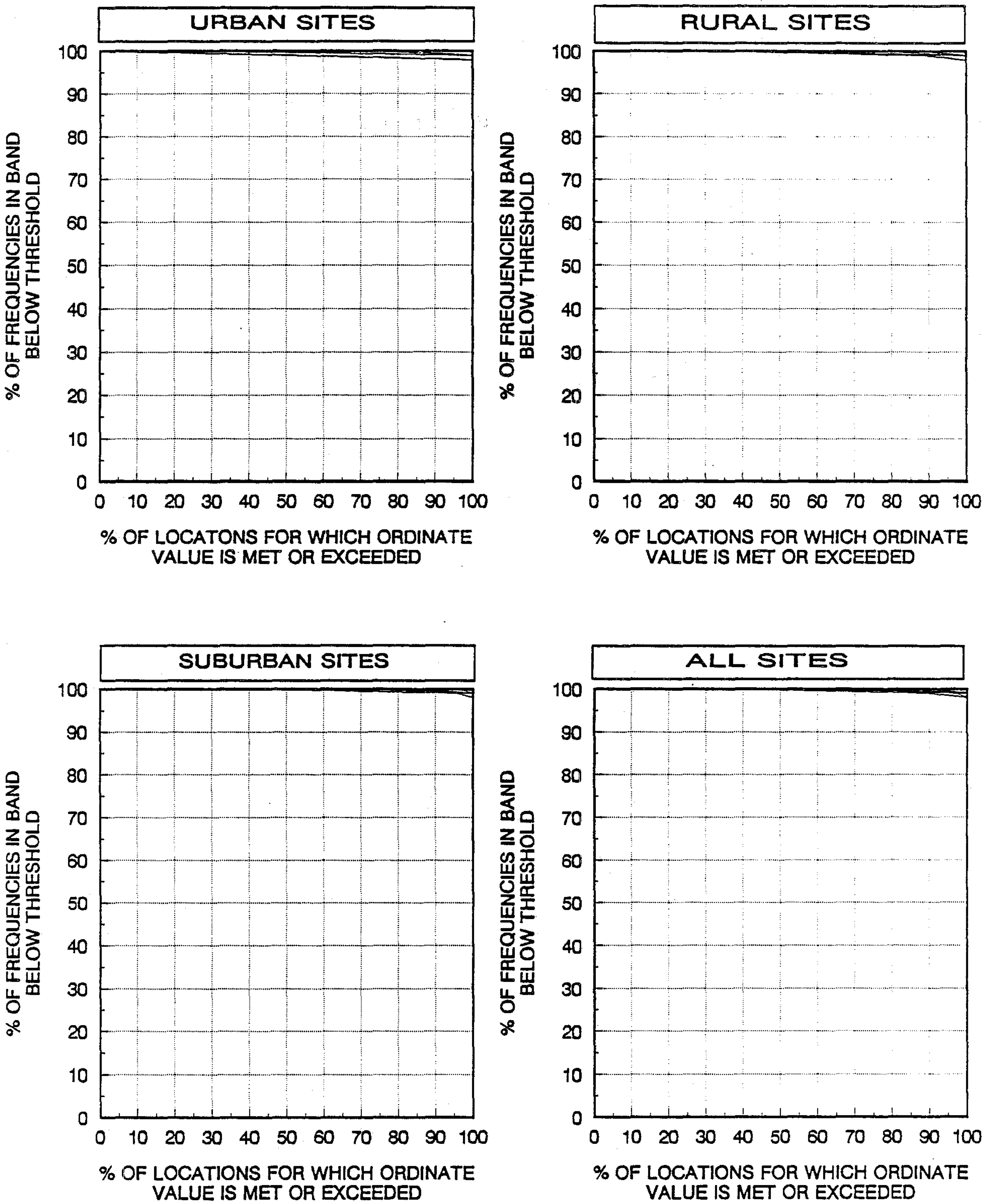

Figure 7.15 Measured band usage plots for urban, suburban, rural, and all site types for Dallas 1850 - 1990 MHz.

7.4 The 2110-2182 MHz Measurement Frequency Band

From the maximum RSL curve of the signal level graph in Figure 7.16, it is clear that in this band, like the 1850-1994 MHz band, only a few broadband and several narrowband signals were detected. The maximum RSL never exceeded -85 dBm. As in the 1850-1994 MHz band, the mean RSL curve shows much lower amplitude signals than the maximum RSL curve. This, of course, suggests that the signals were received at only a few sites. The measured frequency usage graph of Figure 7.16 reveals that the broadband signals in general were seen only at one site, hence most of the sites had these frequencies unused. For the frequencies that correspond to most of the narrowband signals seen in the signal level graph, 85% or more of the sites had these frequencies unused. For the signals at approximately 2150 and 2154 MHz in the signal level graph, 74% and 44% of the sites had these frequencies unused.

Common carrier microwave bands

Figures 7.17 and 7.18 are the measured band usage graphs for the 2110-2130 MHz and 2160-2180 MHz bands respectively. These bands show a very similar low usage. The 2160-2180 MHz band shows slightly more usage than the 2110-2130 MHz band. In it, 94% of all the sites have 98% or more of the band unused. All of the sites have at least 84% of the band unused.

7.5 The 2400-2600 MHz Measurement Frequency Band

Examining the maximum RSL curve of the signal level graph in Figure 7.19 shows what appears to be a wideband signal around 2400 MHz and many narrowband signals. The mean RSL curve suggests that the narrowband signals from 2500-2600 MHz were present at a considerable number of sites and that signals outside of this frequency range were detected at only a few sites. The measured frequency usage graph shows that the frequencies seen from 2500-2600 MHz were unused at as few as 26% of the sites. For signals in the 2400-2500 MHz frequency range, the busiest frequency was unused at 92% of the sites.

ISM and Part 15 band

Figure 7.20, the measured band usage graphs for the 2400-2483.5 MHz band, shows low usage in this band. For all of the sites, 96% of the band is unused.

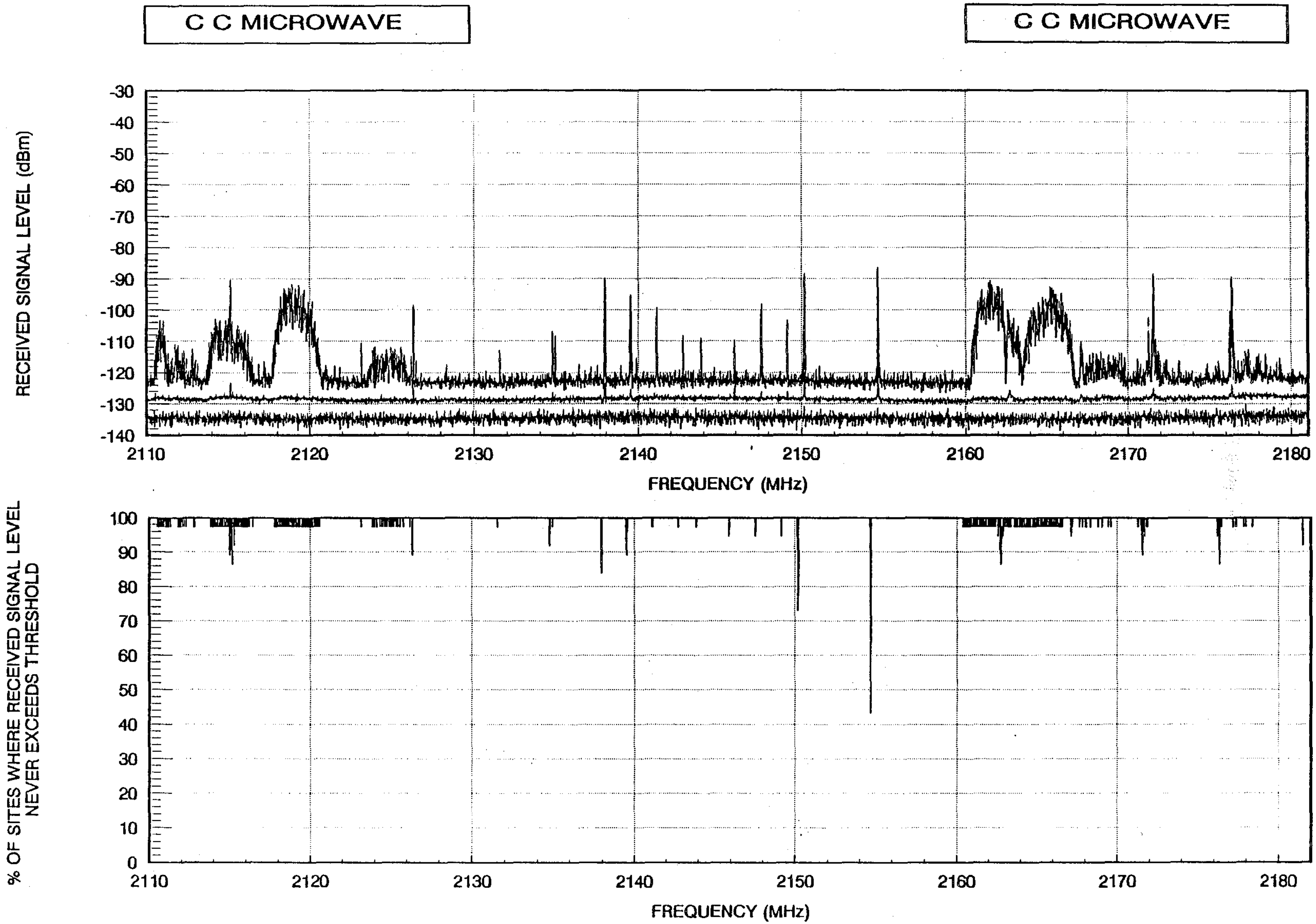

Figure 7.16 Signal level (top) and measured frequency usage (bottom) plots for Dallas 2110 - 2182 MHz.

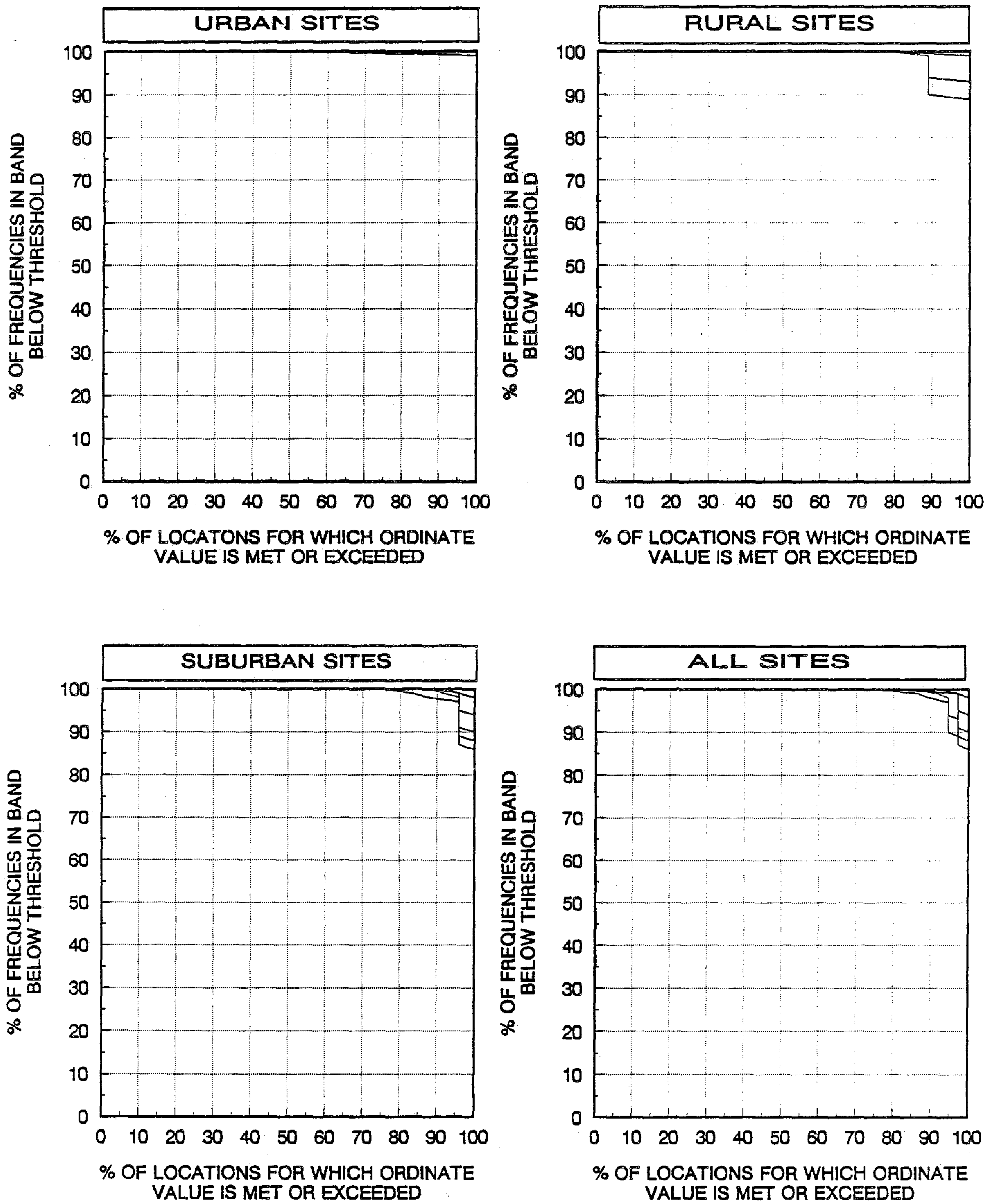

Figure 7.17 Measured band usage plots for urban, suburban, rural, and all site types for Dallas 2110 - 2130 MHz.

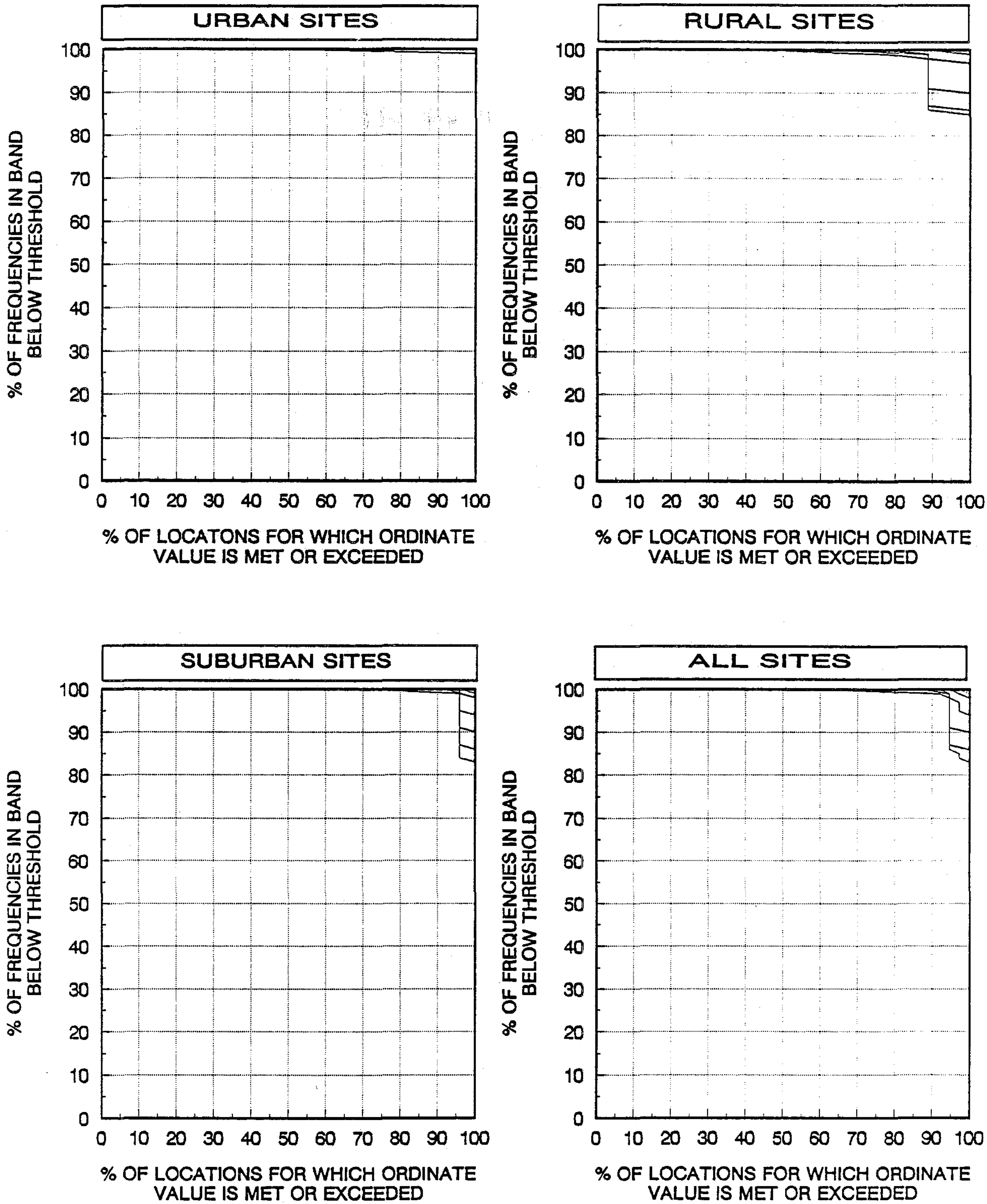

Figure 7.18 Measured band usage plots for urban, suburban, rural, and all site types for Dallas 2160 - 2180 MHz.

ISM, PART 15

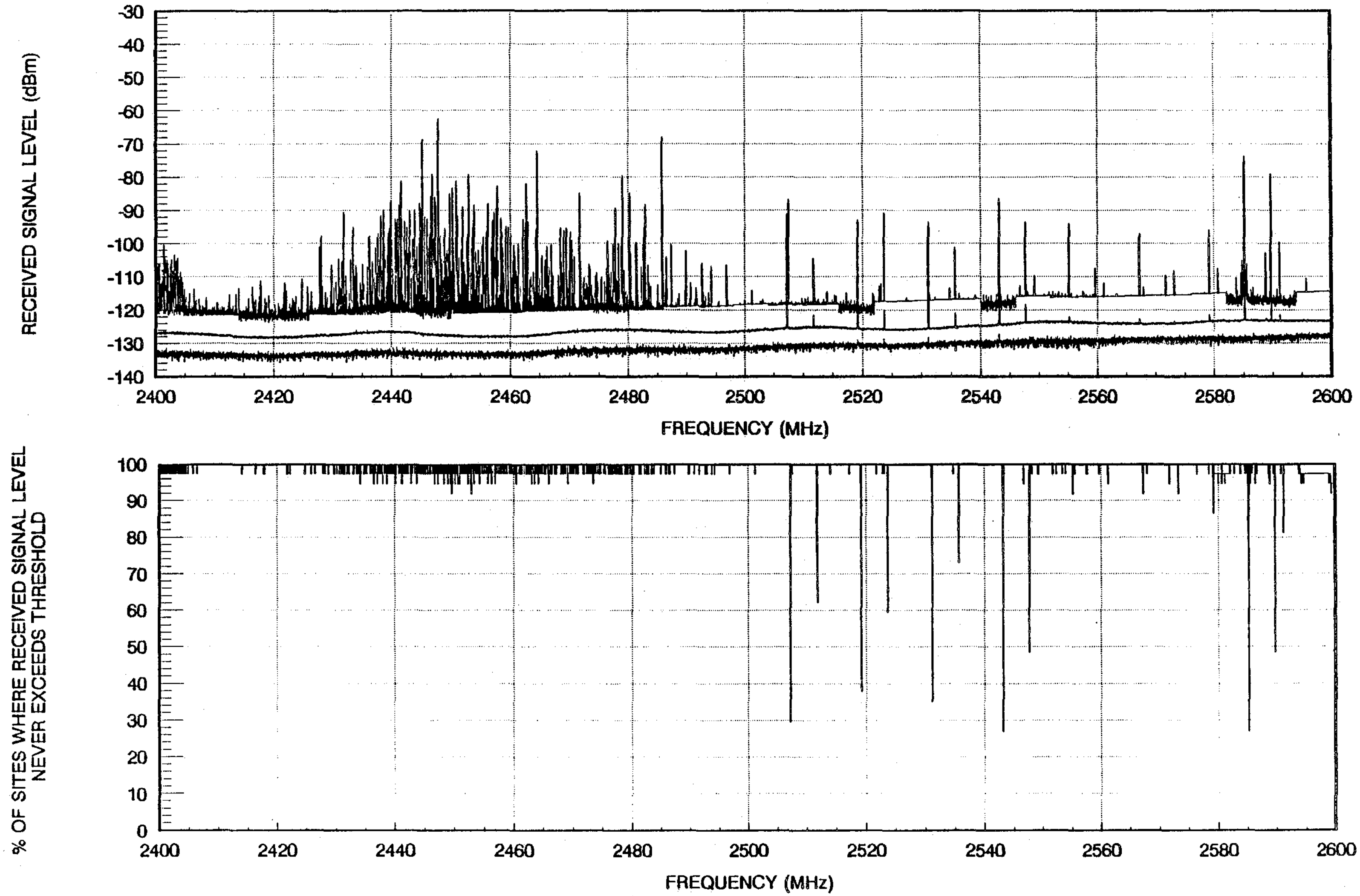

Figure 7.19 Signal level (top) and measured frequency usage (bottom) plots for Dallas 2400 - 2600 MHz.

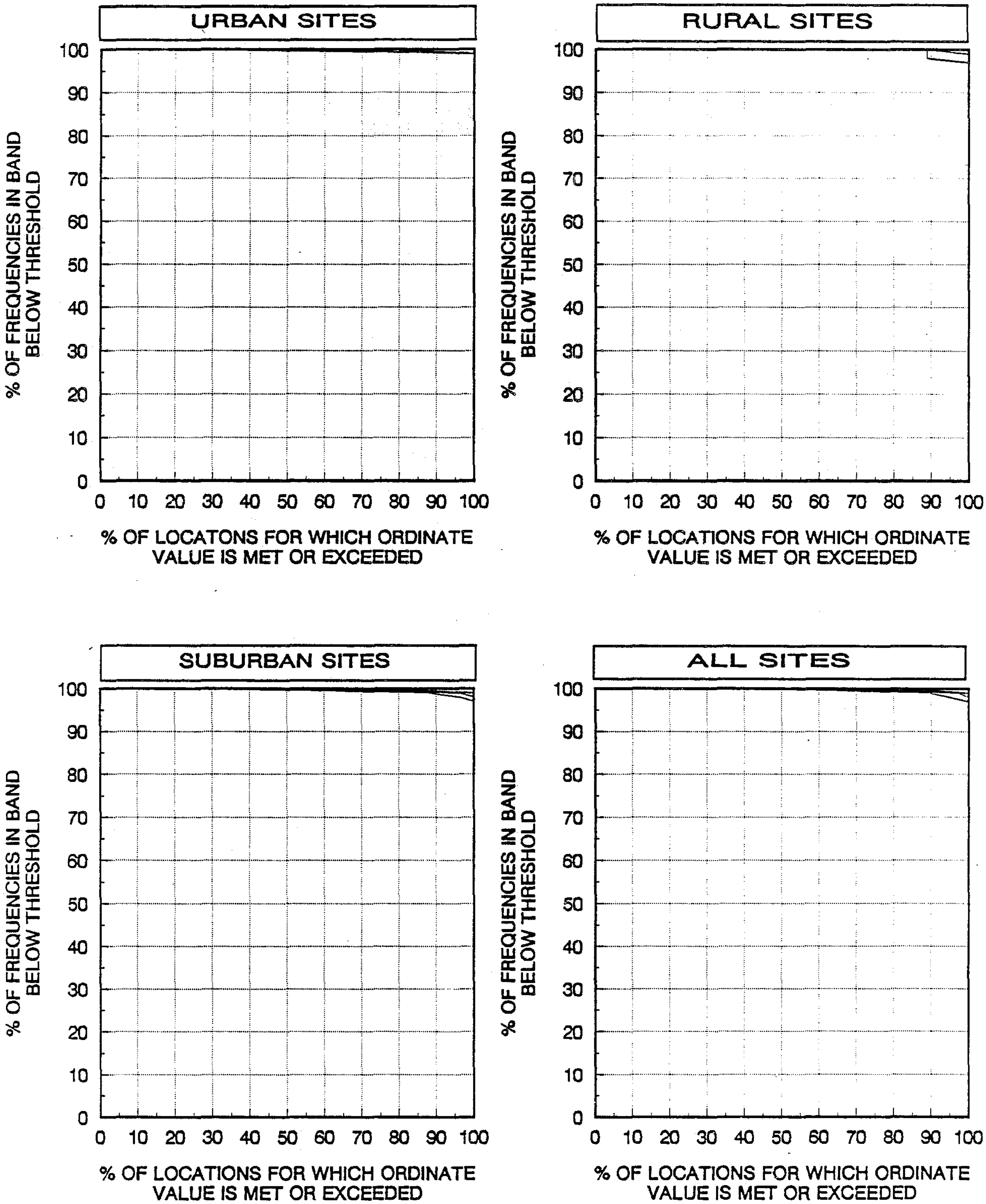

Figure 7.20 Measured band usage plots for urban, suburban, rural, and all site types for Dallas 2400 - 2483.5 MHz.

8. CHICAGO DATA

A map showing the measurement sites in Chicago is shown in Figure 8.1. The square grid was extended here to avoid measurement sites in Lake Michigan. Note that measurements were taken at 38 sites instead of 37 in Chicago to include an additional urban location. Table 8.1 lists the measurement sites according to their zoning classifications (i.e., urban, suburban, and rural).

Table 8.1 Categorization of Numbered Measurement Sites in Chicago

Urban				Suburban				Rural			
2	4	5	25	1	3	6	7	9	10	19	23
				8	11	12	13				
				14	15	16	17				
				18	20	21	22				
				24	26	27	28				
				29	30	31	32				
				33	34	35	36				
				37	38						

Table 8.1 shows that approximately 10.5% of the sites are urban, 79% of the sites are suburban, and 10.5% of the sites are rural. The statistics generated for all site types combined is therefore weighted most heavily by the suburban sites. While extracting information from the data that are presented here, the distribution of site zoning types must be kept in mind. Due to the size of the sample set, the statistics generated for suburban sites provide a fairly accurate representation of suburban sites in this city. The statistics generated for the other site types do not provide as good a representation of their site types in this city, due to the more limited sample size.

For the narrowband measurements, the signal level, measured frequency usage, and measured band usage graphs are presented for the five measurement frequency bands: 614-806 MHz, 824-944 MHz, 1850-1994 MHz, 2110-2182 MHz, and 2400-2600 MHz. The data are simply presented and not discussed in this section. In the Comparison of Data Between Cities section, the salient similarities and differences in the data seen from the different cities will be discussed.

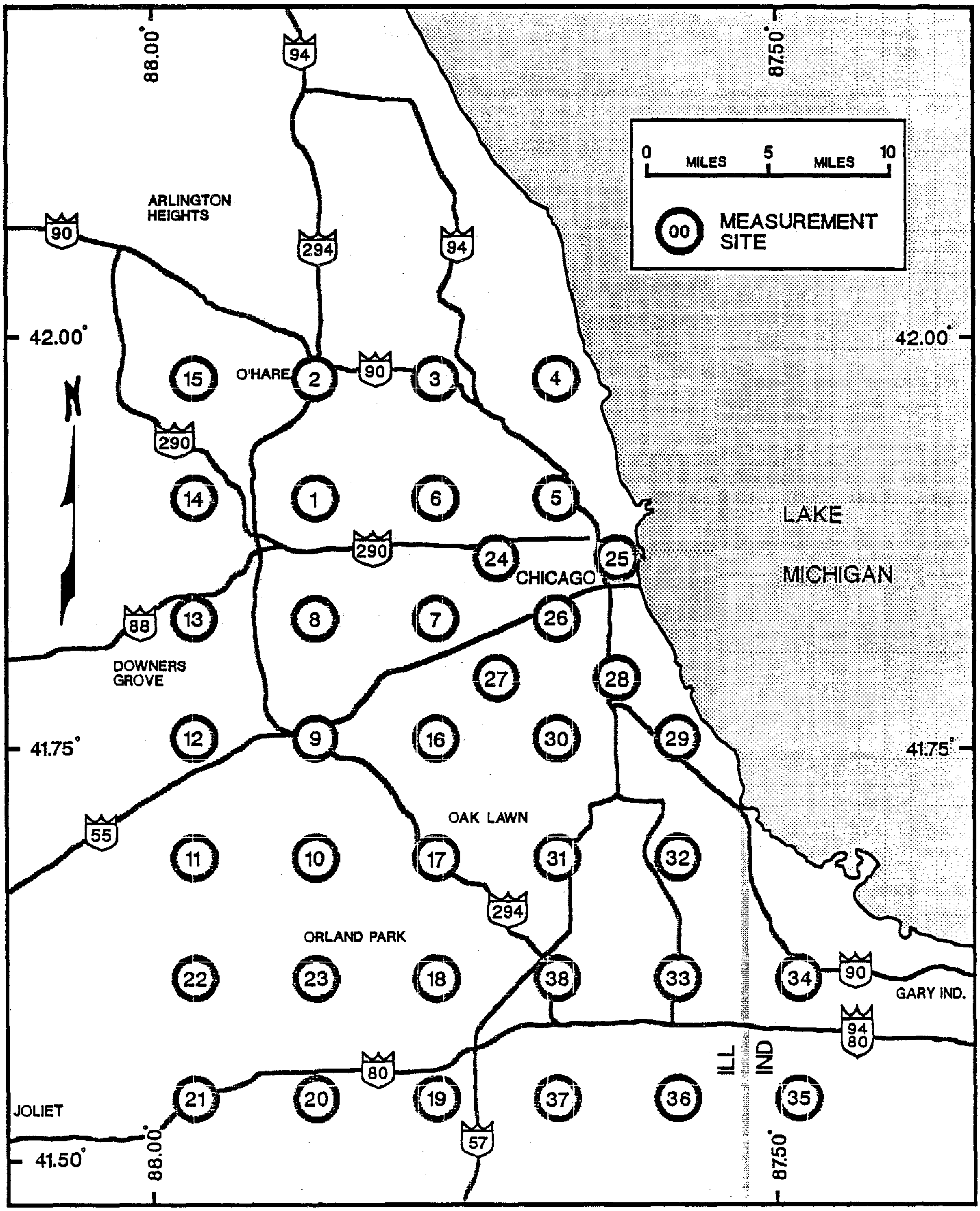

Figure 8.1 Measurement sites in Chicago.

8.1 The 614-806 MHz Measurement Frequency Band

Figure 8.2 shows the signal level and measured frequency usage graphs for the 614-806 MHz (UHF-TV) band. The measured band usage graphs for this band are presented in Figure 8.3.

8.2 The 824-944 MHz Measurement Frequency Band

The signal level and measured frequency usage graphs for the 824-944 MHz band are displayed in Figure 8.4. Figures 8.5 through 8.13 display the measured band usage graphs for the 824-849 MHz, 869-894 MHz, 849-851 MHz, 894-896 MHz, 864-868 MHz, 901-902 MHz, 930-931 MHz, 940-941 MHz, and 902-928 MHz bands respectively.

8.3 The 1850-1994 MHz Measurement Frequency Band

Figure 8.14 shows the signal level and measured frequency usage graphs for the 1850-1994 MHz band. The measured band usage graphs for the 1850-1990 MHz band are presented in Figure 8.15.

8.4 The 2110-2182 MHz Measurement Frequency Band

For the 2110-2182 MHz band, the signal level and measured frequency usage graphs are shown in Figure 8.16. Figures 8.17 and 8.18 depict the measured band usage graphs for the 2110-2130 MHz and 2160-2180 MHz bands respectively.

8.5 The 2400-2600 MHz Measurement Frequency Band

The signal level and measured frequency usage graphs for the 2400-2600 MHz band are displayed in Figure 8.19 while the measured band usage graphs are displayed in Figure 8.20 for the 2400-2483.5 MHz band.

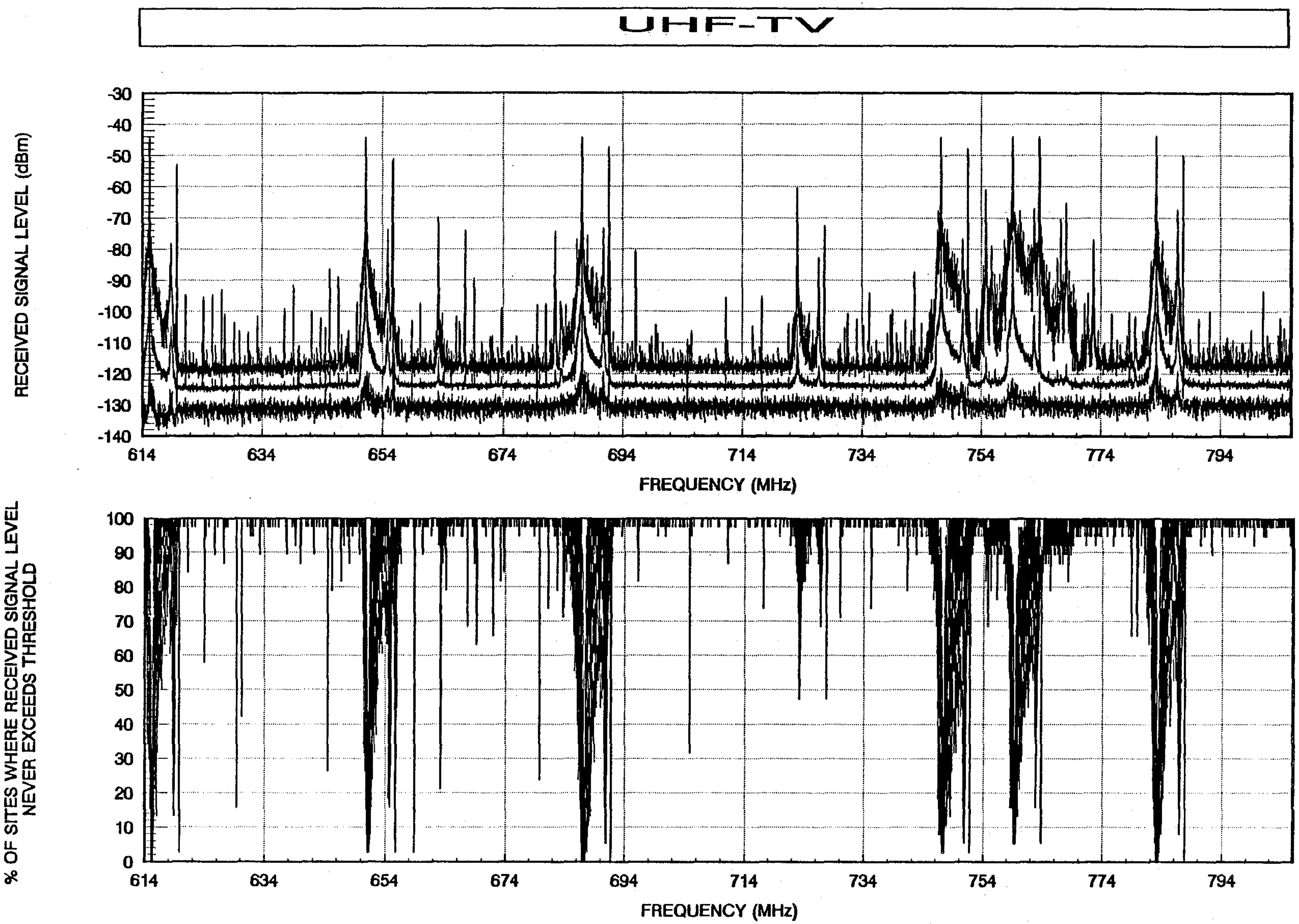

Figure 8.2 Signal level (top) and measured frequency usage (bottom) plots for Chicago 614 - 806 MHz.

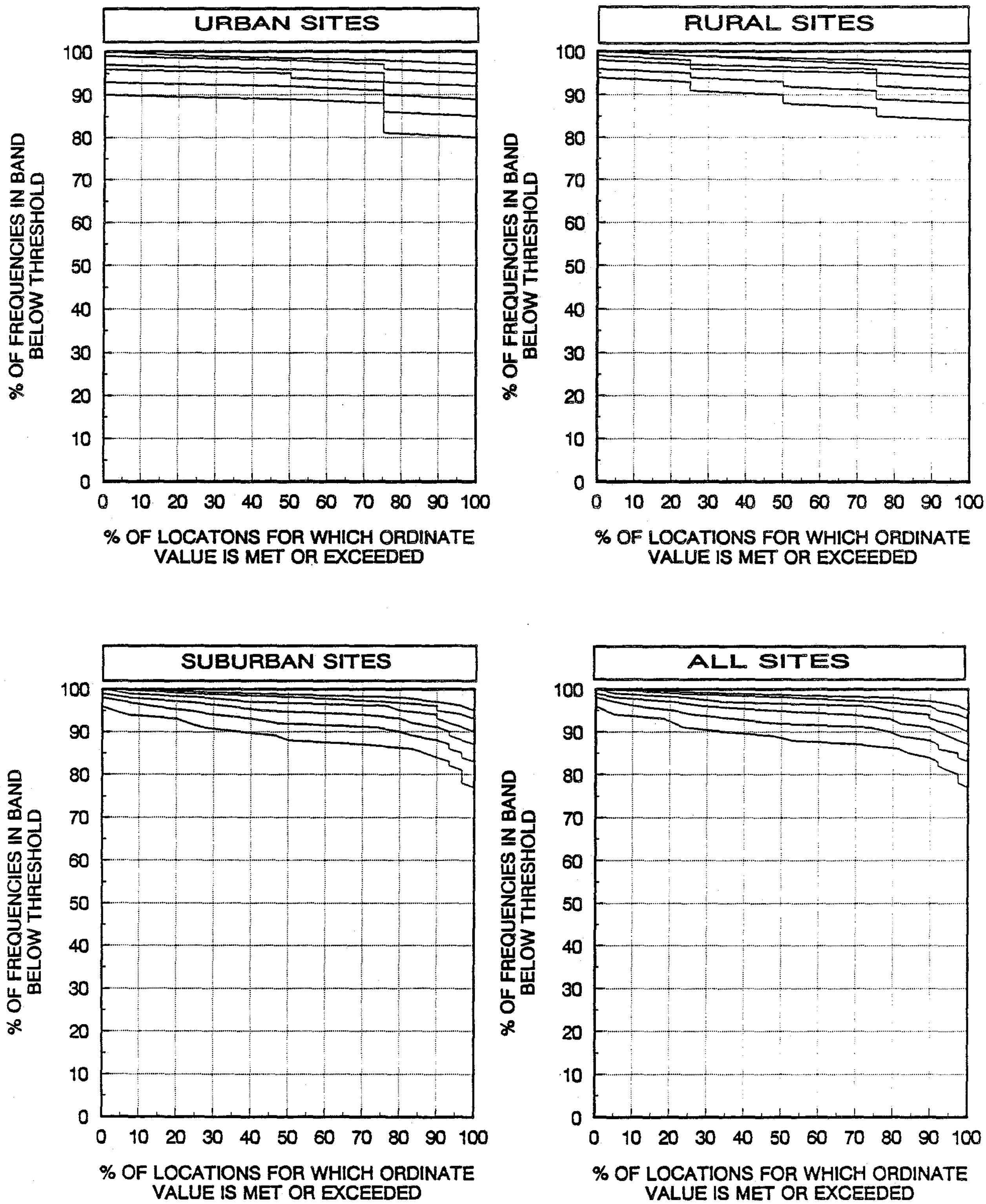

Figure 8.3 Measured band usage plots for urban, suburban, rural, and all site types for Chicago 614 - 806 MHz.

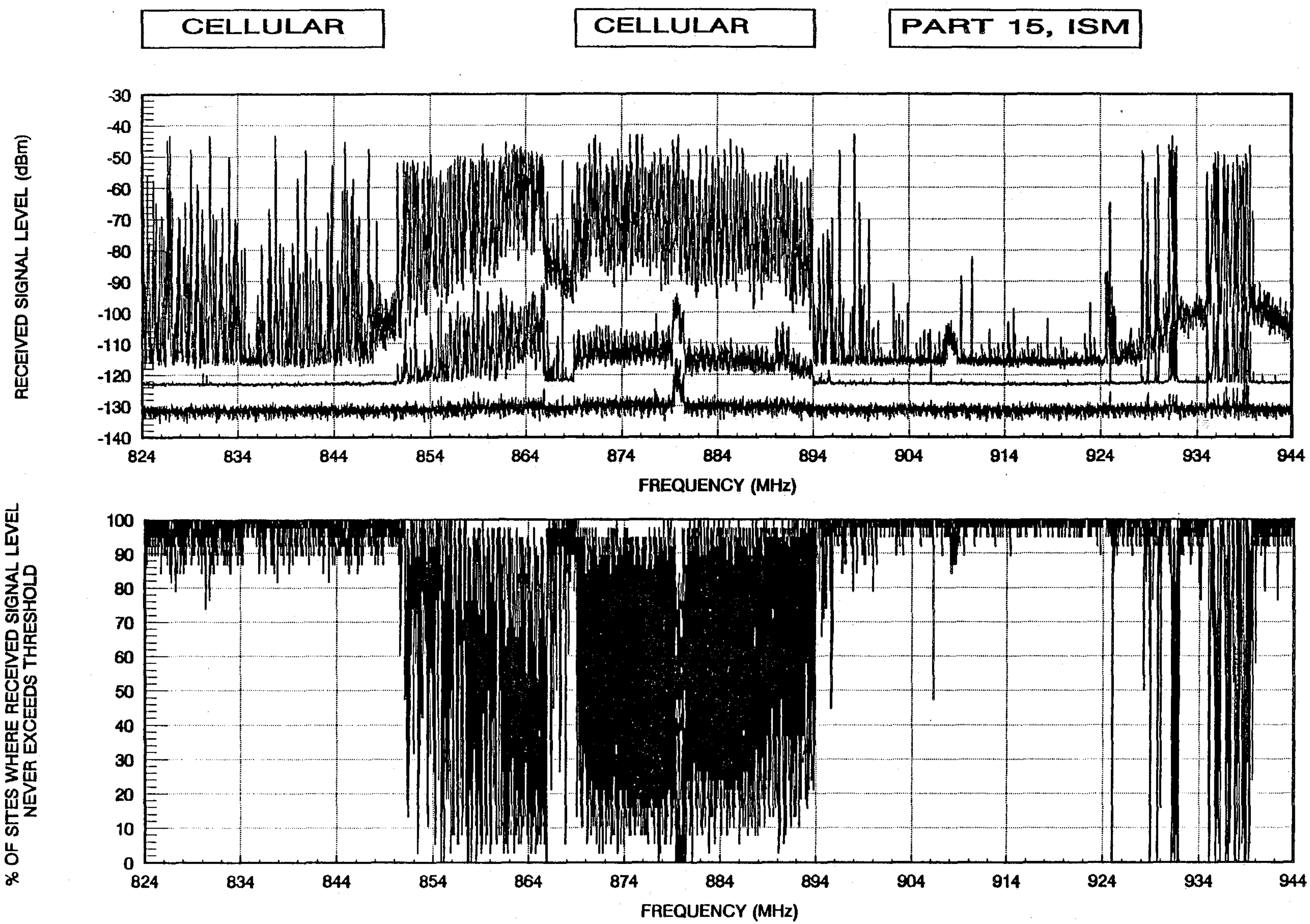

Figure 8.4 Signal level (top) and measured frequency usage (bottom) plots for Chicago 824 - 944 MHz.

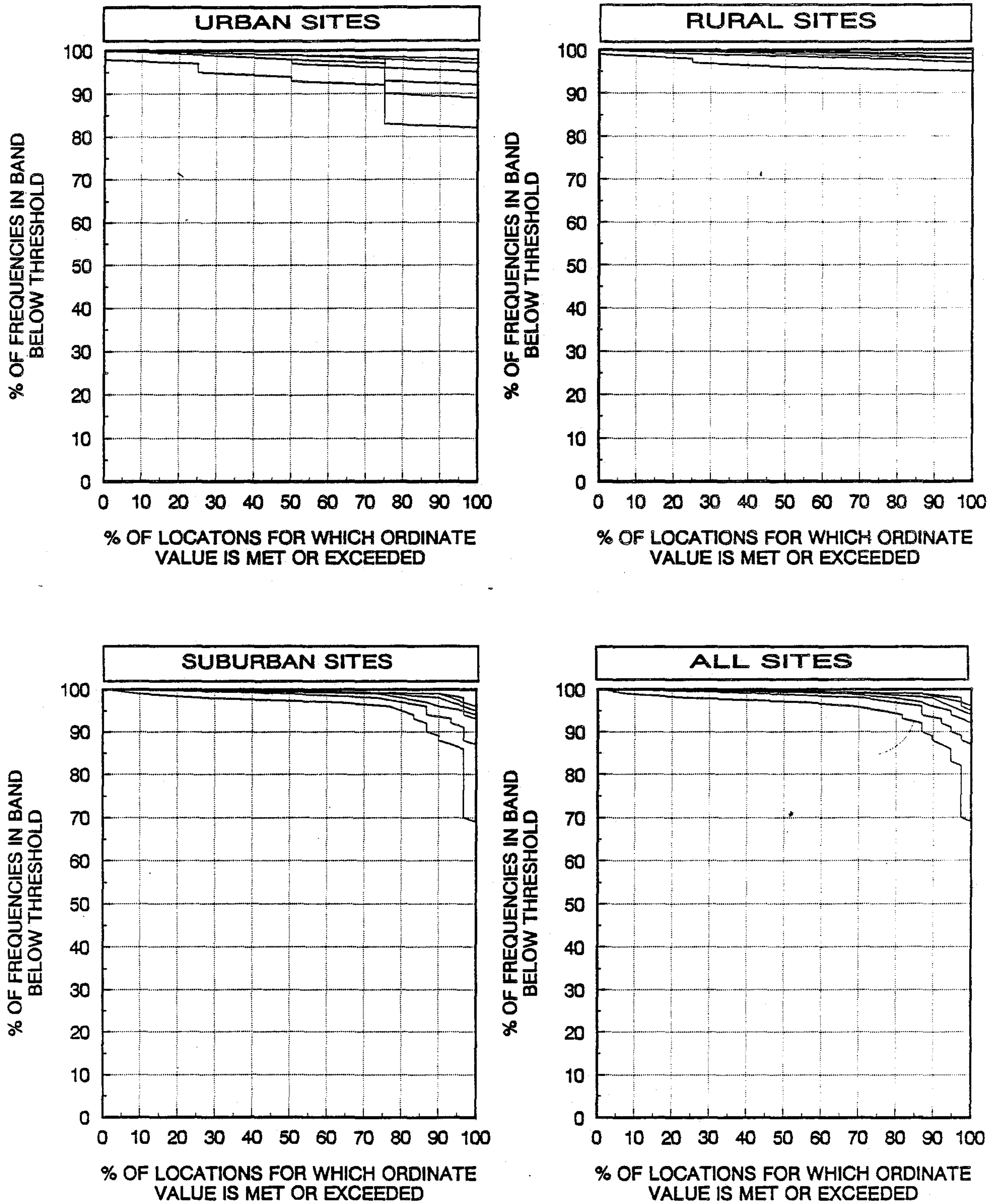

Figure 8.5 Measured band usage plots for urban, suburban, rural, and all site types for Chicago 824 - 849 MHz.

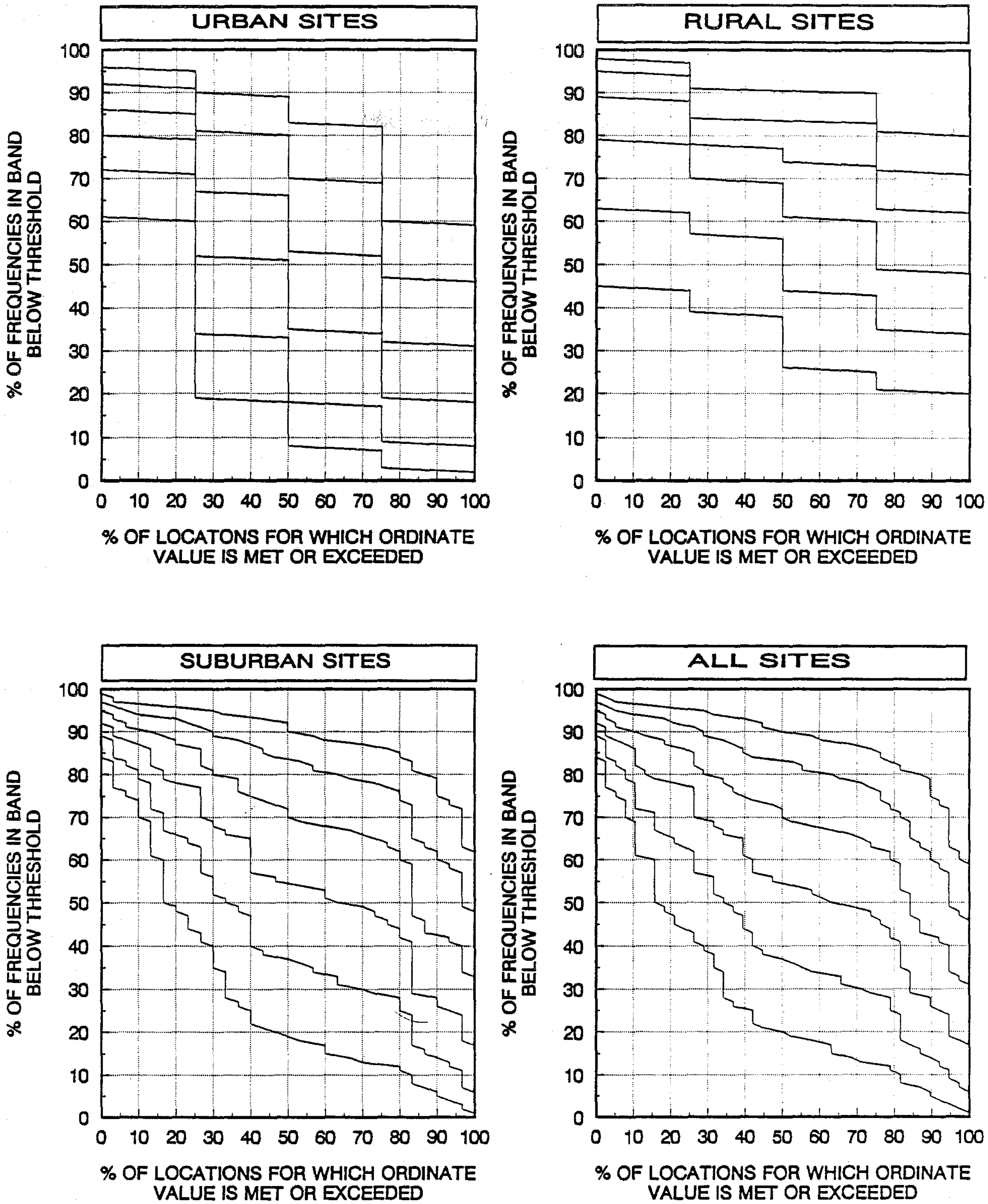

Figure 8.6 Measured band usage plots for urban, suburban, rural, and all site types for Chicago 869 - 894 MHz.

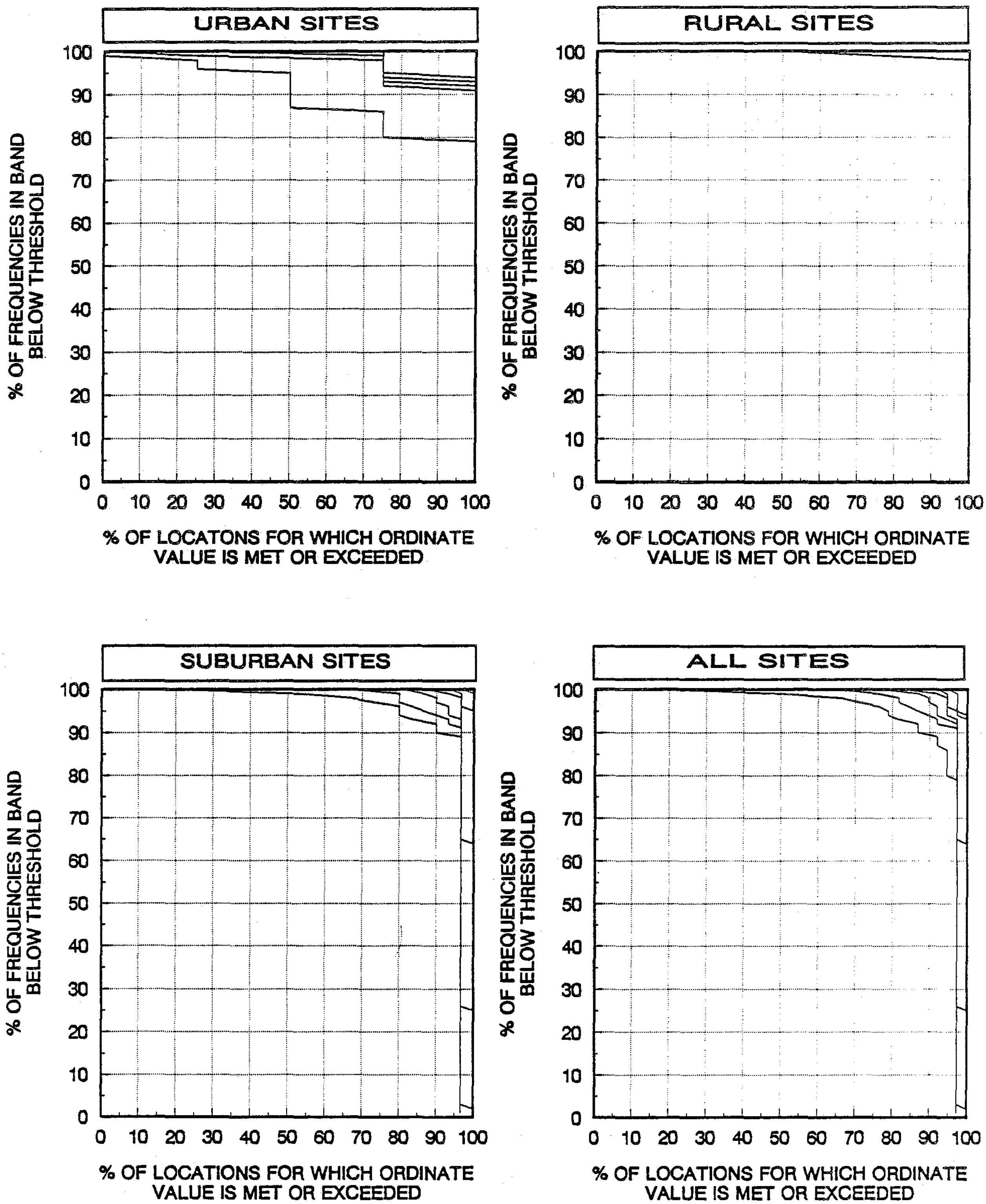

Figure 8.7 Measured band usage plots for urban, suburban, rural, and all site types for Chicago 849 - 851 MHz.

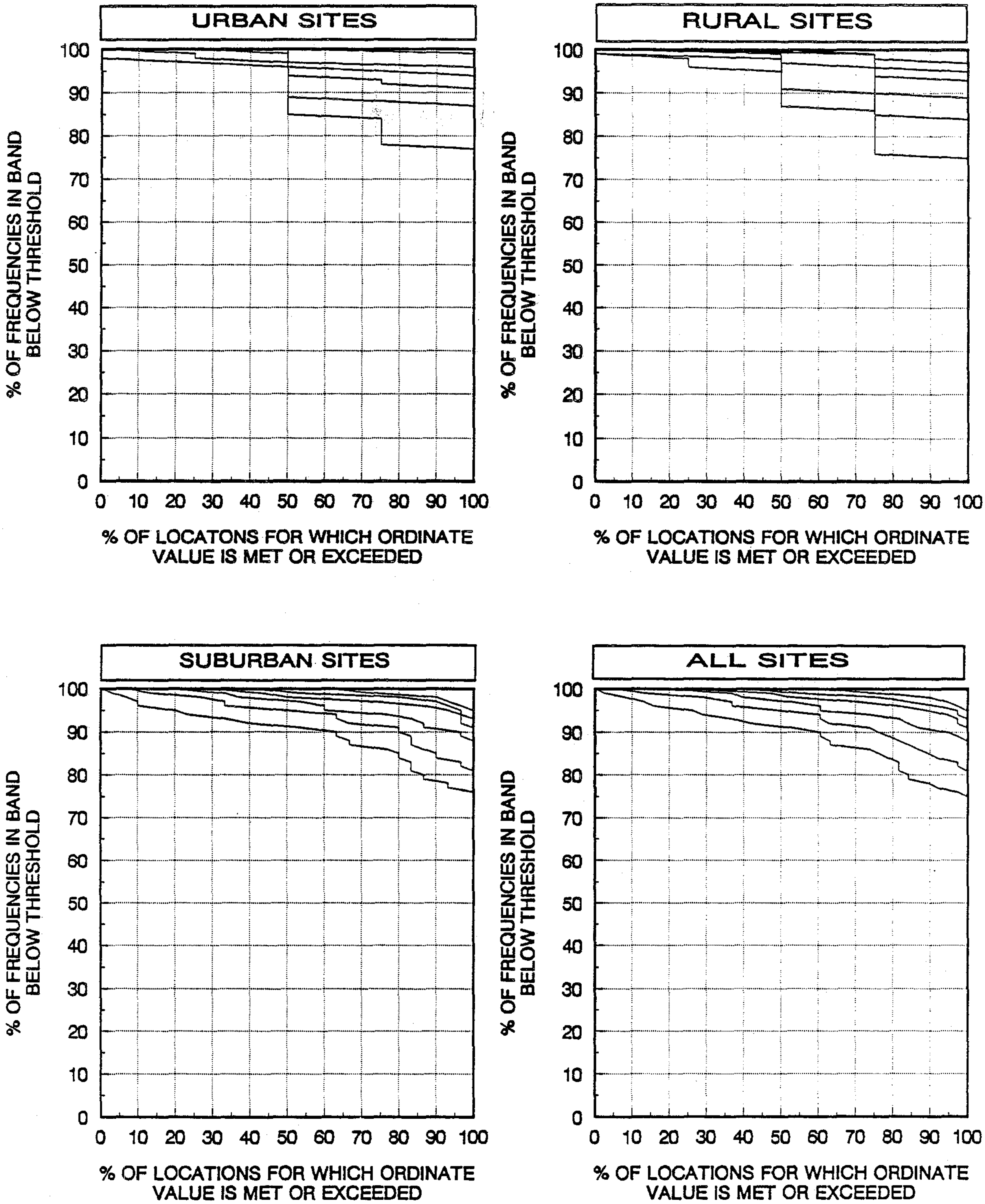

Figure 8.8 Measured band usage plots for urban, suburban, rural, and all site types for Chicago 894 - 896 MHz.

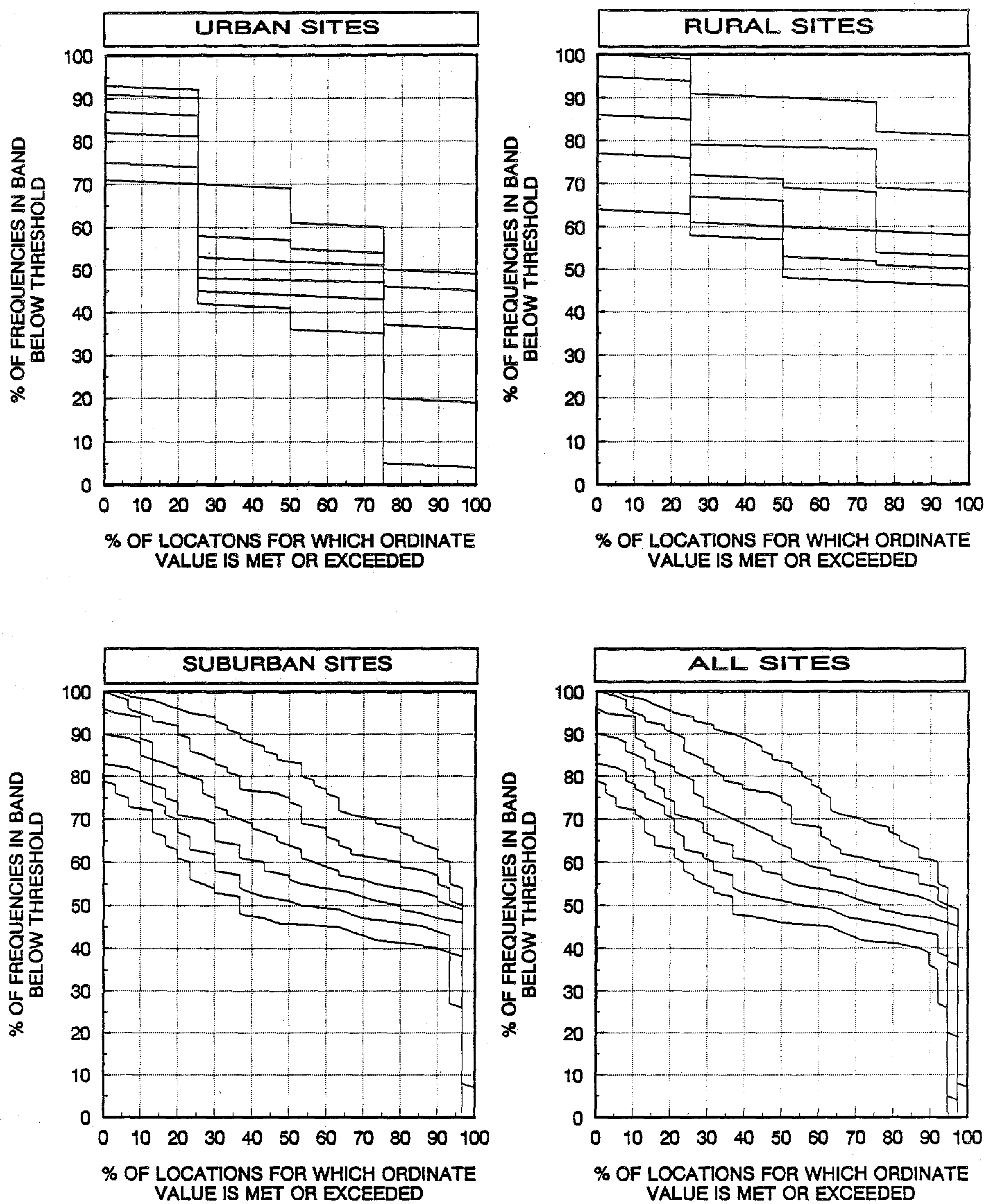

Figure 8.9 Measured band usage plots for urban, suburban, rural, and all site types for Chicago 864 - 868 MHz.

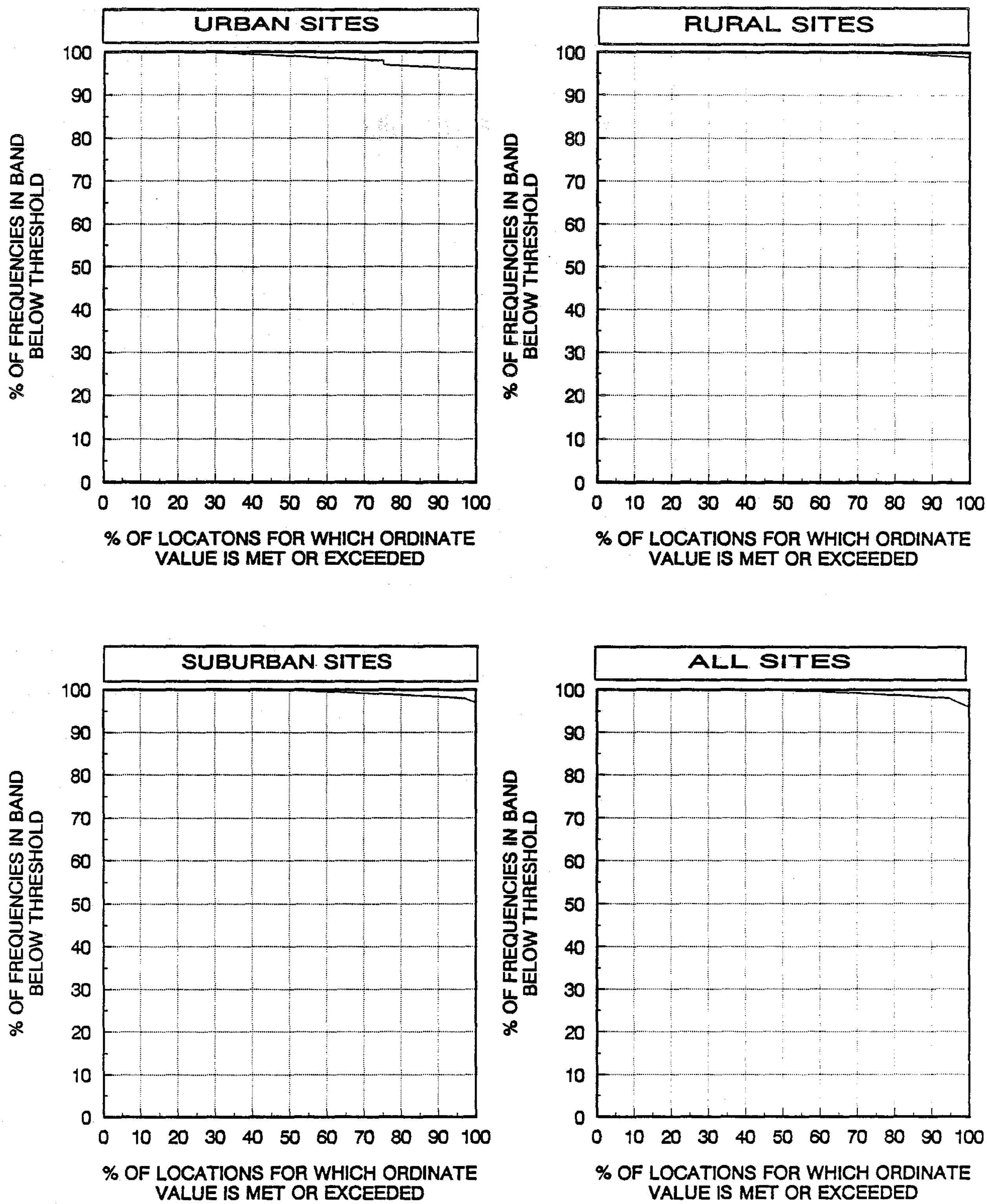

Figure 8.10 Measured band usage plots for urban, suburban, rural, and all site types for Chicago 901 - 902 MHz.

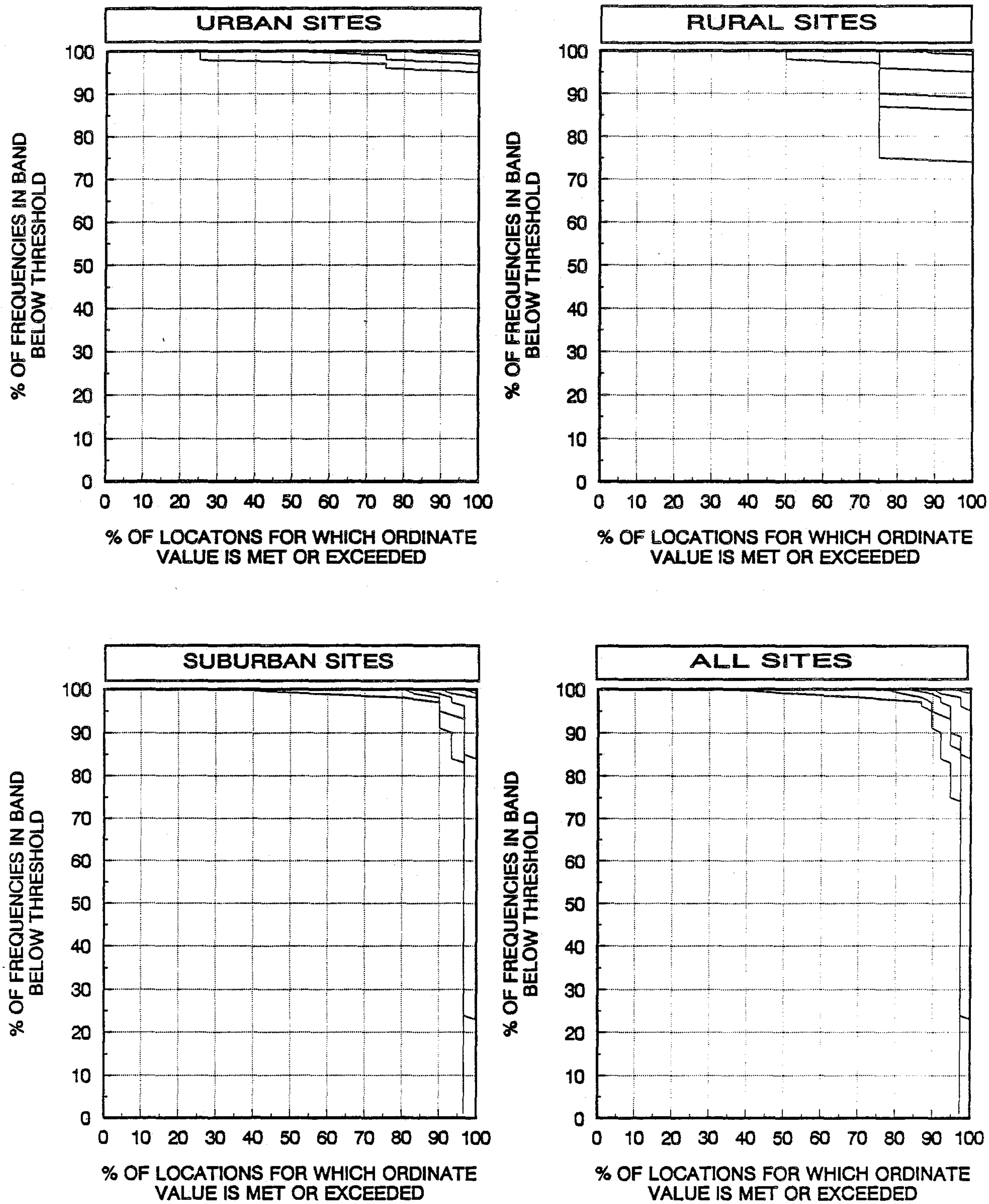

Figure 8.11 Measured band usage plots for urban, suburban, rural, and all site types for Chicago 930 - 931 MHz.

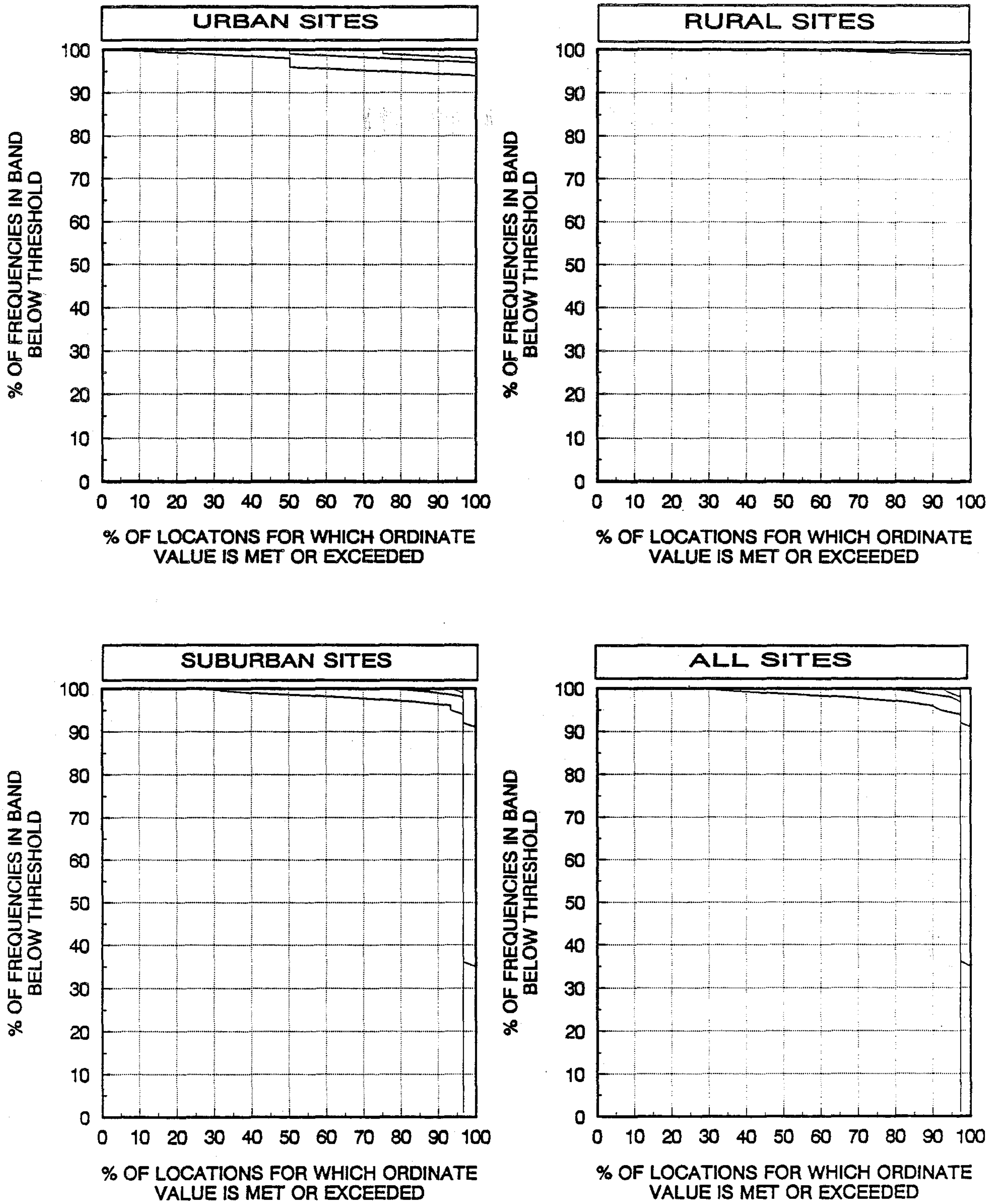

Figure 8.12 Measured band usage plots for urban, suburban, rural, and all site types for Chicago 940 - 941 MHz.

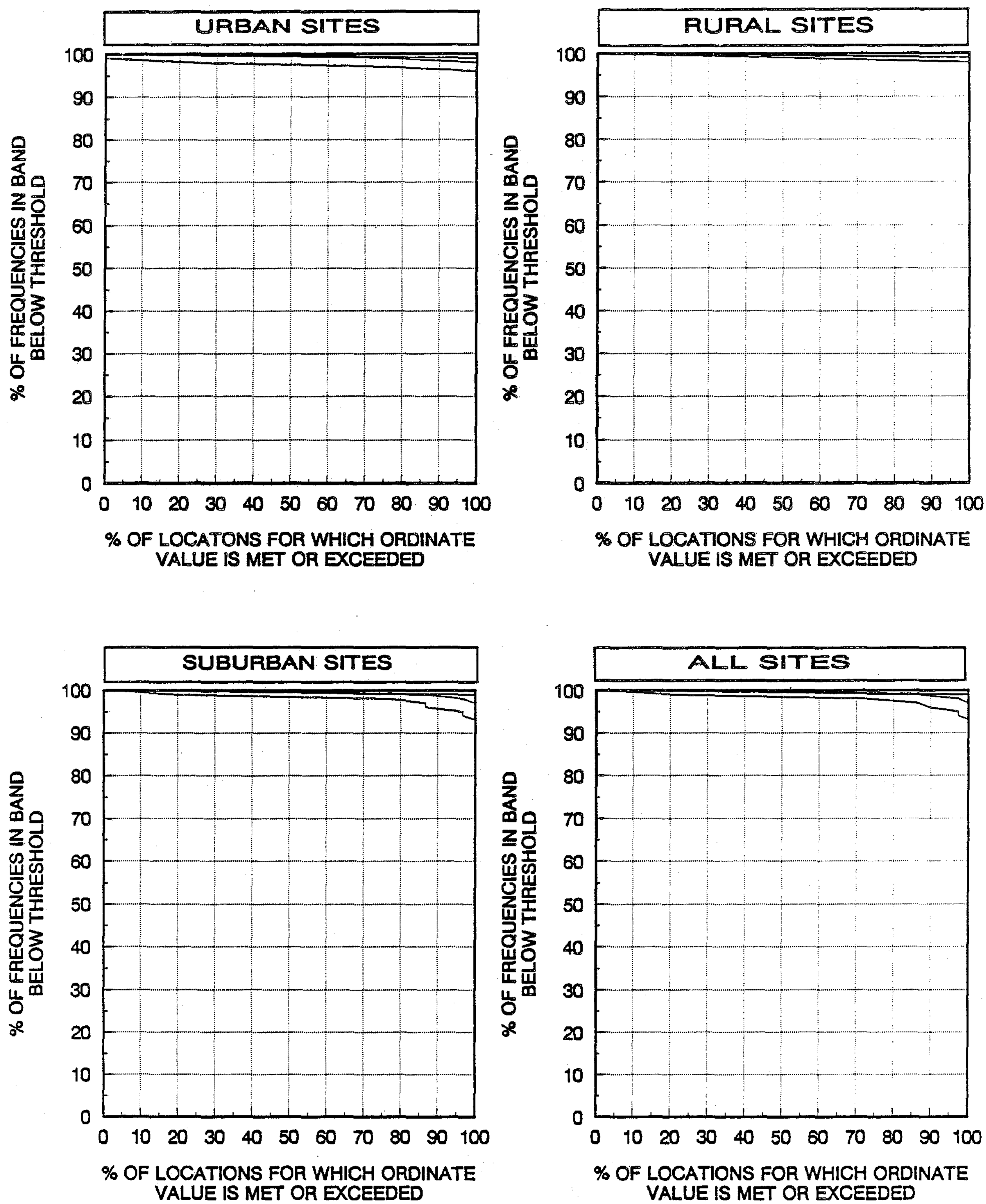

Figure 8.13 Measured band usage plots for urban, suburban, rural, and all site types for Chicago 902 - 928 MHz.

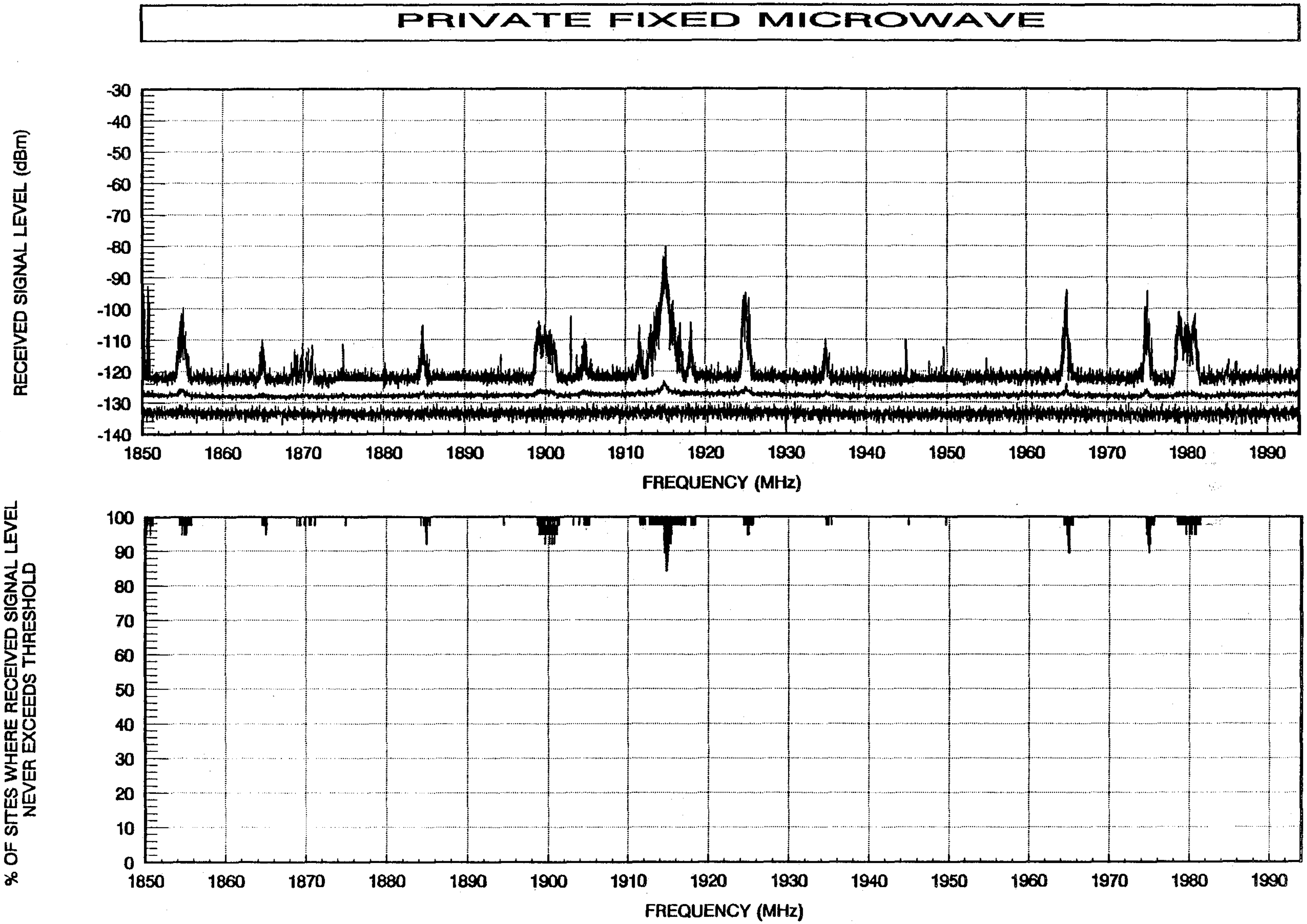

Figure 8.14 Signal level (top) and measured frequency usage (bottom) plots for Chicago 1850 - 1994 MHz.

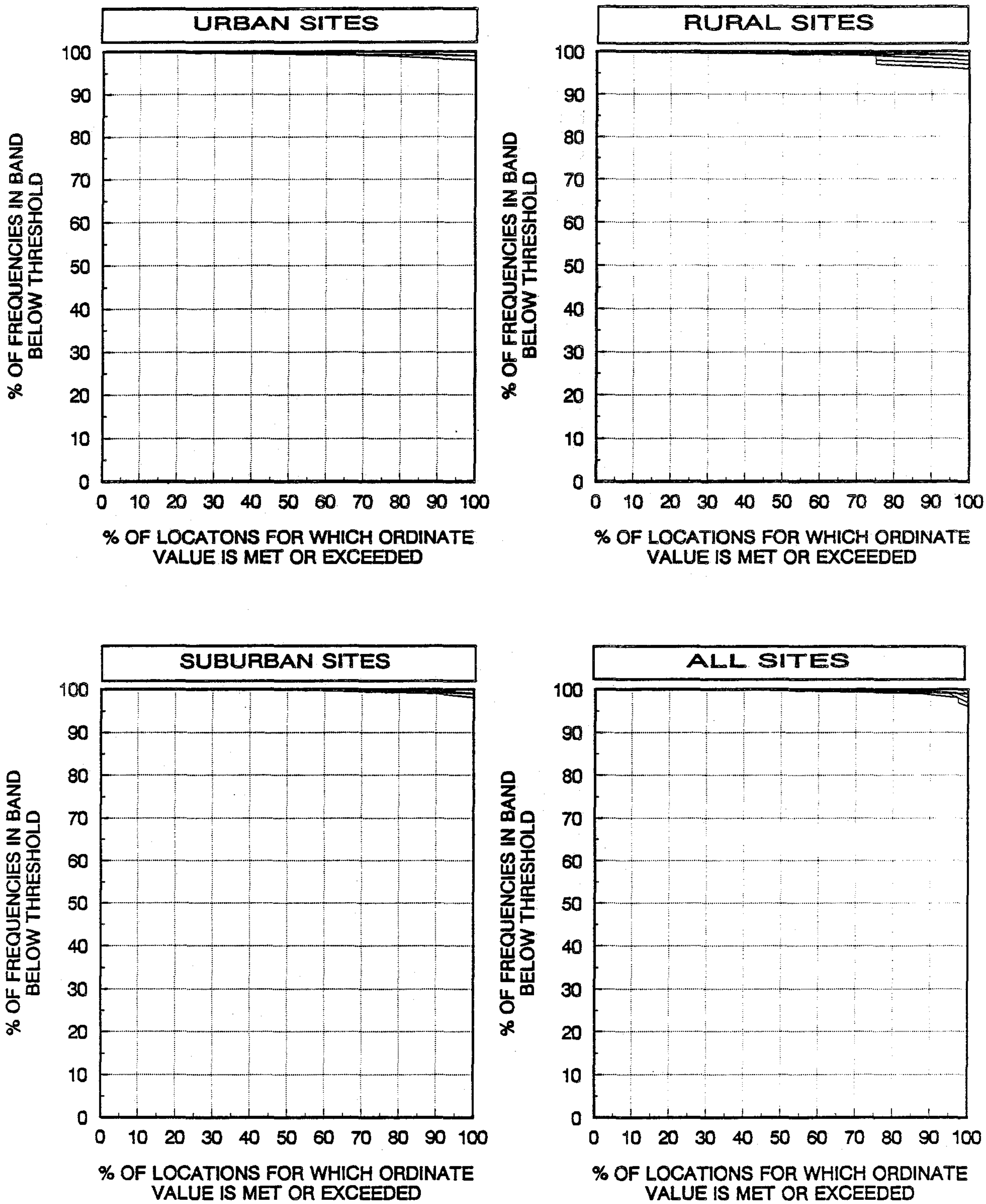

Figure 8.15 Measured band usage plots for urban, suburban, rural, and all site types for Chicago 1850 - 1990 MHz.

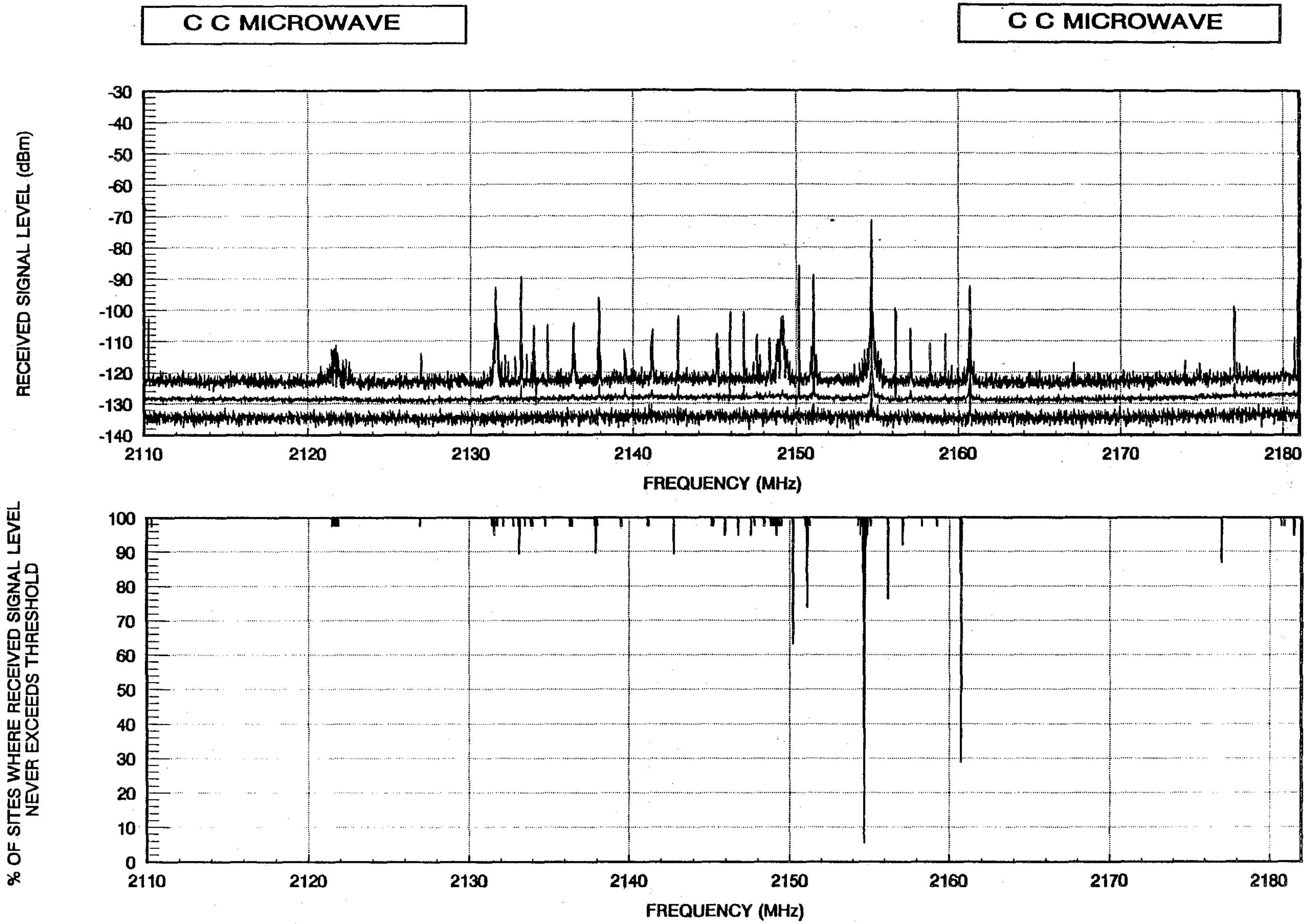

Figure 8.16 Signal level (top) and measured frequency usage (bottom) plots for Chicago 2110 - 2182 MHz.

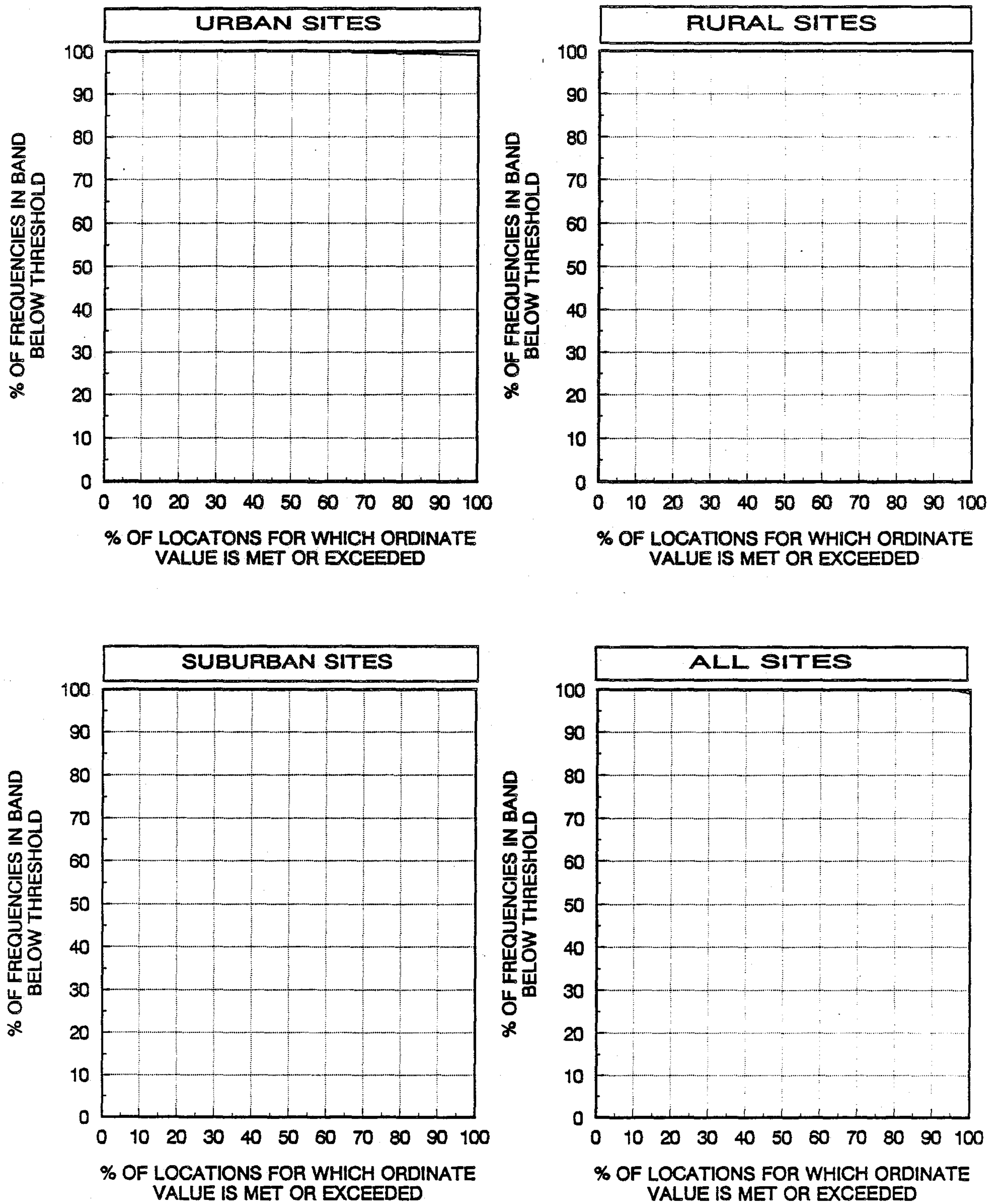

Figure 8.17 Measured band usage plots for urban, suburban, rural, and all site types for Chicago 2110 - 2130 MHz.

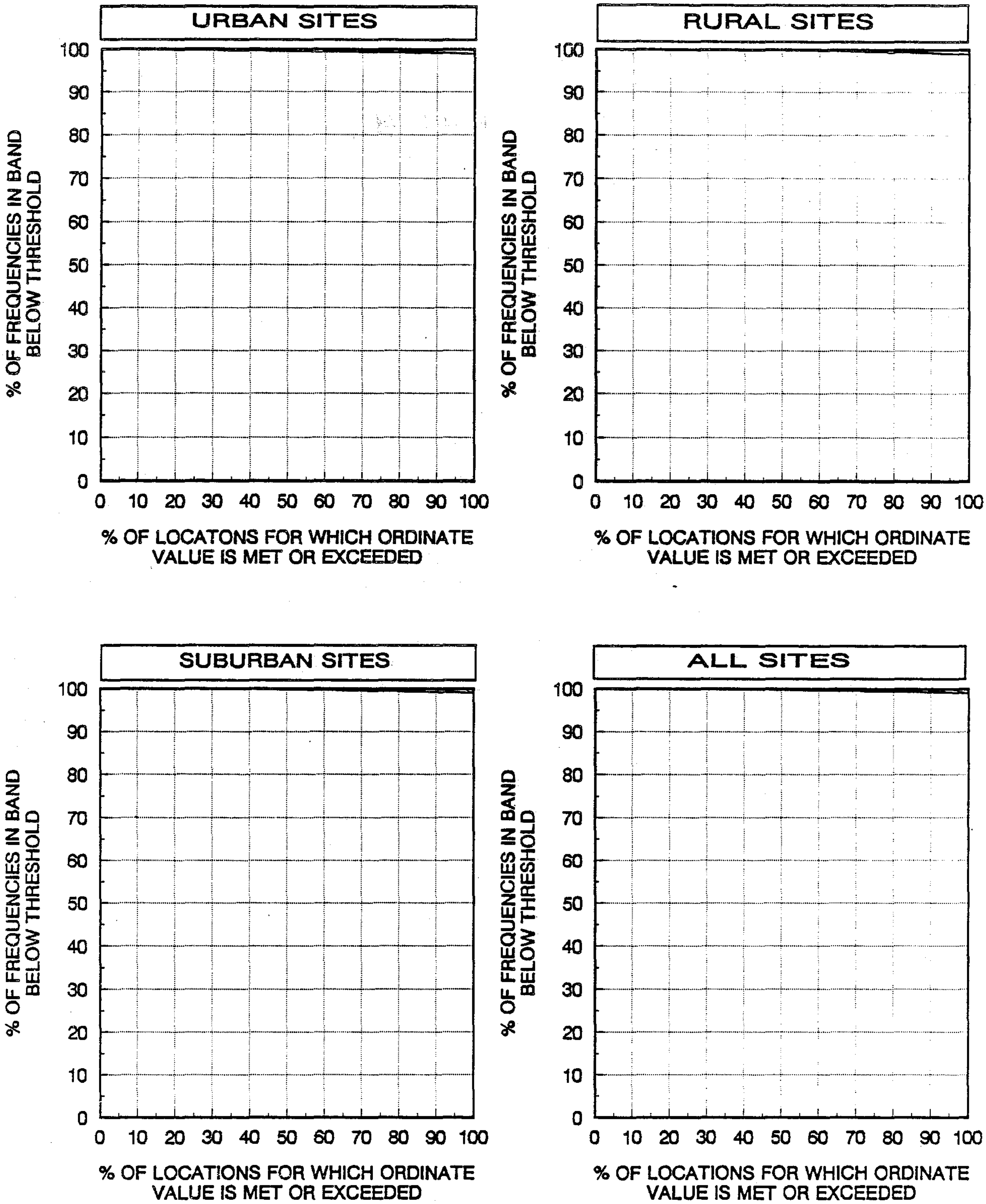

Figure 8.18 Measured band usage plots for urban, suburban, rural, and all site types for Chicago 2160 - 2180 MHz.

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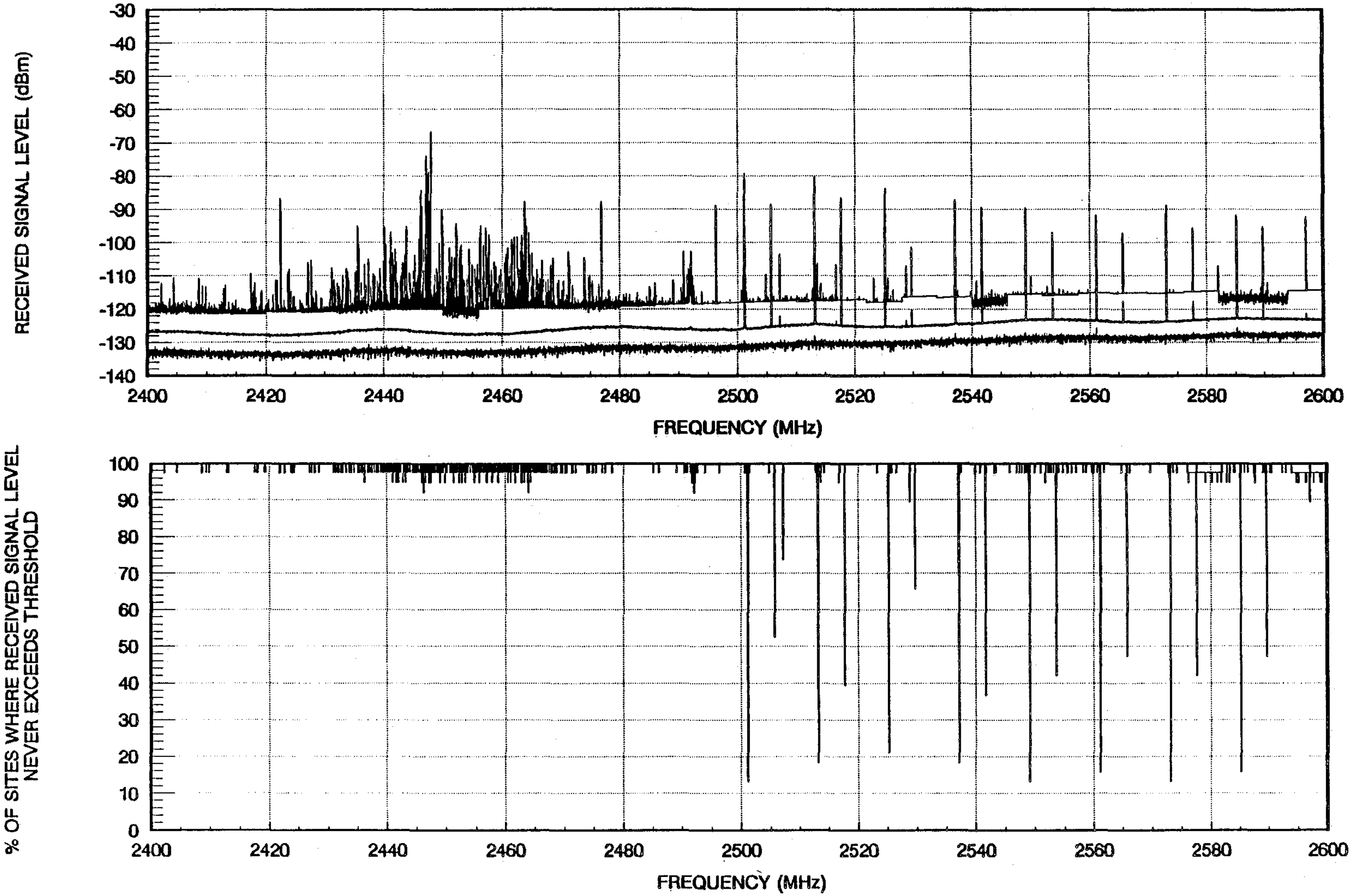

Figure 8.19 Signal level (top) and measured frequency usage (bottom) plots for Chicago 2400 - 2600 MHz.

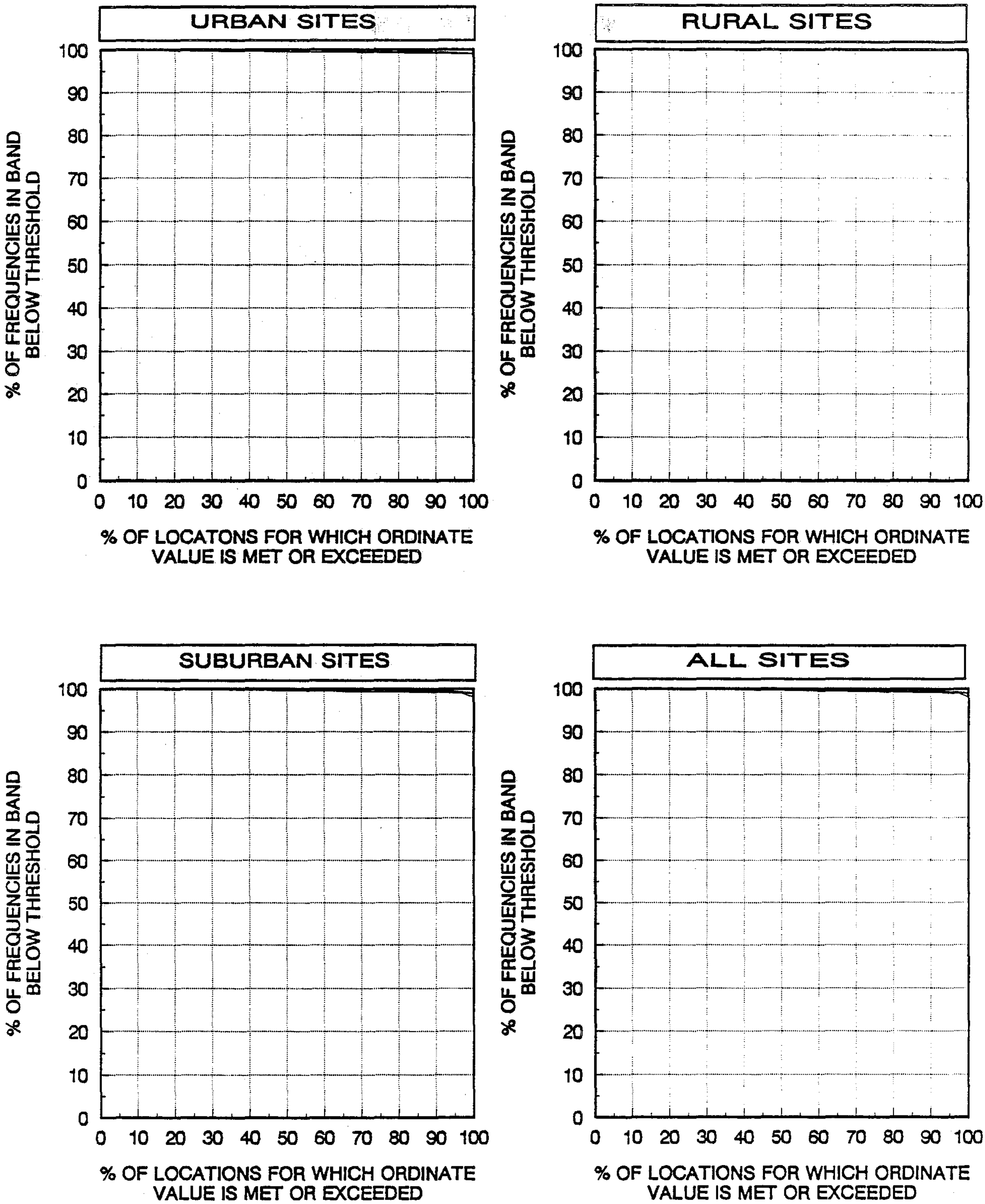

Figure 8.20 Measured band usage plots for urban, suburban, rural, and all site types for Chicago 2400 - 2483.5 MHz.

9. NEW YORK DATA

A map showing the measurement sites in New York is shown in Figure 9.1. Table 9.1 lists the measurement sites according to their zoning classifications (i.e., urban, suburban, and rural).

Table 9.1 Categorization of Numbered Measurement Sites in New York

Urban				Suburban				Rural
5	20	22	23	1	2	3	4	
30	31			6	7	8	9	
				10	11	12	13	
				14	15	16	17	
				18	19	21	24	
				25	26	27	28	
				29	32	33	34	
				35	36	37		

Table 9.1 shows that approximately 16% of the sites are urban, 84% of the sites are suburban, and none of the sites are rural. The statistics generated for all site types combined is therefore weighted most heavily by the suburban sites. While extracting information from the data that are presented here the distribution of site zoning types must be kept in mind. Due to the size of the sample set, the statistics generated for suburban sites provide a fairly accurate representation of suburban sites in this city. The statistics generated for the urban sites do not provide as good a representation of all urban sites in this city, due to the more limited sample size. Note that since none of the sites were rural, the measured band usage graphs for rural sites will not contain any information.

For the narrowband measurements, the signal level, measured frequency usage, and measured band usage graphs are presented for the five measurement frequency bands: 614-806 MHz, 824-944 MHz, 1850-1994 MHz, 2110-2182 MHz, and 2400-2600 MHz. The data are simply presented and not discussed in this section. In the Comparison of Data Between Cities section, the salient similarities and differences in the data seen from the different cities will be discussed.

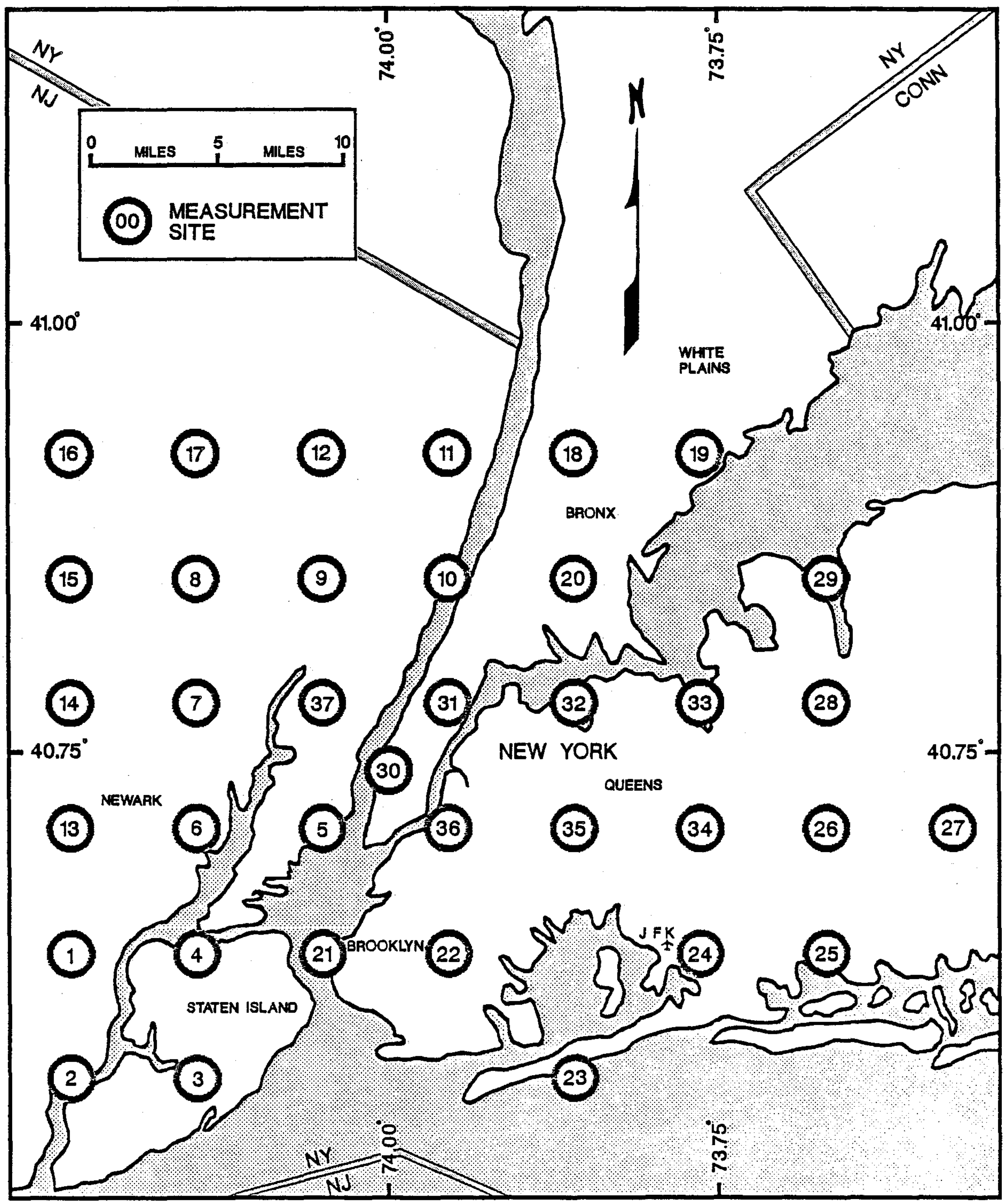

Figure 9.1 Measurement sites in New York.

9.1 The 614-806 MHz Measurement Frequency Band

Figure 9.2 shows the signal level and measured frequency usage graphs for the 614-806 MHz (UHF-TV) band. The measured band usage graphs for this band are presented in Figure 9.3.

9.2 The 824-944 MHz Measurement Frequency Band

The signal level and measured frequency usage graphs for the 824-944 MHz band are displayed in Figure 9.4. Figures 9.5 through 9.13 display the measured band usage graphs for the 824-849 MHz, 869-894 MHz, 849-851 MHz, 894-896 MHz, 864-868 MHz, 901-902 MHz, 930-931 MHz, 940-941 MHz, and 902-928 MHz bands respectively.

9.3 The 1850-1994 MHz Measurement Frequency Band

Figure 9.14 shows the signal level and measured frequency usage graphs for the 1850-1994 MHz band. The measured band usage graphs for the 1850-1990 MHz band are presented in Figure 9.15.

9.4 The 2110-2182 MHz Measurement Frequency Band

For the 2110-2182 MHz band, the signal level and measured frequency usage graphs are shown in Figure 9.16. Figures 9.17 and 9.18 depict the measured band usage graphs for the 2110-2130 MHz and 2160-2180 MHz bands respectively.

9.5 The 2400-2600 MHz Measurement Frequency Band

The signal level and measured frequency usage graphs for the 2400-2600 MHz band are displayed in Figure 9.19 while the measured band usage graphs are displayed in Figure 9.20 for the 2400-2483.5 MHz band.

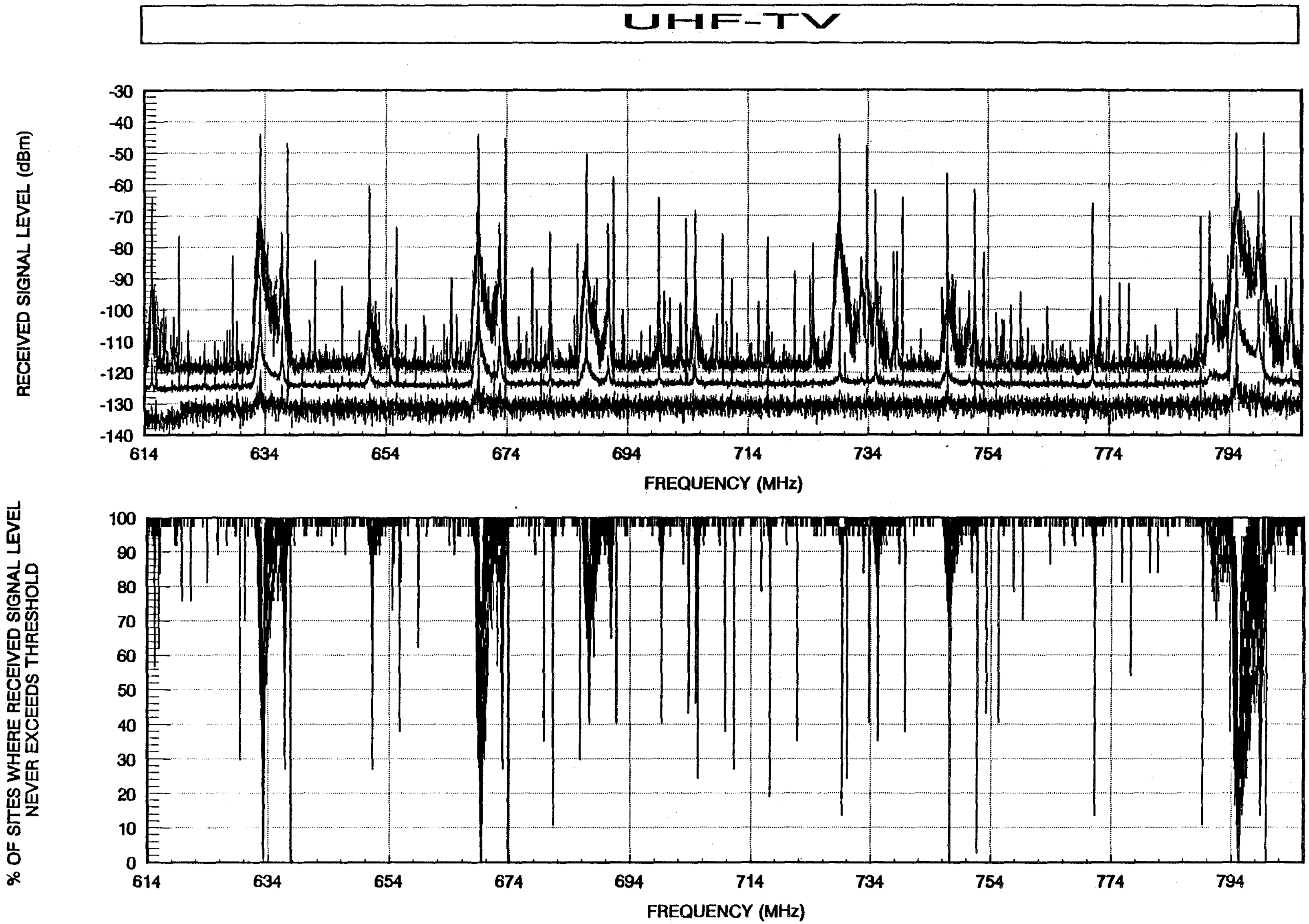

Figure 9.2 Signal level (top) and measured frequency usage (bottom) plots for New York 614 - 806 MHz.

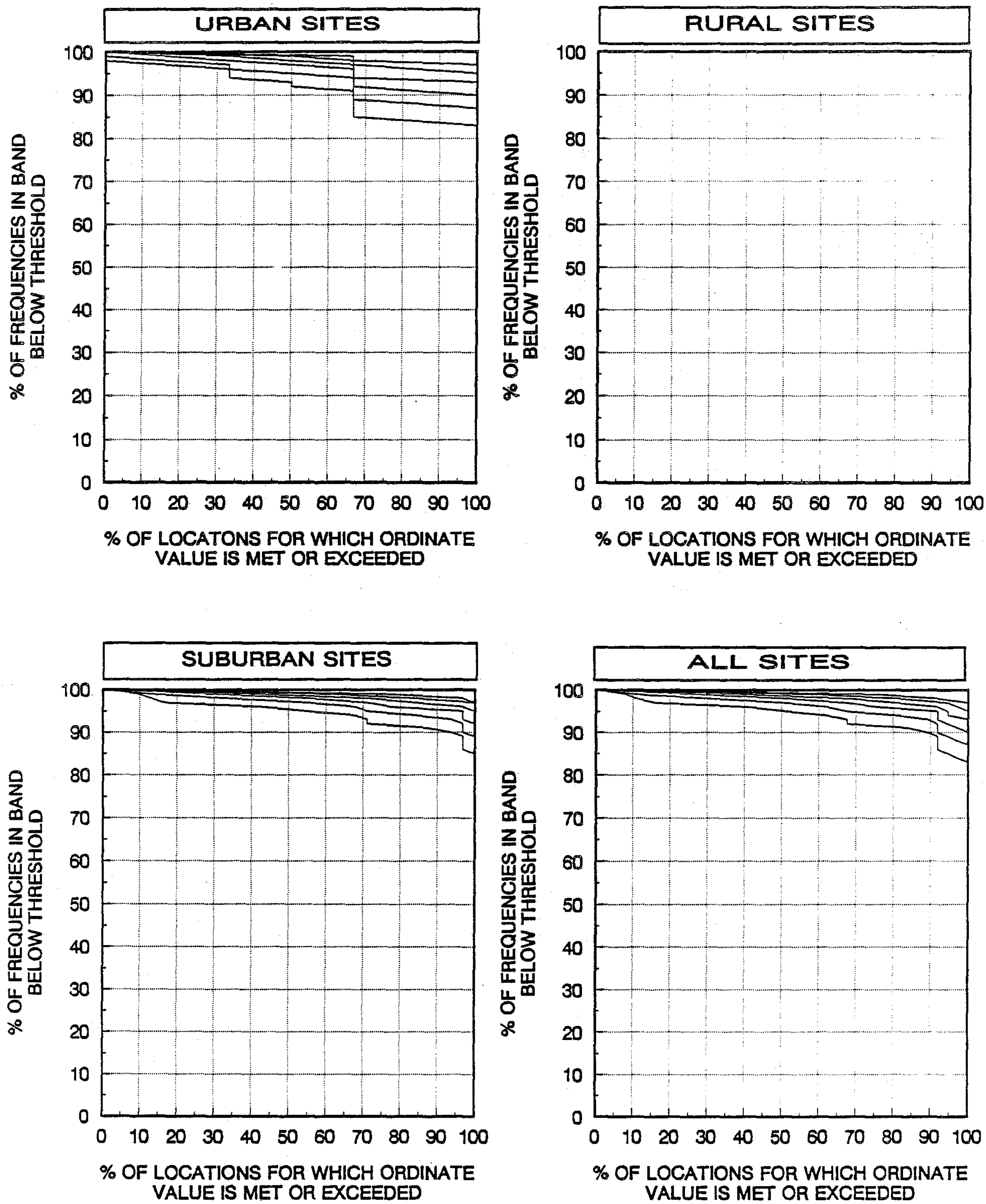

Figure 9.3 Measured band usage plots for urban, suburban, rural, and all site types for New York 614 - 806 MHz.

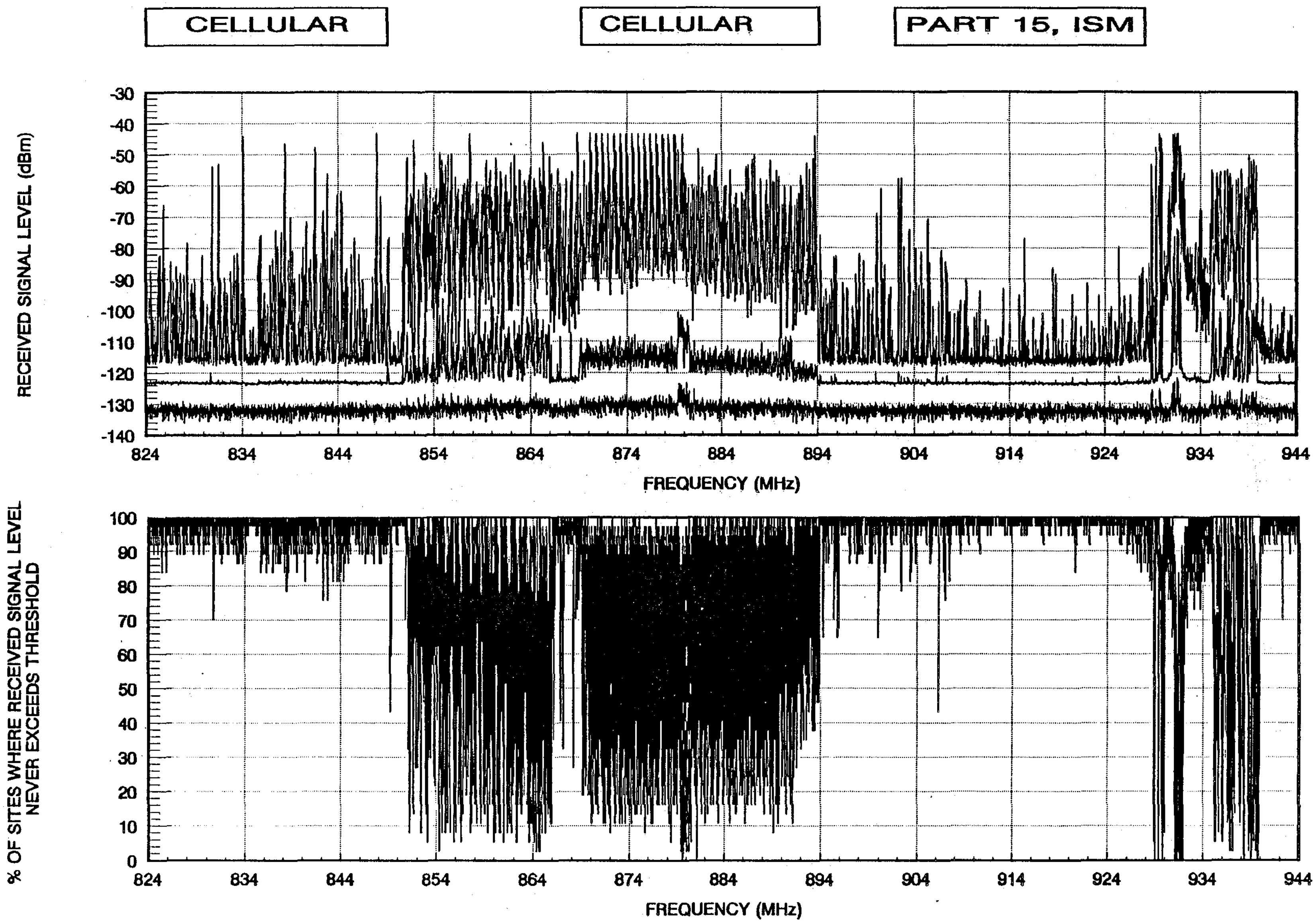

Figure 9.4 Signal level (top) and measured frequency usage (bottom) plots for New York 824 - 944 MHz.

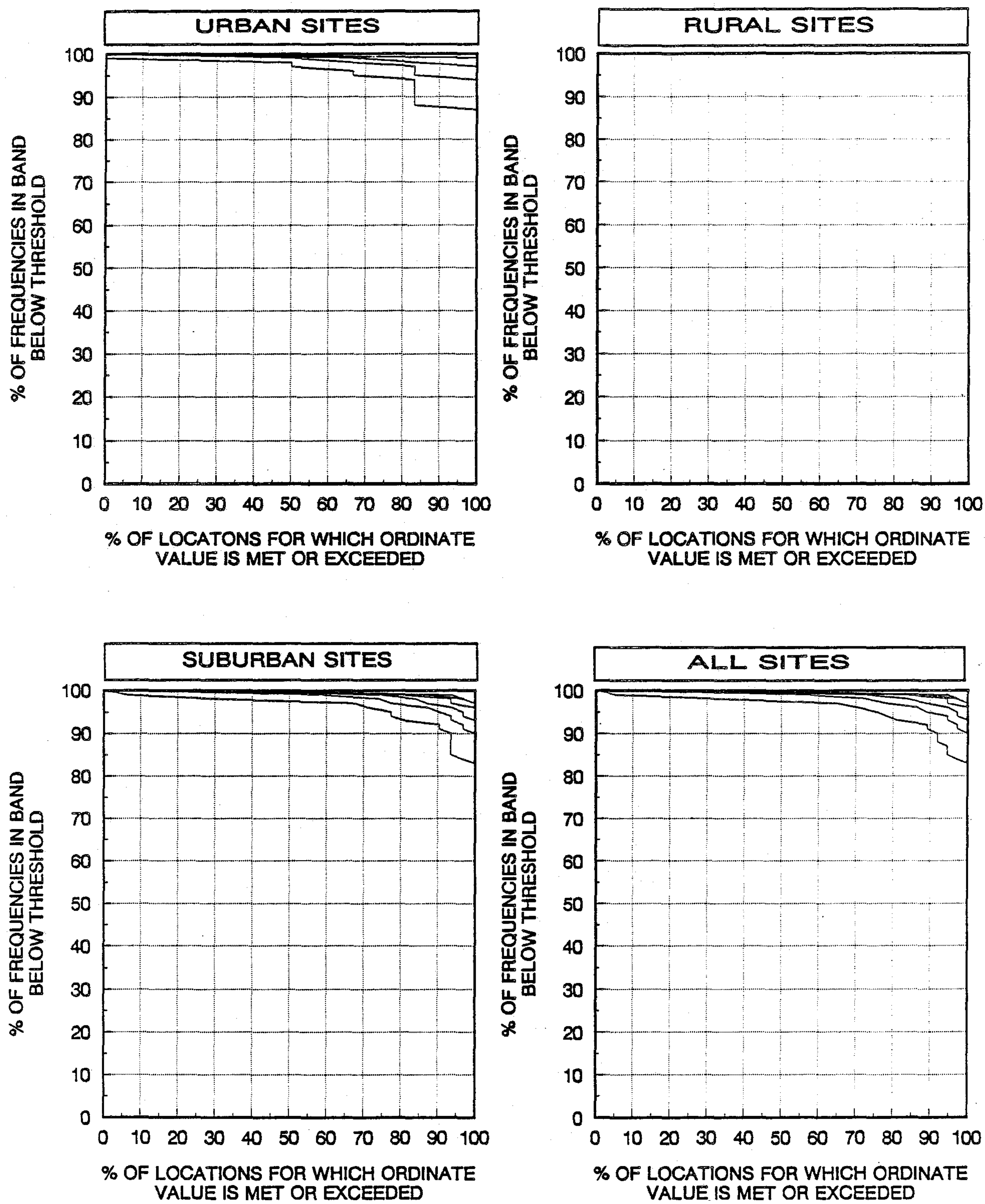

Figure 9.5 Measured band usage plots for urban, suburban, rural, and all site types for New York 824 - 849 MHz.

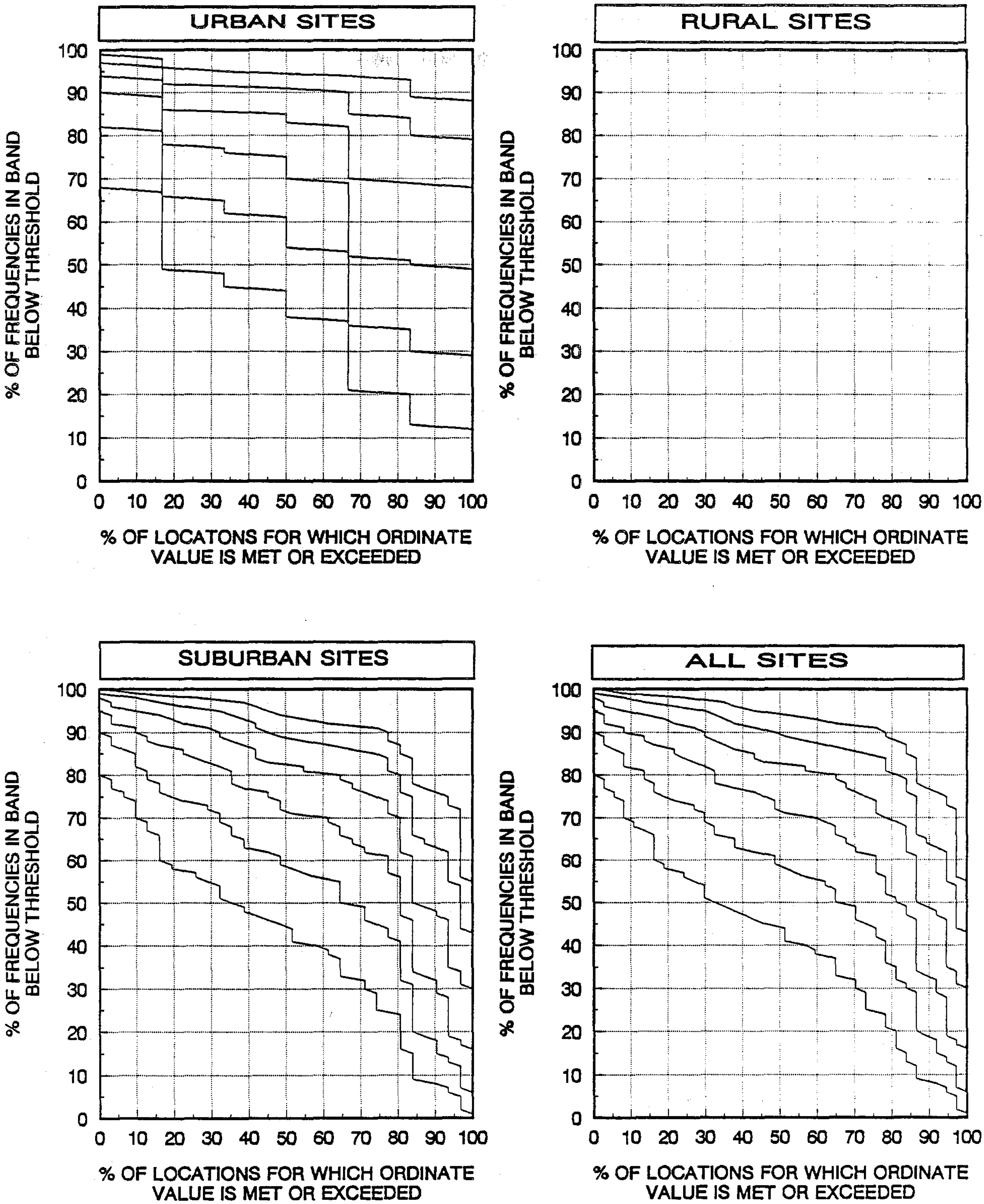

Figure 9.6 Measured band usage plots for urban, suburban, rural, and all site types for New York 869 - 894 MHz.

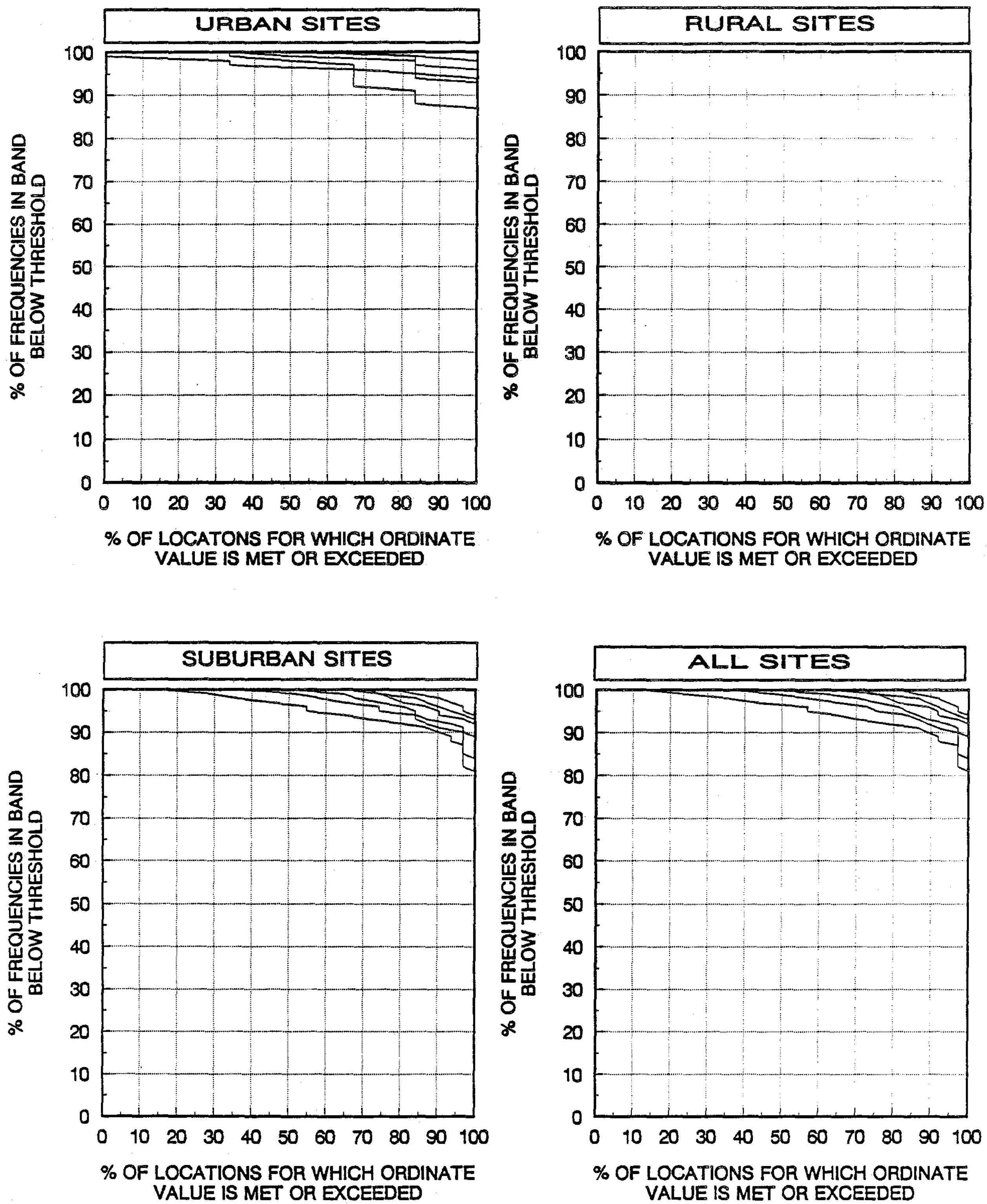

Figure 9.7 Measured band usage plots for urban, suburban, rural, and all site types for New York 849 - 851 MHz.

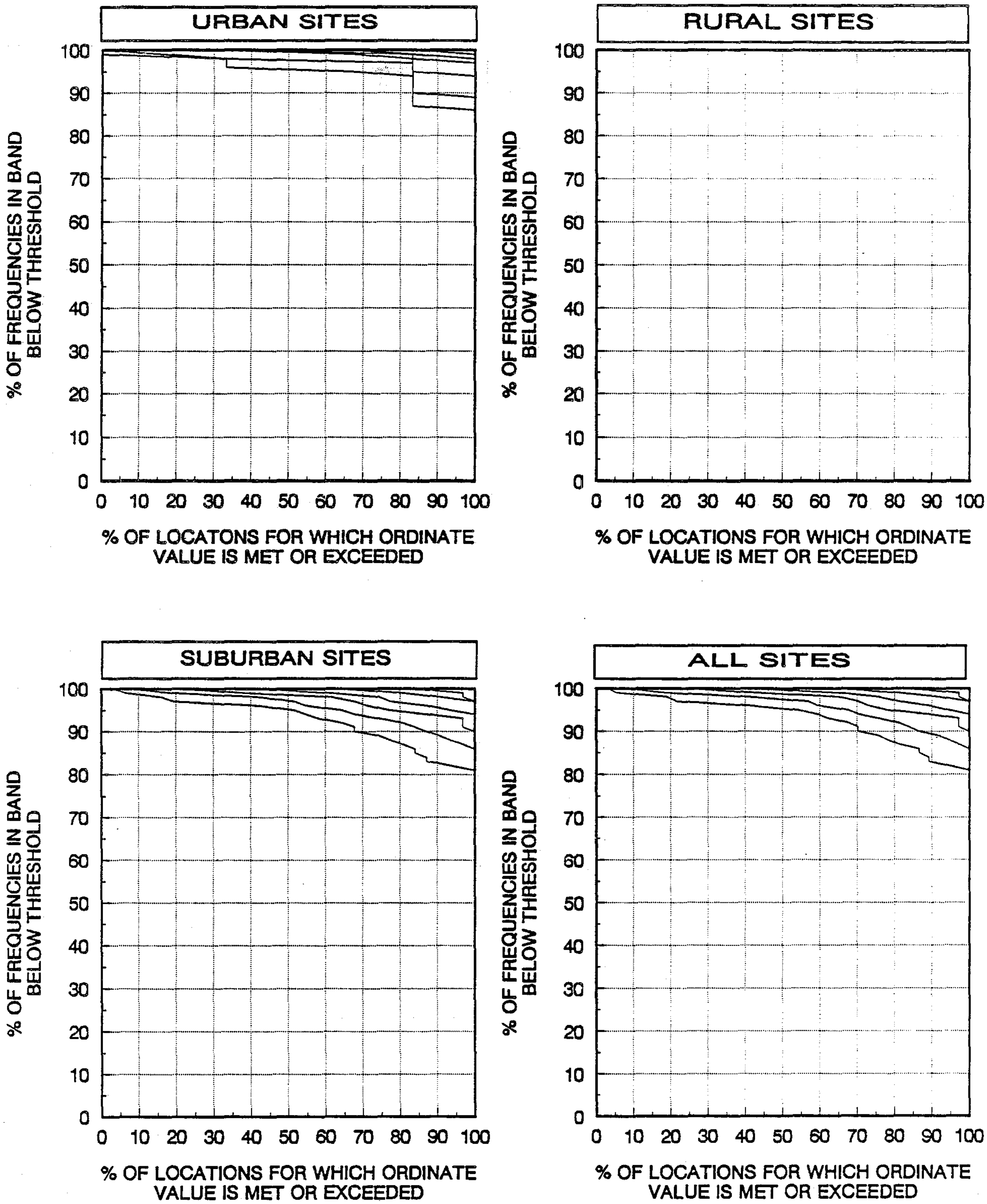

Figure 9.8 Measured band usage plots for urban, suburban, rural, and all site types for New York 894 - 896 MHz.

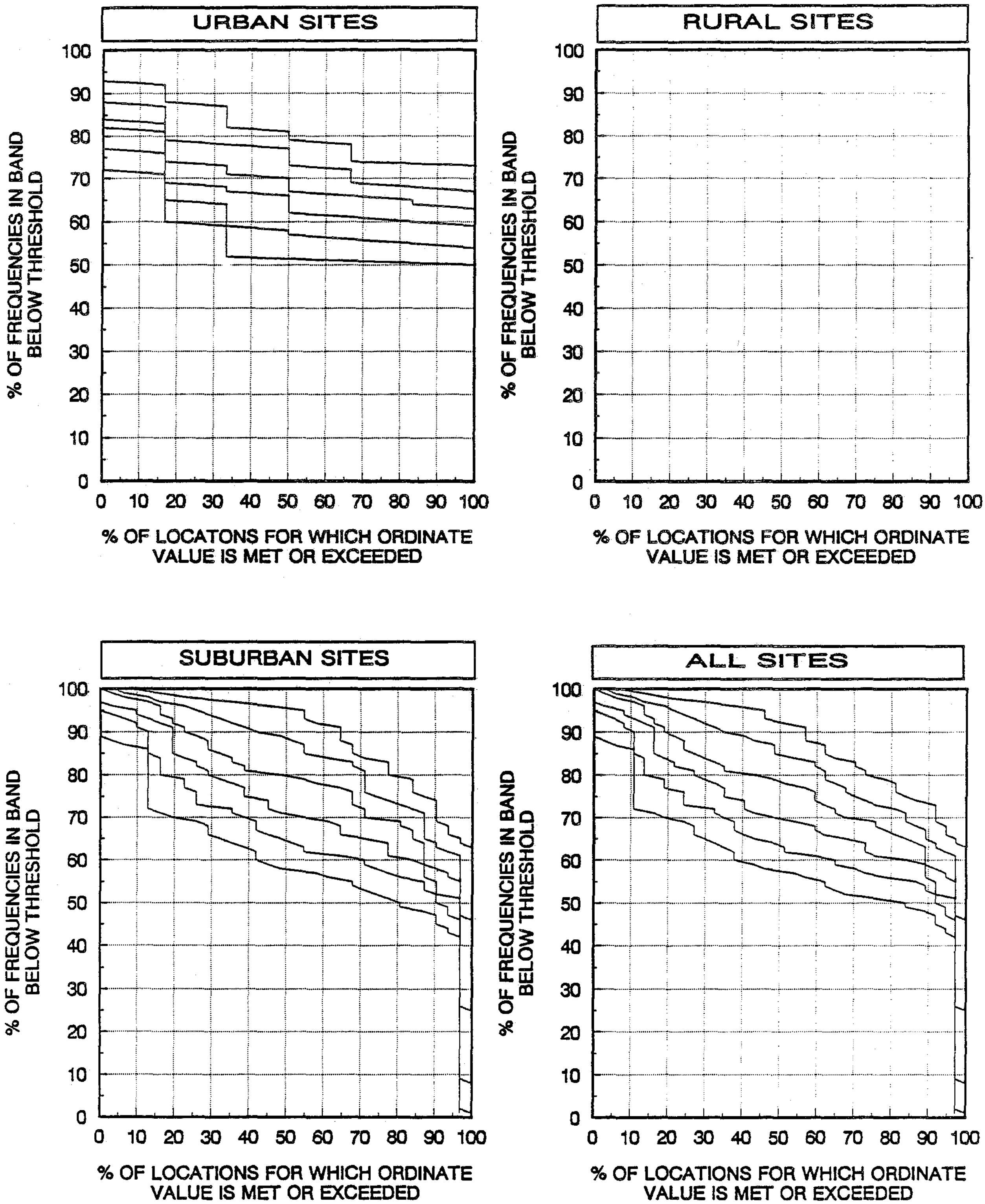

Figure 9.9 Measured band usage plots for urban, suburban, rural, and all site types for New York 864 - 868 MHz.

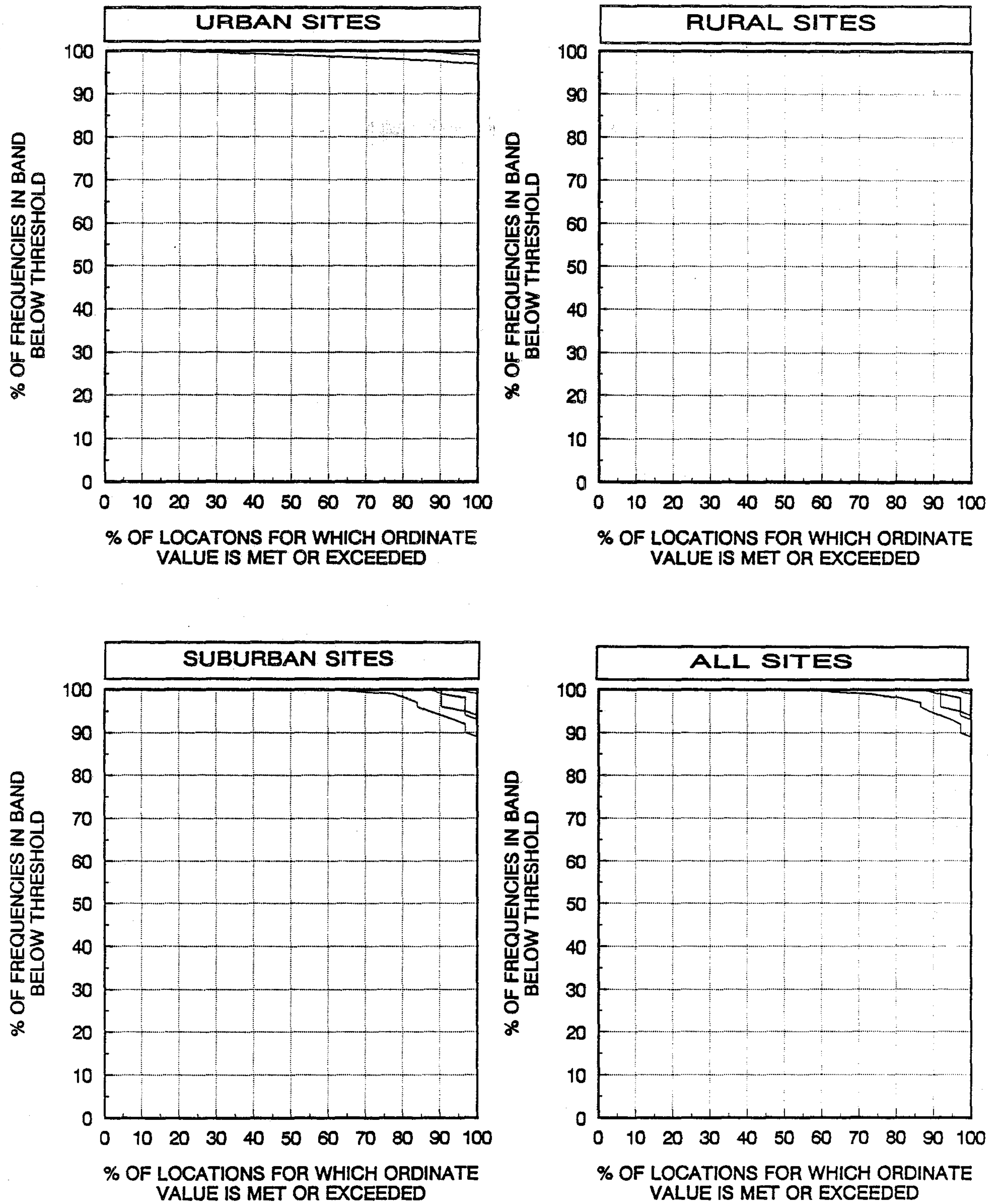

Figure 9.10 Measured band usage plots for urban, suburban, rural, and all site types for New York 901 - 902 MHz.

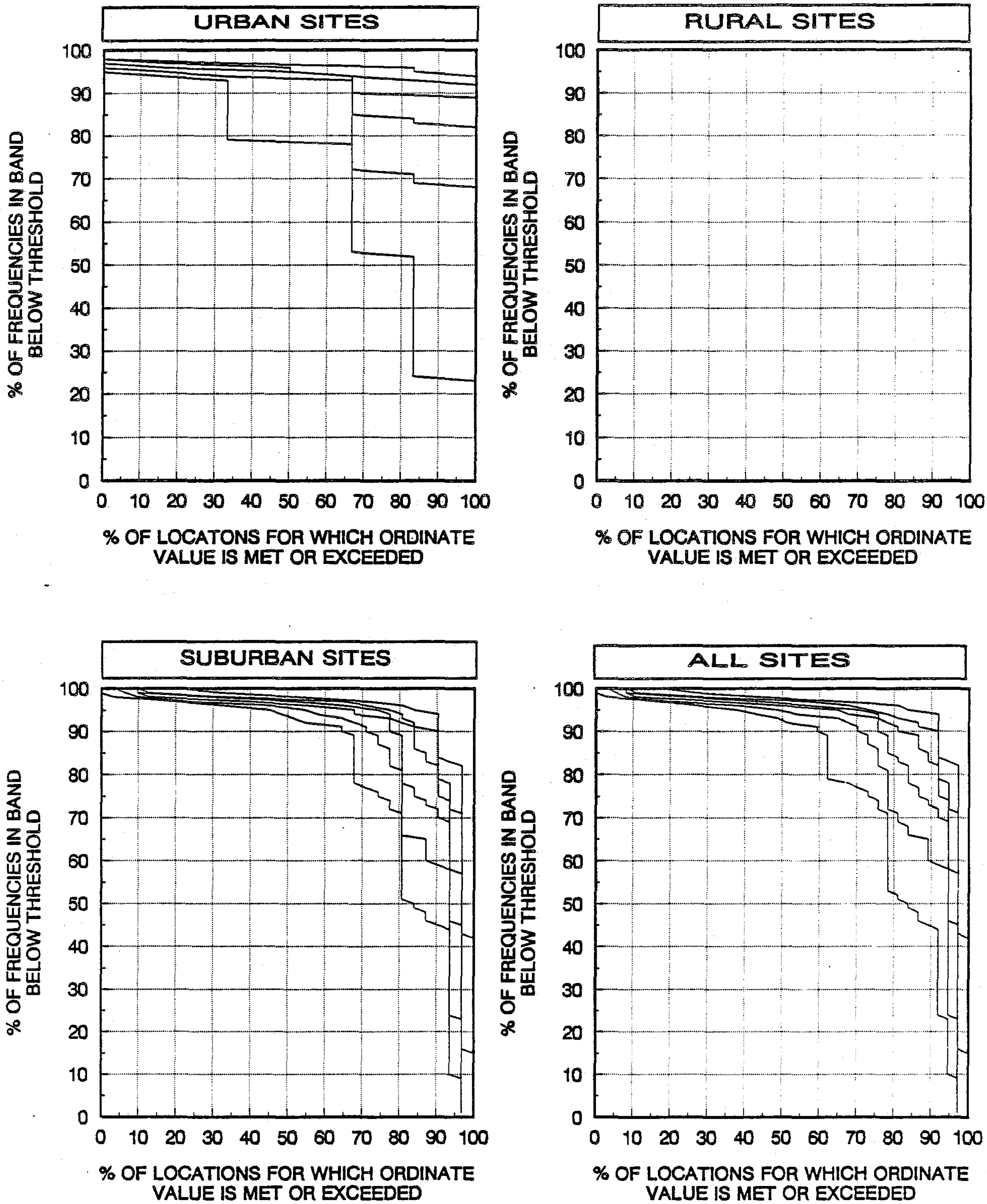

Figure 9.11 Measured band usage plots for urban, suburban, rural, and all site types for New York 930 - 931 MHz.

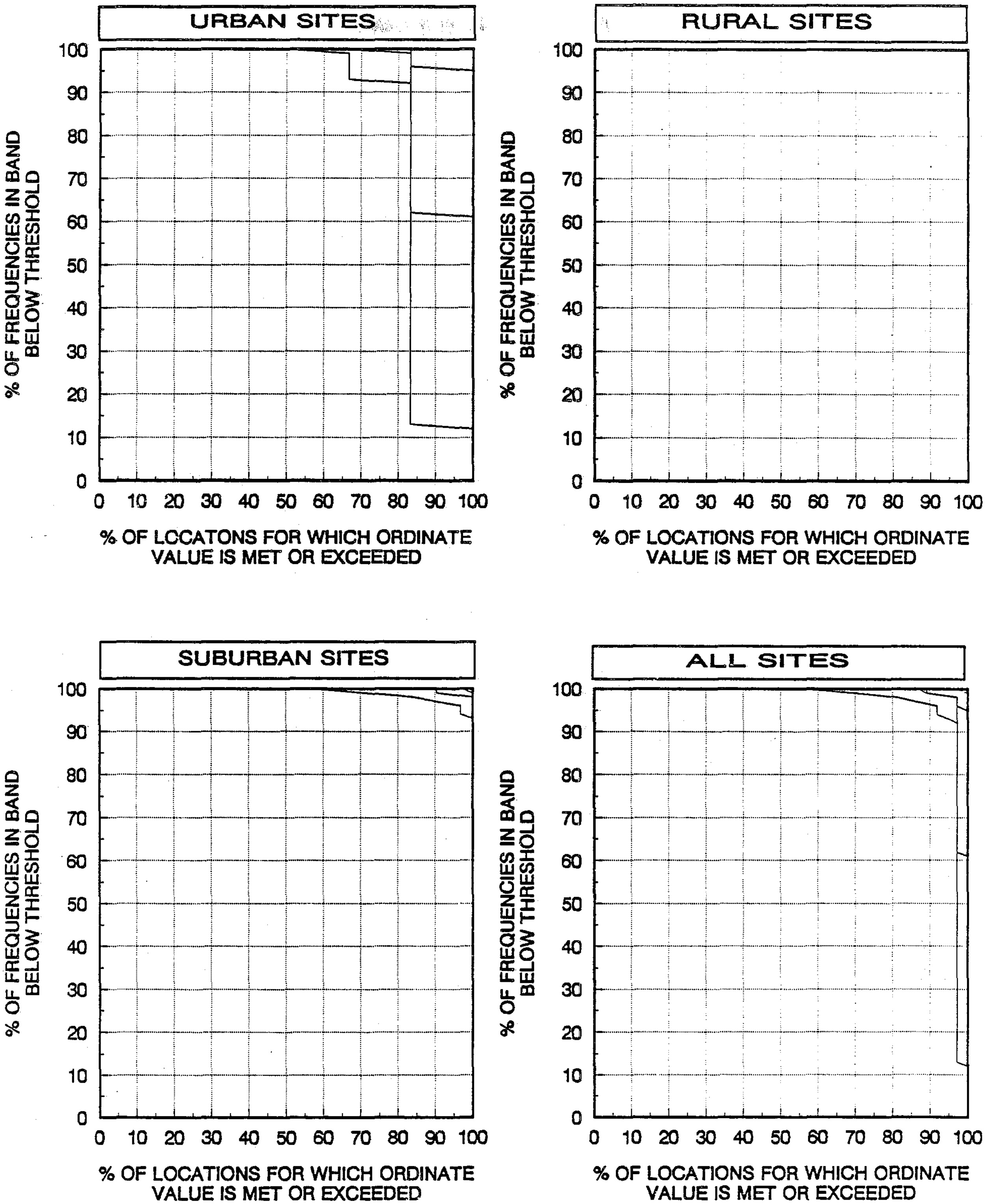

Figure 9.12 Measured band usage plots for urban, suburban, rural, and all site types for New York 940 - 941 MHz.

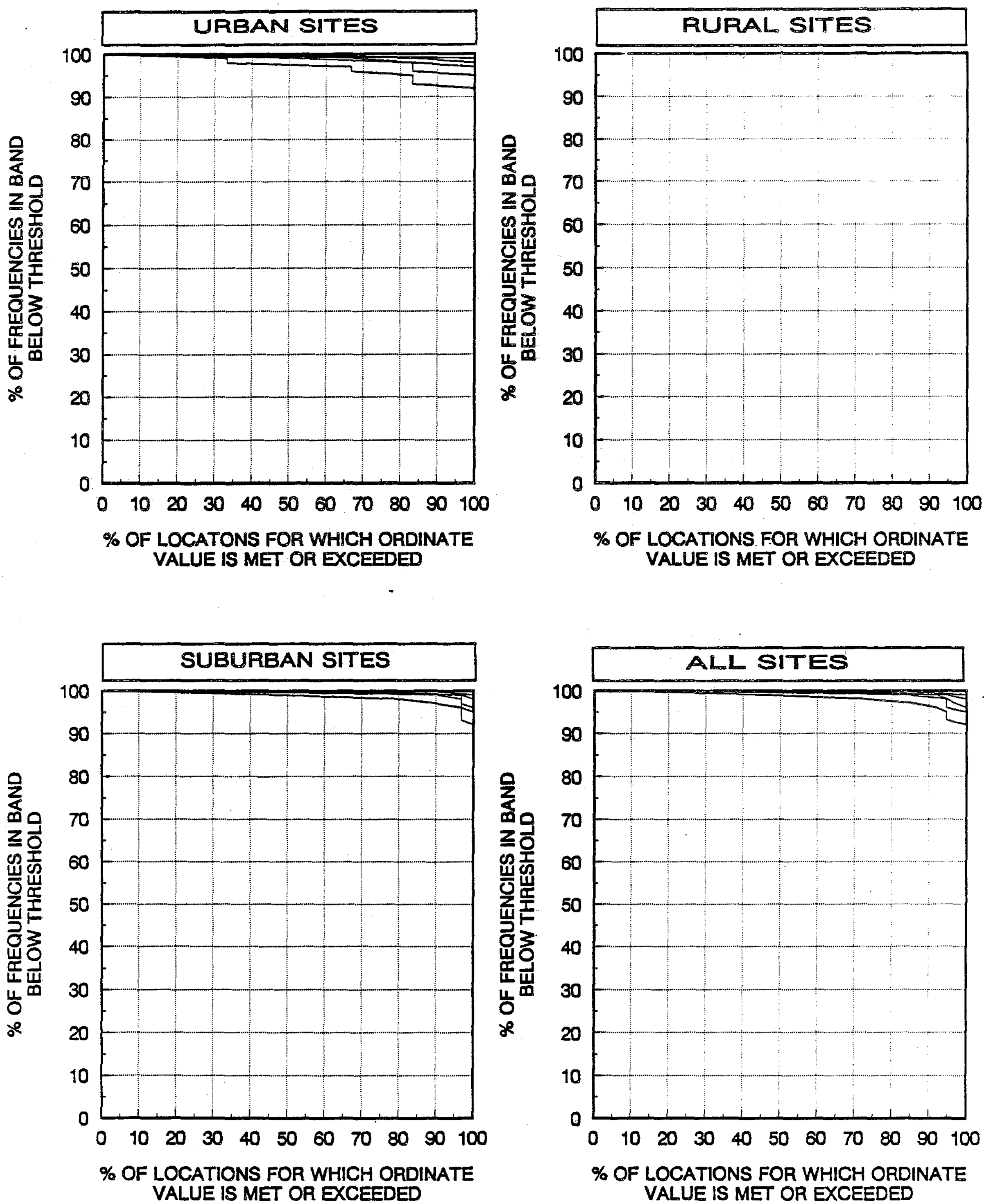

Figure 9.13 Measured band usage plots for urban, suburban, rural, and all site types for New York 902 - 928 MHz.

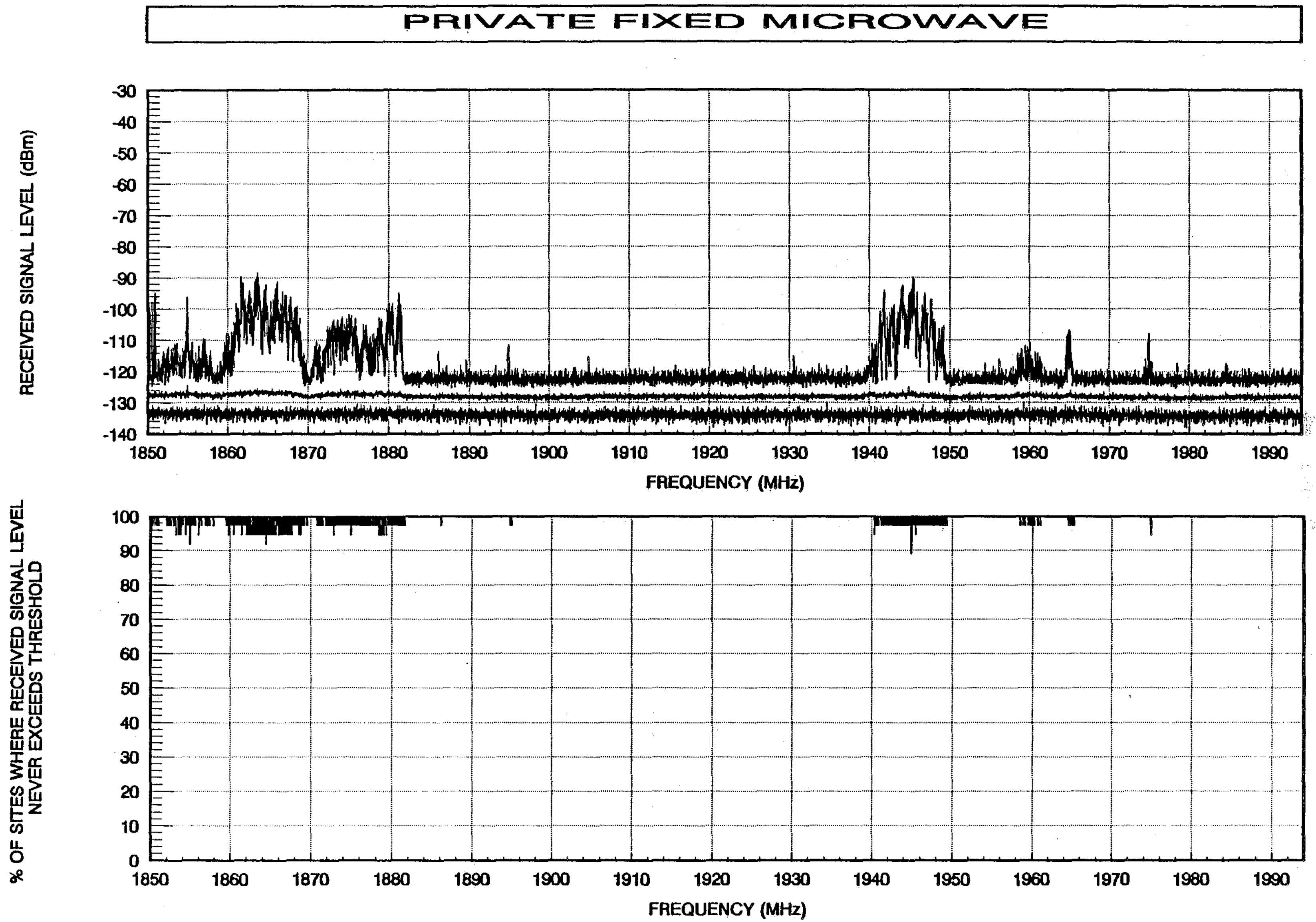

Figure 9.14 Signal level (top) and measured frequency usage (bottom) plots for New York 1850 - 1994 MHz.

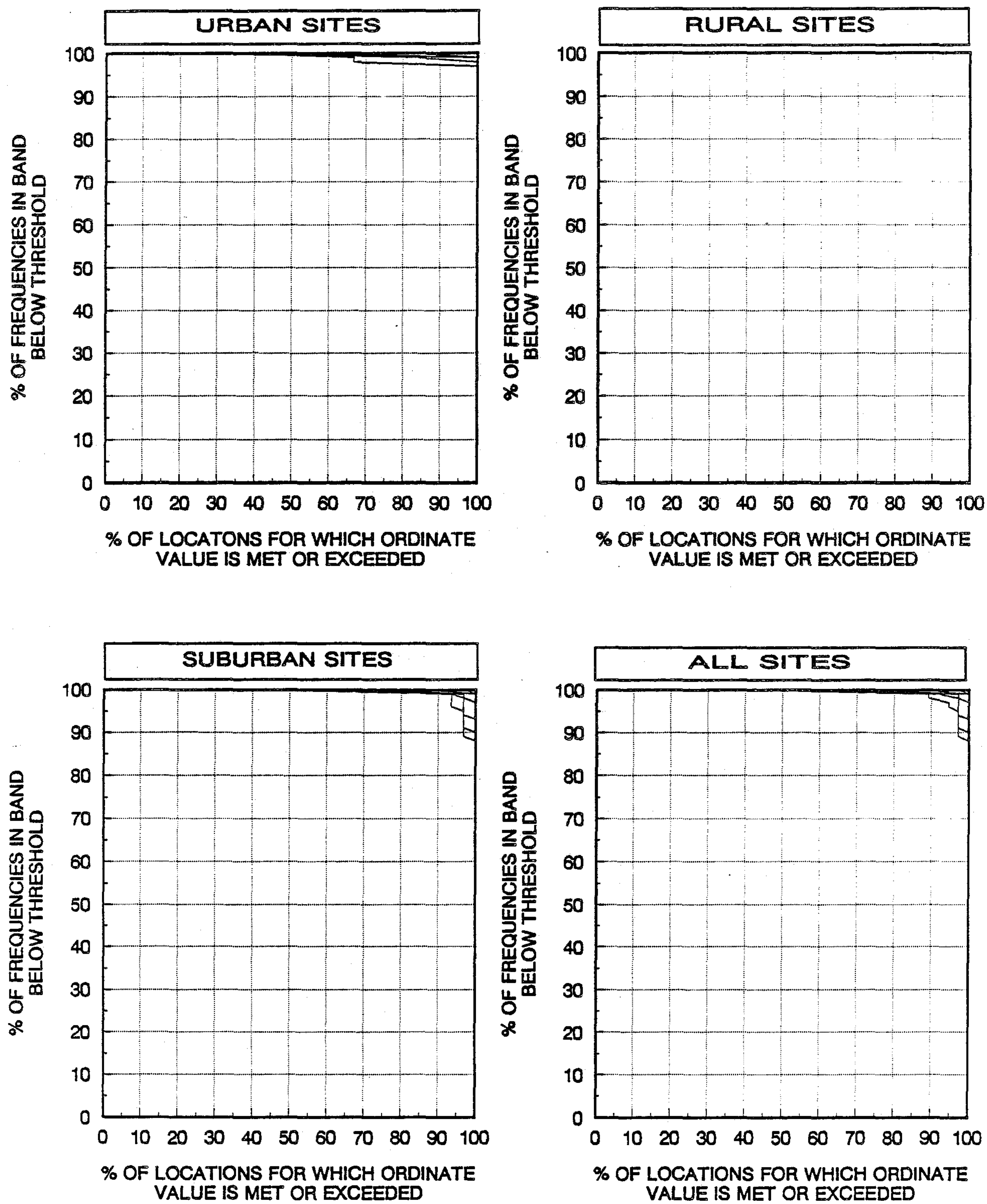

Figure 9.15 Measured band usage plots for urban, suburban, rural, and all site types for New York 1850 - 1990 MHz.

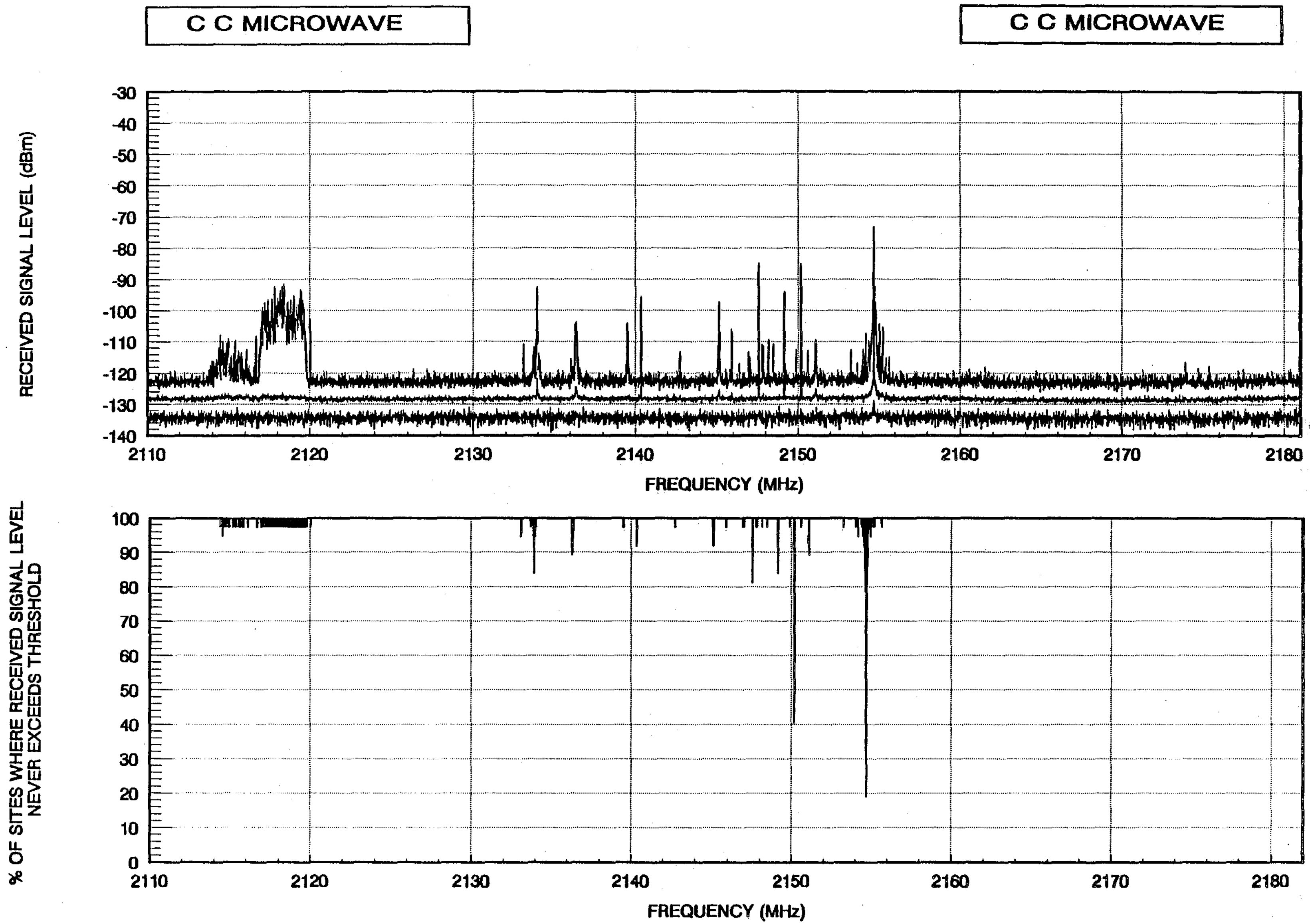

Figure 9.16 Signal level (top) and measured frequency usage (bottom) plots for New York 2110 - 2182 MHz.

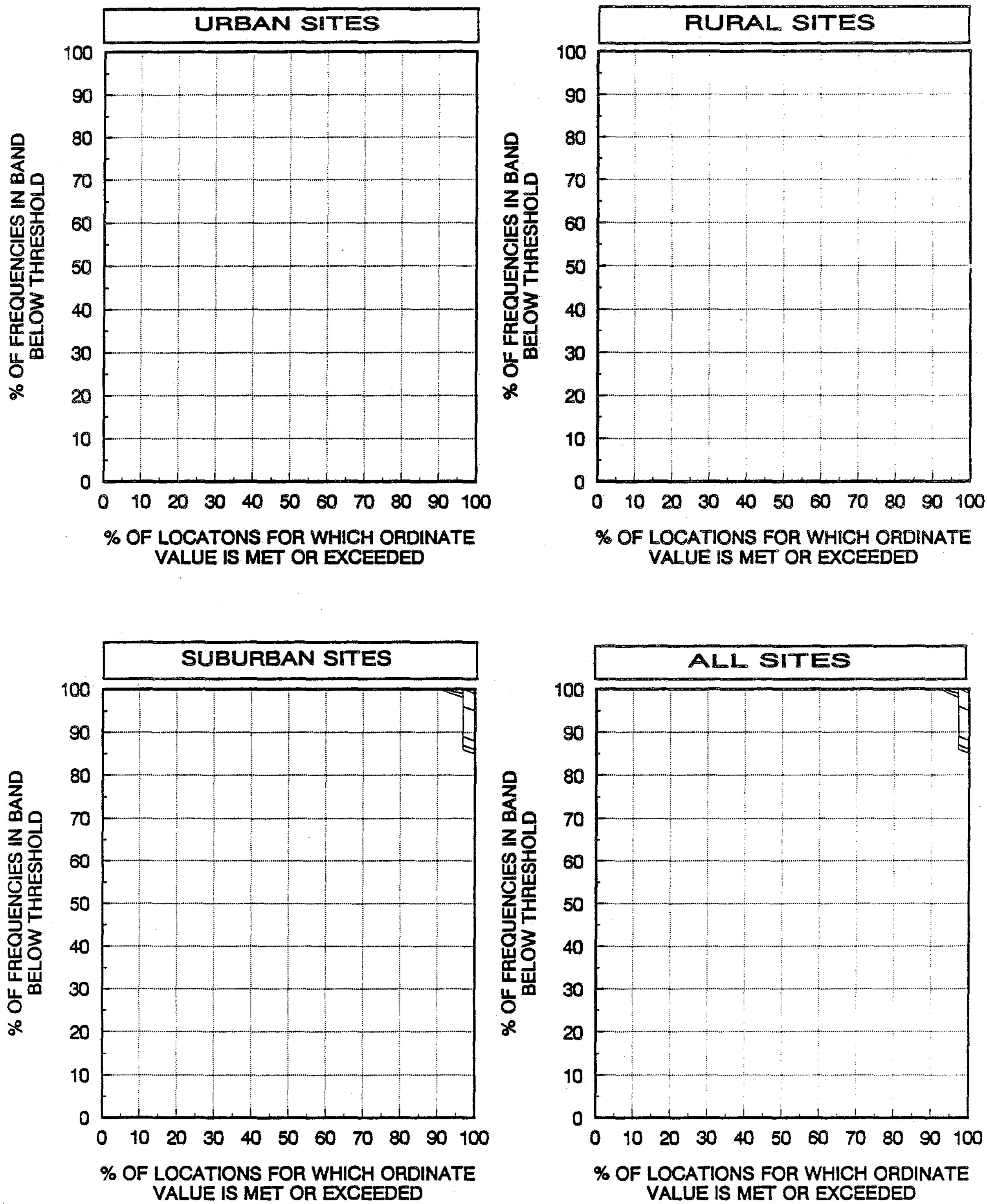

Figure 9.17 Measured band usage plots for urban, suburban, rural, and all site types for New York 2110 - 2130 MHz.

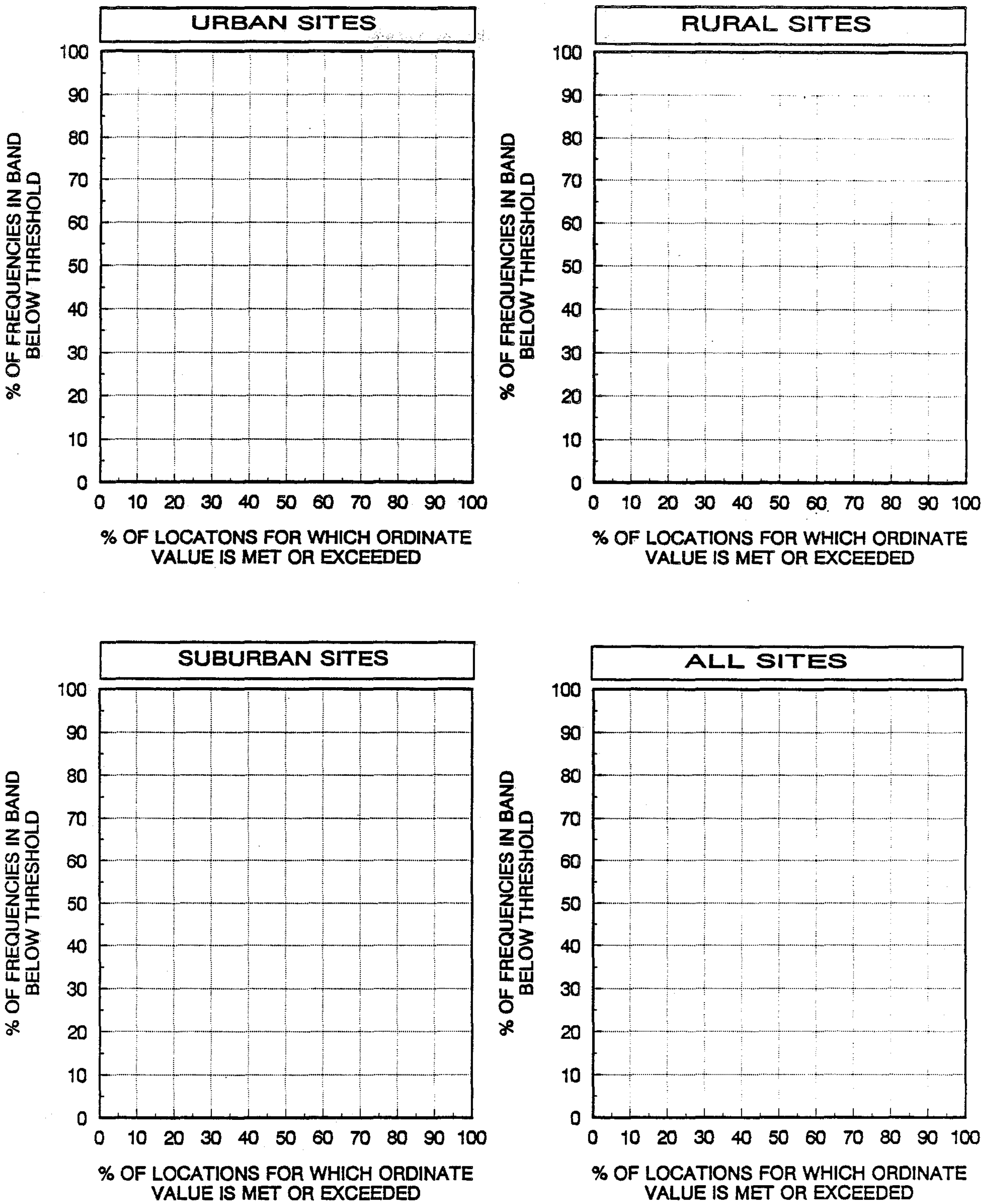

Figure 9.18 Measured band usage plots for urban, suburban, rural, and all site types for New York 2160 - 2180 MHz.

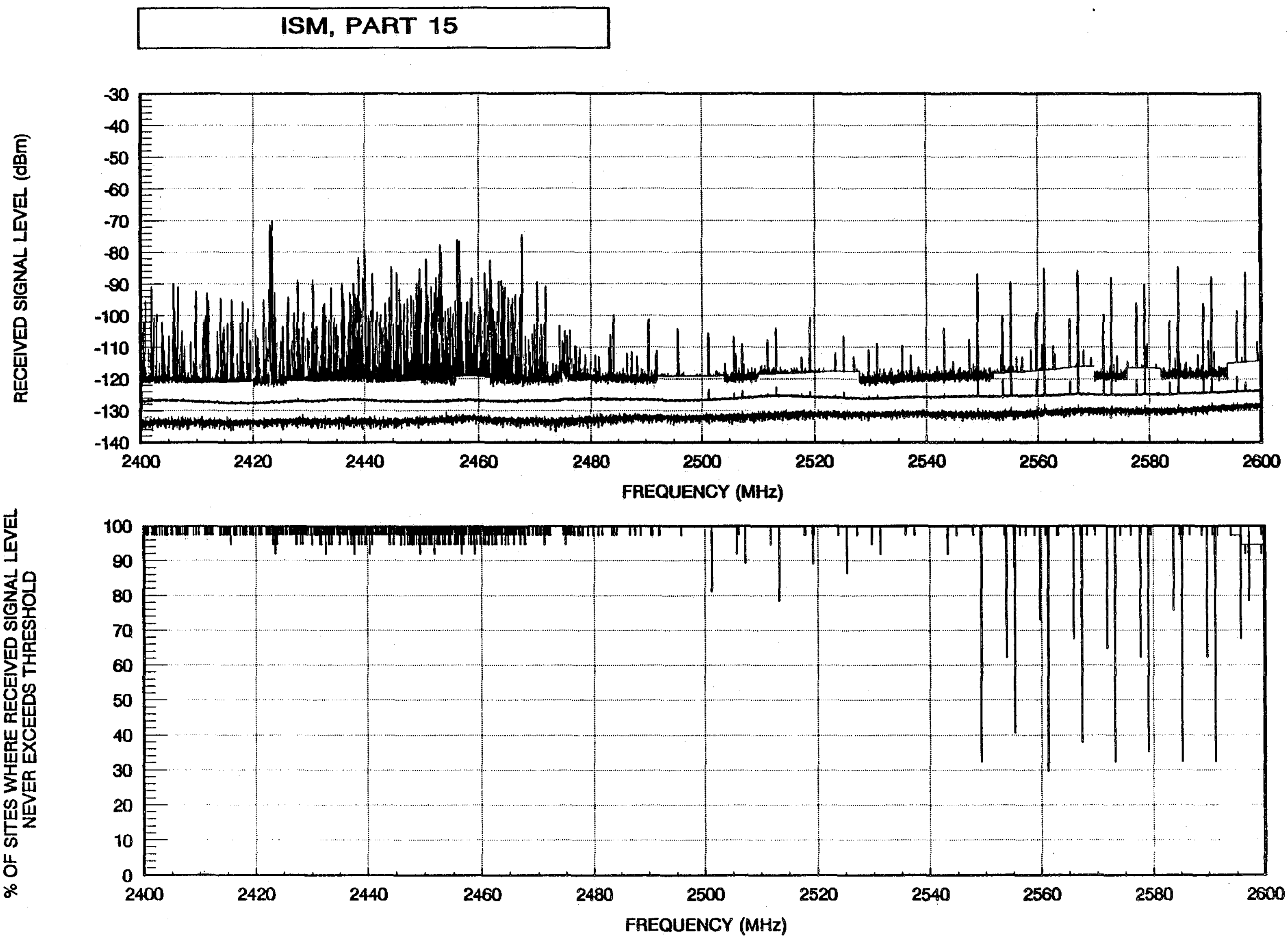

Figure 9.19 Signal level (top) and measured frequency usage (bottom) plots for New York 2400 - 2600 MHz.

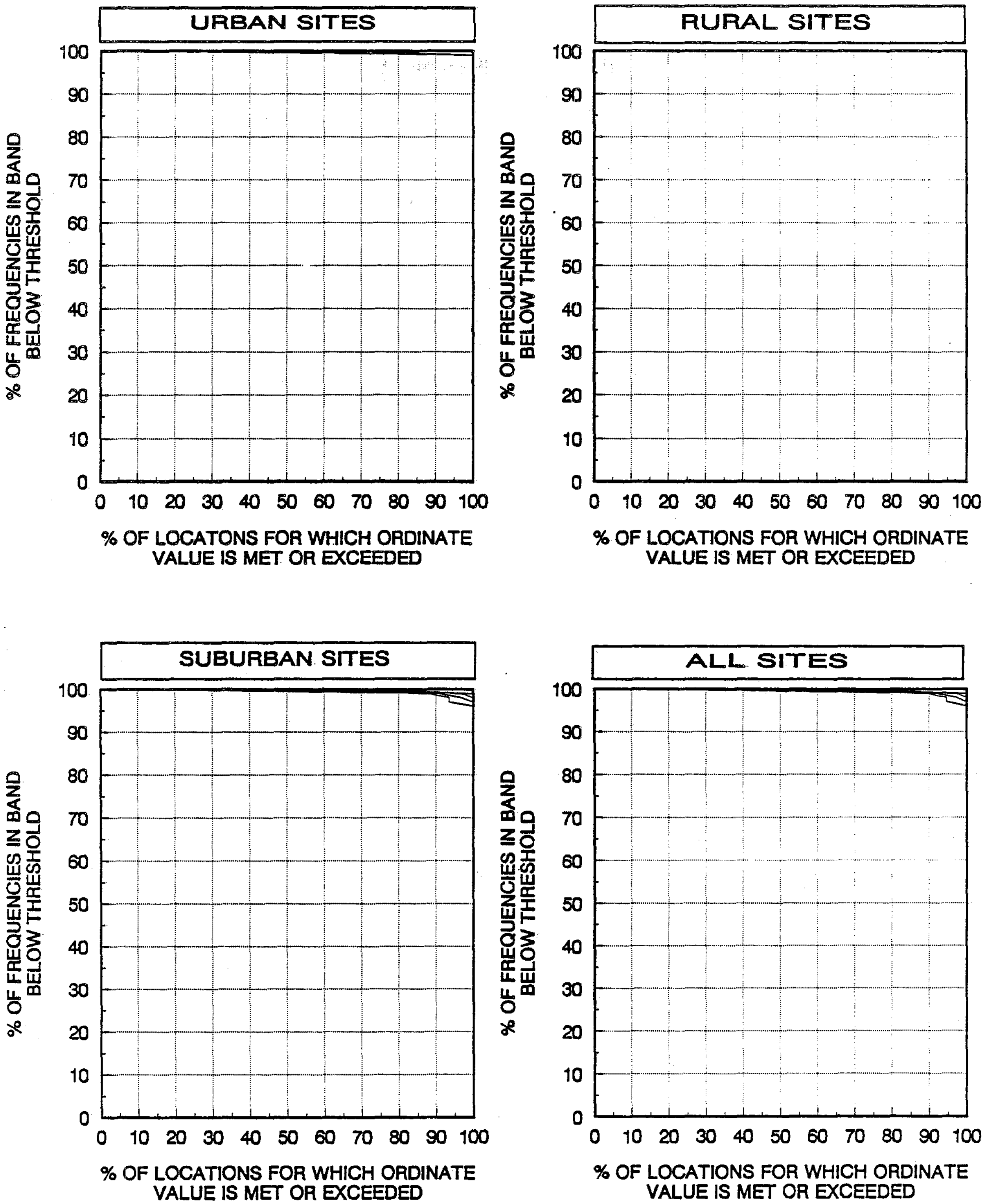

Figure 9.20 Measured band usage plots for urban, suburban, rural, and all site types for New York 2400 - 2483.5 MHz.

10. LOS ANGELES DATA

A map showing the measurement sites in Los Angeles is shown in Figure 10.1. Table 10.1 lists the measurement sites according to their zoning classifications (i.e., urban, suburban, and rural).

Table 10.1 Categorization of Numbered Measurement Sites in Los Angeles

Urban				Suburban				Rural
1	2	3	5	4	10	14	15	28
6	7	8	9	23	24	25	26	
11	12	13	16	27	31	32	33	
17	18	19	20	34	35	36	37	
21	22	29	30					

Table 10.1 shows that approximately 54% of the sites are urban, 43% of the sites are suburban, and 3% of the sites are rural. The statistics generated for all site types combined is therefore weighted most heavily by the urban and suburban sites. While extracting information from the data that are presented here the distribution of site zoning types must be kept in mind. Due to the size of the sample sets, the statistics generated for urban and suburban sites provide a fairly accurate representation of these site types in this city. The statistics generated for the rural site types may not provide a good representation of all the rural sites in this city, since there is only one sample.

For the narrowband measurements, the signal level, measured frequency usage, and measured band usage graphs are presented for the five measurement frequency bands: 614-806 MHz, 824-944 MHz, 1850-1994 MHz, 2110-2182 MHz, and 2400-2600 MHz. The data are simply presented and not discussed in this section. In the Comparison of Data Between Cities section, the salient similarities and differences in the data seen from the different cities will be discussed.

10.1 The 614-806 MHz Measurement Frequency Band

Figure 10.2 shows the signal level and measured frequency usage graphs for the 614-806 MHz (UHF-TV) band. The measured band usage graphs for this band are presented in Figure 10.3.

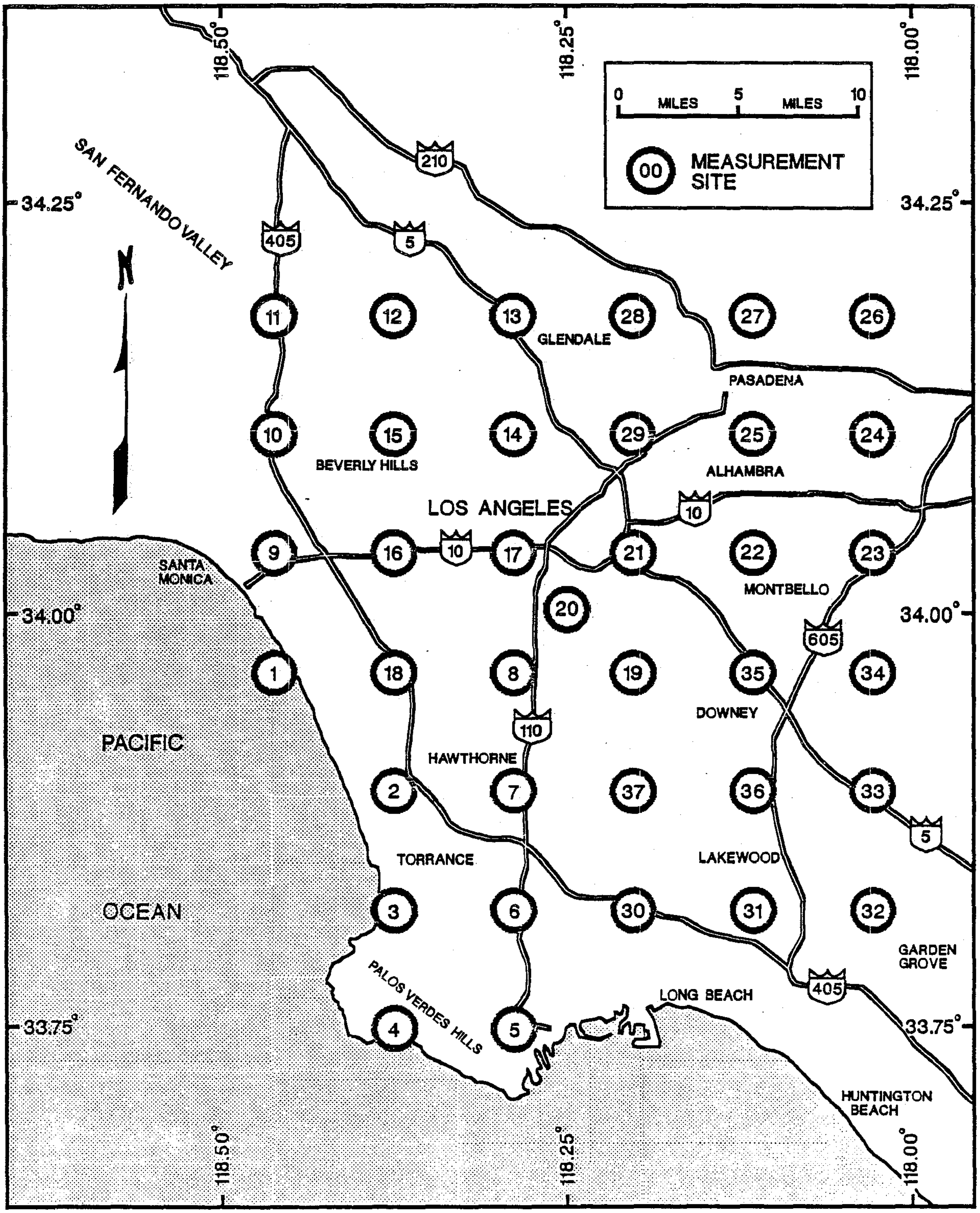

Figure 10.1 Measurement sites in Los Angeles.

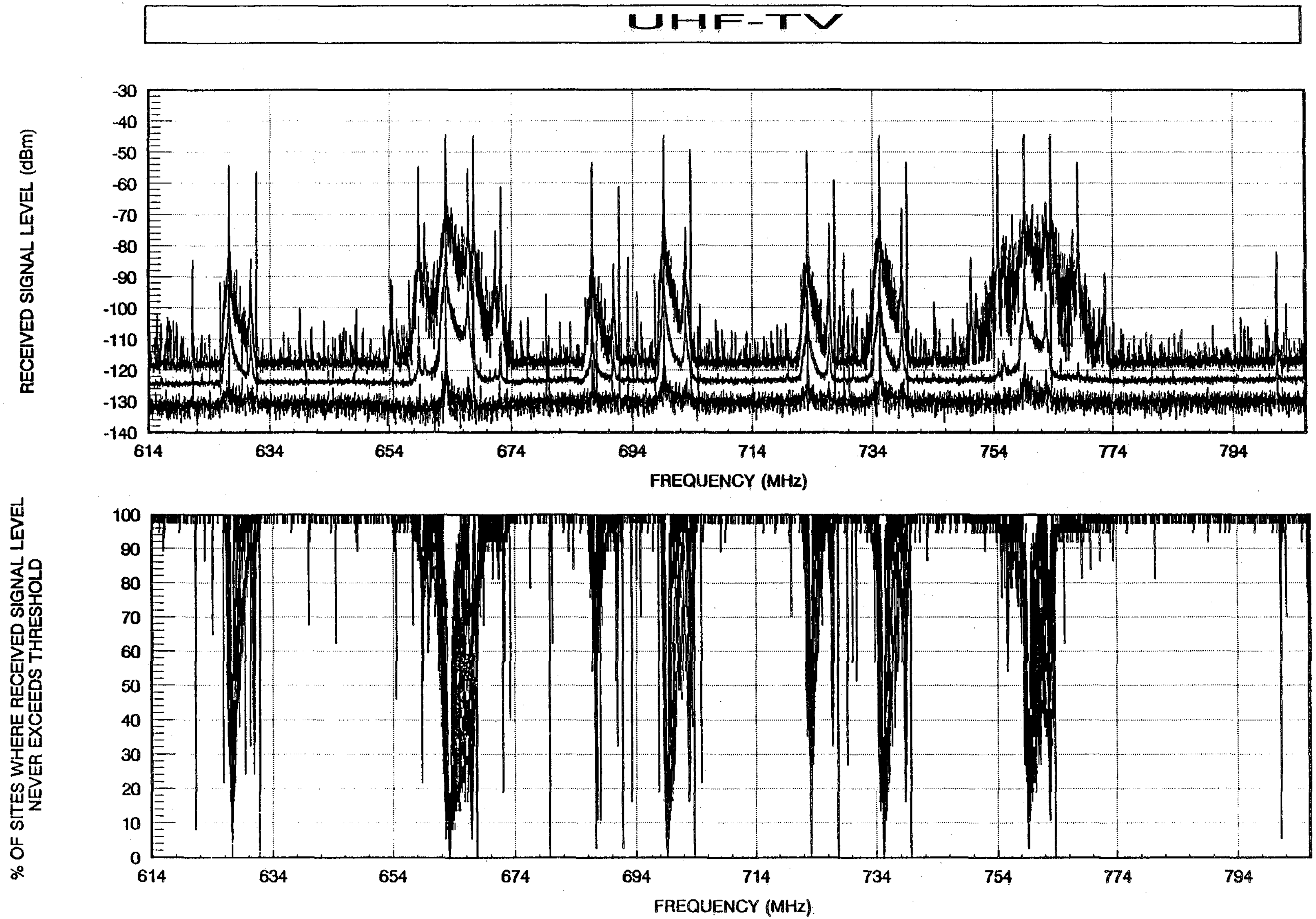

Figure 10.2 Signal level (top) and measured frequency usage (bottom) plots for Los Angeles 614 - 806 MHz.

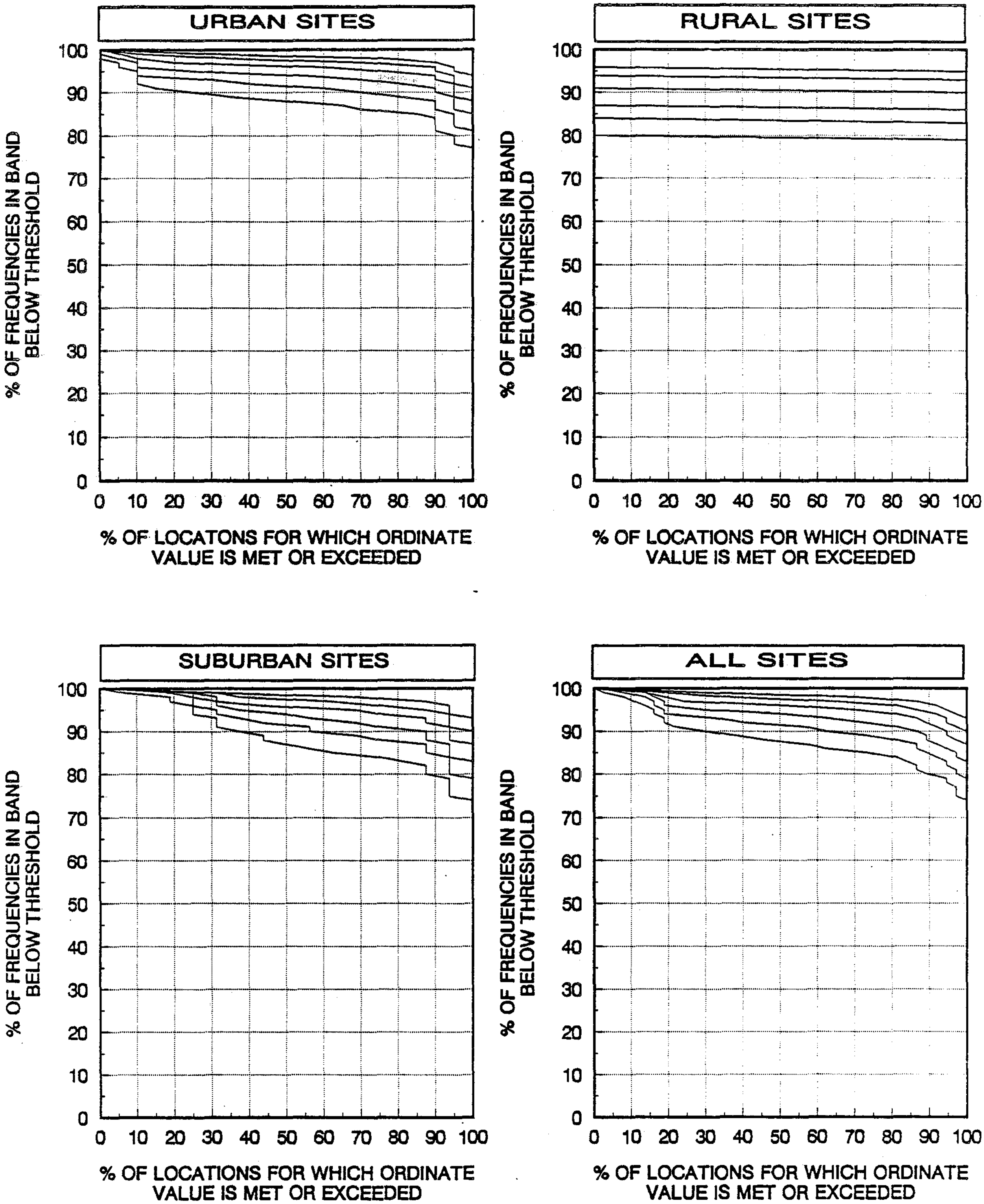

Figure 10.3 Measured band usage plots for urban, suburban, rural, and all site types for Los Angeles 614 - 806 MHz.

10.2 The 824-944 MHz Measurement Frequency Band

The signal level and measured frequency usage graphs for the 824-944 MHz band are displayed in Figure 10.4. Figures 10.5 through 10.13 display the measured band usage graphs for the 824-849 MHz, 869-894 MHz, 849-851 MHz, 894-896 MHz, 864-868 MHz, 901-902 MHz, 930-931 MHz, 940-941 MHz, and 902-928 MHz bands respectively.

10.3 The 1850-1994 MHz Measurement Frequency Band

Figure 10.14 shows the signal level and measured frequency usage graphs for the 1850-1994 MHz band. The measured band usage graphs for the 1850-1990 MHz band are presented in Figure 10.15.

10.4 The 2110-2182 MHz Measurement Frequency Band

For the 2110-2182 MHz band, the signal level and measured frequency usage graphs are shown in Figure 10.16. Figures 10.17 and 10.18 depict the measured band usage graphs for the 2110-2130 MHz and 2160-2180 MHz bands respectively.

10.5 The 2400-2600 MHz Measurement Frequency Band

The signal level and measured frequency usage graphs for the 2400-2600 MHz band are displayed in Figure 10.19 while the measured band usage graphs are displayed in Figure 10.20 for the 2400-2483.5 MHz band.

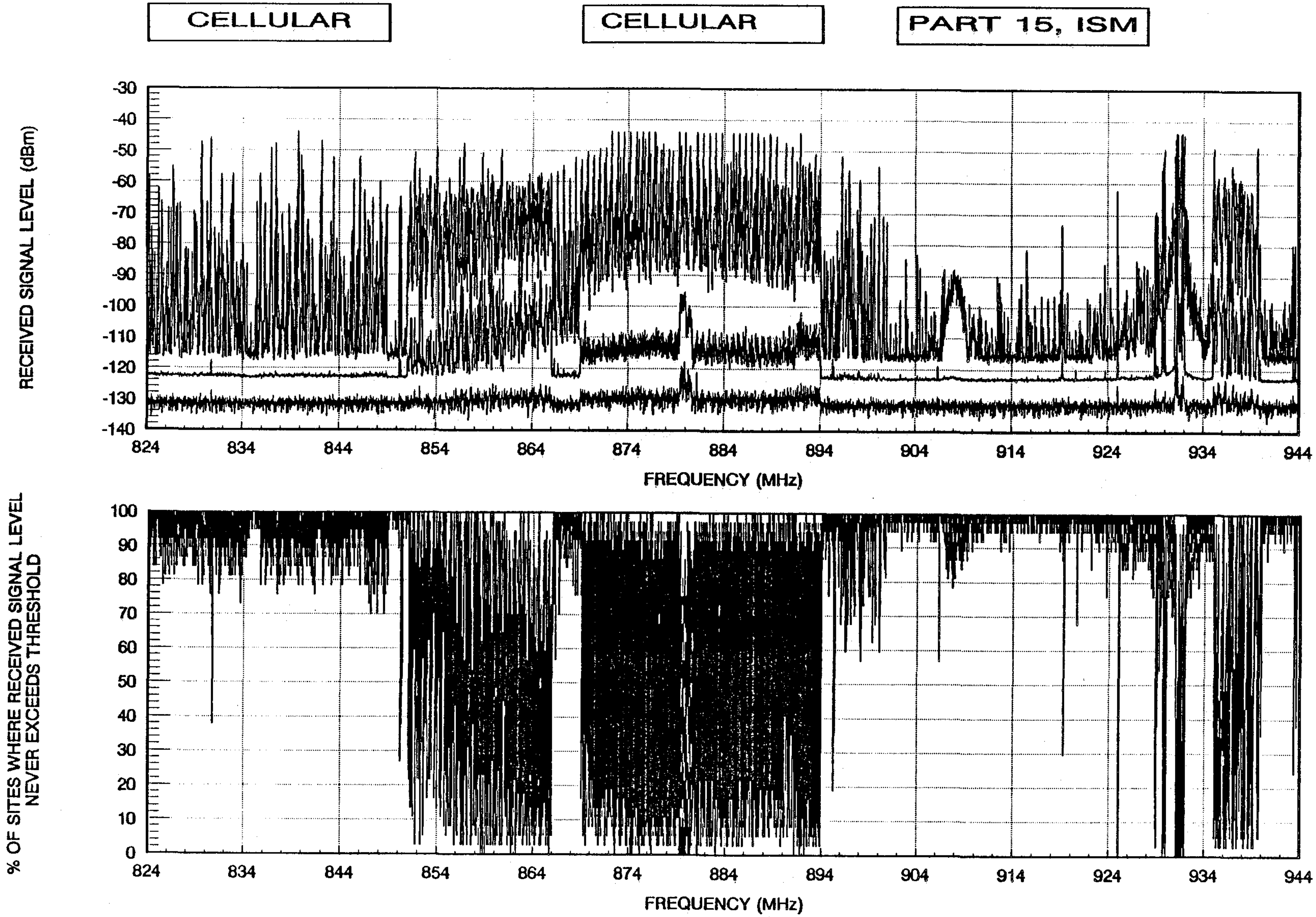

Figure 10.4 Signal level (top) and measured frequency usage (bottom) plots for Los Angeles 824 - 944 MHz.

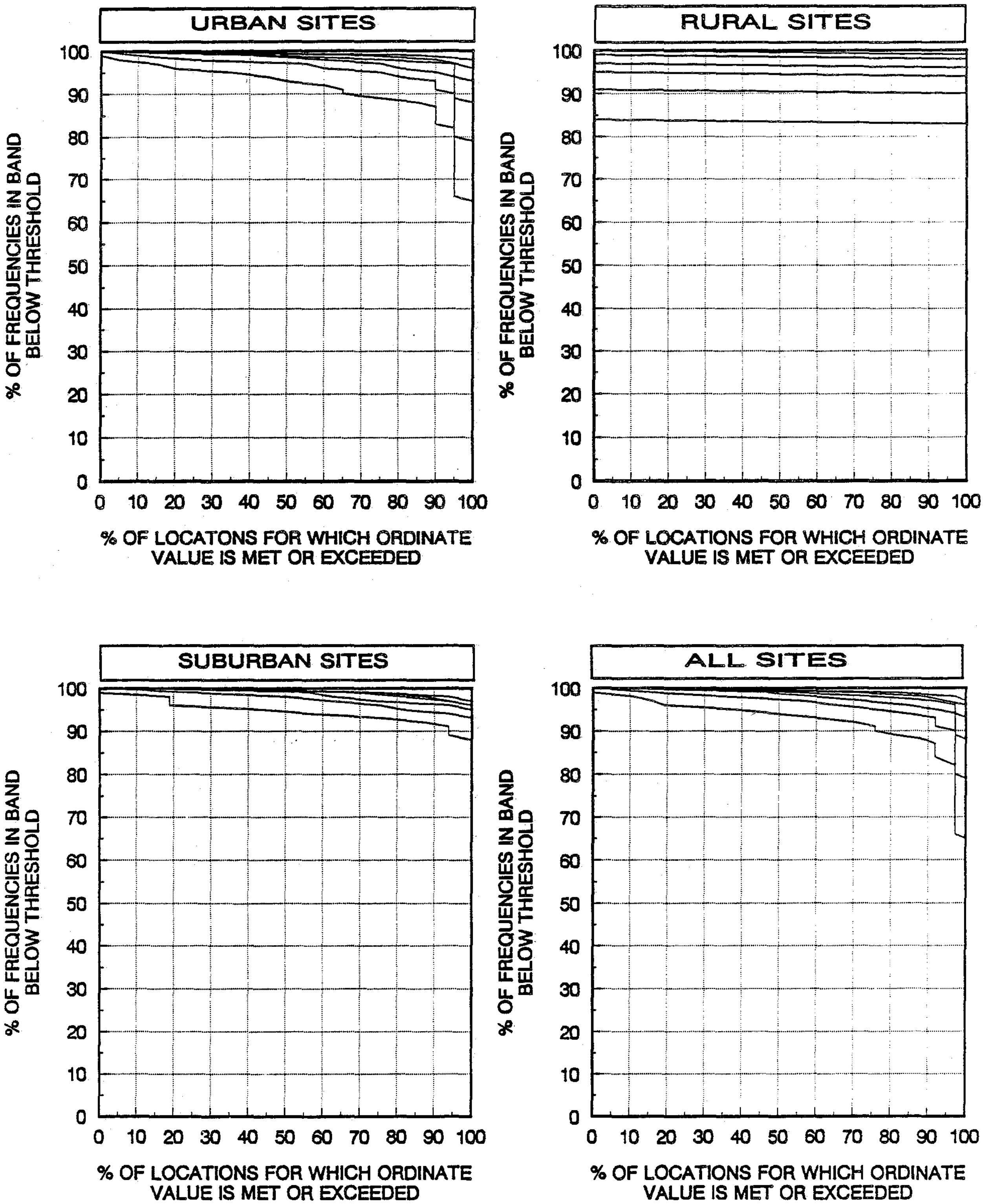

Figure 10.5 Measured band usage plots for urban, suburban, rural, and all site types for Los Angeles 824 - 849 MHz.

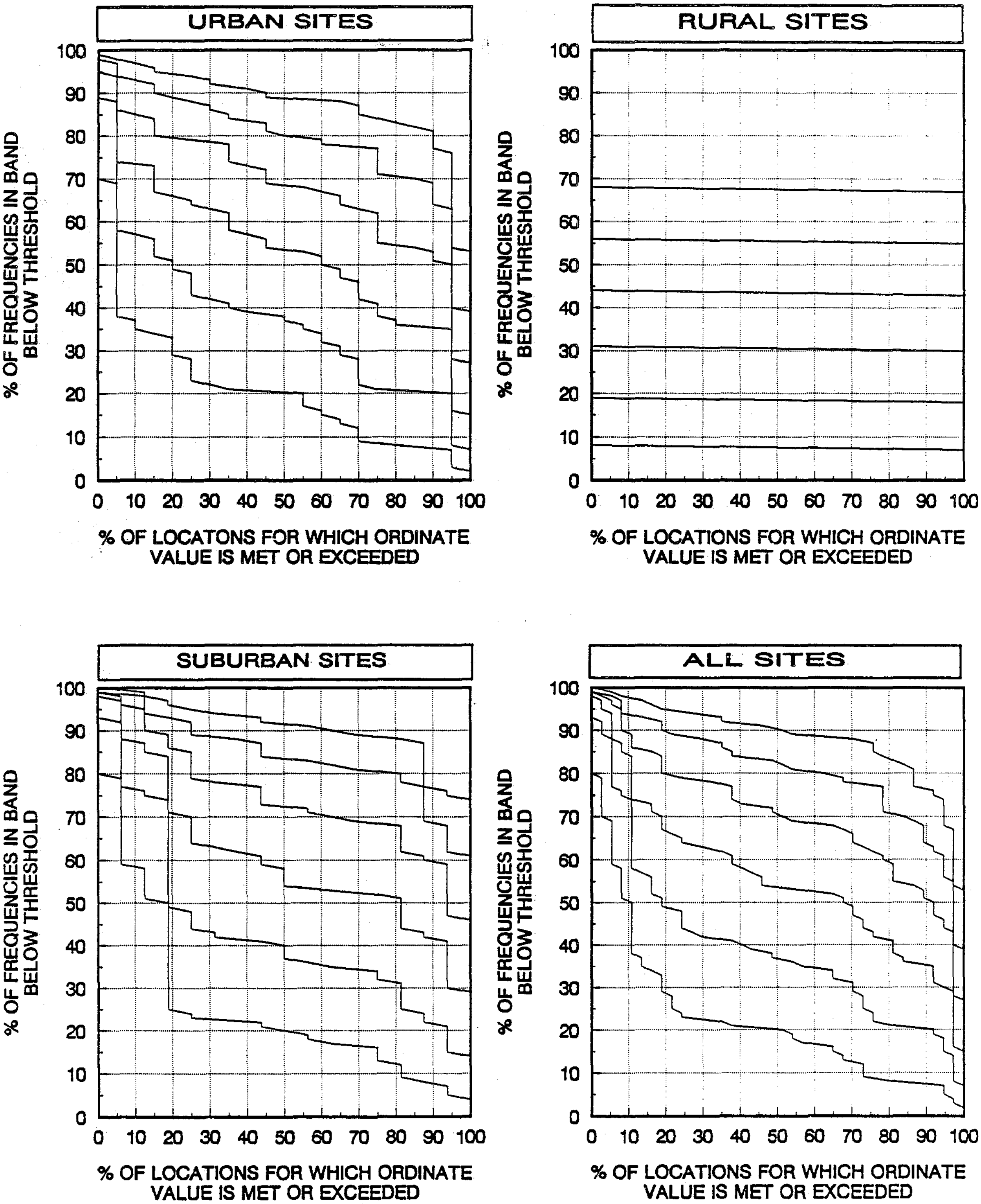

Figure 10.6 Measured band usage plots for urban, suburban, rural, and all site types for Los Angeles 869 - 894 MHz.

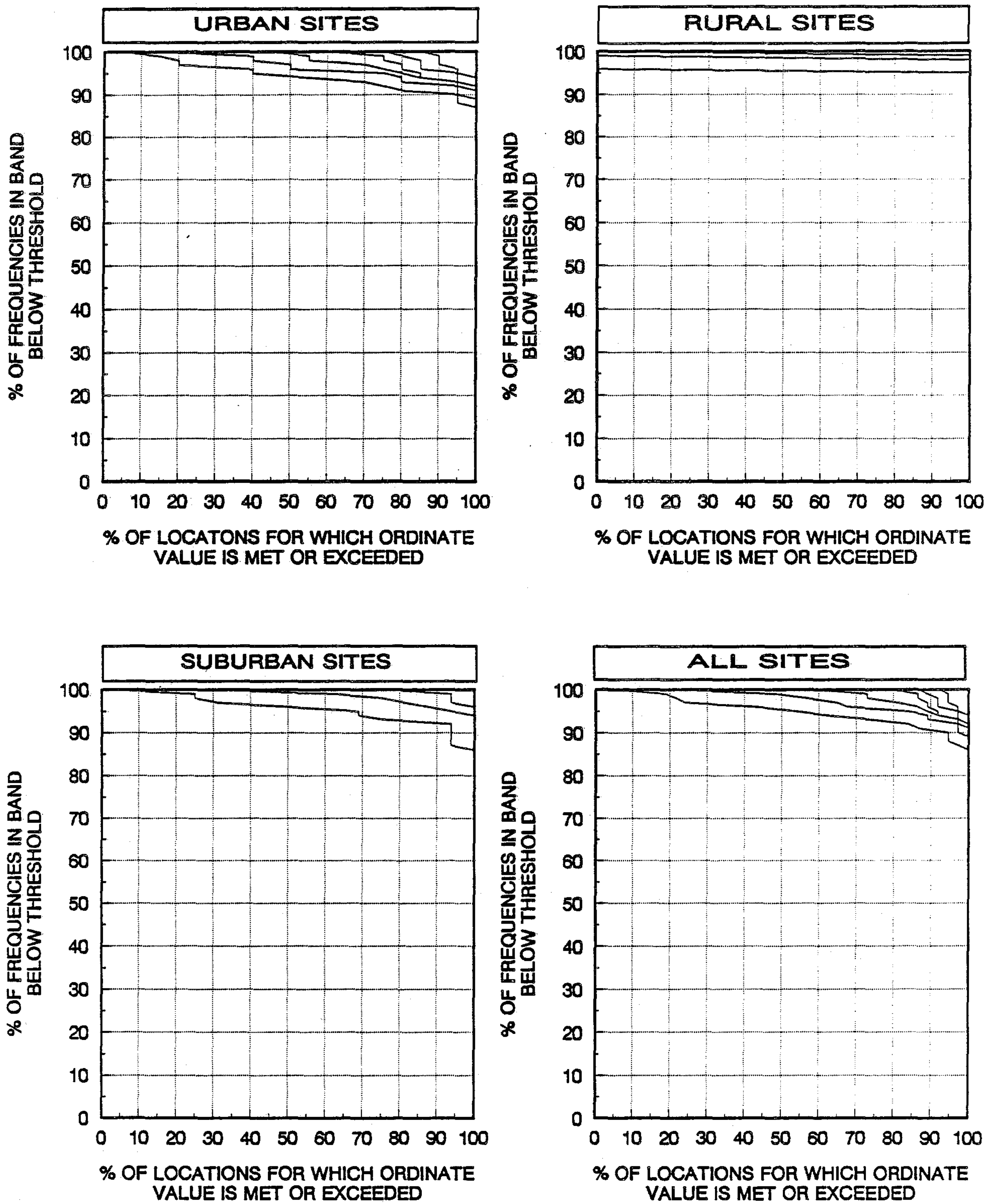

Figure 10.7 Measured band usage plots for urban, suburban, rural, and all site types for Los Angeles 849 - 851 MHz.

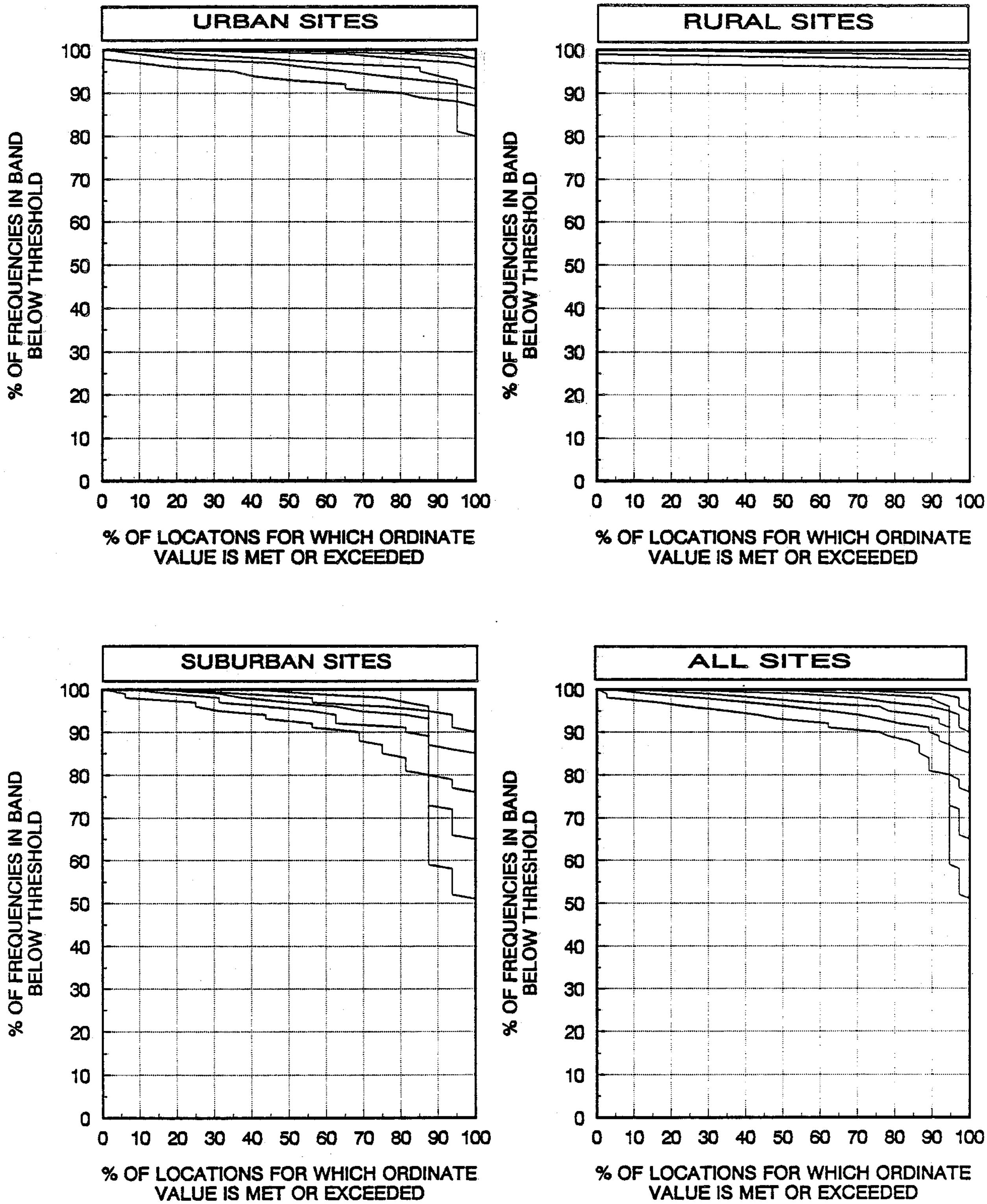

Figure 10.8 Measured band usage plots for urban, suburban, rural, and all site types for Los Angeles 894 - 896 MHz.

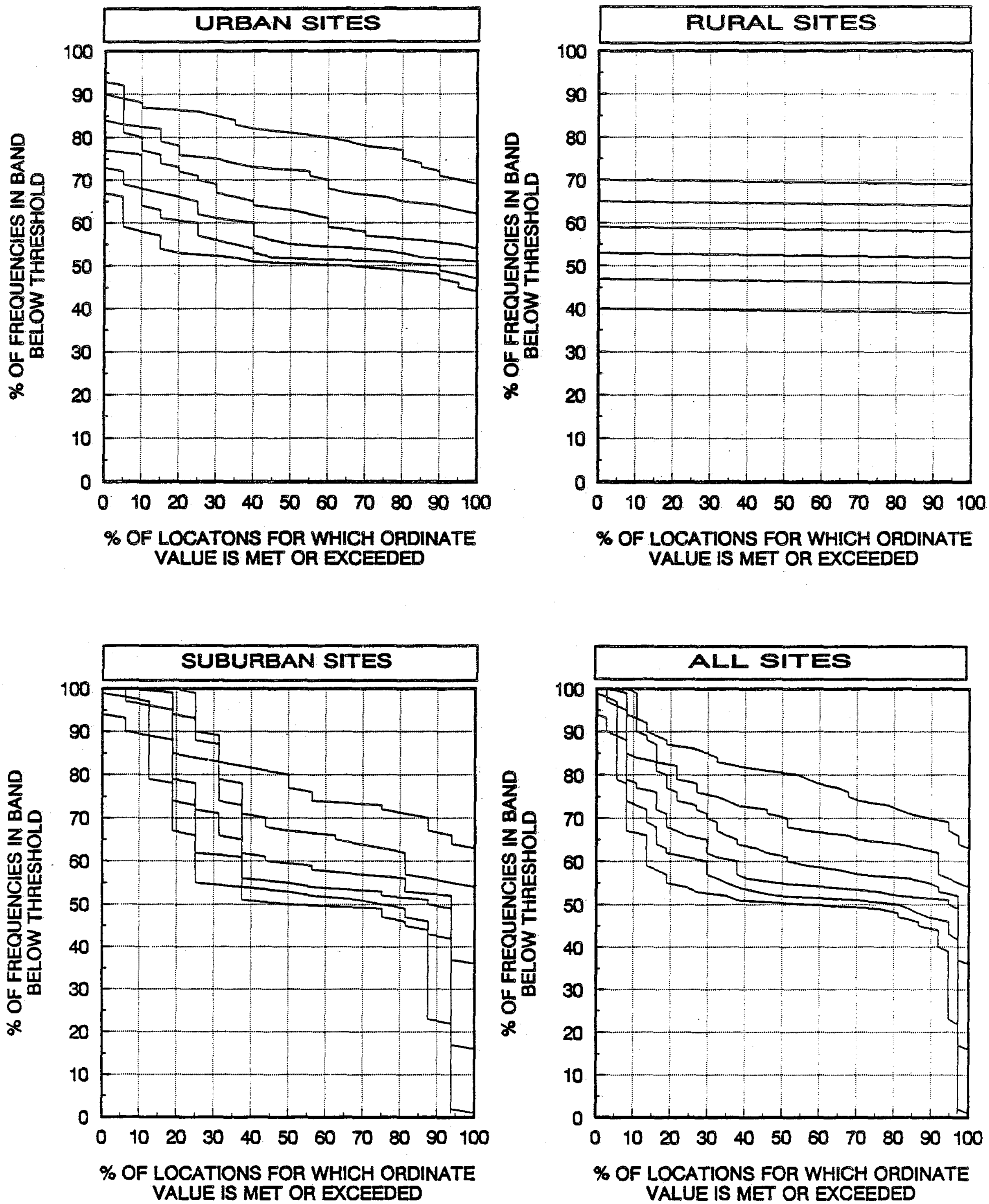

Figure 10.9 Measured band usage plots for urban, suburban, rural, and all site types for Los Angeles 864 - 868 MHz.

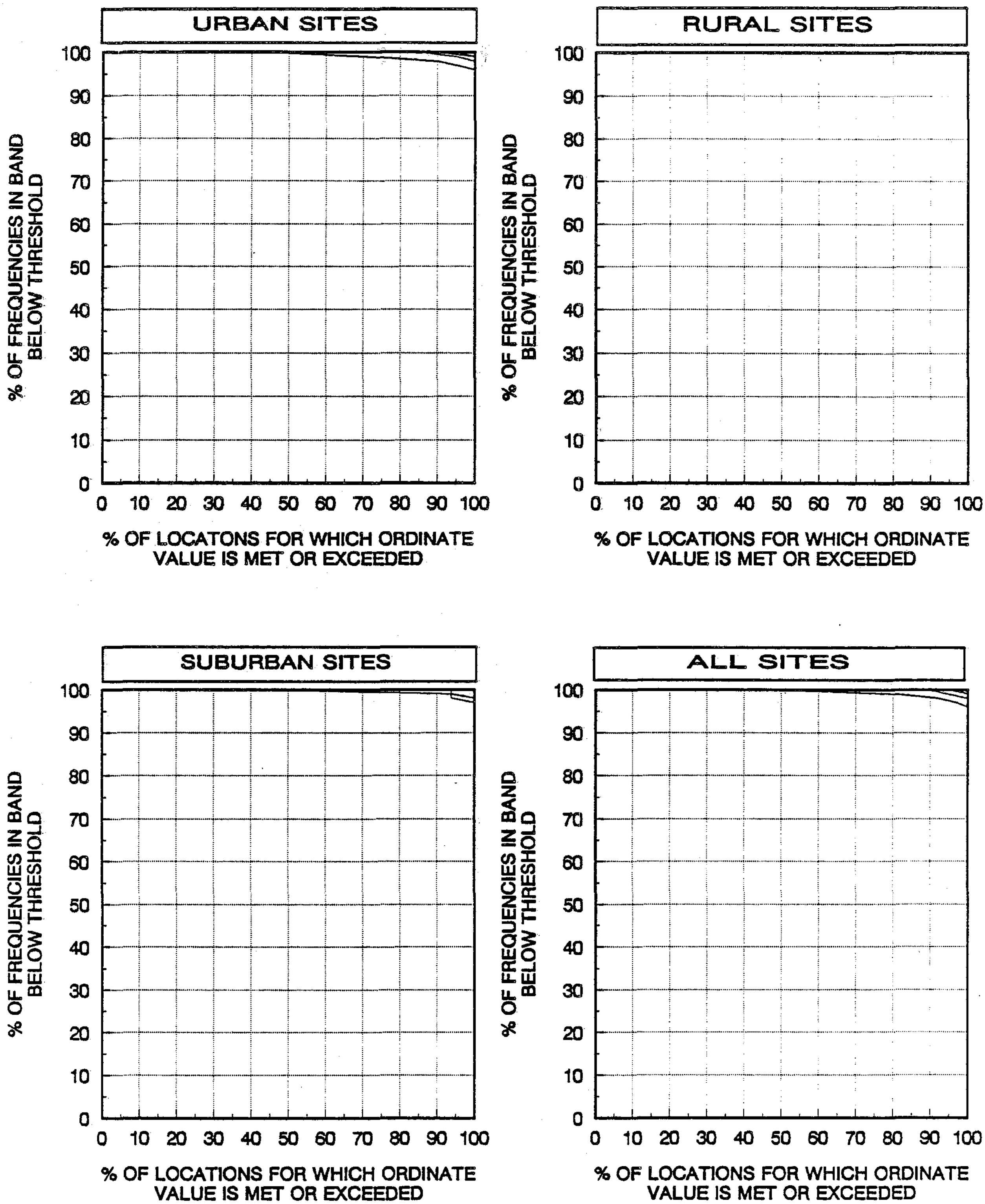

Figure 10.10 Measured band usage plots for urban, suburban, rural, and all site types for Los Angeles 901 - 902 MHz.

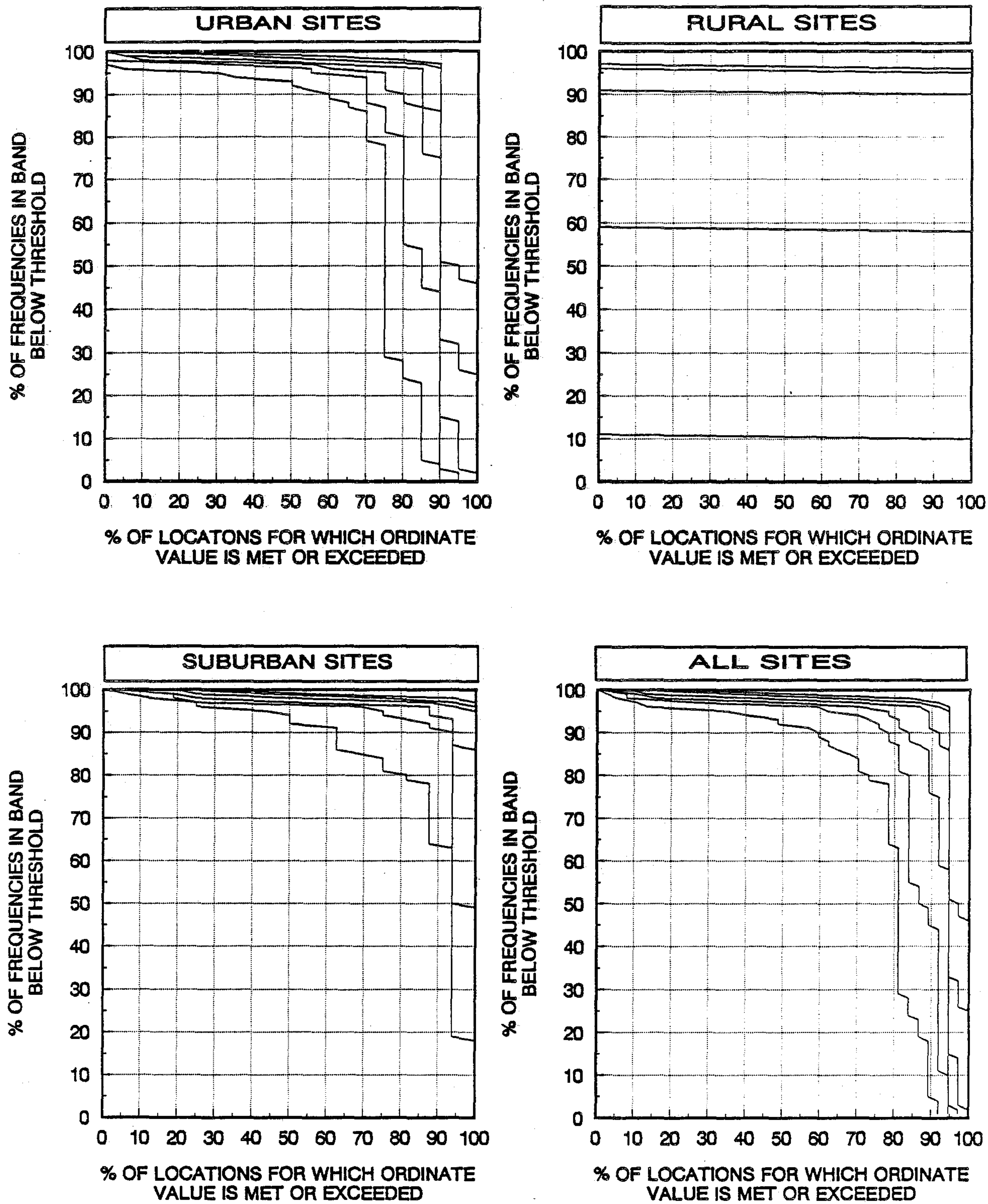

Figure 10.11 Measured band usage plots for urban, suburban, rural, and all site types for Los Angeles 930 - 931 MHz.

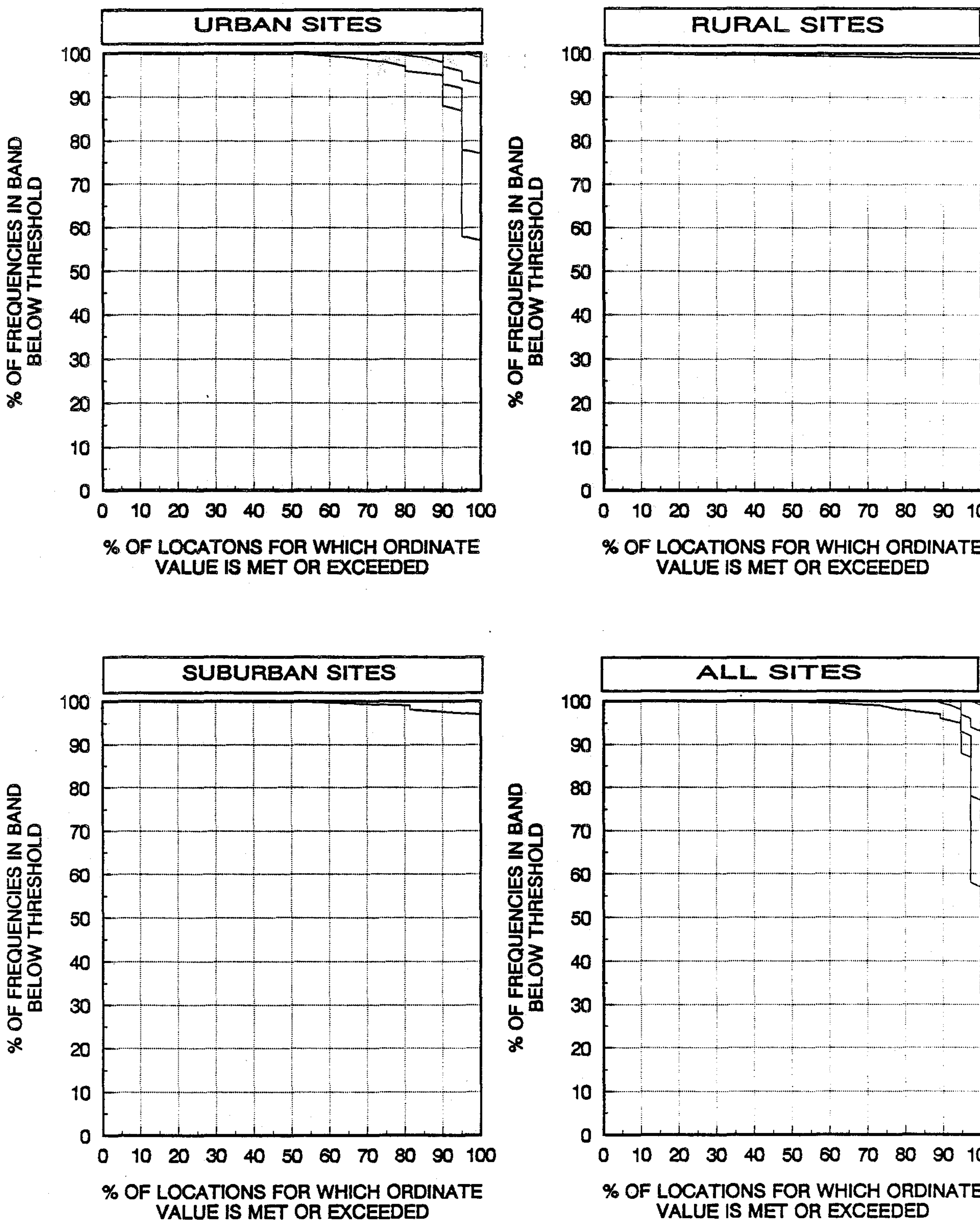

Figure 10.12 Measured band usage plots for urban, suburban, rural, and all site types for Los Angeles 940 - 941 MHz.

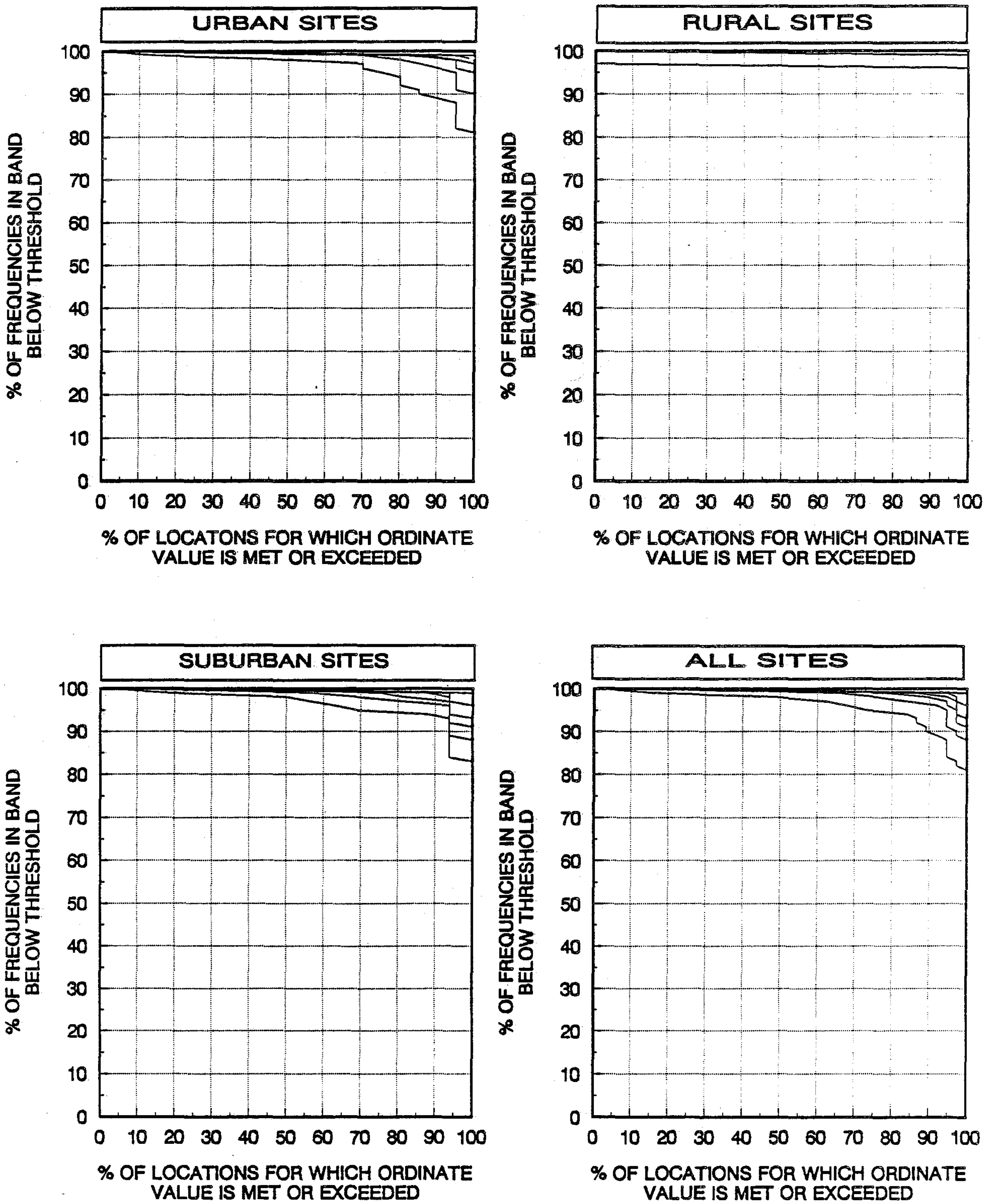

Figure 10.13 Measured band usage plots for urban, suburban, rural, and all site types for Los Angeles 902 - 928 MHz.

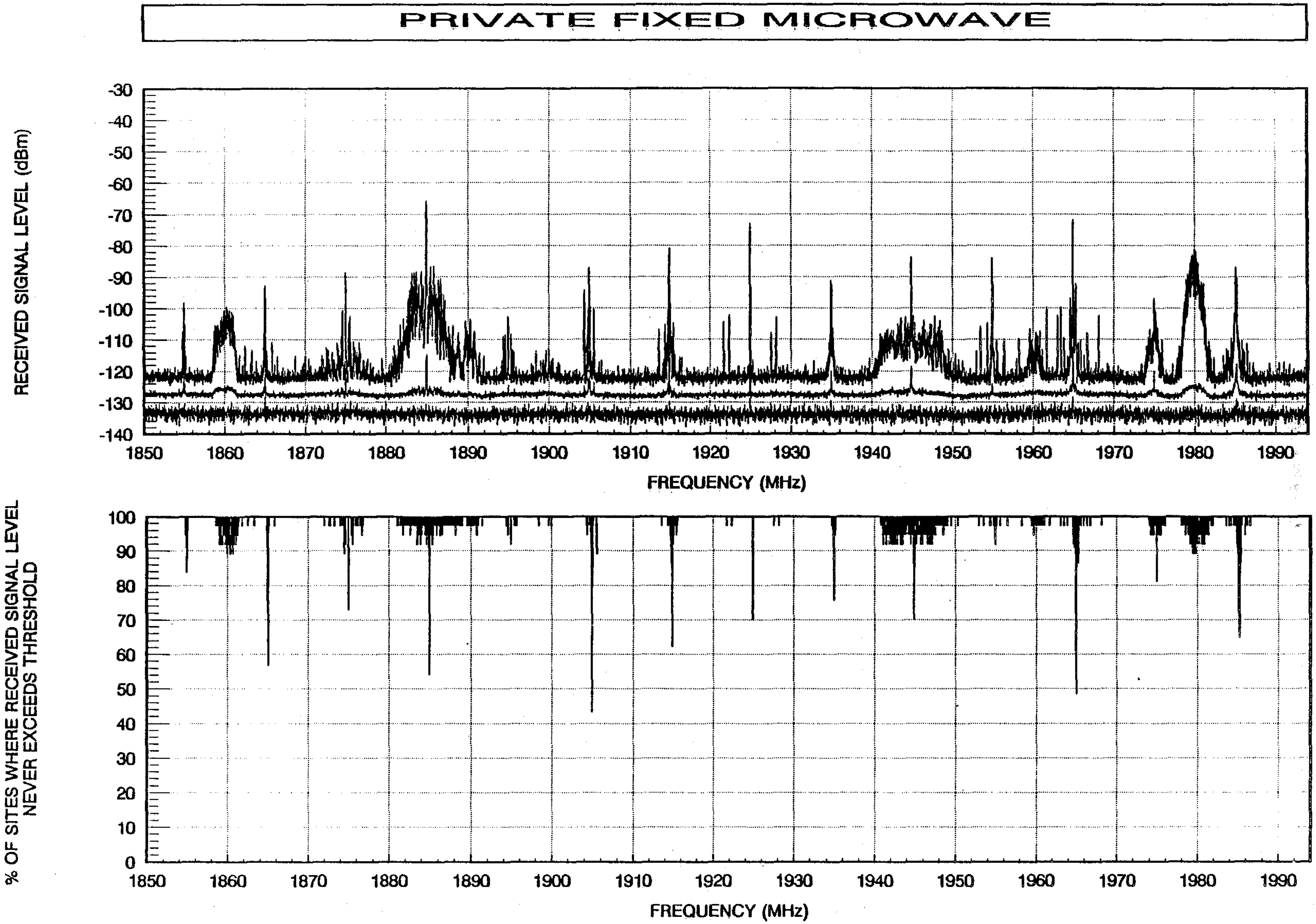

Figure 10.14 Signal level (top) and measured frequency usage (bottom) plots for Los Angeles 1850 - 1994 MHz.

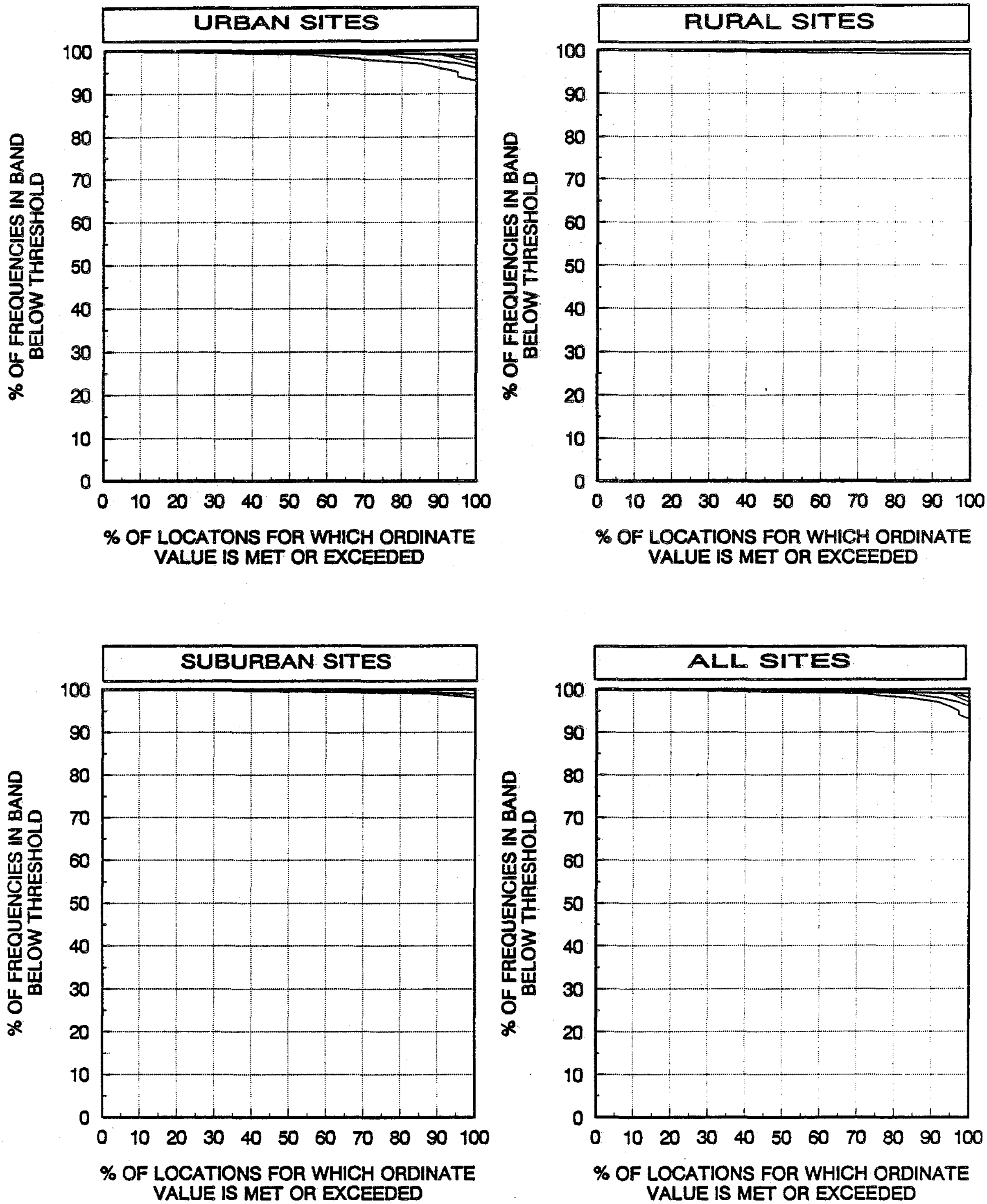

Figure 10.15 Measured band usage plots for urban, suburban, rural, and all site types for Los Angeles 1850 - 1990 MHz.

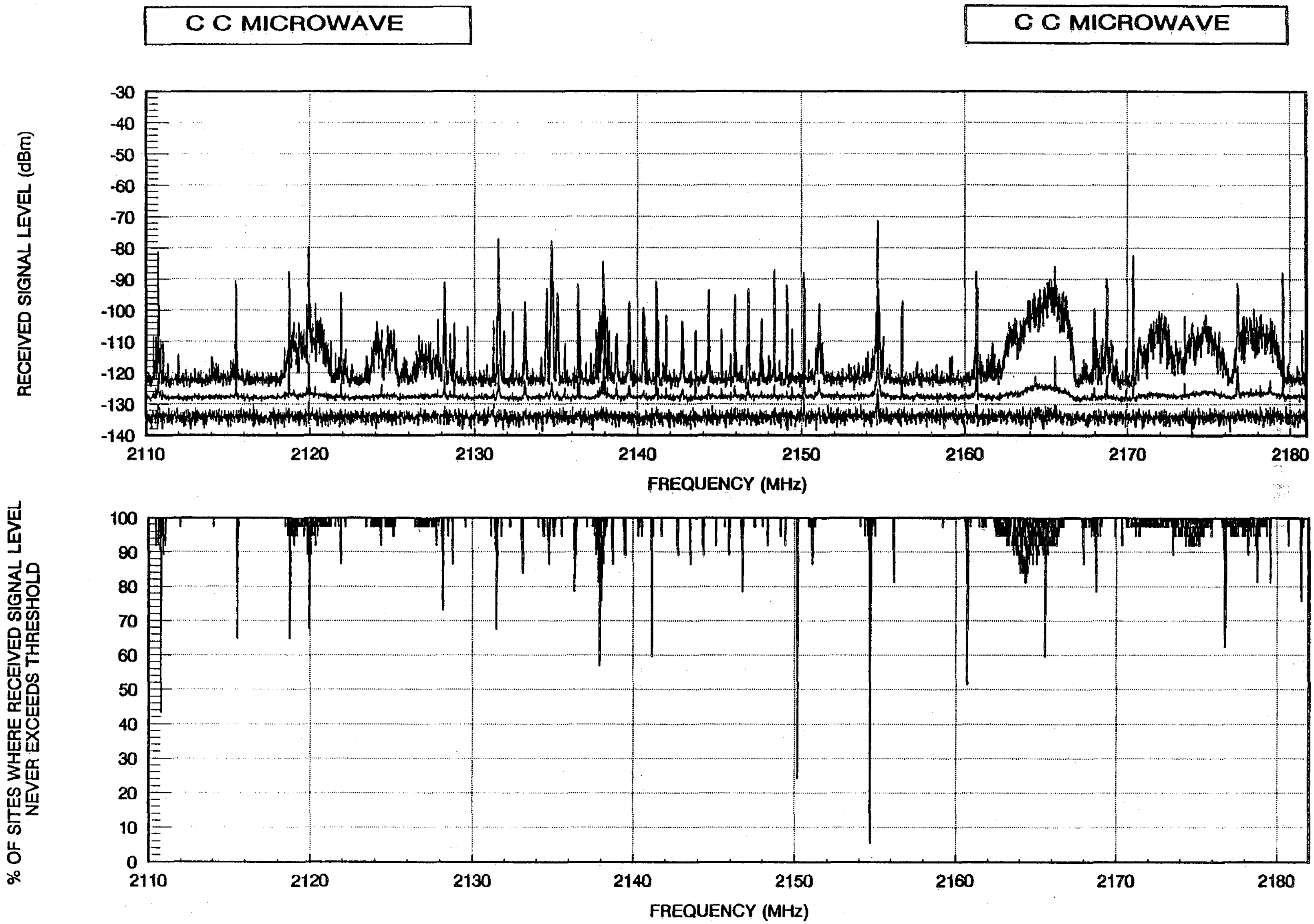

Figure 10.16 Signal level (top) and measured frequency usage (bottom) plots for Los Angeles 2110 - 2182 MHz.

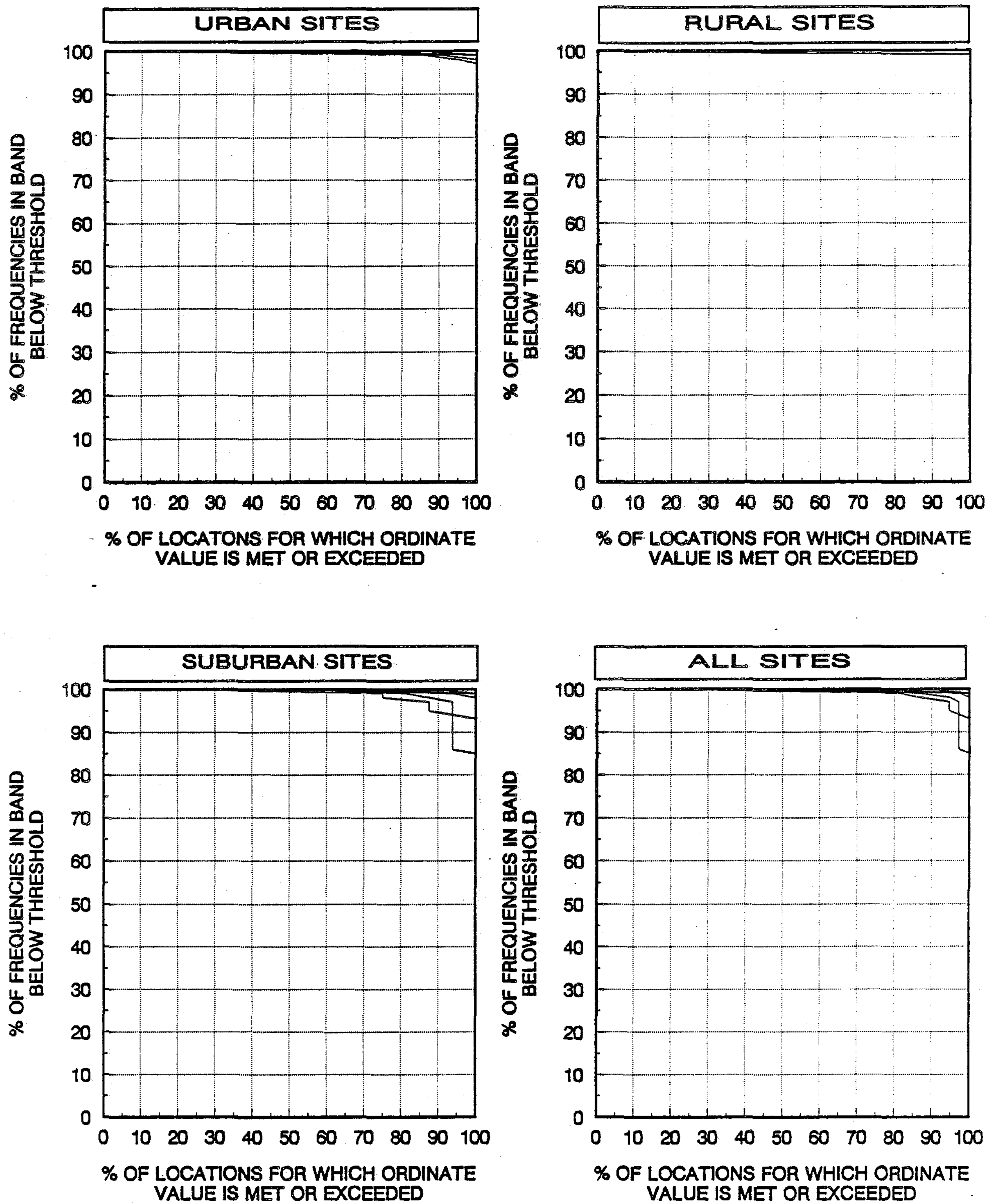

Figure 10.17 Measured band usage plots for urban, suburban, rural, and all site types for Los Angeles 2110 - 2130 MHz.

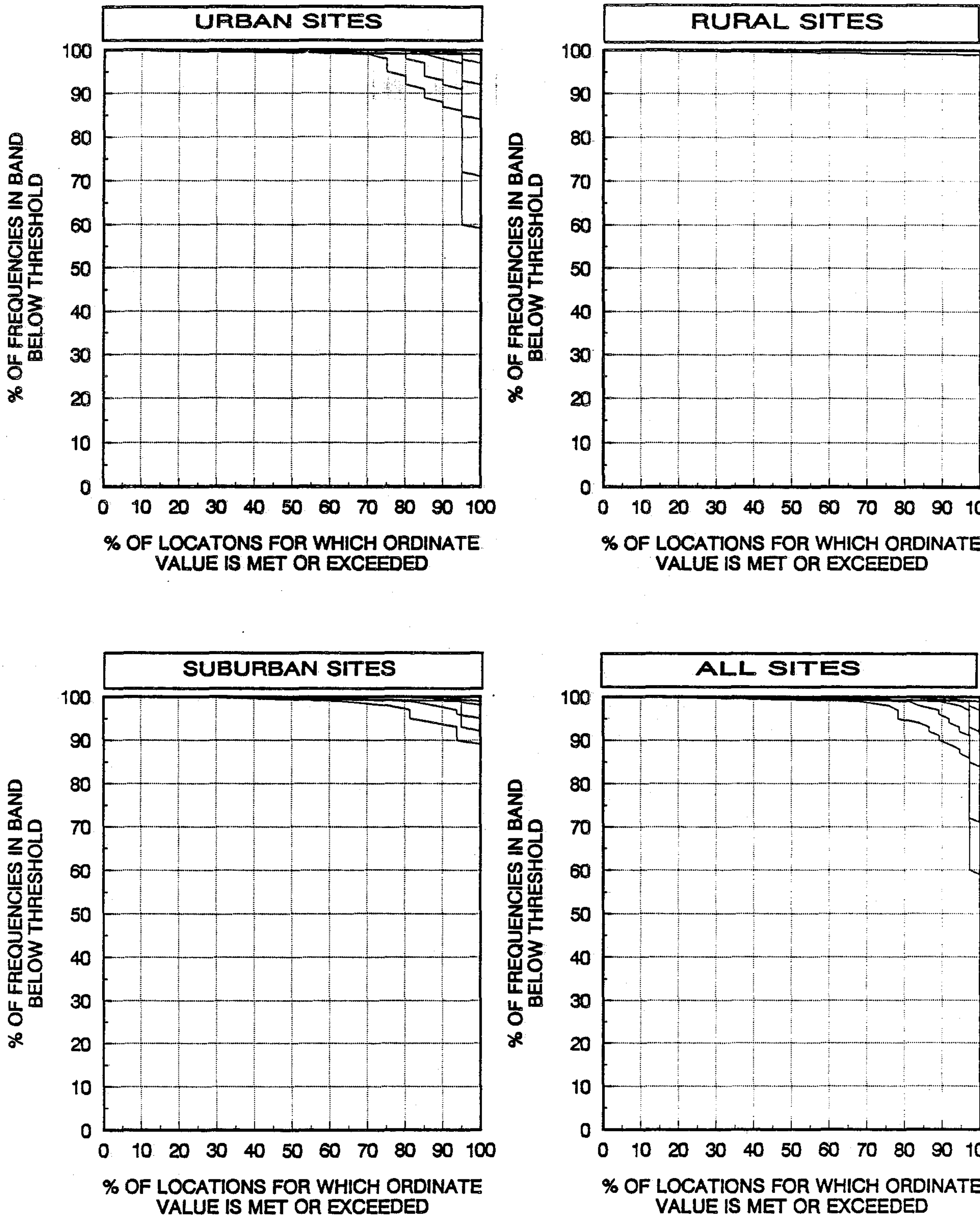

Figure 10.18 Measured band usage plots for urban, suburban, rural, and all site types for Los Angeles 2160 - 2180 MHz.

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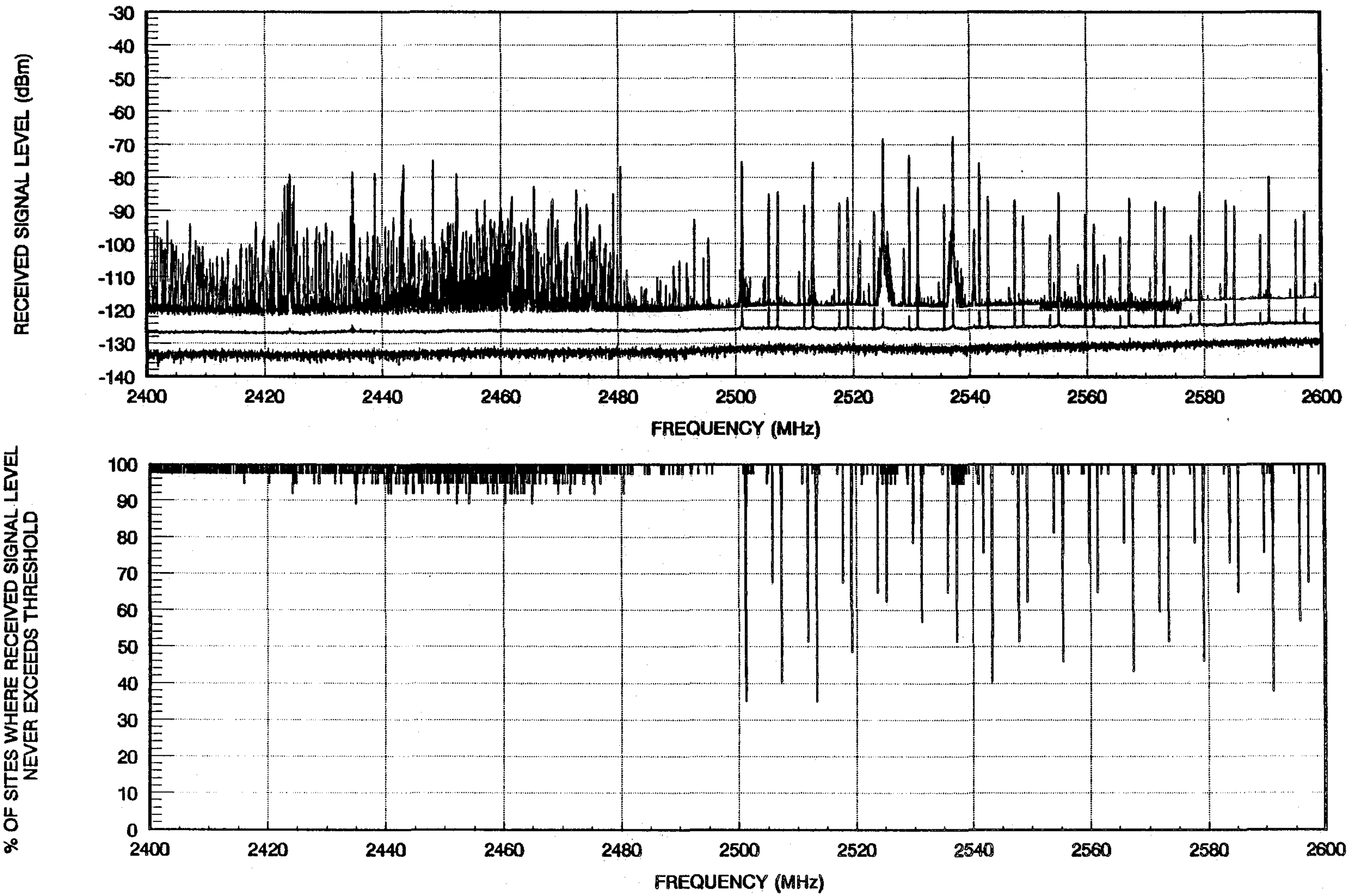

Figure 10.19 Signal level (top) and measured frequency usage (bottom) plots for Los Angeles 2400 - 2600 MHz.

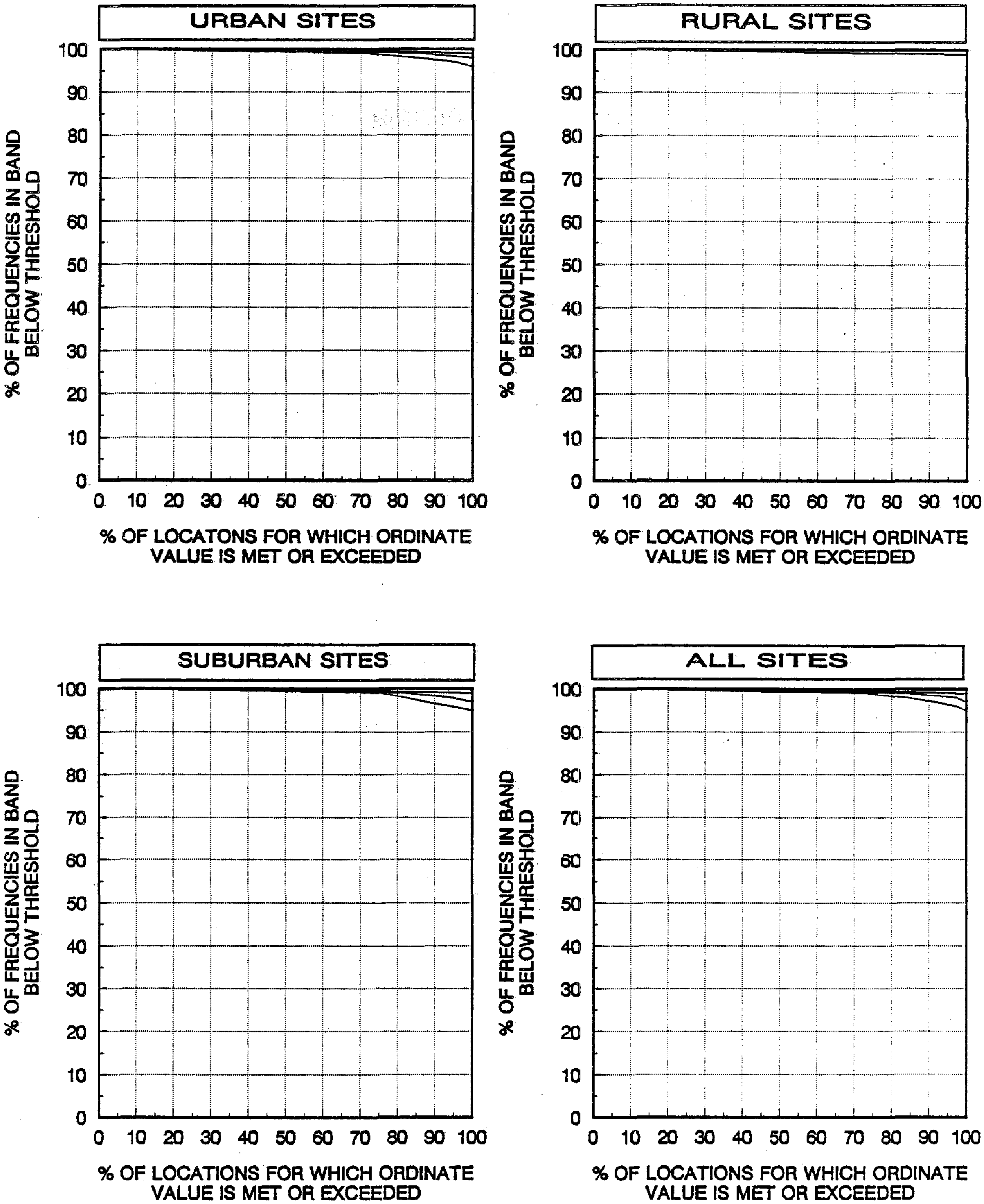

Figure 10.20 Measured band usage plots for urban, suburban, rural, and all site types for Los Angeles 2400 - 2483.5 MHz.

11. SAN FRANCISCO DATA

A map showing the measurement sites in San Francisco is shown in Figure 11.1. Table 11.1 lists the measurement sites according to their zoning classifications (i.e., urban, suburban, and rural).

Table 11.1 Categorization of Numbered Measurement Sites in San Francisco

Urban				Suburban				Rural			
1	2	8	9	3	4	5	7	6	12	13	16
24	36			10	11	14	15	17	19	20	21
				18	22	23	25	29	32	33	35
				26	27	28	30				
				31	34	37					

Table 11.1 shows that approximately 16% of the sites are urban, 51.5% of the sites are suburban, and 32.5% of the sites are rural. The statistics generated for all site types combined is therefore weighted most heavily by the suburban sites. While extracting information from the data that are presented here the distribution of site zoning types must be kept in mind. Due to the size of the sample sets, the statistics generated for suburban and rural sites provide a fairly accurate representation of all suburban and rural site types in this city. The statistics generated for the urban sites do not provide as good a representation of all urban sites in this city, due to the more limited sample size.

For the narrowband measurements, the signal level, measured frequency usage, and measured band usage graphs are presented for the five measurement frequency bands: 614-806 MHz, 824-944 MHz, 1850-1994 MHz, 2110-2182 MHz, and 2400-2600 MHz. The data are simply presented and not discussed in this section. In the Comparison of Data Between Cities section, the salient similarities and differences in the data seen from the different cities will be discussed.

11.1 The 614-806 MHz Measurement Frequency Band

Figure 11.2 shows the signal level and measured frequency usage graphs for the 614-806 MHz (UHF-TV) band. The measured band usage graphs for this band are presented in Figure 11.3.

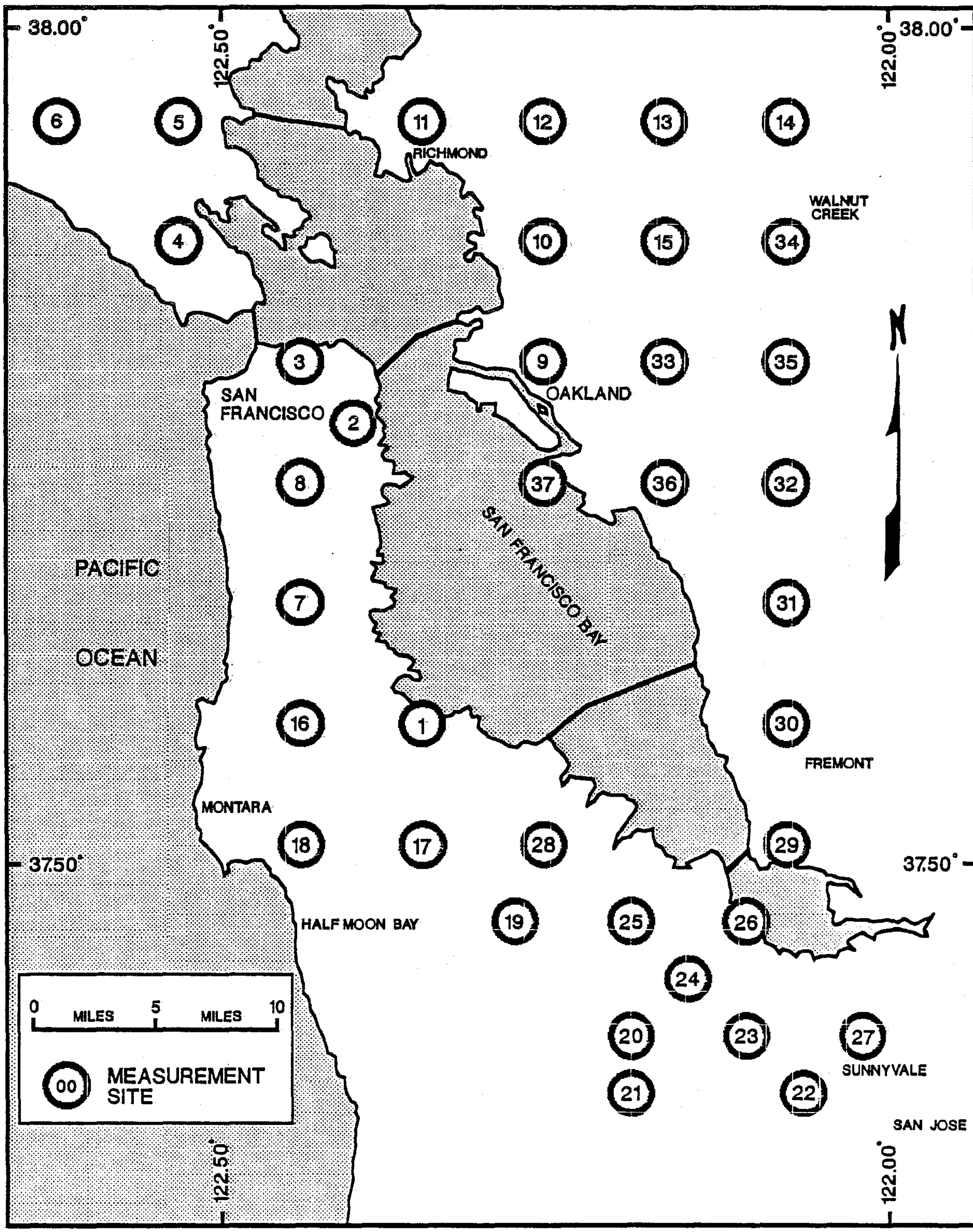

Figure 11.1 Measurement sites in San Francisco.

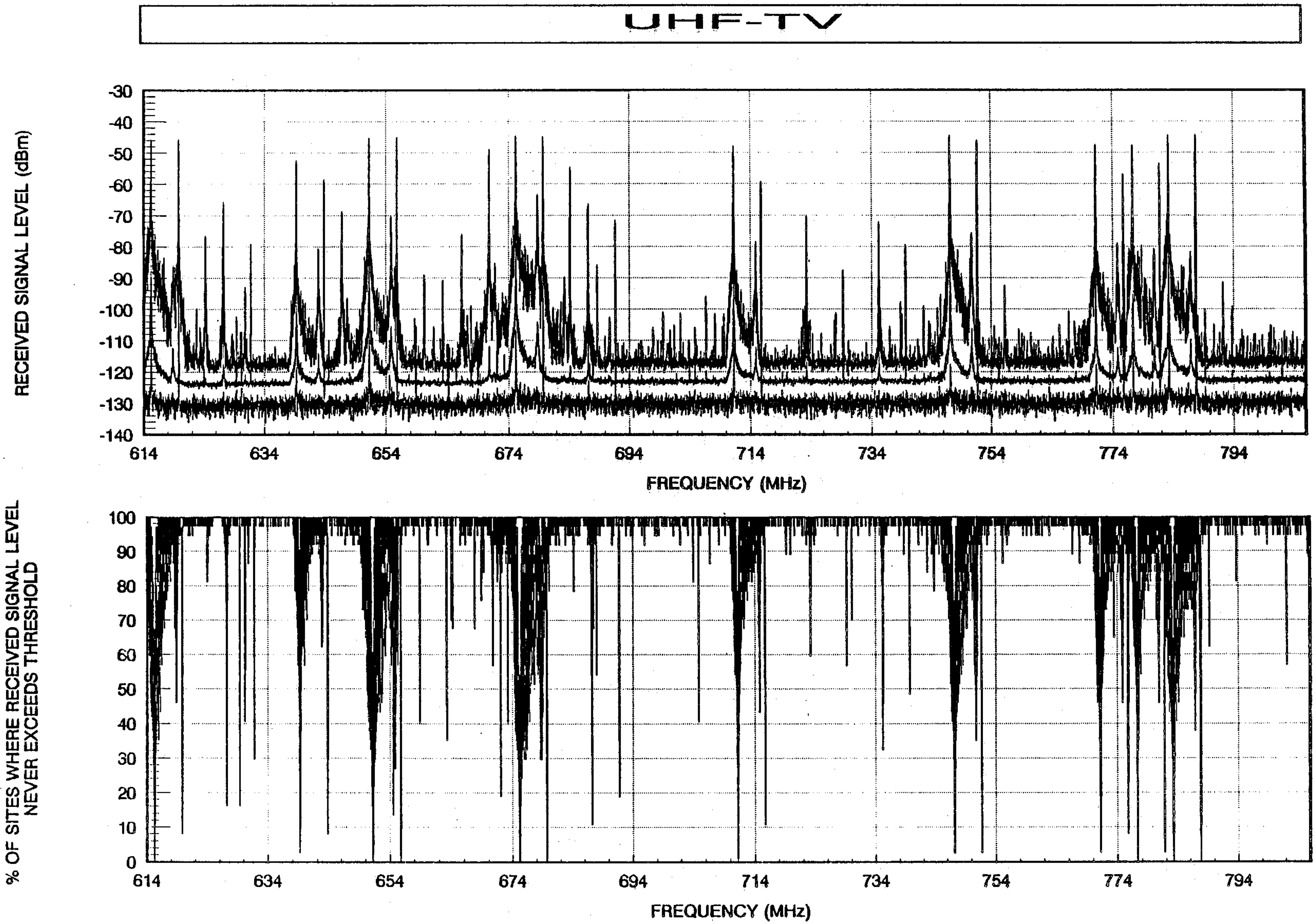

Figure 11.2 Signal level (top) and measured frequency usage (bottom) plots for San Francisco 614 - 806 MHz.

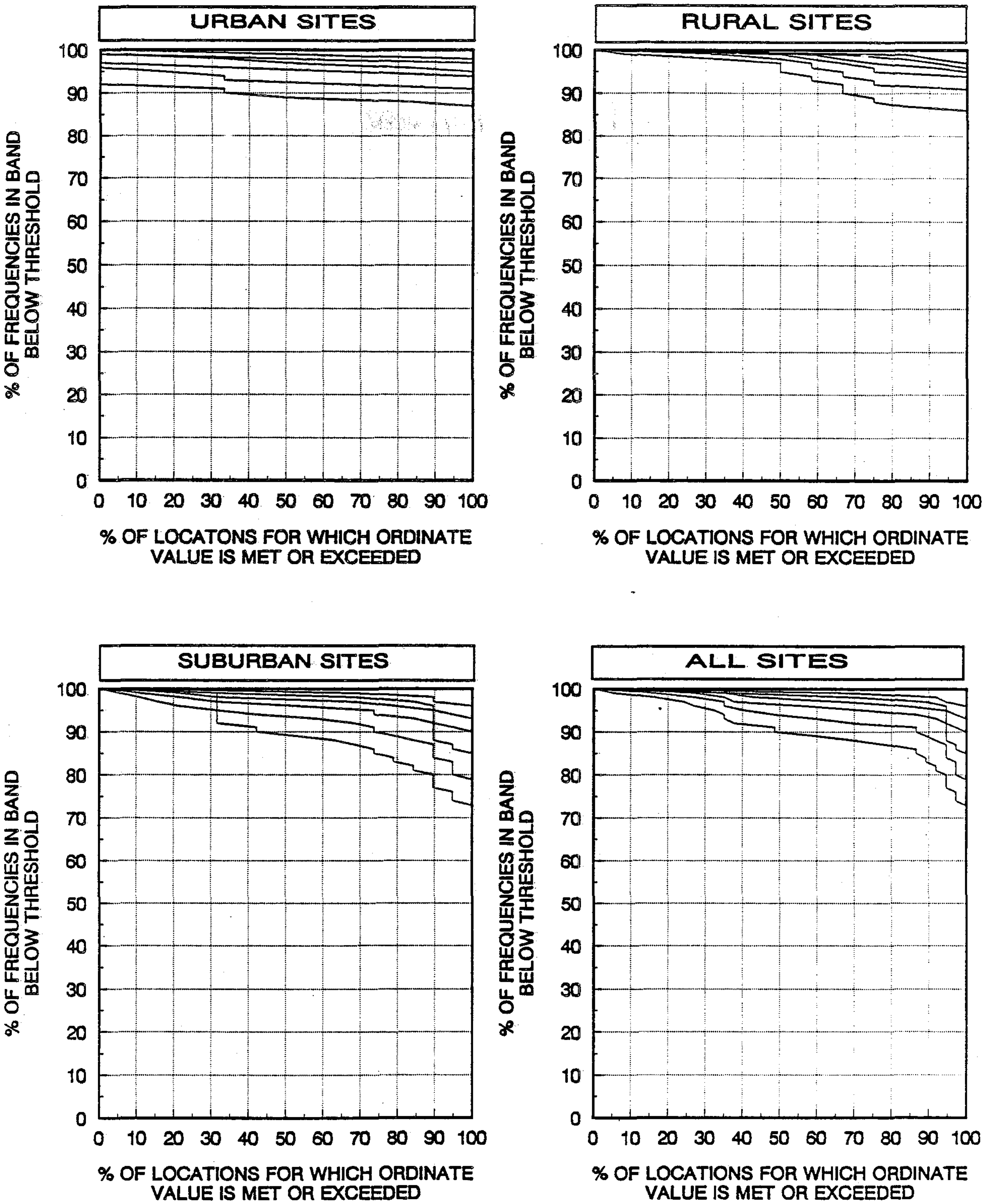

Figure 11.3 Measured band usage plots for urban, suburban, rural, and all site types for San Francisco 614 - 806 MHz.

11.2 The 824-944 MHz Measurement Frequency Band

The signal level and measured frequency usage graphs for the 824-944 MHz band are displayed in Figure 11.4. Figures 11.5 through 11.13 display the measured band usage graphs for the 824-849 MHz, 869-894 MHz, 849-851 MHz, 894-896 MHz, 864-868 MHz, 901-902 MHz, 930-931 MHz, 940-941 MHz, and 902-928 MHz bands respectively.

11.3 The 1850-1994 MHz Measurement Frequency Band

Figure 11.14 shows the signal level and measured frequency usage graphs for the 1850-1994 MHz band. The measured band usage graphs for the 1850-1990 MHz band are presented in Figure 11.15.

11.4 The 2110-2182 MHz Measurement Frequency Band

For the 2110-2182 MHz band, the signal level and measured frequency usage graphs are shown in Figure 11.16. Figures 11.17 and 11.18 depict the measured band usage graphs for the 2110-2130 MHz and 2160-2180 MHz bands respectively.

11.5 The 2400-2600 MHz Measurement Frequency Band

The signal level and measured frequency usage graphs for the 2400-2600 MHz band are displayed in Figure 11.19 while the measured band usage graphs are displayed in Figure 11.20 for the 2400-2483.5 MHz band.

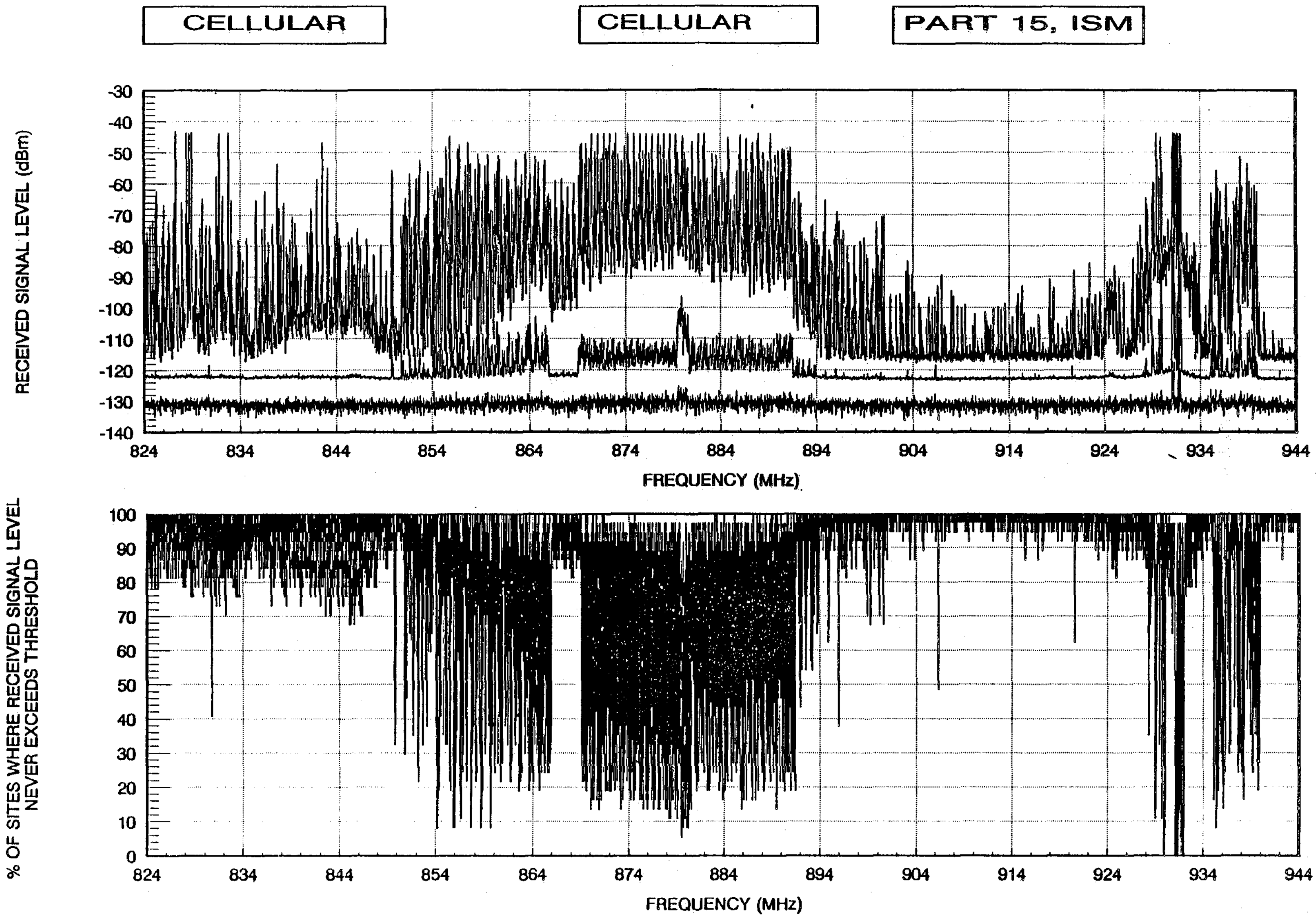

Figure 11.4 Signal level (top) and measured frequency usage (bottom) plots for San Francisco 824 - 944 MHz.

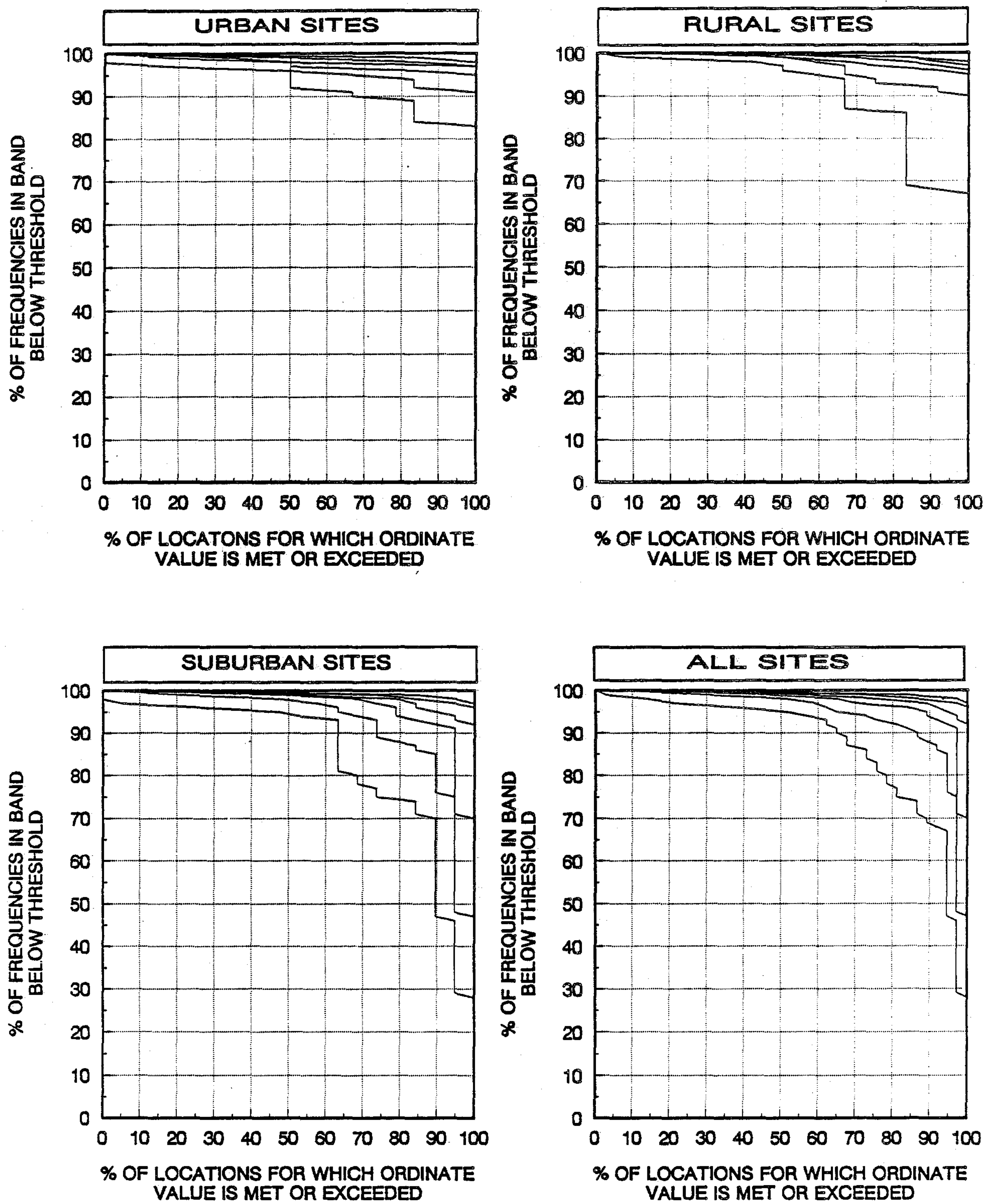

Figure 11.5 Measured band usage plots for urban, suburban, rural, and all site types for San Francisco 824 - 849 MHz.

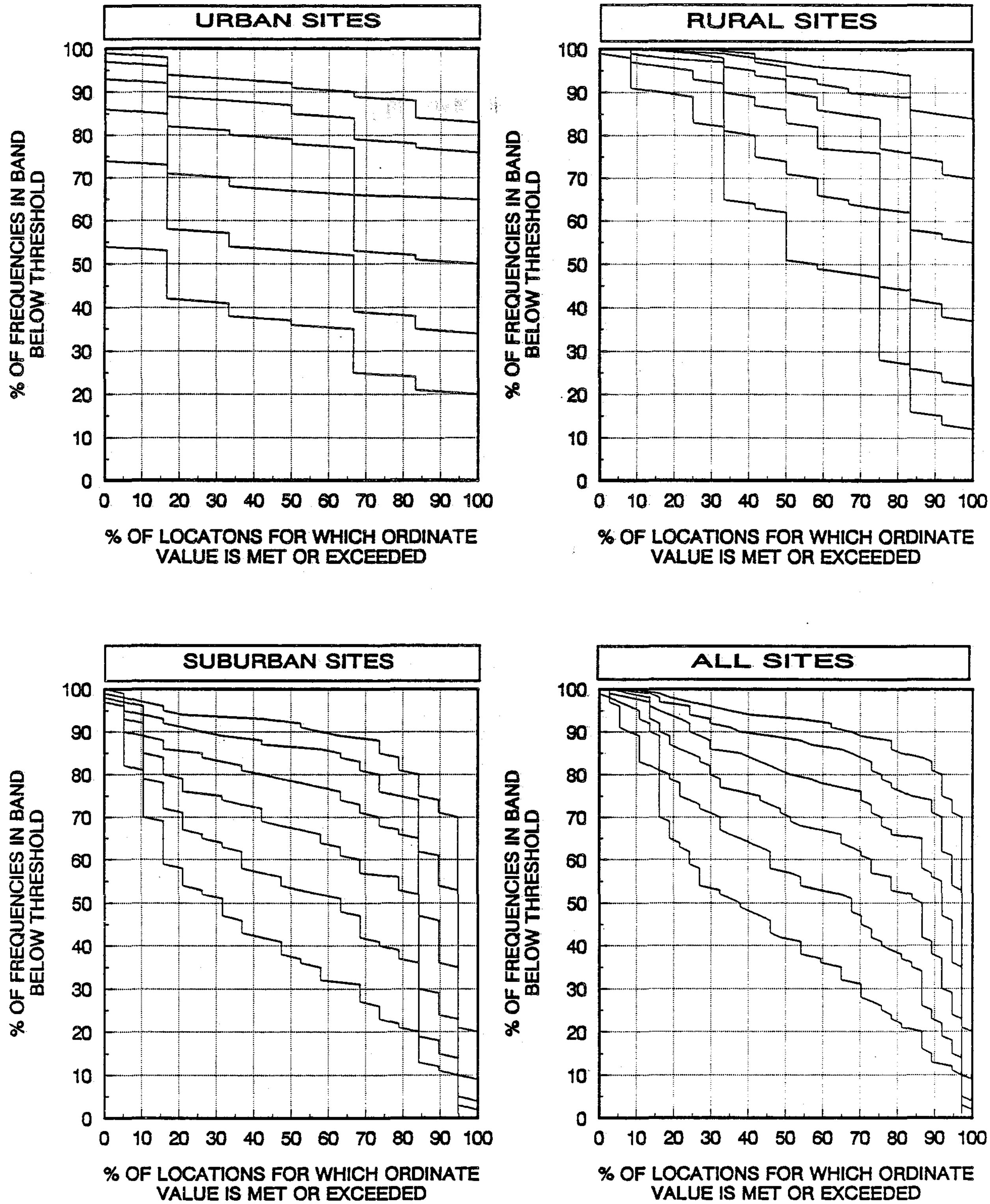

Figure 11.6 Measured band usage plots for urban, suburban, rural, and all site types for San Francisco 869 - 894 MHz.

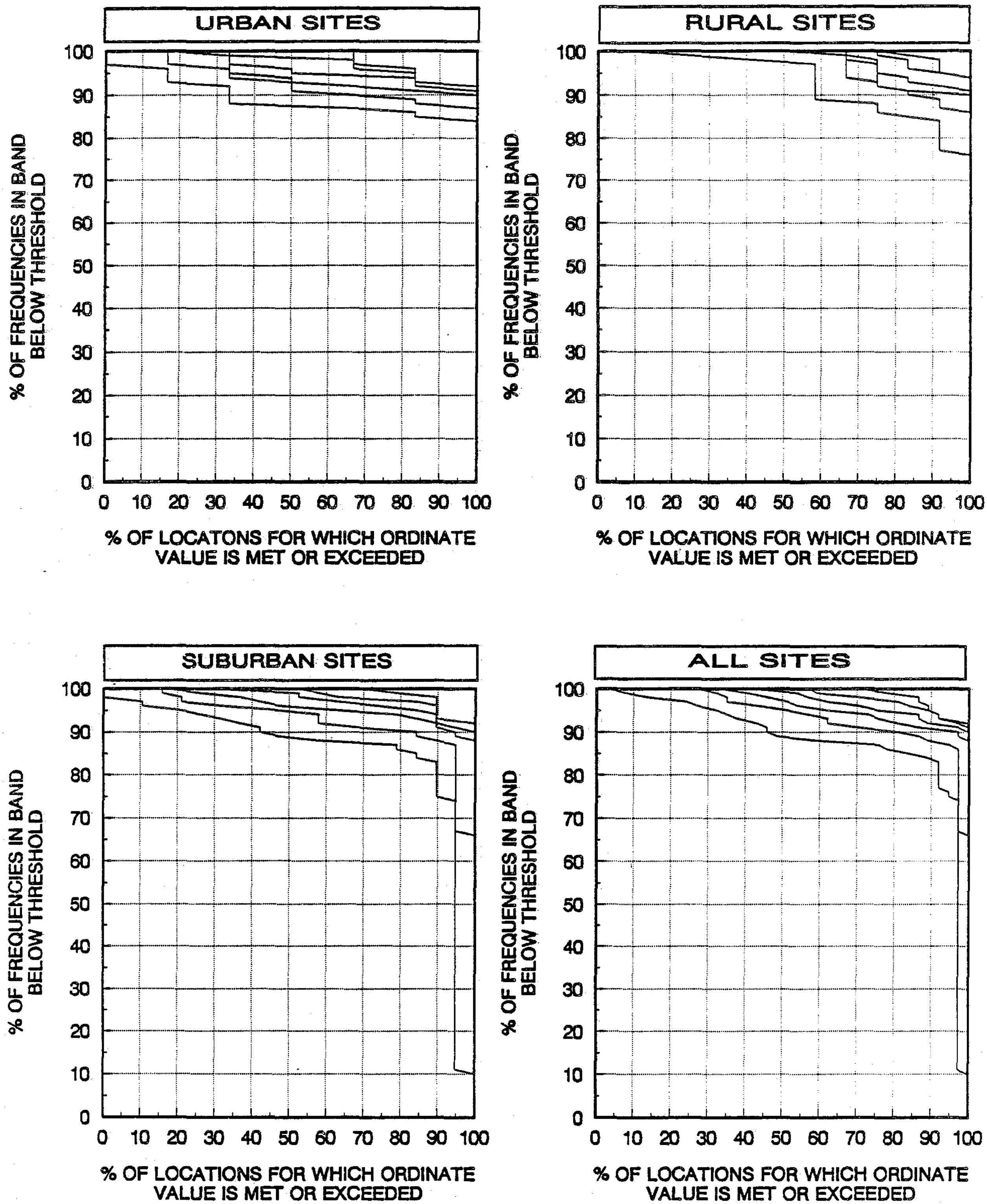

Figure 11.7 Measured band usage plots for urban, suburban, rural, and all site types for San Francisco 849 - 851 MHz.

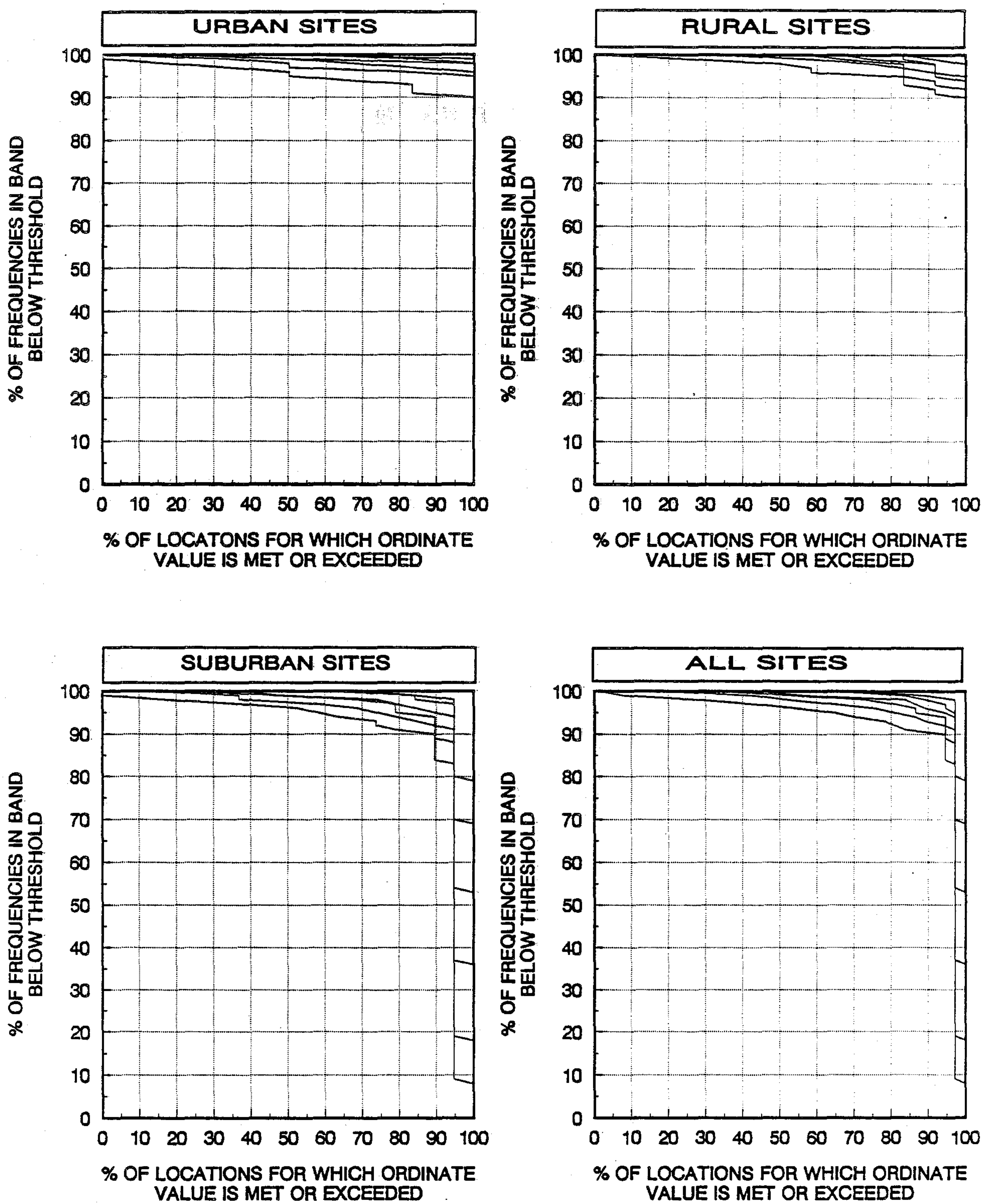

Figure 11.8 Measured band usage plots for urban, suburban, rural, and all site types for San Francisco 894 - 896 MHz.

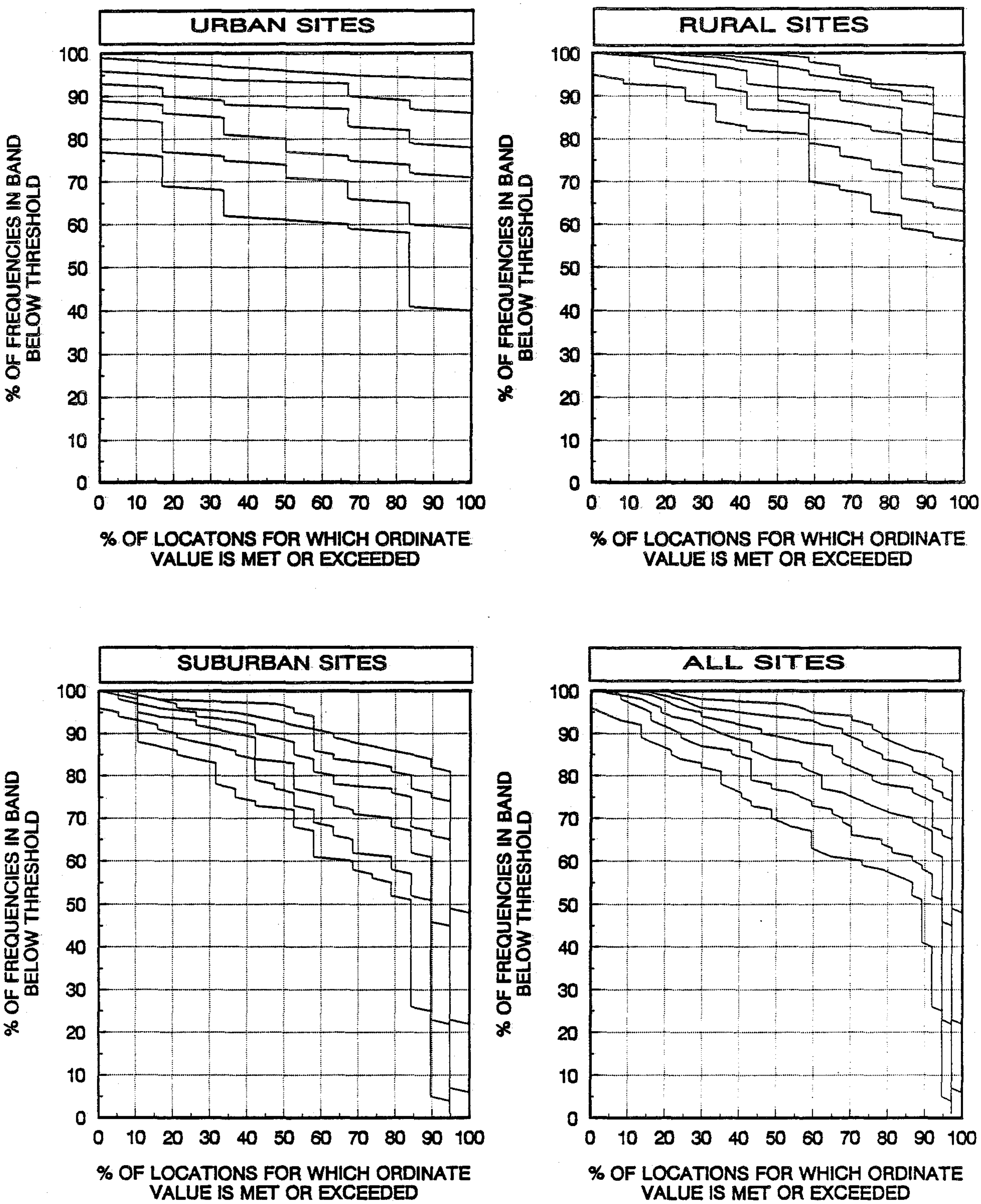

Figure 11.9 Measured band usage plots for urban, suburban, rural, and all site types for San Francisco 864 - 868 MHz.

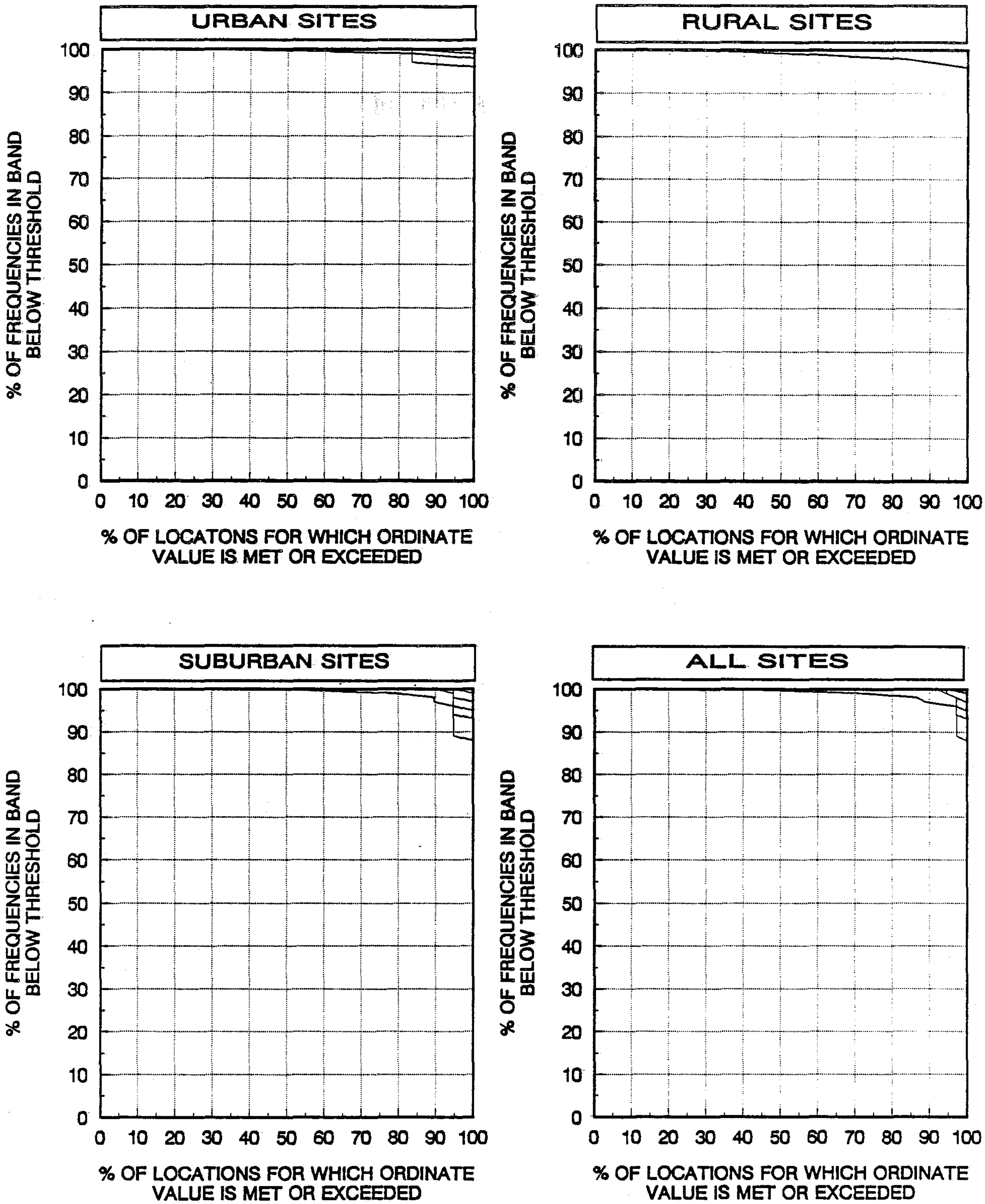

Figure 11.10 Measured band usage plots for urban, suburban, rural, and all site types for San Francisco 901 - 902 MHz.

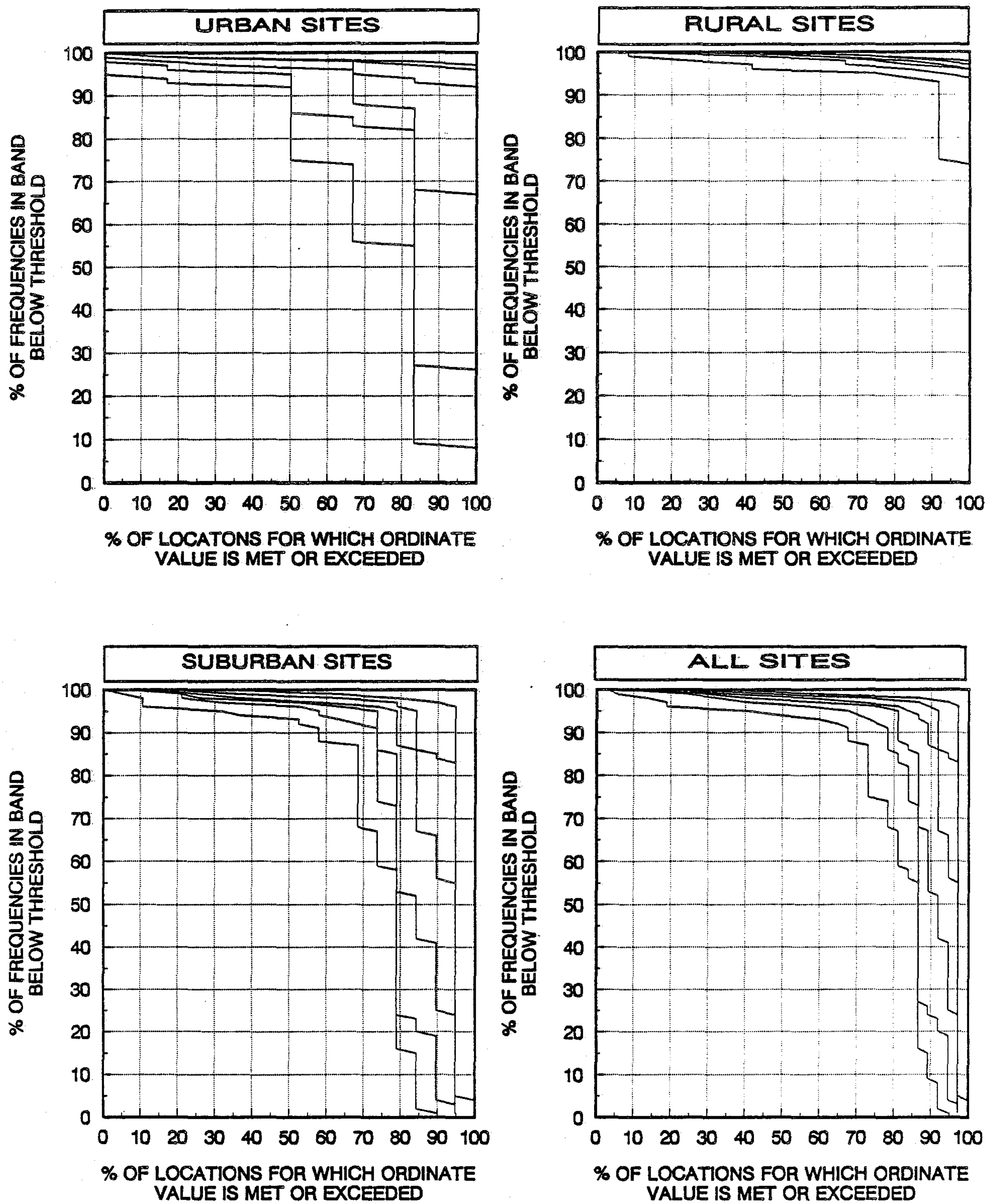

Figure 11.11 Measured band usage plots for urban, suburban, rural, and all site types for San Francisco 930 - 931 MHz.

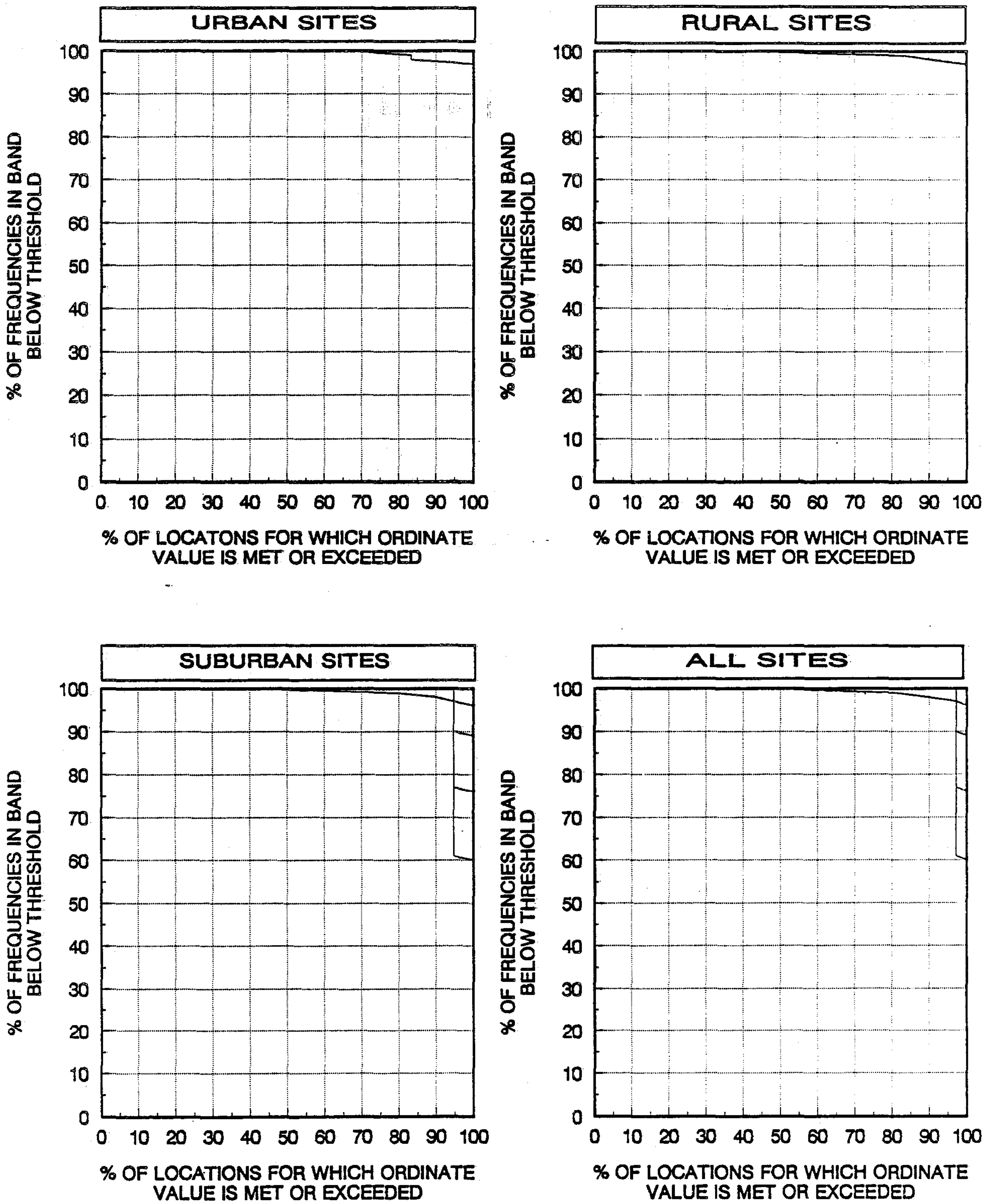

Figure 11.12 Measured band usage plots for urban, suburban, rural, and all site types for San Francisco 940 - 941 MHz.

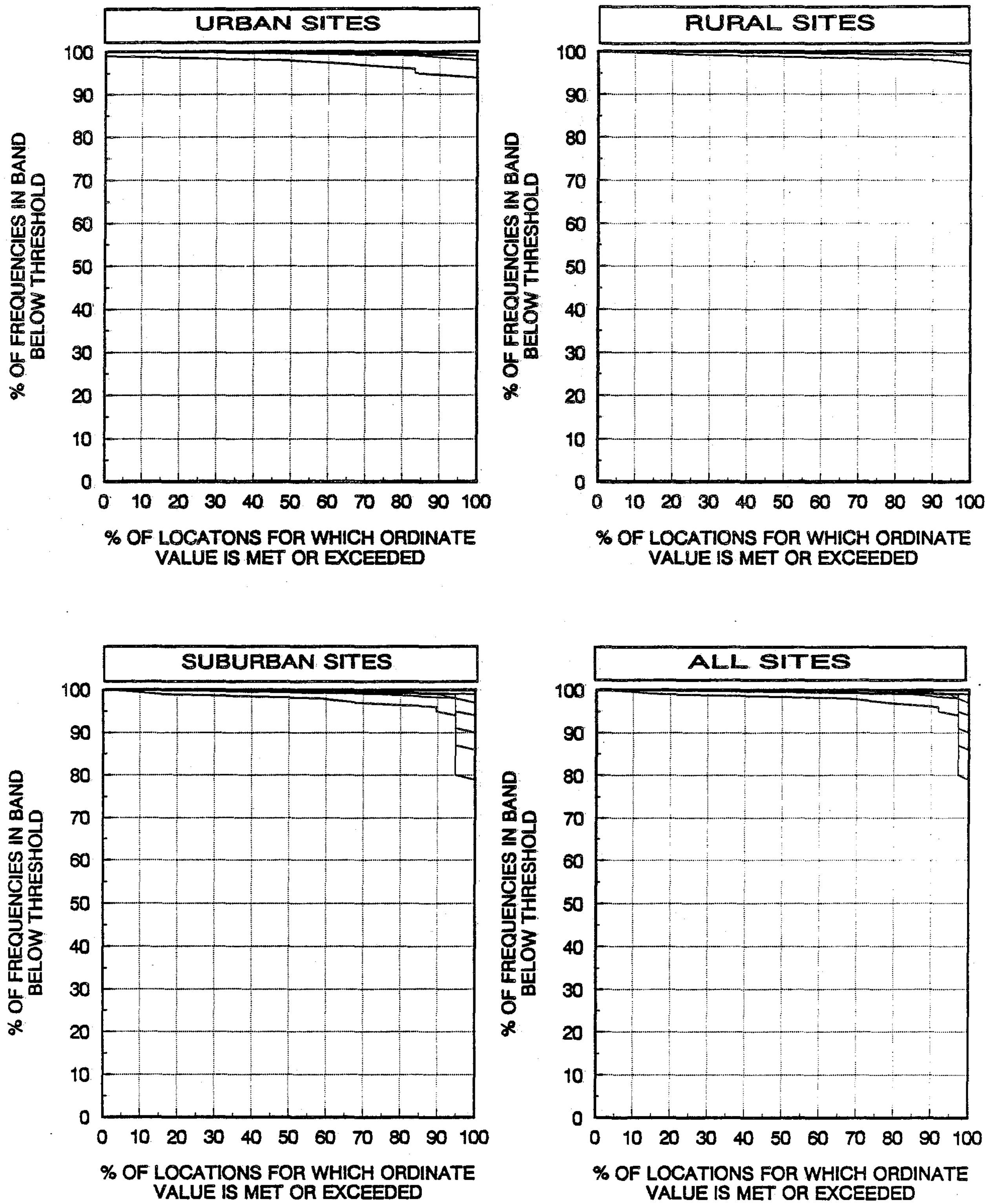

Figure 11.13 Measured band usage plots for urban, suburban, rural, and all site types for San Francisco 902 - 928 MHz.

PRIVATE FIXED MICROWAVE

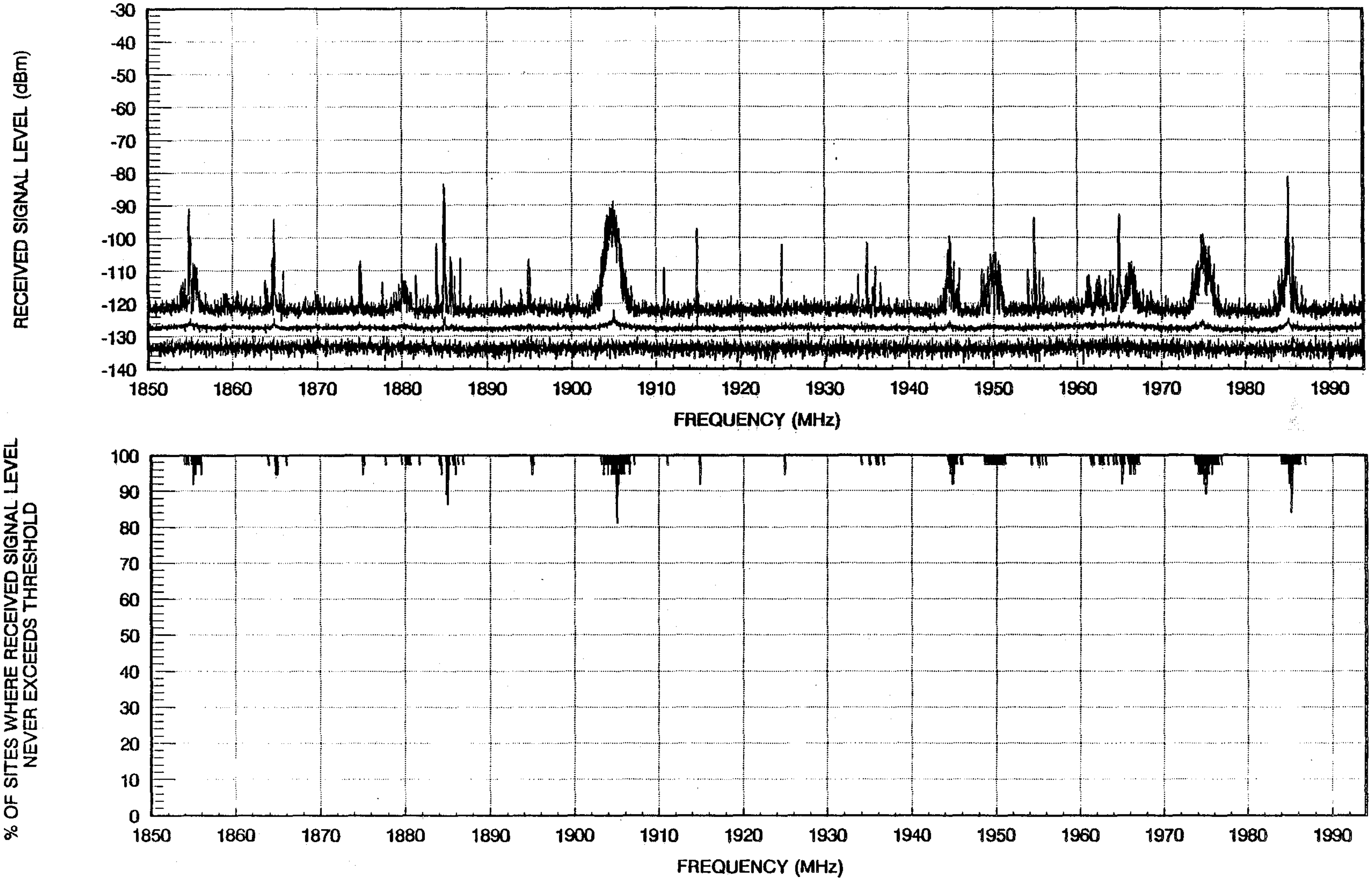

Figure 11.14 Signal level (top) and measured frequency usage (bottom) plots for San Francisco 1850 - 1994 MHz.

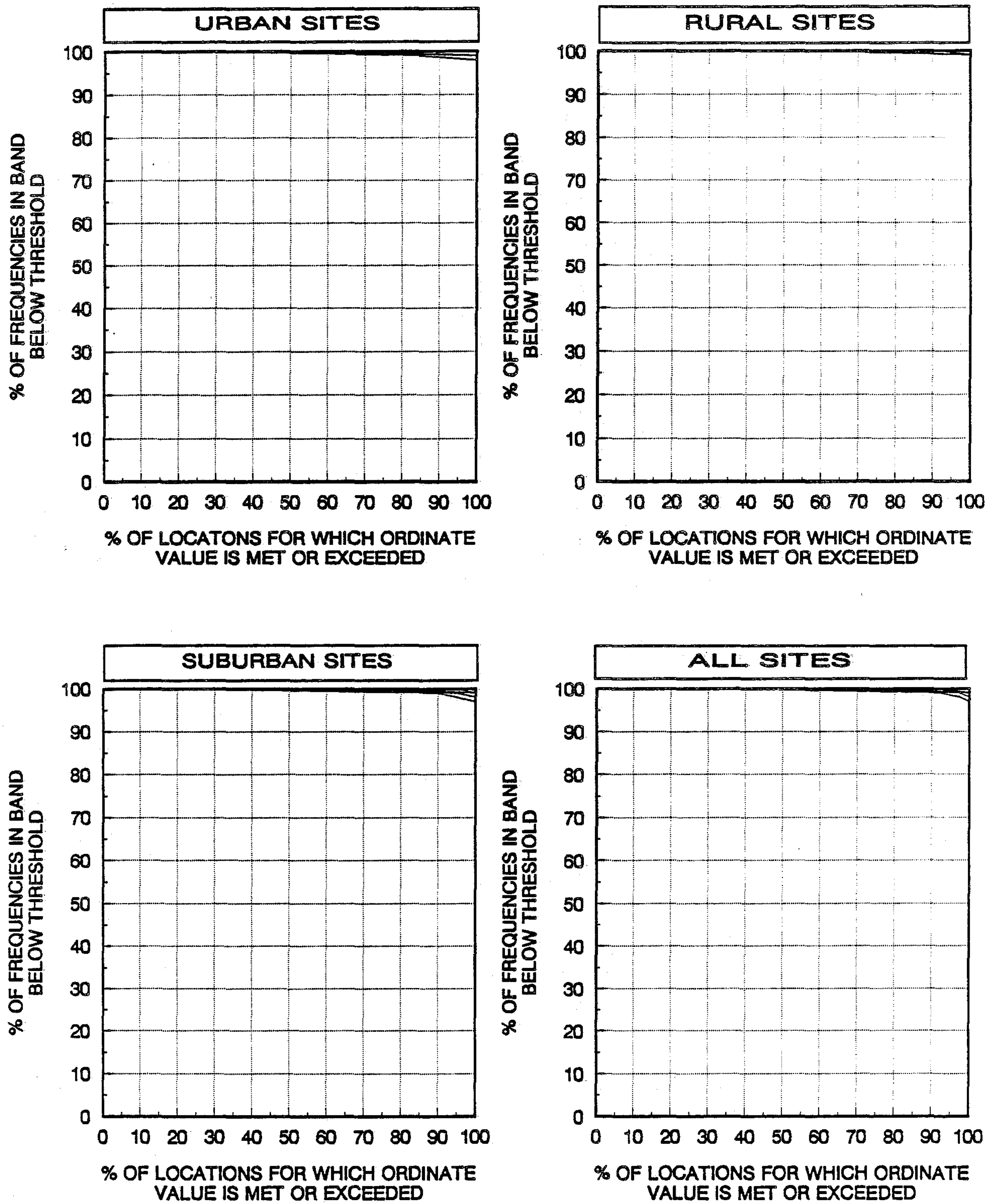

Figure 11.15 Measured band usage plots for urban, suburban, rural, and all site types for San Francisco 1850 - 1990 MHz.

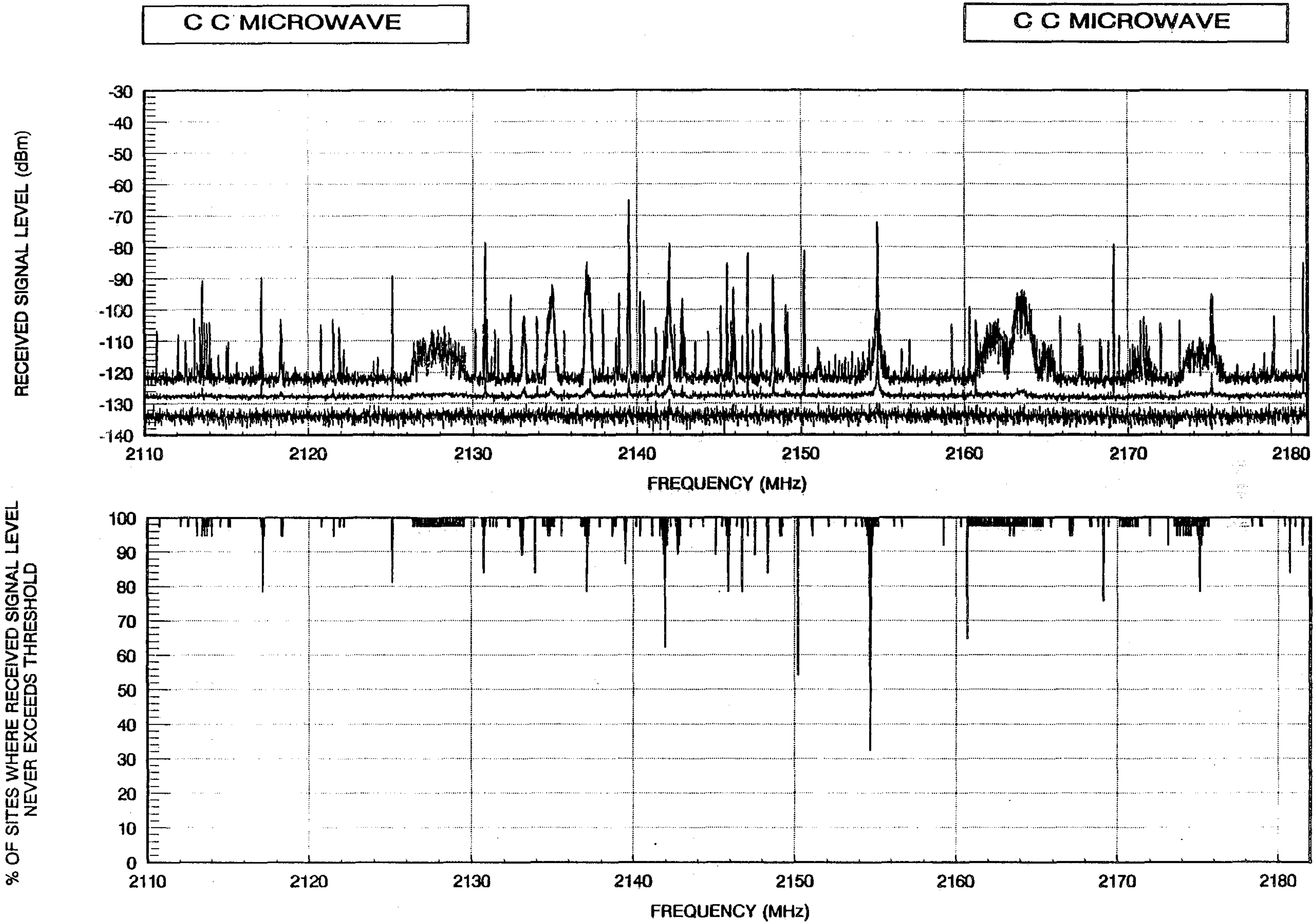

Figure 11.16 Signal level (top) and measured frequency usage (bottom) plots for San Francisco 2110 - 2182 MHz.

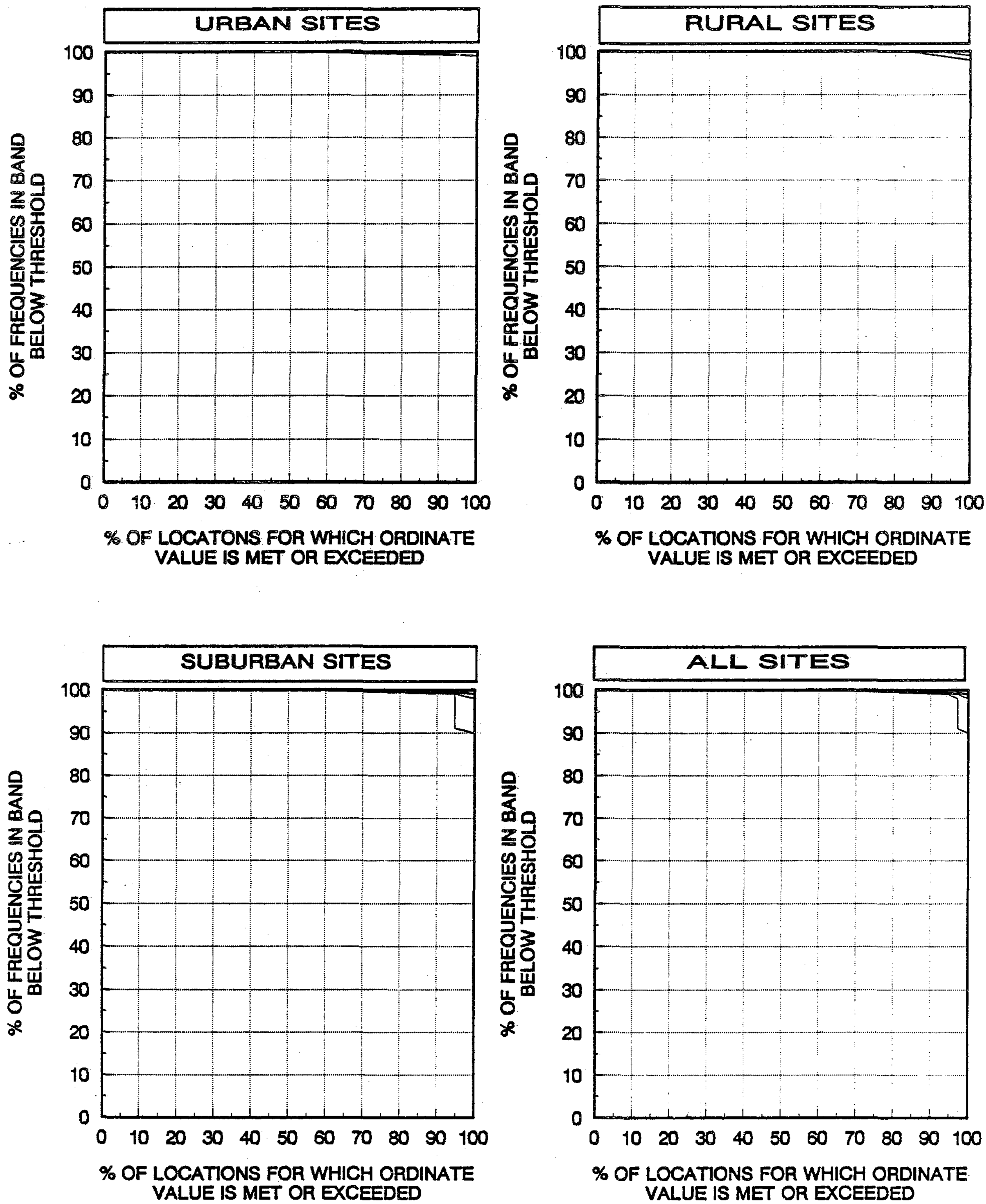

Figure 11.17 Measured band usage plots for urban, suburban, rural, and all site types for San Francisco 2110 - 2130 MHz.

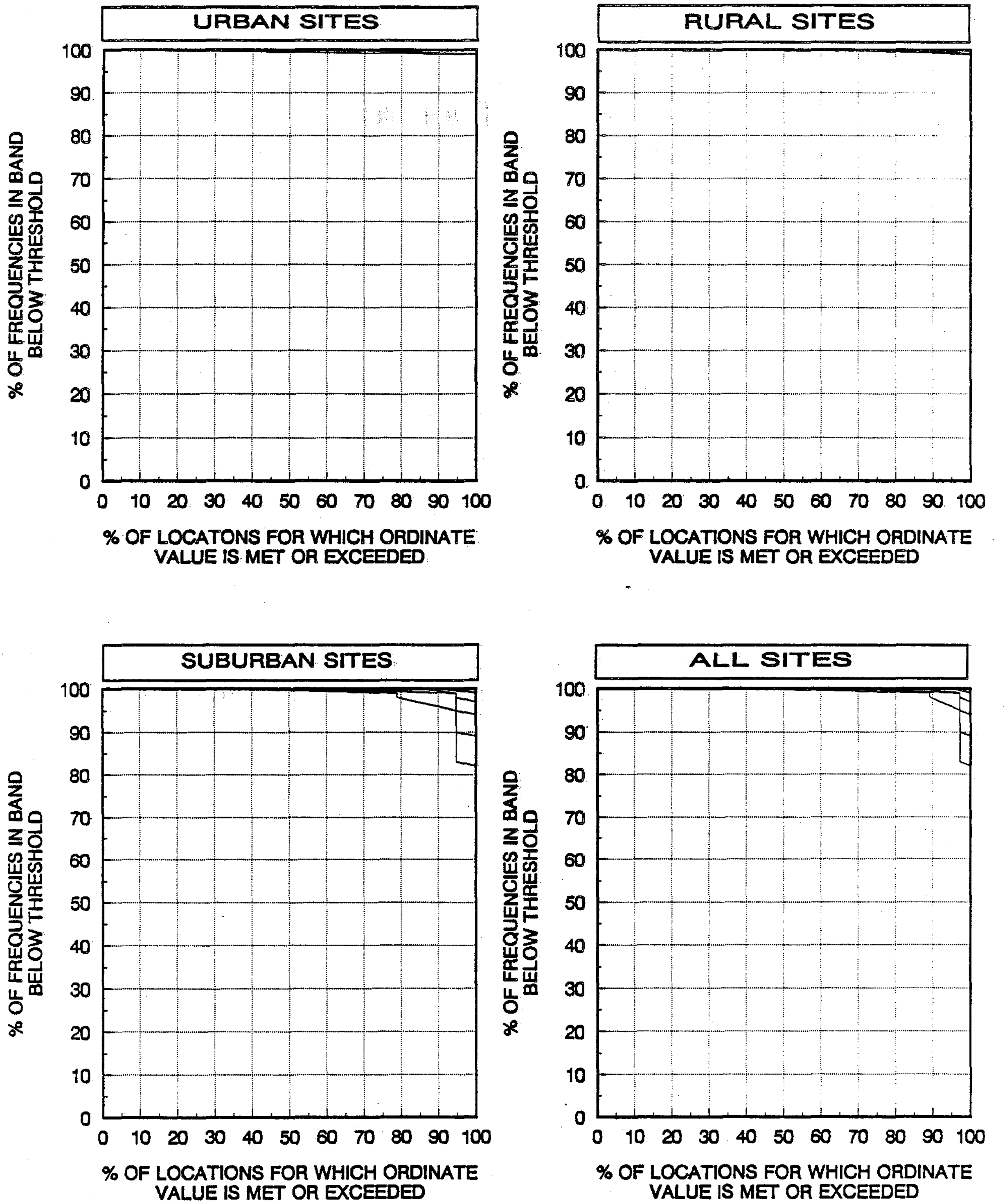

Figure 11.18 Measured band usage plots for urban, suburban, rural, and all site types for San Francisco 2160 - 2180 MHz.

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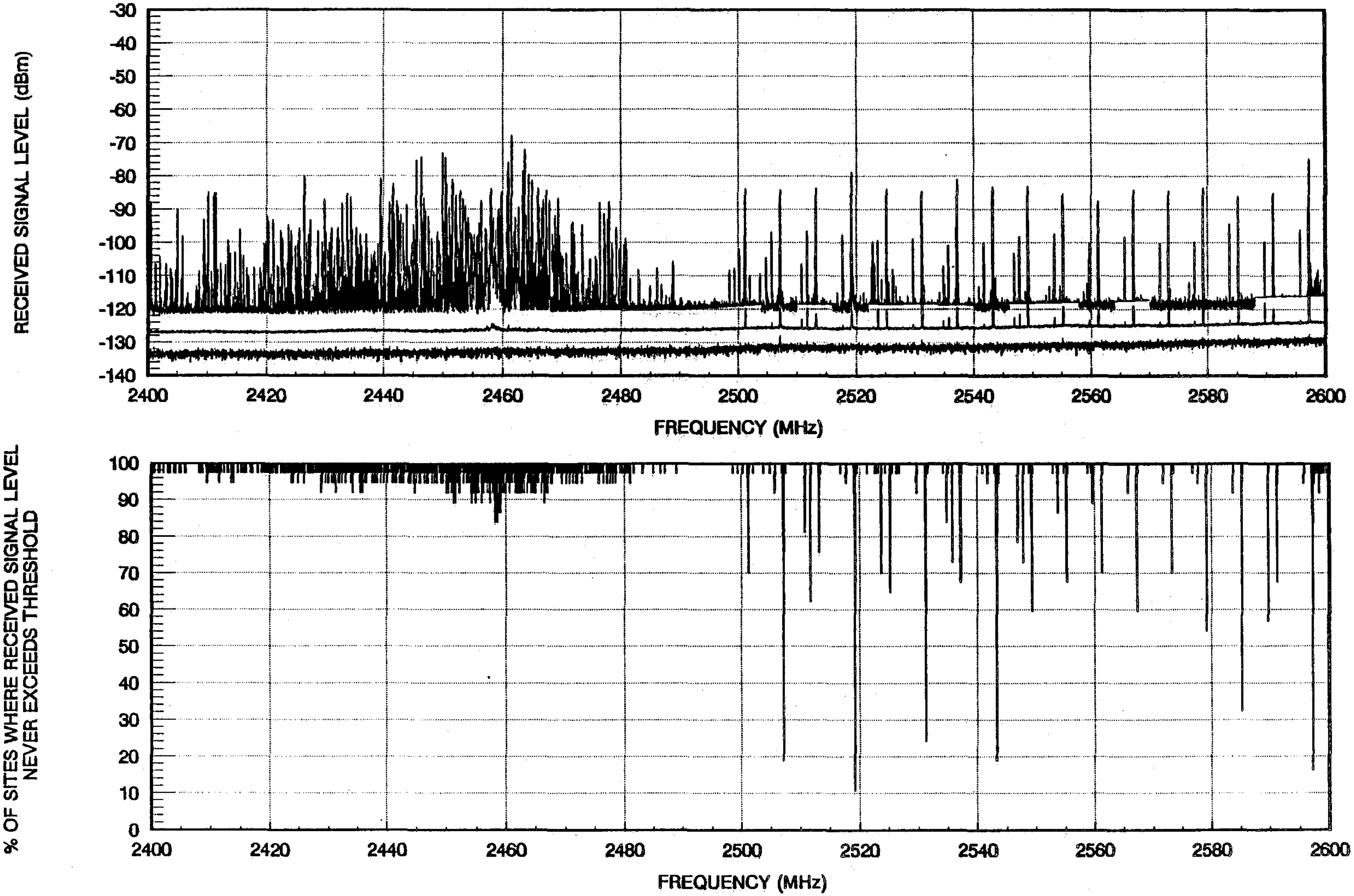

Figure 11.19 Signal level (top) and measured frequency usage (bottom) plots for San Francisco 2400 - 2600 MHz.

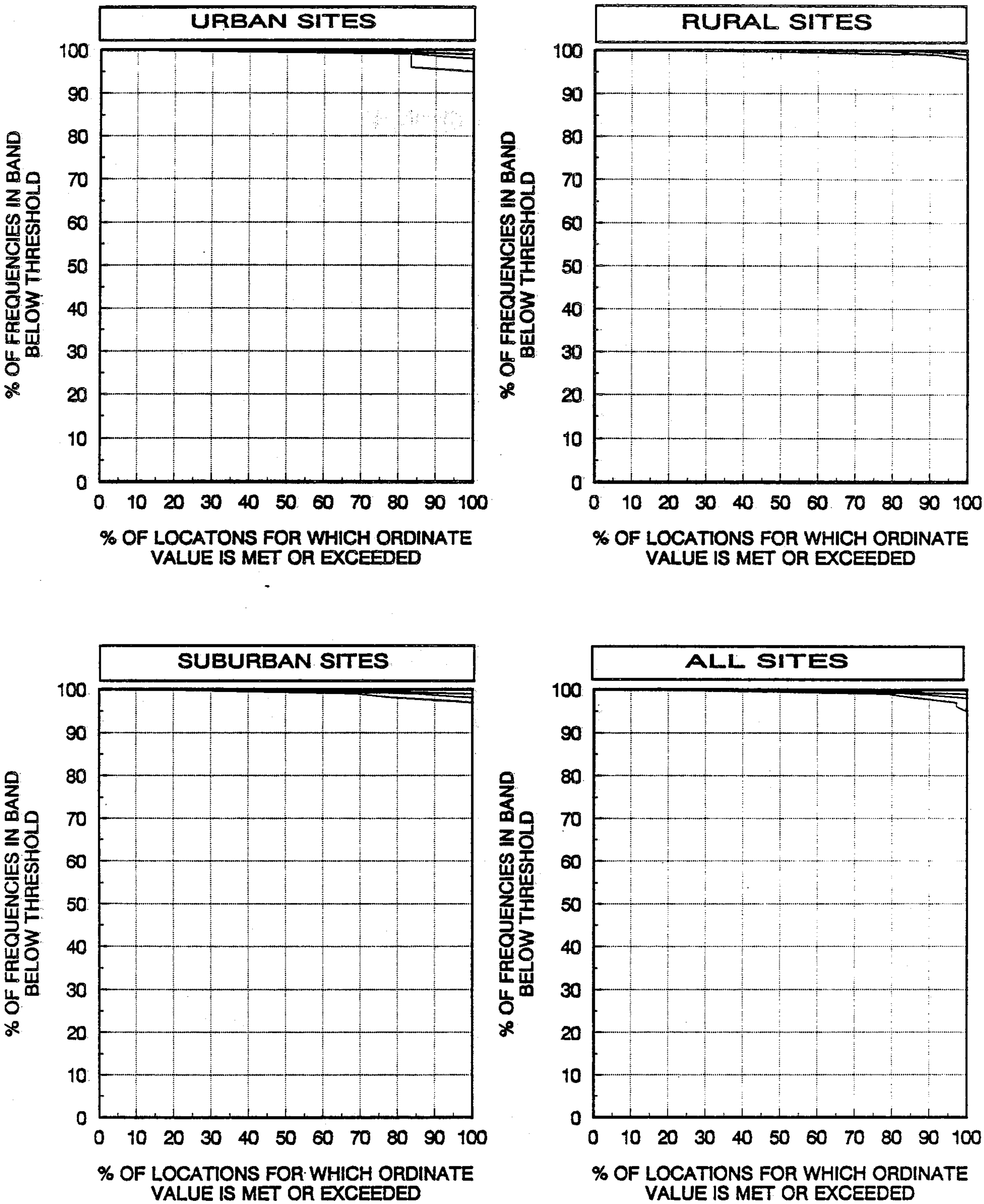

Figure 11.20 Measured band usage plots for urban, suburban, rural, and all site types for San Francisco 2400 - 2483.5 MHz.

12. COMPARISON OF DATA BETWEEN CITIES

In this section a comparison of the data taken from all cities is given. To make this comparison, the data from the measured band usage graphs are presented in the form of bar graphs for each frequency band defined in Table 2.1. Each bar graph shows the minimum percentage of the band unused[5] at 50%, 90%, and 100% of the sites in each of the five cities. These cities are denoted on the bar graph as DA (Dallas), CH (Chicago), NY (New York), LA (Los Angeles), and SF (San Francisco). The 100% number may be thought of as the percentage of the band that was unused at the busiest site. The 90% number is the percentage of the band unused at the busiest site after the busiest 10% of the sites have been eliminated. The 50% number is the percentage of the band unused at the typical (median) site (i.e., it is the percentage of the band unused at the busiest site after the busiest 50% of the sites have been eliminated). Note that 83% of the band unused at 100% of the sites does not mean that the same 83% of the frequencies were unused at all sites. It means that no less than 83% of the frequencies were unused at each site.

Additionally, each bar graph includes averaged data over all of the cities. Three separate averages are computed: the "50% all-cities average", "90% all-cities average", and "100% all-cities average". These averages are computed by taking the minimum percentage of the band unused (for 50%, 90% and 100% of the sites respectively) in each city individually (as described in the preceding paragraph) and averaging over all five cities. The -115 dBm threshold is used in all of the bar graphs. The signal level graphs, shown in previous sections, are referred to when the information provided by these graphs adds to understanding the data presented in the bar graphs.

12.1 The 614-806 MHz Measurement Frequency Band

The bar graph comparing the measured band usage between the cities for the 614-806 MHz band (UHF-TV) is given in Figure 12.1. This shows that even the busiest site (100% of sites) in the busiest city (San Francisco) had 73% of the band unused. The 50% all-cities average shows a minimum of 91% of the band unused. The large amount of spectrum unused in this band is due mainly to the UHF-TV "taboos" which prevent adjacent channels from being assigned in the same geographic area.

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5 For definition of the percentage of the band unused see page 19.

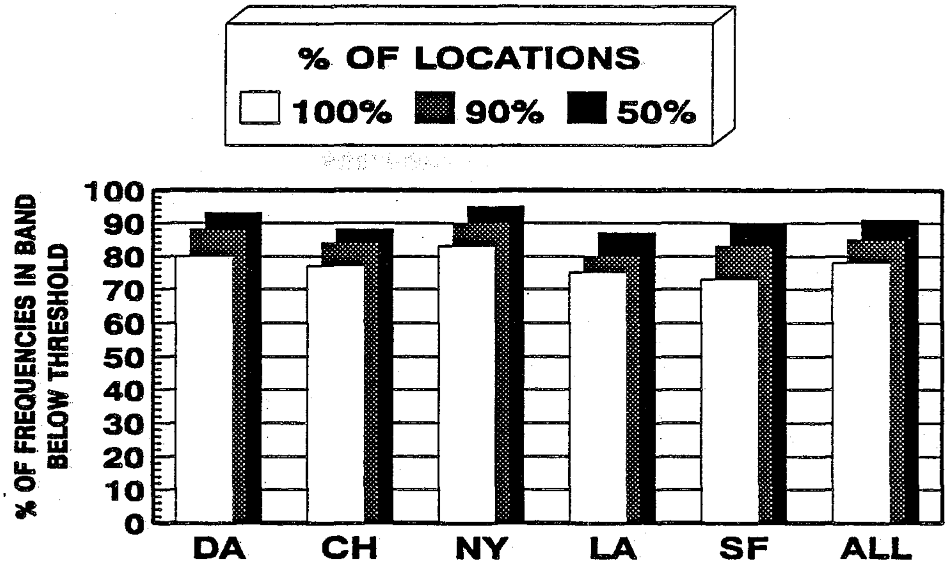

Figure 12.1 Measured band usage for all cities in the 614-806 MHz band.

12.2 The 824-944 MHz Measurement Frequency Band

Cellular bands

Figure 12.2 shows the measured band usage in the different cities for the 824-849 MHz (cellular mobile-to-base station) band. Note that the highest usage for all of the sites occurs in San Francisco where only 28% or more of the band is unused. The lowest usage for all of the sites occurred in Dallas where at least 88% of the band is unused. The 90% all-cities average shows a minimum of 86% of the band unused.

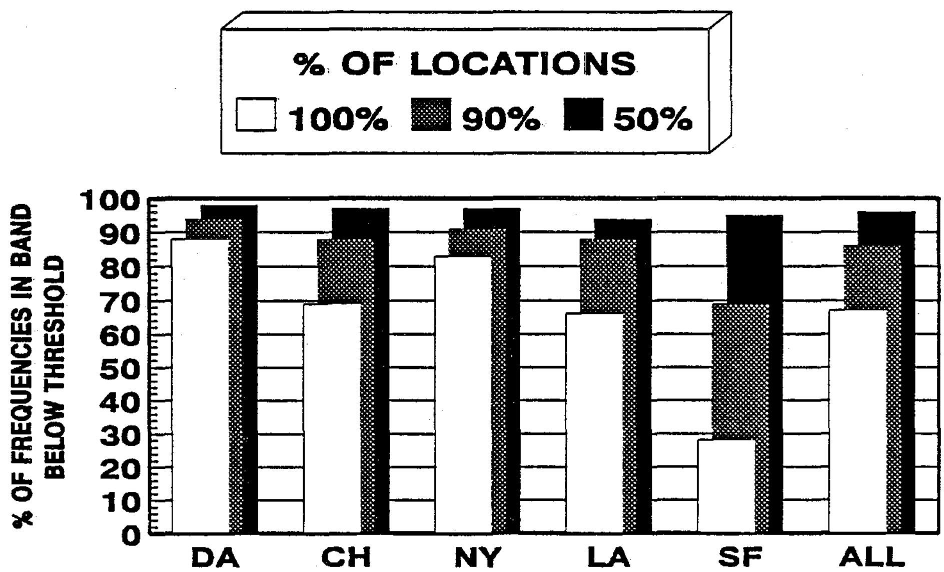

Figure 12.2 Measured band usage for all cities in the 824-849 MHz band.

Measured band usage in each city for the 869-894 MHz band (cellular base station-to-mobile) is portrayed in Figure 12.3. This band shows high usage; the 100% all-cities average shows a minimum of only 3% of the band unused. The 50% all-cities average shows a minimum of 33% of the band unused. The difference in apparent spectrum usage in the two cellular bands occurs because the propagation losses are higher from the typical cellular mobile unit (with a low antenna) to the measurement receiver than from the cellular base station (with a higher antenna) to the measurement receiver. Therefore, the base station signals are seen much better than the mobile signals.

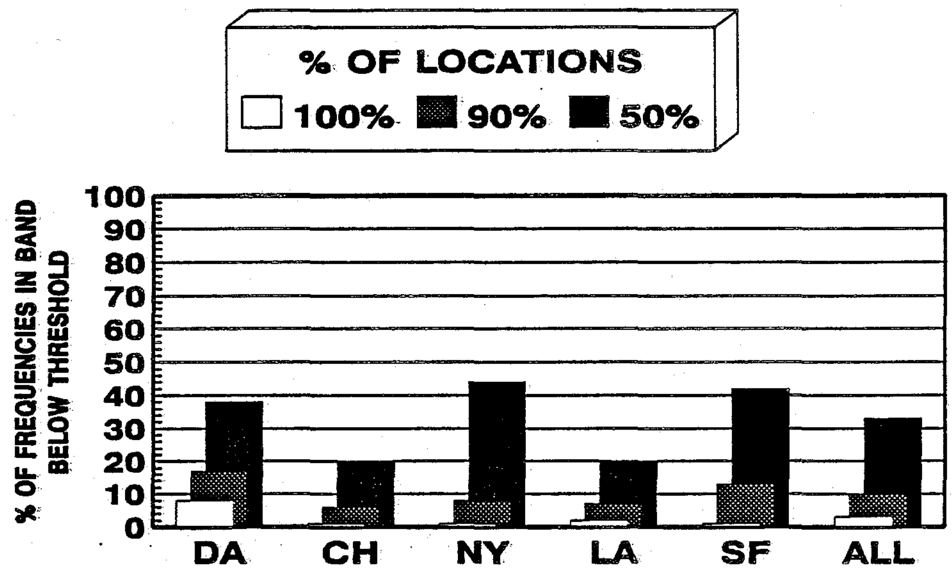

Figure 12.3 Measured band usage for all cities in the 869-894 MHz band.

Air-to-ground bands

Figure 12.4 shows the measured band usage in the 849-851 MHz band. The percentage of the band unused in the busiest sites (100% of sites) in Chicago and San Francisco was low (1% and 10%, respectively), but the 90% all-cities average showed a minimum of 89% of the band unused. This indicated that very few sites showed heavy usage. By examining the maximum RSL curves in the signal level graphs for the 824-944 MHz band in Chicago and San Francisco (Figure 8.4 and 11.4 respectively), it appears that either transmitter noise sidebands or broadband signals are present in the 849-851 MHz band. Since these signals/noise sidebands are above the -115 dBm threshold, it causes an apparent high usage. Since the mean RSL curves are not affected much, it can be deduced that these signals/noise sidebands were detected at most at only a few sites.

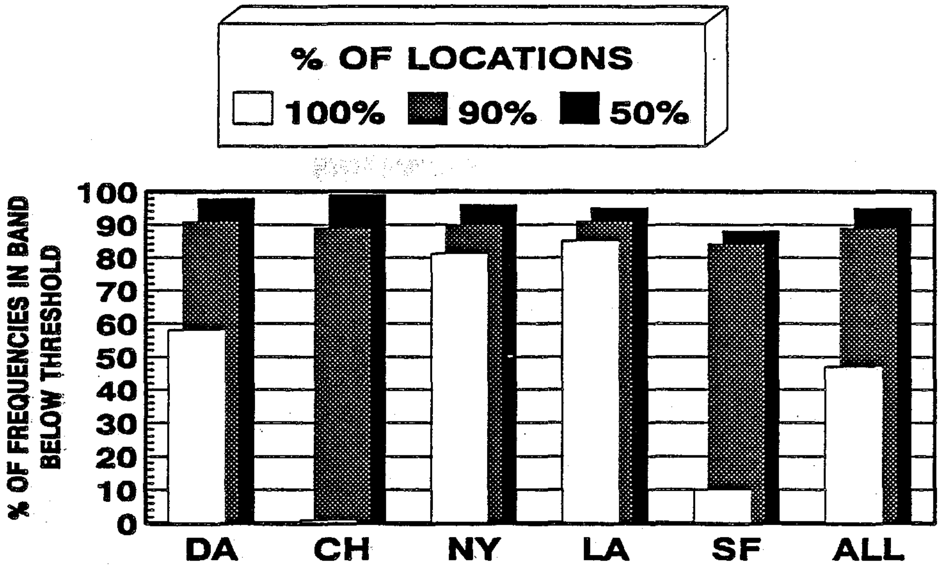

Figure 12.4 Measured band usage for all cities in the 849-851 MHz band.

As seen in Figure 12.5, the 90% all-cities average (showing a minimum of 84% of the 894-896 MHz band unused) is very similar to that in the 849-851 MHz band. In the 894-896 MHz band for San Francisco, at most a few of the sites showed high usage. Again, this appeared to be caused by either transmitter noise sidebands from the adjacent cellular band or by a broadband signal.

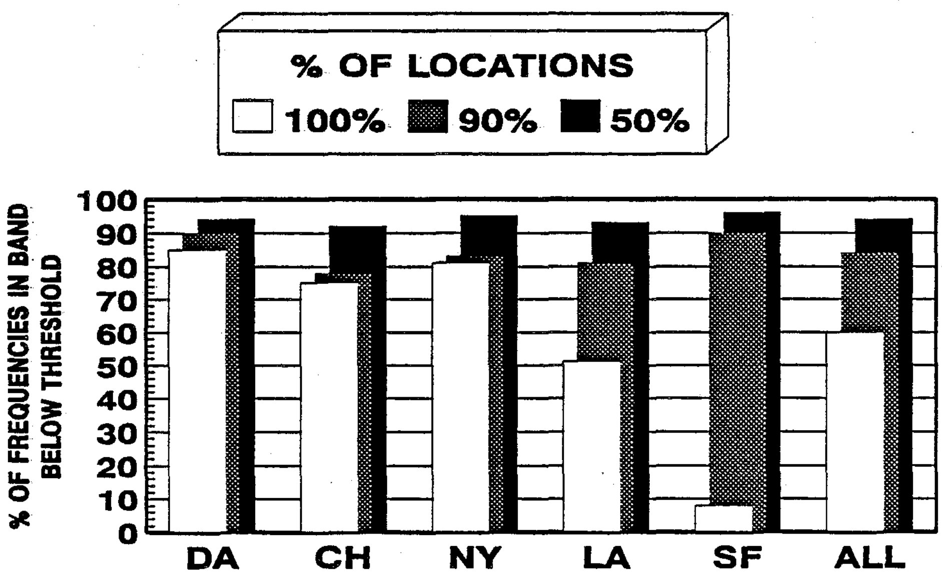

Figure 12.5 Measured band usage for all cities in the 894-896 MHz band.

SMR band

The 864-868 MHz band is another band that shows high usage. Studying the bar graph for measured band usage in Figure 12.6 shows that the busiest sites in each city had only about 1% of the band unused. Observing the maximum RSL curves over the 864-868 MHz band in the signal level graphs of Figures 7.4, 8.4, 9.4, 10.4, and 11.4, transmitter noise sidebands from adjacent bands or receiver intermodulation from the measurement system that affect band usage is suspected at most at a few sites. Note that the 90% all-cities average shows a minimum of 42% of the band unused while the 50% all-cities average shows a minimum of 57% of the band unused.

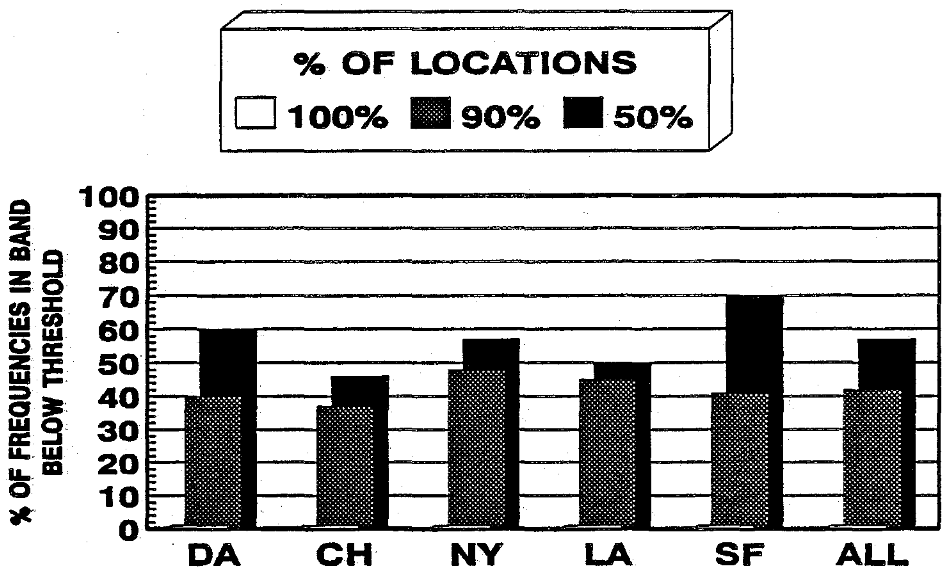

Figure 12.6 Measured band usage for all cities in the 864-868 MHz band.

GPMRS bands

From the measured band usage comparison graph for the 901-902 MHz band shown in Figure 12.7, low usage is seen. The 100% all-cities average shows a minimum of 93% of the band unused.

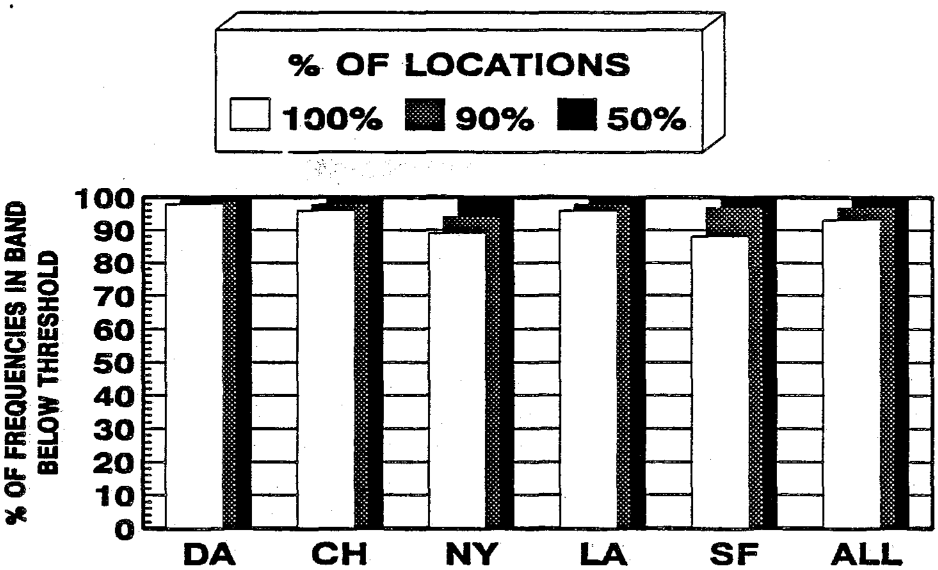

Figure 12.7 Measured band usage for all cities in the 901-902 MHz band.

By inspecting the bar graph for the 930-931 MHz band in Figure 12.8, and the signal level graphs for each city over the 824-944 MHz band (Figures 7.4, 8.4, 9.4, 10.4, and 11.4), it appears that transmitter noise sidebands or receiver intermodulation distortion from the measurement system have caused a noticeably high usage at some of the sites in all cities except Dallas. When considering the 50% all-cities average the band shows low usage (a minimum of 96% of the band unused). For 90% of all sites in each city, Los Angeles and San Francisco have at least 4% and 8% of the band unused respectively. Chicago and Dallas, on the other hand, have at least 91% and 96% of the band unused respectively. The 90% all-cities average shows a minimum of 49% of the band unused.

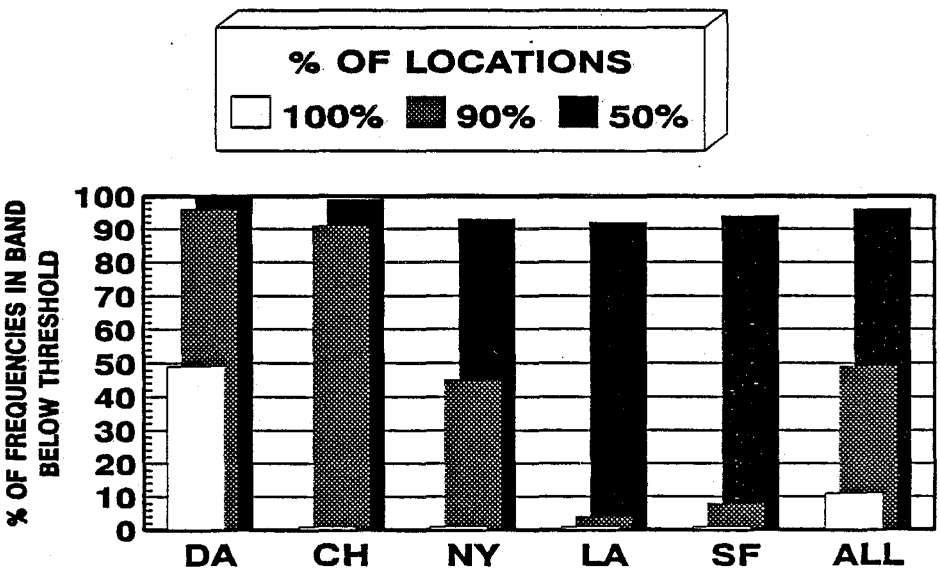

Figure 12.8 Measured band usage for all cities in the 930-931 MHz band.

Figure 12.9, depicting measured band usage for the 940-941 MHz band, demonstrates that for both 50% and 90% of the sites in each city almost all of the band is unused. The signal level graphs for each city over the 824-944 MHz band (Figures 7.4, 8.4, 9.4, 10.4, and 11.4), display either transmitter noise sidebands from the adjacent land mobile radio band or receiver intermodulation distortion from the measurement system in the 940-941 MHz band for Chicago and New York. This of course shows up as high band usage for these cities when considering all of the sites in each city. From Figure 12.9, it seems that the noise sidebands or intermodulation distortion was detected at only a few of the sites in Chicago and New York.

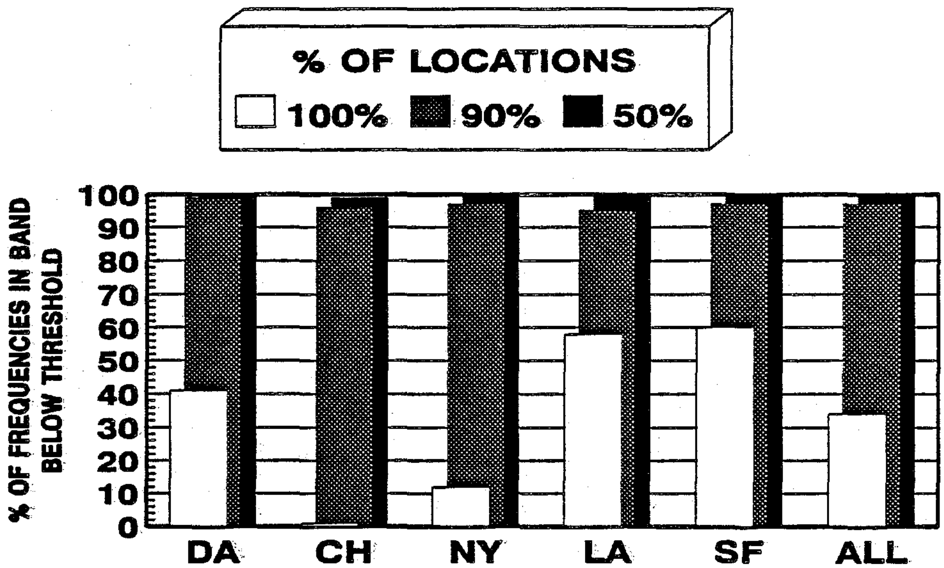

Figure 12.9 Measured band usage for all cities in the 940-941 MHz band.

ISM and Part 15 band

The 902-928 MHz band, as seen in Figure 12.10 shows relatively low usage. The 100% all-cities average shows a minimum of 89% of the band unused while the 50% all-cities average shows a minimum of 98% of the band unused.

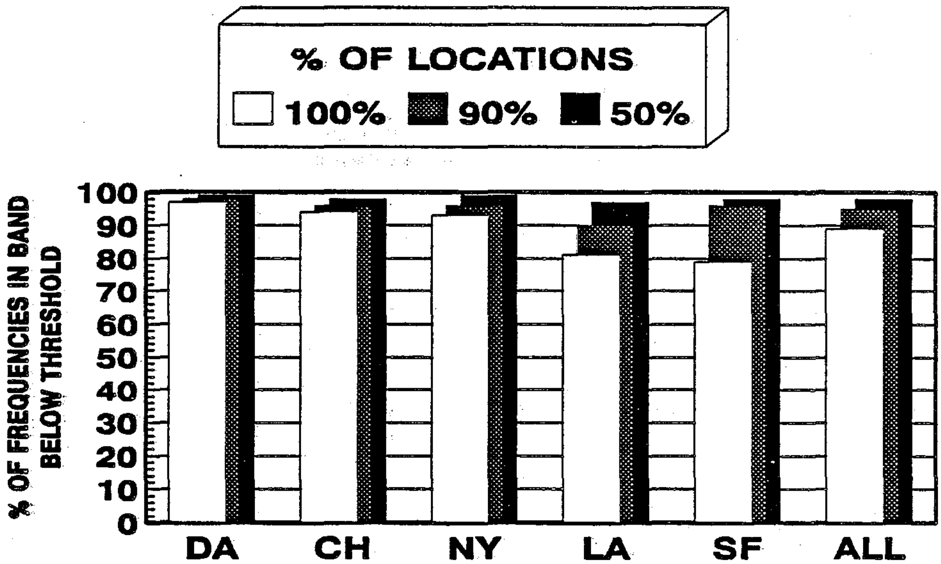

Figure 12.10 Measured band usage for all cities in the 902-928 MHz band.

12.3 The 1850-1990 MHz Frequency Band

The usage in this band is shown in Figure 12.11 to be low. The busiest site out of all sites in all cities shows 88% of the band unused. The 50% all-cities average shows a minimum of 99% of the band unused.

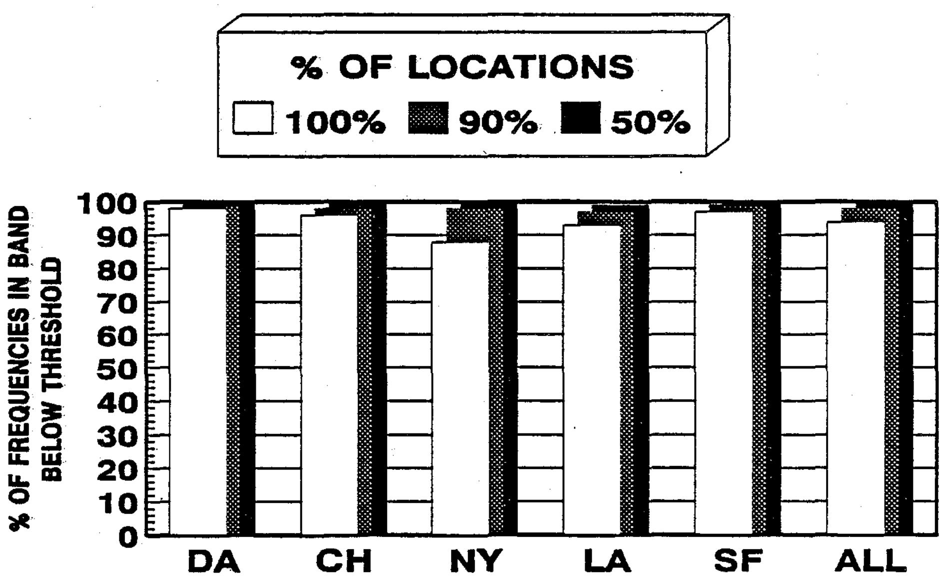

Figure 12.11 Measured band usage for all cities in the 1850-1990 MHz band.

12.4 The 2110-2182 MHz Measurement Frequency Band

Figure 12.12 shows the measured band usage in the 2110-2130 MHz band. In this band, the 100% all-cities average shows a minimum of 89% of the band unused. The 90% all-cities average shows a minimum of 99% of the band unused.

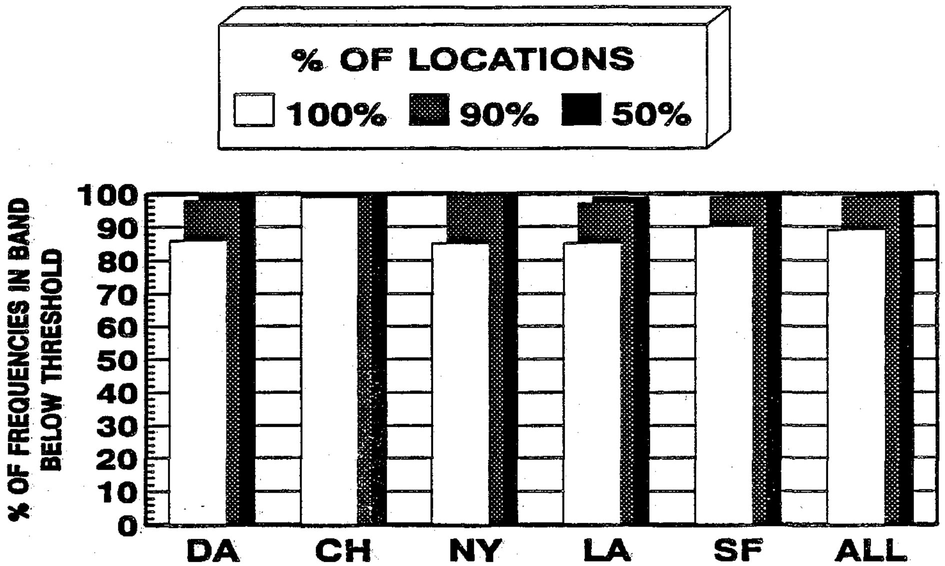

Figure 12.12 Measured band usage for all cities in the 2110-2130 MHz band.

The bar graph in the 2160-2180 MHz band, as seen in Figure 12.13, shows a little more usage than the 2110-2130 MHz band. The 100% all-cities average shows a minimum of 85% of the band unused while the 90% all-cities average shows a minimum of 97% of the band unused.

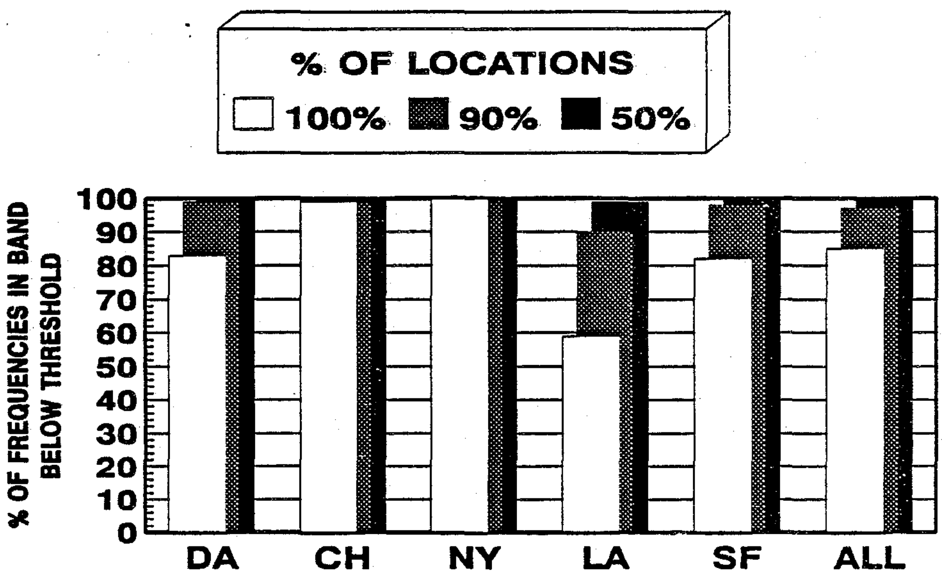

Figure 12.13 Measured band usage for all cities in the 2160-2180 MHz band.

12.5 The 2400-2600 MHz Measurement Frequency Band

Examining Figure 12.14 demonstrates a low usage in the 2400-2483.5 MHz band. The 100% all-cities average shows a minimum of 96% of the band unused.

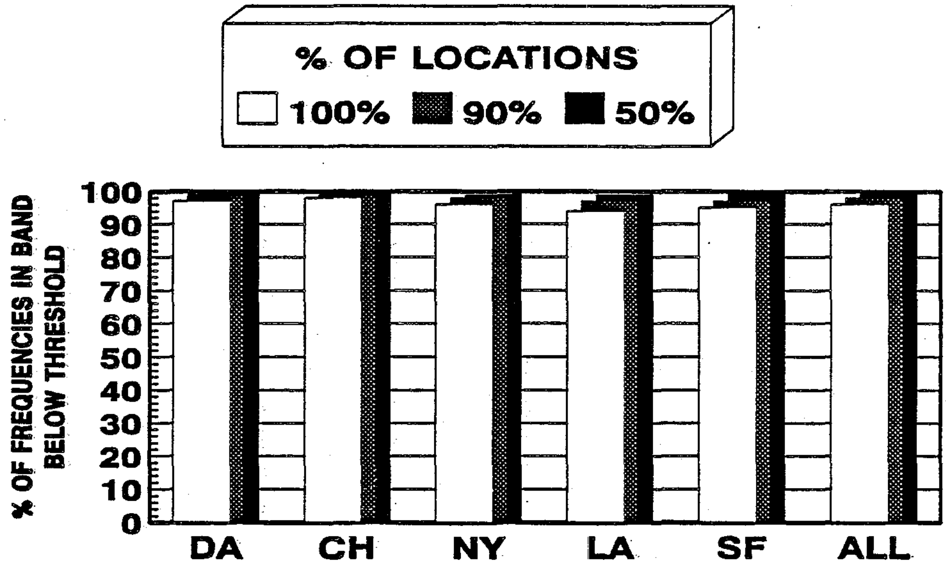

Figure 12.14 Measured band usage for all cities in the 2400-2483.5 MHz band.

13. SUMMARY AND CONCLUSIONS

This report discussed the ITS field experiment to measure spectrum usage in several potential PCS frequency bands in the 600 to 2600 MHz range in five U.S. cities. The basic objective of the measurements was to determine the degree of current spectrum usage for all frequency bands listed in the TTL PCS Experimental License. In particular, the geographic dependence (within a city) of spectrum usage was determined for all of the cities. In each city, measurements were typically made at 37 sites with a five mile spacing between sites. Each of these sites was classified as urban, suburban, or rural according to a predefined set of criteria. The measurements were made using a mobile, computer-controlled, automated measurement system that measures rf signals in the 600-2600 MHz frequency range. This measurement system was installed in a mini-van and used an omnidirectional vertically polarized receive antenna mounted approximately one foot above the roof of the vehicle.

The measurement system was calibrated with a noise diode twice a day while the antenna and bulkhead connector cabling were tested once a day. The raw data taken at each site consisted of RSLs (in dBm) for each frequency measured. These data were processed to provide signal level, measured frequency usage, and measured band usage graphs. The signal level graphs show minimum, maximum, and mean RSLs at each frequency as measured at all sites in each city. The measured frequency usage graphs display the percentage of sites where a frequency was unused[6] during the measurement periods. The percentage of sites that had a certain percentage or more of the frequency band unused[7] during the measurement periods is depicted in the measured band usage graphs.

Every frequency was measured with three different sets of measurement parameters: narrowband, wideband, and peak. Even though measurements made with the different measurement parameters show results that appear different, they are all accurate representations of the data. The data presented in this report were primarily from the narrowband measurements since they provided the most sensitive measurements.

The Data Comparison between Cities section presented the quantitative results of the data analysis using only the narrowband measurement parameters. Several conclusions can be drawn by examining the measured band usage bar graphs in all cities over the 14 frequency bands listed in the TTL Experimental License (see Table 2.1). The highest usage was seen in the 869-894 MHz and the 864-868 MHz bands. The 100% all-cities average showed a minimum of 2% of the 869-894 MHz band unused and a minimum of 1% of the 864-868 MHz band unused. The bands showing the lowest usage were the 2400-2483.5 MHz, 1850-1990 MHz, and 901-902 MHz bands. In these bands, the 100% all-cities averages showed a minimum between 93% and 96% of the band unused. Other bands showing low usage were the 902-928 MHz, 2110-2130 MHz, 2160-2180 MHz, and 614-806 MHz bands where the 100% all-cities averages showed a minimum between 78% and 89% of the band unused.

6,7 For definitions of unused frequency and the percentage of band unused see page 19.

When considering these usage results, several factors that affect apparent spectrum usage must be kept in mind. The percentage of the band unused was determined from the data that used the narrowband measurement parameters (10 kHz bandwidth, 3 kHz video filter, sampling detector). Communications systems whose receivers operate using the same parameters should expect to see the same spectrum being used. For receivers operating with different bandwidths, the amount of spectrum being used would appear different. Wider bandwidth systems would see a higher apparent spectrum usage. The -115 dBm threshold was used in showing the usage results. By using higher thresholds, less usage would be shown. The measurements made in this experiment indicate spectrum usage as determined by reception of transmitted signals. No provision was made to determine additional frequency use that could be prohibited by potential interference from a PCS system to existing receivers. Since the measurements in this experiment were made exclusively outdoors, PCS systems operating indoors would see higher usage than that indicated from these measurements in the bands with indoor transmitters (such as the ISM and Part 15 bands). Finally, since a vertically polarized antenna was used for the measurements, horizontally polarized signals appeared weaker than they actually were. If horizontally polarized signals had been received with a horizontally polarized antenna, the apparent usage would have been higher.

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15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Spectrum usage measurements were made in several potential Personal Communication Services (PCS) frequency bands in the 600 to 2600 MHz range in five U.S. cities. Geographic dependence (within a city) of spectrum usage was determined for all of the cities. Measurements were made using a mobile, computer-controlled, automated radio frequency measurement system that was installed in a mini-van. The raw data taken at each site consisted of received signal levels for each frequency measured. These were processed to provide signal level, measured frequency usage, and measured band usage graphs. The heaviest usage for all cities was seen in the 869-894 MHz (cellular base station-to-mobile) band and the 864-868 MHz (SMR) band. The frequency bands showing the least usage in all cities were the 901-902 MHz (GPMRS), 1850-1990 MHz (Private Fixed Microwave), and the 2400-2483.5 MHz (ISM and Part 15) bands.

16. Key Words *(Alphabetical order, separated by semicolons)*
measured band usage; measured frequency usage; PCS; Personal Communication Services; received signal level; spectrum usage

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