A Survey of Spectrum Utilization in Chicago

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March 7, 2007

Abstract

An investigation into the utilization of radio frequency spectrum for wireless communication is undertaken. The spectrum range falls in the range of 960-2500 MHz. Using test equipment, the electromagnetic energy was measured in several frequency bands over a period of several minutes on November 18, 2005, in downtown Chicago. The data was tabulated to estimate the occupnancy in each band. The issues affecting an estimate of spectrum utilization are discussed. We conclude that certain bands in the spectrum are heavily utilized and others which appear to be under utilized, particularly in the L-band above 1 GHz. There exist some opportunities for reallocation of spectrum, but there is a need for a better metric of spectrum utilization than spectrum occupancy which can lead to erronious conclusions as the the availability of free spectrum.

Contents

1 Introduction

A spectrum occupancy study is an experimental survey of electromagnetic energy occurring in a broad range of radio frequency (RF) bands over a given period of time. The purpose of the study is to identify which frequencies are most heavily used as communication channels, and which frequency bands are under utilized and available for wireless communications.

As part of an broader effort to research capacity and utilization of wireless communication channels, a spectrum occupancy study was undertaken. Under an National Science Foundation grant, the Wireless Interference Laboratory (WIL) of the Illinois Institute of Technology (IIT) contracted with Shared Spectrum Inc. to perform a study of radio activity on the urban campus of IIT. Shared Spectrum had performed several similar studies at other locations around the country and their report on the spectrum utilization is published separately. Along with the larger spectrum occupancy, the company made available a smaller data set taken with some simple commercial components to allow a base-line comparison to the broader data set. The data presented in this paper is based on that truncated data set.

The data allows for a snapshot of the spectrum occupancy and enables a closer look at some of the conclusions that were raised in the broader survey. Each band is examined in terms of the current frequency allocations as cataloged by the government. The authors of the original survey considered all parts of the RF spectrum as equally valid candidates for wireless communication channels. The estimation of spectrum occupancy is based solely on the energy detected above a threshold for the band in question. This simple, and rather arbitrary, criterion raises questions about the value of the spectrum occupancy figure. A more interesting statistic would be the utilization of the available channels: How full is the pipe? A closer look at the data in perspective of the current channel allocations calls into question the widely held conclusion that there are multitudes of unused communication channels.

2 The Experimental Procedure

The data was collected on November 18, 3:30 PM on the roof-top of the IITRI tower located at 10 W.35th St., Chicago, IL. The equipment used was a Log-Periodic Array (LPA) antenna with a frequency range of 900 to 2500 MHz which fed the received signal to a Rockwell XGS spectrum analyzer. The spectrum analyzer converted the received signal into power versus frequency traces using an internal mixer, sampler, and a computational Fast-Fourier Transform (FFT) engine. The collected traces from the spectrum analyzer were transferred to a laptop computer where the raw data was stored. The stored data was transferred to the WIL researchers on a permanent media (CDROM). The apparatus is listed in Table 1.

The data was collected by setting the spectrum analyzer to one of several discrete frequency bands. The spectrum analyzer then was allowed to collect data for anywhere from two to six minutes. This raw data was later processed with a program to plot the data and to estimate the occupancy statistics. As a final check the aparatus was set to sweep all frequencies from DC to 2.5 GHz.

Device	Description
Log-Normal Array	Broad-band antenna for the frequency range of 900-2500 MHz.
Rockwell XGS Sensor	Digital Spectrum Analyzer
Laptop Computer	Data Acquisition and Control System

Table 1: Apparatus used for base-line spectrum study

While the antenna was not intended to operate at those low frequencies, the band below 1 GHz includes all of the conventional broadcast stations which transmit at high power for robust detection.

3 The Collected Data

The data is presented in three plots for each frequency band. The first plot is the power spectrum plot of accumulated data for the frequency band in question. The first trace (which appears as the upper trace) is the "maximum hold" of all the traces collected over the time period. This indicates the peak power of the received signal at each discrete frequency. The second trace (which appears as the lower trace) is the "minimum hold" of all the traces collected over the time period. It provides an indication of the noise floor of the test equipment where there is no (or intermittent) energy present. Where this trace rises above the noise floor, that indicates that there is always a minimum signal present which may correlate to a transmission source of a constant power carrier wave. The third trace is an energy threshold (which appears as a flat line) which is used to assess the presence or absence of a communication signal. The signal threshold was set to -95 dBm in all cases to reflect the minimum detectable power level of the equipment. If the power ever went above this threshold, the channel was deemed to be in use, or occupied. If the power ever went below this threshold, the channel was deemed unused, or unoccupied.

The second plot gives an indication of utilization of the frequency band over time. As with the first plot, the horizontal axis is the frequency, the vertical axis is now the time that the trace was taken, and the third axis, represented by the intensity of the pixel in the contour map, is the detection of power at that frequency at that time. the intensity of the pixel represents the occupancy. If the detected power exceeds the threshold, then occupancy is indicated as a black dot.

The third plot presents the occupancy of each "channel" in the band over the duration of the experiment. It displays the percentage of time that the frequency channel is occupied. If there is a constant signal above the threshold, as would be the case with a carrier wave broadcast transmission, then there would be a solid vertical line on the utilization spectrograph (the second plot), and a 100% occupancy percentage in the third plot. If there was an intermittently used channel, such as a half-duplex keyed channel like a CB radio, then there would be segmented vertical lines on the time spectrograph, and and utilization figure, $0 < U < 100$ percent on the third graph. If no signal is ever detected at the frequency in question, then the occupancy figure will be zero.

The data for each frequency range is considered in more detail.

3.1 The 960-1240 MHz Frequency Band

The data for this band is shown in Figure 9. The FCC allocates this band for aeronautical and satellite radio-navigation. There is a keyed signal at 1090 MHz, indicated by the hashed line on the second plot. The Air Traffic Control Radar Beacon System (ATCRBS) uses this channel as as a air-to-ground transponder channel. Aircraft overhead are automatically sending flight data to the air traffic control system. The ATCRBS also transmits a signal at 1030 MHz to query the aircraft transponders. This appears in the power plot, but is lower in power and less frequent and hence does not appear on the occupancy plot. The constant power indication at 1215 MHz may be an FAA air-traffic radar.

3.2 The 1240-1710 MHz Frequency Band

The data for this band is shown in Figure 1. This is a very broad band that is designated for many uses but the primary use is satellite communications, radio astronomy, and passive earth exploration. With the exception of a couple of visible carrier lines, the band appears to be entirely unused. However, several frequencies are designated as radio quiet zones for radio astronomy. Hydrogen ions and hydroxyl (OH) have their spectral lines in this band and so scientist search these bands for cosmological activity. These quiet zones are also used for passive earth exploration by satellites. Because of the unique character, these channels cannot be used for terrestrial communication without interfering with the this important research. Also, satellite communication systems use this bands. Satellites may be as near as 100 kilometers or as far as tens of thousands of kilometers from the ground based user. Satellites have limited transmitter power which when received on the earth may have attenuated by hundreds of dB. The long path loss puts the power of these signals well below the noise floor of the equipment employed in this experiment. Land based satellite receivers usually employ high gain dish antennas and have highly sensitive receiver circuits. So while the graph indicates that the band is unused, we can not make that conclusion given that the apparatus is not sufficiently sensitive to detect the activity that is allocated in the channel.

3.3 The 1710-1850 MHz Frequency Band

The data for this band is shown in Figure 2. This band is allocated for fixed-mobile communication systems. The "minimum hold" trace seems to indicate that there are several constant carrier waves present in the band. However, all but one falls short of the -95 dBm threshold level. Again the conclusion that the band is under utilized is dubious.

3.4 The 1850-1990 MHz Frequency Band

The data for this band is shown in Figure 3. This band is allocated for Land Mobile Communication Systems. This commonly known as the Personal Communication Services (PCS) band which is a popular cellular telephone system. The frequencies from 1850 to 1910 MHz are assigned to up-link channels (the mobile device transmitting to the land-based network) and the frequencies from 1930 to 1990 MHz are assigned to down-link channels (the fixed site base stations transmitting to mobile devices). Because the base stations are connected to the power grid, they can transmit a great deal of power (as much as 100 watts). Because the base stations are large and stationary, they have expensive and bulky receivers that have a high degree of sensitivity. On the other hand, the mobile devices are small and lower power, hence they do not transmit as much power (perhaps 100 miliwatts) and there their receivers are lower in sensitivity. This asymmetry in transmitter power is clearly visible in the spectrum plots: The up-link side mirrors the down-link side but has 30 dB less power than the down-link side. As a consequence the down-link side registers above the indication threshold, and the up-link side falls below the threshold. In the utilization statistic, it appears as if the down-link side is fully occupied and the up-link side is not occupied. This cannot be the case because duplex telephone channels listen as often as they talk, so the utilization should be the same on both the up-link and down-link side. Because cellular phone service providers try to maximize their frequency utilization in order to maximize their revenues, the obvious conclusion is that this band has a nearly 100% utilization, yet the occupancy figure measures in at only 35%.

3.5 The 1990-2110 MHz Frequency Band

The data for this band is shown in Figure 4. This band is allocated for television (TV) auxiliary broadcasting, cable TV relays, and local TV transmission. On the spectrum plots, there indications for three TV signals, which may be the limit for this band. The occupancy figure is only 10% for this band, but the television signals are on contantly during the interval in question as can be seen on the duty cycle plot. Because they are analog signals, they may require the band gap to keep stations from interfereing with each other. The university operates a television transmission system which may transmit on these frequencies.

3.6 The 2110-2200 MHz Frequency Band

The data for this band is shown in Figure 5. This band is designated for Local Television Transmission Systems (LTTS), paging systems, utilities and railroads ,and satellite down-links. It is also used for microwave communication links and the new *IMT-2000* 3G communication systems. Only two carriers were detected above the power threshold and hence the occupancy figure is very low (not registering at all).

3.7 The 2200-2360 MHz Frequency Band

The data for this band is shown in Figure 6. The lower end of this band (2200-2290 MHz) is designated for space exploration usage. Communications and control to the space shuttle occurs in this band. A portion of this band (2290-2300 MHz) is designated for deep space probes. These vehicles can be several millions of miles from the earth, and the time delay is on the order of hours. The Voyager probe has moved beyond the solar system and is still communicating with large earth receiving stations. Because of the enormous distances, power levels are very low and the receiving stations require very large aperture antennas with cryogenic amplifiers in order to detect the signals. These signals will not be detected on commercial spectrum analyzers. The upper end of this band (2300 to 2360 MHz) is designated for Wireless Communication Systems (WCS) and Digital Audio Radio Services (DARS). Two DARS systems operate as the Sirius Radio (2320-2333.5 MHz) and XM Satellite Radio (2333.5-2345 MHz). While they operate as satellite systems for rural mobile customers, they are supplemented by terrestrial repeaters in urban settings. Hence the power indication shows that they fully occupy their respective broadcast bands. On the other hand, the WCS frequencies are unused.

3.8 The 2360-2390 MHz Frequency Band

The data for this band is shown in Figure 7. This band is designated for radio location (RADAR) systems. The only indication of any signal is at 2377 MHz which has very low utilization. This is typical of a RADAR system which directs energy around the plane and so it appears as an periodic beacon signal to any receivers of that frequency. Transmitters in the same band would interfere with the radio location function of RADAR and hence the band is not available for communication channels.

3.9 The 2390-2500 MHz Frequency Band

The data for this band is shown in Figure 8. The low end of this band (2390-2400) is designated for amateur radio usage and appears unused during the duration of the survey. The largest portion of this band is the Industrial, Scientific, and Medical (ISM) band (2400-2483.5 MHz). This is allocated for unlicensed low power spread spectrum communication systems. The power limit of one watt limits the range of such devices to approximately 100 feet. Devices in this band include microwave ovens, cordless phones, wireless networking and wireless instrumentation devices. The spectrum plot indicates that the band is fully used, but the occupancy (duty-cycle) figure is low. That may be due to the location of the receiver 200 feet above the ground. Also there may have been low activity in the time period under study. In the occupancy plot, there is one carrier wave present at 2420 MHz which may correspond to a cordless phone in the office tower which was off-hook. Our experience in the WIL is that this band sees much activity due to the proliferation of wireless networking devices. The occupancy figure of 2% seems suspicicious. At the high end of this band (2483.5-2500 MHz) is a satellite down-link band and oddly enough, it registers some activity.

3.10 Full Band Frequency Occupancy Plots

The last set of plots, Figure 10, is the occupancy of the full range of the instrument from nearly DC to to 2.5 GHz. The LPA antenna was not intended to operate below 900 MHz, but the frequencies below this limit are primarily allocated for broadcast communication sytems which transmit high power levels in order to be detected by ineffienct small antennea on simple receivers. Because of the nature of the high power broadcast channels, the communication channels were easily detected by the equipment. It is interesting to note that the band below 1 GHz appears to be fully occupied, while the band above 1 GHz (the range we have studied above) appears to be unoccupied. This explains the 31% occupancy for the full band. The bottom third is nearly 100% occupied and the upper two thirds are nearly unoccupied. While the band below 1 GHz may be fully occupied, we know that many of these legacy broadcast systems are not the most efficient users of spectrum (television and radio can radio can benefit from modern digital compression) and many include carrier waves which convey no information but are necessary for simple envelope dectection. In the low portion of the band the high occupancy figure may not correleate to efficient utilization. On the other hand, the low occupancy figures above 1 GHz may not necesarily mean that the spectrum is unutilized, it only means the activity (if there was any) was undetectable by the instrumentation. It is therefore dificult to base conclusions on efficient spectrum managemant from a snap shot of the occupancy figures.

4 Spectrum Occupancy or Spectrum Efficiency?

As was stated at the outset, the goal is identify heavily used spectrum, which may be overcrowded, and under utilized spectrum which may be available for new wireless communication services and technologies. The metric that is employed of spectrum occupancy may not be the best way to assess the efficient use of this valuable natural resource.

Several issues mitigate against using the spectral occupancy as a measure of efficient allocation practices. First there is the limitations of the experiment and the adequacy of the equipment to detect spectrum usage. Several of the bands use communication equipment with asymmetric channels. One side may have much transmit power power and high receiver sensitivity while the other side of the channel has low transmit power and limited receiver sensitivity. This is true of satellite systems, where common test equipment can not detect the low signal powers of the satellites. It is also true land-mobile systems which exhibit this power asymmetry on their up-link and down-link sides.

Another problem with measuring the occupancy of the channel is the peculiar nature of some wireless systems. In some systems, like analog broadcast radio and television, much of the power is transmitted in carrier waves which contain no information, but which register as occupied spectrum. Also, these system transmit much redundant data, like stereo channels, and color palettes. Their frequency allocation is used, but the efficiency may be low. Many legacy analog systems are particularly vulnerable to interference. It has been suggested that data can be sent in the null point of the television horizontal rescan signal, but that may cause some television sets to loose their horizontal sync and the quality of the reception would be impacted. Also, most communication systems require some degree of latency. Air traffic channels share one channel with many planes. The messages are very brief so that the channel can be kept open. It would be a dangerous prospect if others exploited the "unused" air time. A better measure would be the amount of information transferred and the relative value of that information. Such a metric would be ideal, but would be difficult to measure in practice.

The third factor mitigating against the occupancy figure as a useful measure of utilization is the underlying assumption that all RF spectrum is equally available, equally valuable, and easily exploited as a communication channel. There are some economically valuable uses of the limited RF spectrum that do not involve communication systems. Radio location systems (RADAR) is one case in point. Another example is radio astronomy which uses very sensistive instruments detect very low signals from cosmological sources. The assumption that communication services are the most valuable user of the radio spectrum is belied by the large amount spectrum allocated to commercial media outlets - for free!

5 Conclusions

We have studied the spectrum occupancy in the range of 960-2500 MHz. This is an attractive spectrum space for communication systems because the wavelengths are small enough for compact devices, and the frequencies are low enough to operate with common commercial electronics.

It is difficult to draw conclusions about the availability of RF channels and the utilization of spectrum bands due to the nature of frequency allocations, the limitations of the monitoring equipment, and the unique location and time frame of the experiment. Based on the occupancy measures, the conclusion can not be drawn that spectrum allocations are under utilized or inefficient.

References

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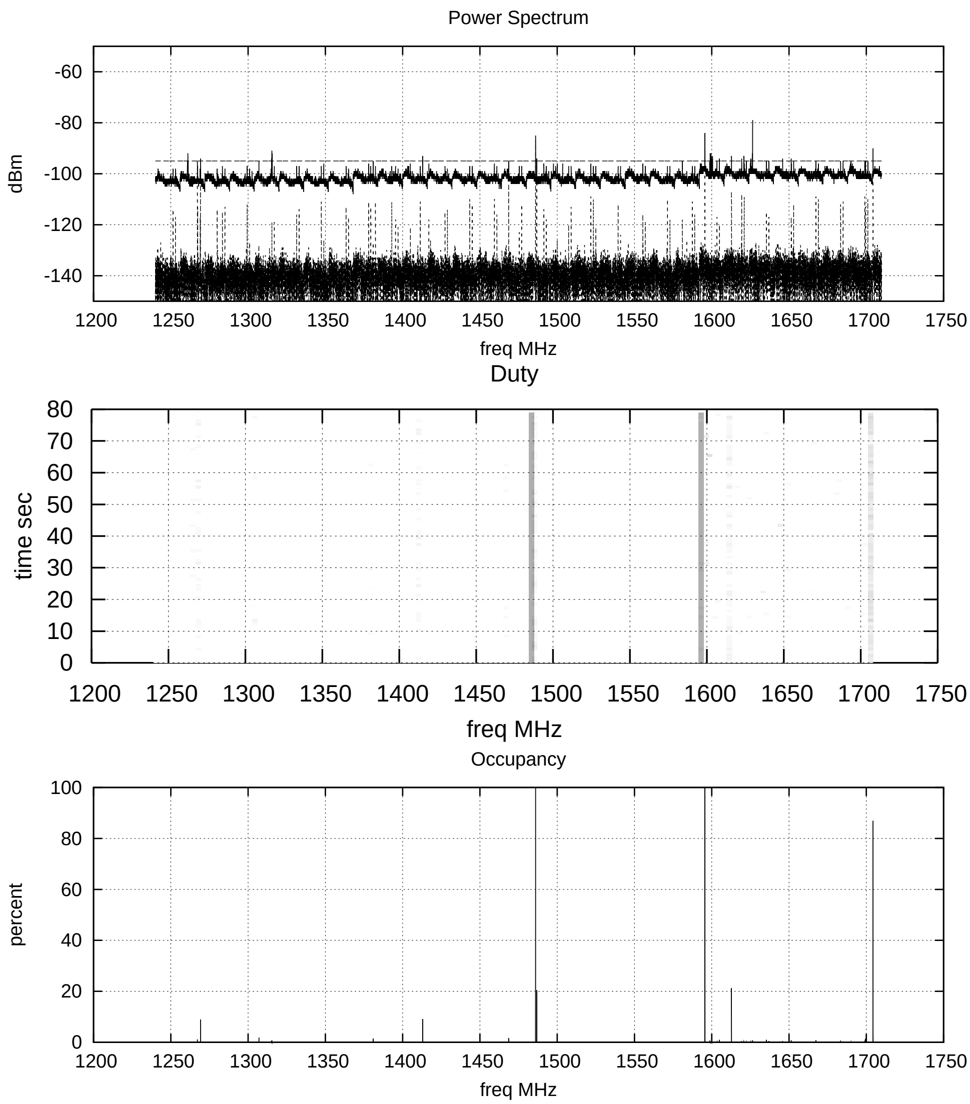
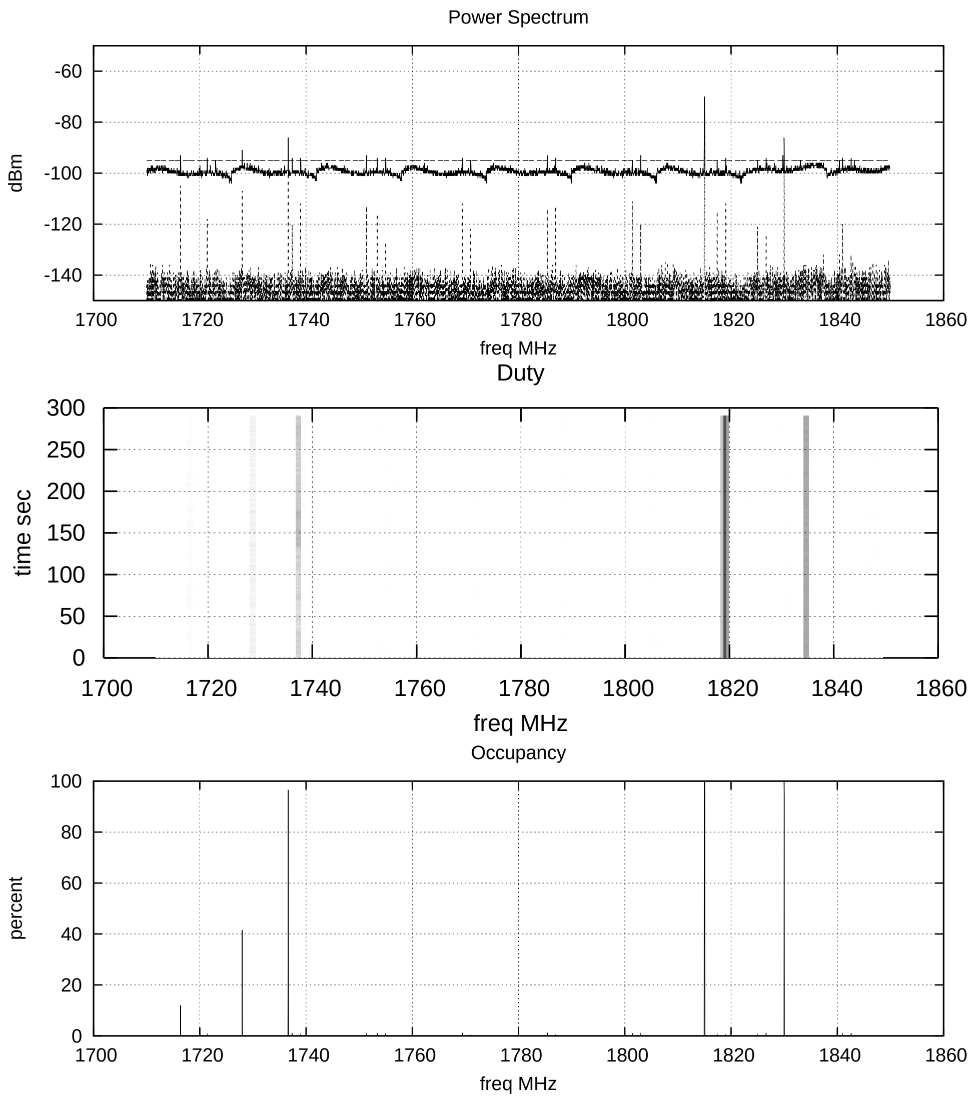
[5] Frank. H. Sanders and V.S.Lawrence, *Broadband Spectrum Survey at Denver, Colorado*, Report to the National Telecommunications and Information Administration of the US Department of Commerce, NTIA Rep. 95-321, September 1995



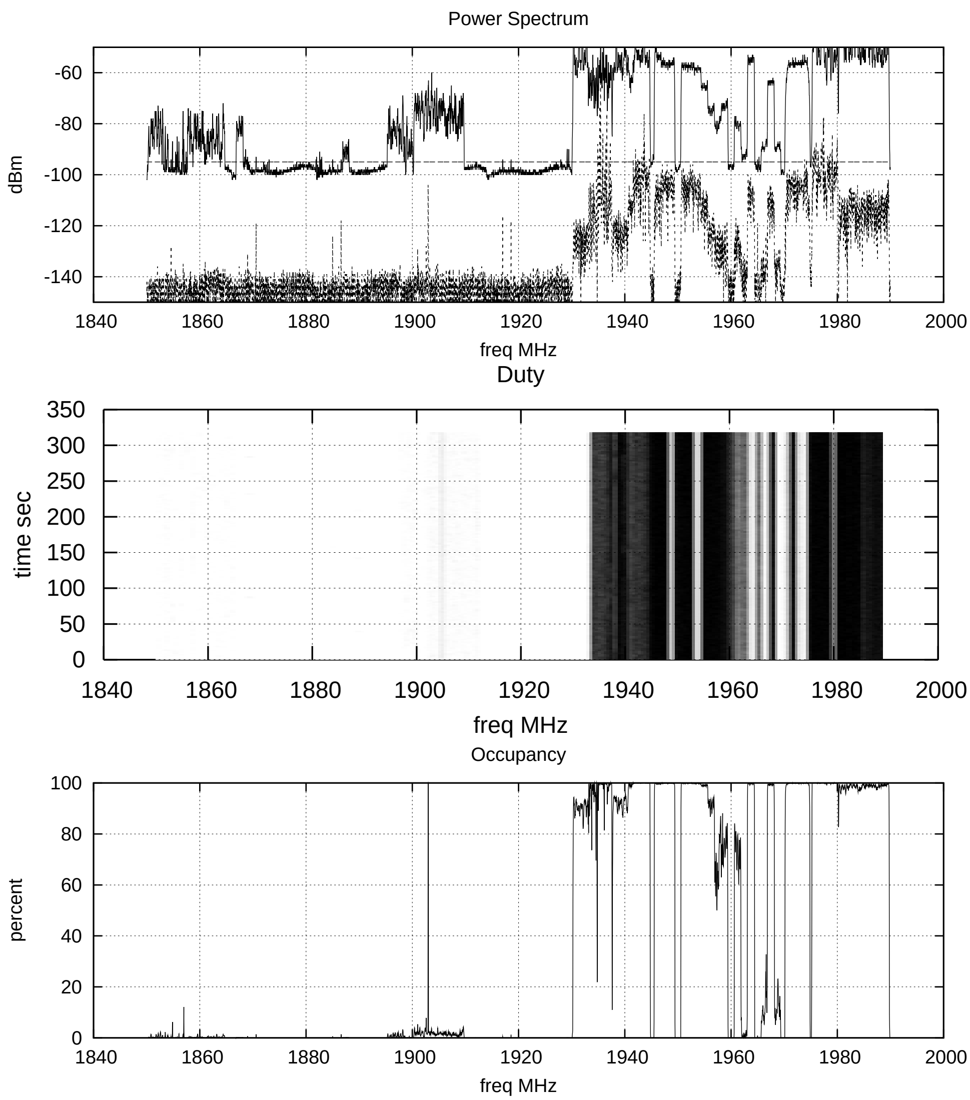
Start Freq.	1240	MHz
Stop Freq.	1710	MHz
Resolution	25	KHz
Attenuation	0	dB
Sample Points	18800	
Occupancy	0	Percent

Figure 1: Spectrum occupancy in the range of 1240-1710 MHz



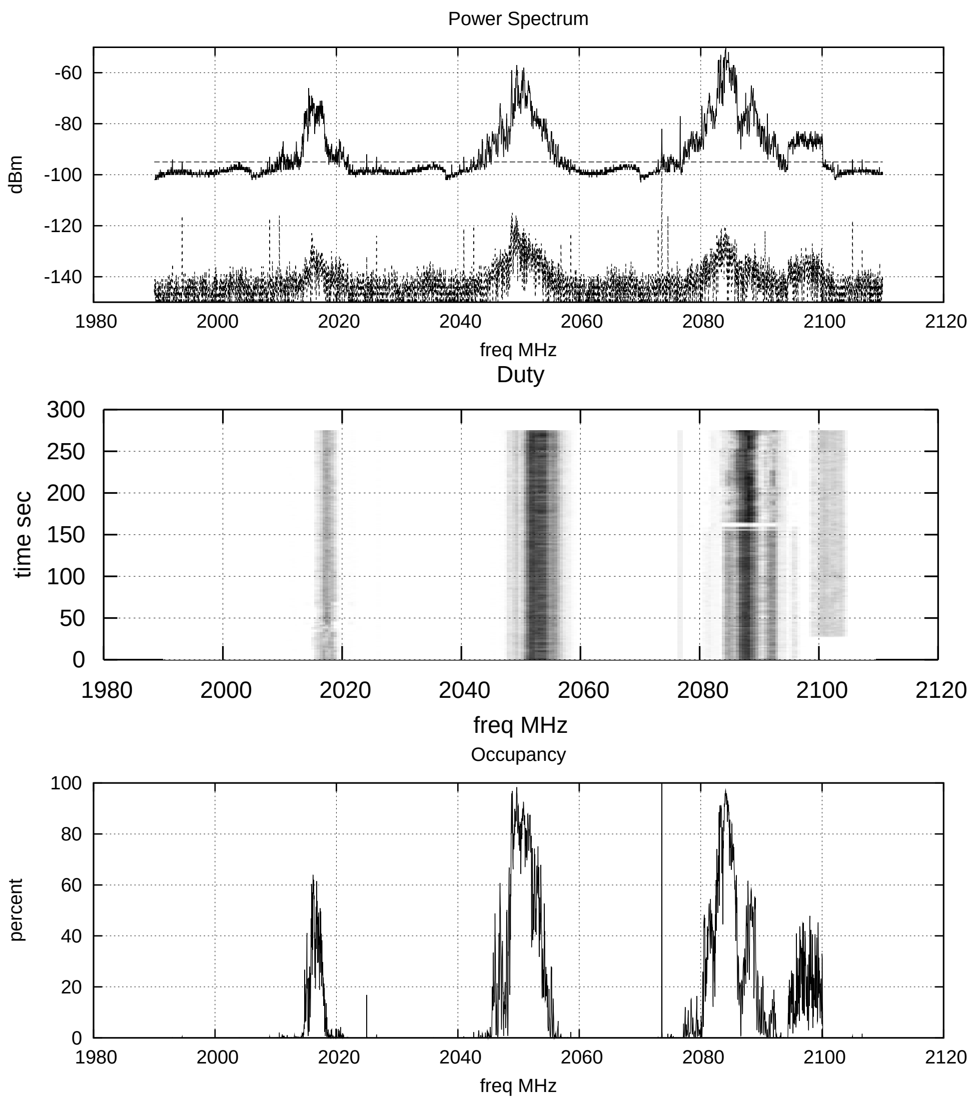
Start Freq.	1710	MHz
Stop Freq.	1850	MHz
Resolution	25	KHz
Attenuation	0	dB
Sample Points	5600	
Occupancy	0	Percent

Figure 2: Spectrum occupancy in the range of 1710-1850 MHz



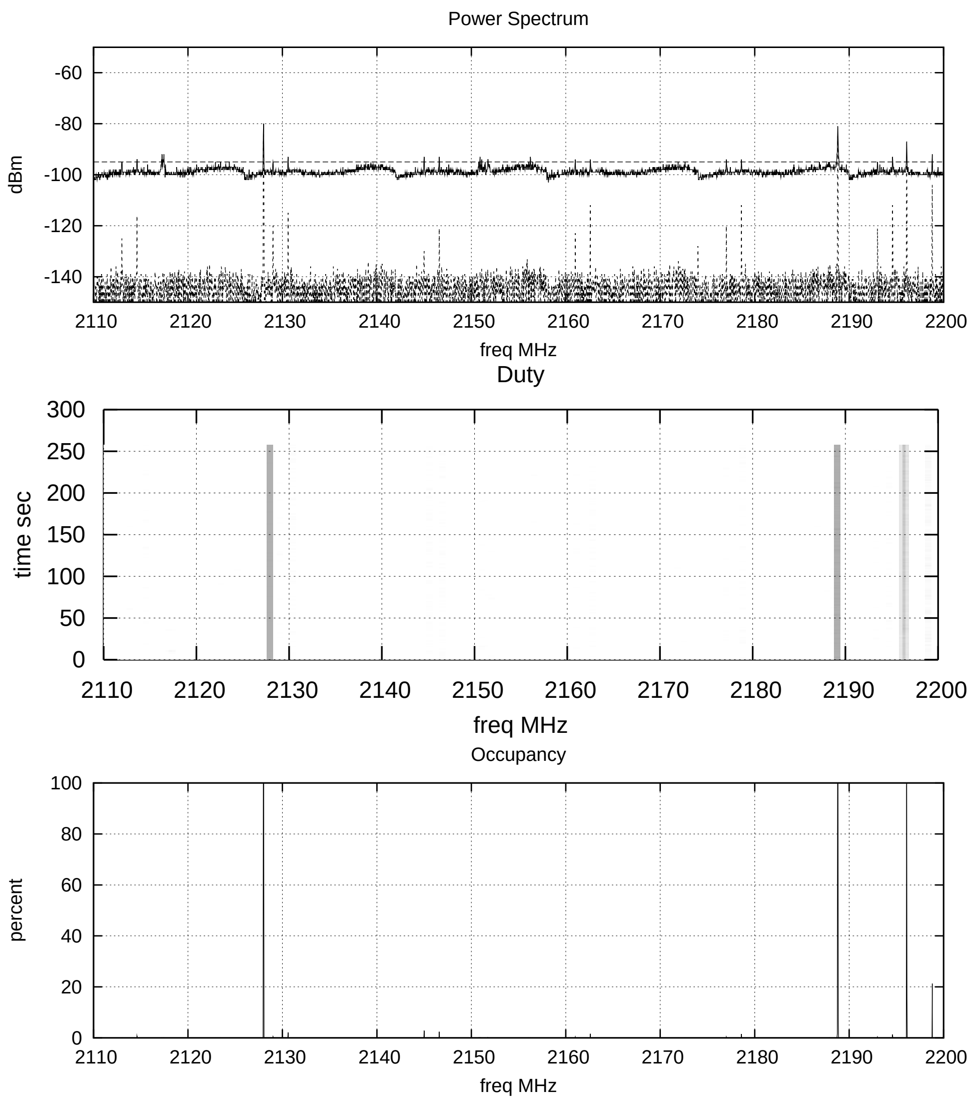
Start Freq.	1850	MHz
Stop Freq.	1990	MHz
Resolution	25	KHz
Attenuation	0	dB
Sample Points	5600	
Occupancy	35	Percent

Figure 3: Spectrum occupancy in the range of 1850-1990 MHz



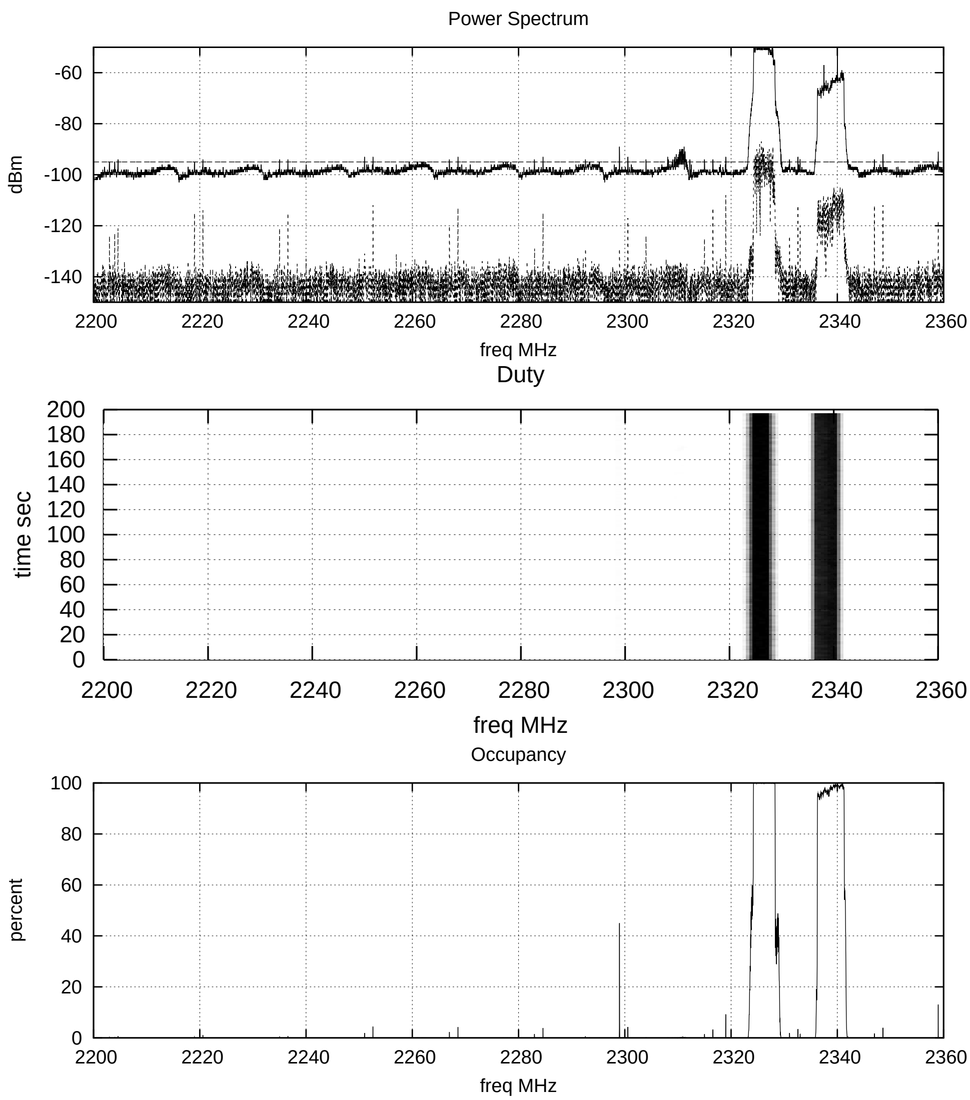
Start Freq.	1990	MHz
Stop Freq.	2110	MHz
Resolution	25	KHz
Attenuation	0	dB
Sample Points	4800	
Occupancy	10	Percent

Figure 4: Spectrum occupancy in the range of 1990-2110 MHz



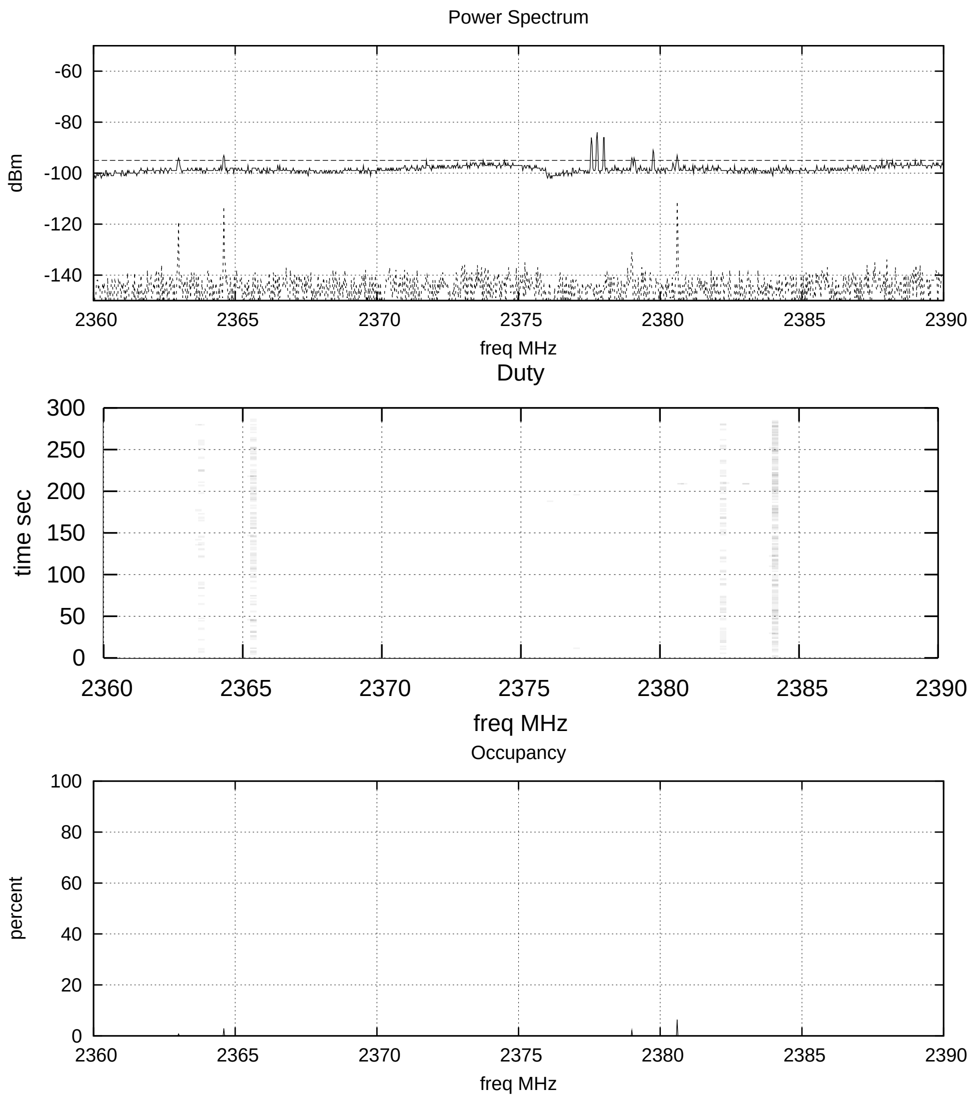
Start Freq.	2110	MHz
Stop Freq.	2200	MHz
Resolution	25	KHz
Attenuation	0	dB
Sample Points	3600	
Occupancy	0	Percent

Figure 5: Spectrum occupancy in the range of 2110-2200 MHz



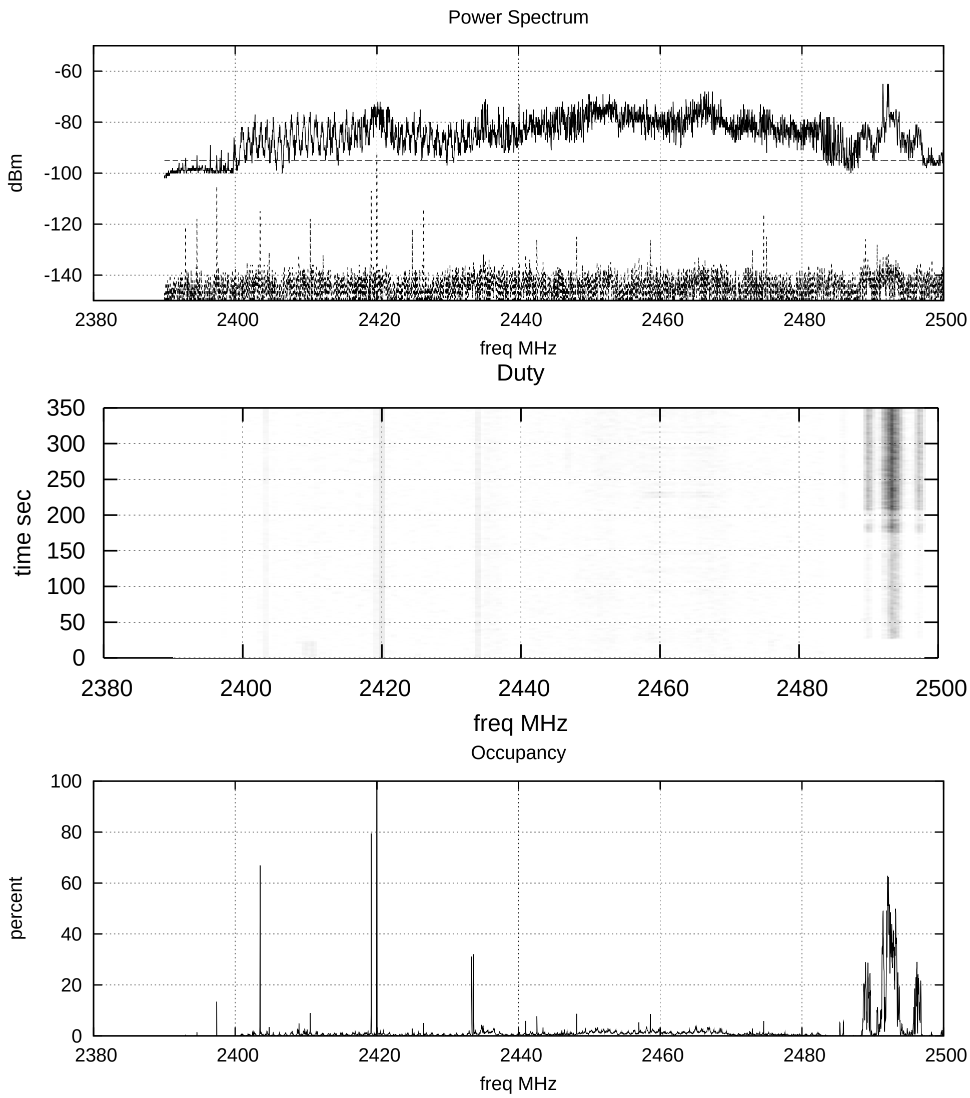
Start Freq.	2200	MHz
Stop Freq.	2360	MHz
Resolution	25	KHz
Attenuation	0	dB
Sample Points	6400	
Occupancy	6	Percent

Figure 6: Spectrum occupancy in the range of 2200-2360 MHz



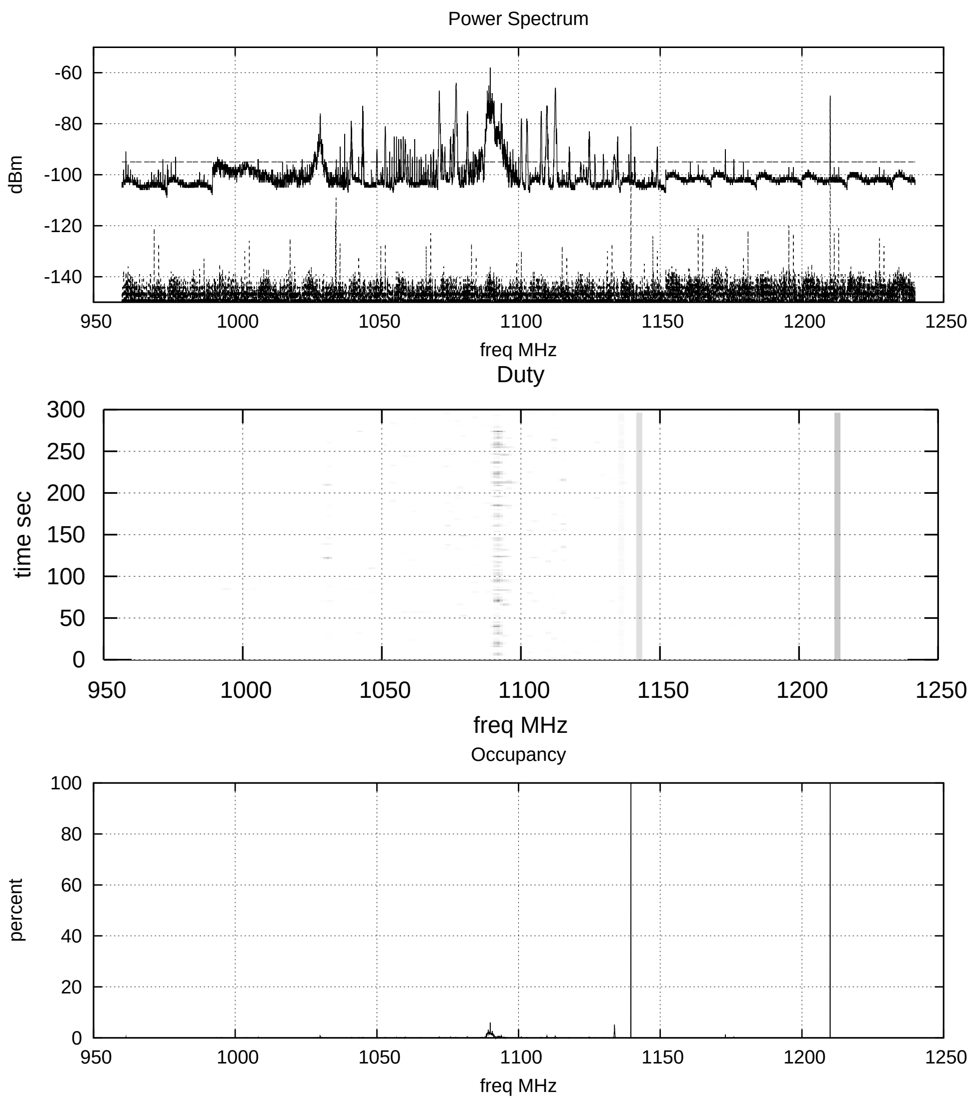
Start Freq.	2360	MHz
Stop Freq.	2390	MHz
Resolution	25	KHz
Attenuation	0	dB
Sample Points	1200	
Occupancy	0	Percent

Figure 7: Spectrum occupancy in the range of 2360-2390 MHz



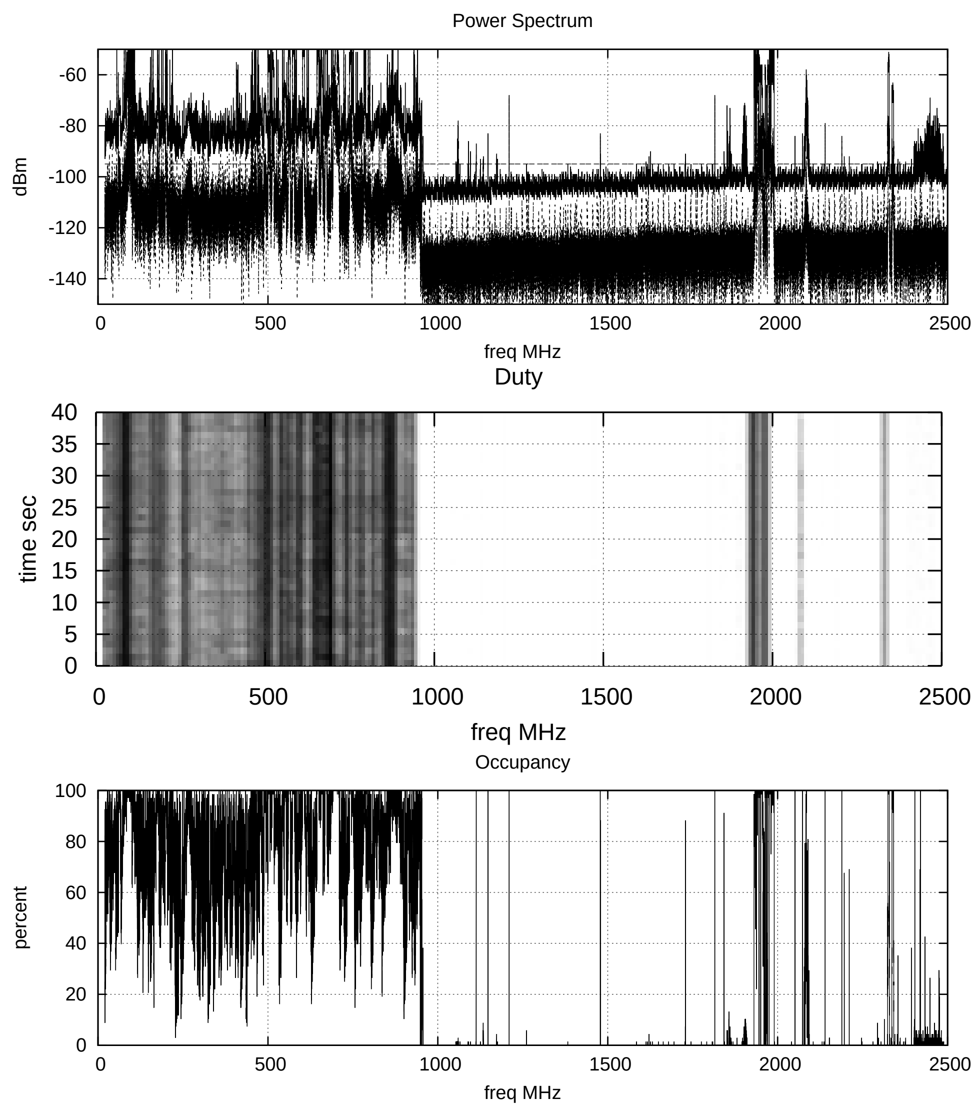
Start Freq.	2390	MHz
Stop Freq.	2500	MHz
Resolution	25	KHz
Attenuation	0	dB
Sample Points	4400	
Occupancy	2	Percent

Figure 8: Spectrum occupancy in the range of 2390-2500 MHz



Start Freq.	960	MHz
Stop Freq.	1240	MHz
Resolution	25	KHz
Attenuation	0	dB
Sample Points	11200	
Occupancy	0	Percent

Figure 9: Spectrum occupancy in the range of 960-1240 MHz



Start Freq.	20	MHz
Stop Freq.	2500	MHz
Resolution	25	KHz
Attenuation	0	dB
Sample Points	99200	
Occupancy	31	Percent

Figure 10: Spectrum occupancy in the range of 20-2500 MHz