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MEASUREMENTS TO CHARACTERIZE AGGREGATE SIGNAL EMISSIONS IN THE 2400-2500 MHz FREQUENCY RANGE

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ABSTRACT

This report provides the results of radio spectrum measurements performed to characterize the aggregate signal emissions present in the 2400-2500 MHz industrial, scientific, and medical (ISM) band and adjacent frequency bands. These measurements were performed at locations near Denver, Colorado and Los Angeles, California, and included various frequency domain and time domain tests utilizing omni-directional and directive antennas. The information contained in this report can serve as an aid to designers developing equipments to operate in these frequency bands, as well as authorities seeking to enhance compatibility between ISM devices and other radio services. It should be noted that the frequency bands 2400-2402, 2402--2417 and 2417-2450 MHz have recently been reallocated from Federal use to non-Federal use in response to the requirements of Title IV -- Communications Licensing and Spectrum Allocation Improvement -- of the Omnibus Budget Reconciliation Act of 1993. This further enhances the attractiveness of these frequency bands to equipment manufacturers.

KEY WORDS

Industrial, Scientific and Medical (ISM) Equipment
Microwave Ovens
Aggregate Environment
2300-2600 MHz

ACKNOWLEDGEMENT

This report could not have been completed without the efforts of the National Telecommunications and Information Administration (NTIA) Institute for Telecommunications Sciences (ITS). The ITS Spectrum Use Measurement Group provided data collected with the Radio Spectrum Measurement System. In particular, technical support from John Ewan was essential to the completion of the measurements.

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SECTION 1

INTRODUCTION

BACKGROUND

The National Telecommunications and Information Administration (NTIA) is responsible for managing the Federal Government's use of the radio frequency spectrum. NTIA's responsibilities include establishing policies concerning spectrum assignment, allocation and use, and providing the various departments and agencies with guidance to ensure that their conduct of telecommunications activities is consistent with these policies (NTIA Manual of Regulations and Procedures for Federal Radio Frequency Management). In support of these responsibilities, NTIA has undertaken a number studies to assess, spectrum utilization, identify existing and/or potential compatibility problems between systems of various departments and agencies, provide recommendations for resolving any compatibility conflicts, and recommend changes to promote efficient and effective use of the radio spectrum and to improve spectrum management procedures.

Increased demand for spectrum for mobile services has focused attention within the national and international radio communications community on the frequency bands between one and three gigahertz (GHz). Most of the new technologies will facilitate implementation of radio uses in the terrestrial personal mobile environment, including business and residential areas. Some will involve satellite technology, and manufacturers have considered this frequency range for both uplinks and downlinks. Aside from the identification and allocation of spectrum exclusively for these uses, sharing with existing activities could provide needed spectrum. In order to share spectrum with other radio frequency (RF) uses, the emission characteristics of those uses must be known.

Some service providers and manufacturers have developed new systems near or in the 2400-2500 MHz band, including, for example, a family of products to connect Ethernet local area networks in buildings up to five kilometers apart. The International Telecommunication Union (ITU) designates 2450 ± 50 MHz for use by industrial, scientific, and medical (ISM) equipment.[1] Among the ISM devices operating at that frequency are domestic microwave ovens. The presence of approximately 80 million of these ovens within the United States and over 200 million worldwide, and the investment in terms of industry costs and public outlays, make microwave ovens a major factor in considering options for future radio use of 2400-2500 MHz

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[1] *ITU Radio Regulations $752,* International Telecommunication Union, Geneva, Switzerland, 1990, p. RR8-105.

and surrounding bands.[2] While some potential radio services may operate in an environment where signals from individual ovens are the primary concern, for other radio services the aggregate microwave oven emissions may have a greater impact. Therefore, characteristics of both individual and aggregate microwave oven emissions must be determined. The potential economic impact of these radio-based technologies makes resolution of issues related to compatibility with microwave ovens essential.

In 1991, the NTIA undertook a study to determine if the Broadcast Satellite (Sound) Service (BSS) could be accommodated between 2300 and 2400 MHz. Measurements performed by the Institute for Telecommunications Sciences (ITS) showed that microwave ovens emit RF energy across a wide spectrum, with high peak levels outside the frequency band designated for ISM use. Subsequent analysis concluded that microwave oven emissions must be taken into account in BSS system design through incorporation of sophisticated signal processing techniques, such as time and frequency interleaving and forward error correction.[3]

The results of this previous NTIA study, and the requirement to ensure that U.S. manufacturers and radio users are adequately considered in the CISPR deliberations, necessitated additional testing and analysis to more accurately determine the level of emissions from individual ovens, the level of aggregate emissions in large metropolitan areas, and the level of emissions outside the 2400-2500 MHz band acceptable to authorized radio services. On this basis, NTIA began a three-part effort to

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[2] Other ISM devices include, for example, industrial and commercial grade ovens or heaters for curing and drying of commodities, medical diathermy equipment, and plasma generators. Though many of these systems operate at higher power levels than domestic microwave ovens, their fewer numbers may lower the impact on use of radio systems near the 2400-2500 MHz band. One other potential use of the 2400-2500 MHz band which may become significant in future years involves the development of "RF light bulbs". These devices, incorporating microwaves bombarding gaseous compounds, have been touted as cheaper, safer, and more environmentally friendly than traditional incandescent and fluorescent lights. If they can provide those benefits, and become commercially available, they could become significant sources of concern to radio systems developed for that band.

[3] Filippi, C.A., R.L. Hinkle, K.B. Nebbia, B.J. Ramsey, and F.H. Sanders, NTIA Technical Memorandum 92-154, *Accommodation of Broadcast Satellite (Sound) and Mobile Satellite Services in the Band 2300-2450 MHz,* Department of Commerce, National Telecommunications and Information Administration, January 1992, p. 2-3.

1. measure the emissions from a number of new microwave ovens, checking the impact of measurement procedures on the results, and reviewing the utility of measurement procedures in assessing compatibility of oven emissions,

2. measure the aggregate levels of emissions in the 2300-2600 MHz band near large metropolitan areas,

3. determine the level of emissions acceptable to a variety of receiver technologies and formulate appropriate emission limits and methods of measurement.

The first of these tasks was completed in early 1994, and the results presented in an NTIA document titled “Radio Spectrum Measurements of Individual Microwave Ovens.”[4] This report provides documentation of the data collected in support of the second task -- namely characterization of the aggregate emissions in the 2300-2600 MHz band near large metropolitan areas. Though the majority of the data collected is concentrated within the 2400-2500 MHz band, data were collected which are representative of the surrounding frequencies.

OBJECTIVE

The objective of this task is to provide data to characterize the aggregate signal emissions present in the 2400-2500 MHz ISM band and adjacent frequency bands.

APPROACH

Due to the large number of unanswered questions about potential communications equipments for the 2400-2500 MHz frequency band (e.g. receiver bandwidth, type of receiving antenna, etc.), care was taken to make the tests as generic as possible. Toward this end, six types of data were collected:

A. Frequency Domain Data (versus measurement bandwidth and time of day),
B. Time Waveform Data (20 millisecond sweep, peak detected),
C. Time Waveform Data (20 millisecond sweep, sample detected),
D. Time Waveform Data (60 second sweep, peak detected),
E. Time Waveform Data (60 second sweep, sample detected), and
F. Omni Antenna versus Directional Antenna Tests,

and each is described in detail in the following paragraphs.

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4 Gawthrop, P.E., F.R. Sanders, K.B. Nebbia, and J.J. Sell, NTIA Report 94-303-1 and - 2, *Radio Spectrum Measurements of Individual Microwave Ovens, 2* Volumes, Department of Commerce, National Telecommunications and Information Administration, March 1994.

The Frequency Domain data were intended to provide the system developer with both an indication of band usage as "viewed through" a variety of different receiver bandwidths, and with an insight into the expected diurnal cycle of microwave oven usage. The diurnal cycle data were also utilized to ensure that the time waveform and antenna type data were collected during the periods of peak activity. A complete listing of measurement parameters is contained in Appendix A.

The time waveform tests (B-E) were intended to provide "snapshots" of the type of signals present in the environment, both over the short term, and over a longer "averaged" time interval. Both "worst case" and "average" characterizations were made.

One potential use postulated for this band involves some form of fixed point-to-point microwave service. This type of usage would most probably involve a directional receive (and probably transmit as well) antenna. As a result, tests were performed to determine if the aggregate environment somehow changed when the receive antenna was directive instead of omnidirectional -- for example did the use of a directional antenna allow single ISM transmitters to be discriminated from the aggregate environment?

SECTION 2

RULES AND REGULATIONS

ALLOCATIONS

In the United States the 2400-2500 MHz frequency band is allocated as shown in Table 1.

Table 1: Current United States Frequency Allocations (2400-2500 MHz)

Band (MHz)	Govt. Allocation	Non-Govt. Allocation	Remarks
2400-2402		AMATEUR	ISM 2450±50 MHz
2402-2417		AMATEUR	
2417-2450	RADIOLOCATION	AMATEUR	
2450-2483.5		FIXED MOBILE Radiolocation	
2483.5-2500	RADIODETERMINATION-SATELLITE (space-to-Earth) MOBILE-SATELLITE (space-to-Earth)	RADIODETERMINATION-SATELLITE (space-to-Earth) MOBILE-SATELLITE (space-to-Earth)	

Enhancing the attractiveness of this band to equipment manufacturers is the fact that required by Title VI -- Communications Licensing and Spectrum Allocation Improvement -- of the Omnibus Budget Reconciliation Act of 1993, the Secretary of Commerce has provided, from the spectrum allocated for Federal use, an aggregate of 235 MHz for allocation by the Federal Communications Commission (FCC) to non-Federal users.[5] Included in these 235 MHz, are 50 MHz from the 2400-2500 MHz band. Specifically, the 2400-2402 MHz band, and the 2402-2417 and 2417-2450 MHz bands have recently been reallocated.

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5 Hurt G.F., E.A. Cerezo, E.F. Drocella Jr., D.E. Kitzmiller, R.C. Wilson, NTIA Special Publication 95-32, *Spectrum Reallocation Final Report*, Department of Commerce, National Telecommunications and Information Administration, February 1995.

Reallocation of the entire 2400-2450 MHz band provides the FCC with the opportunity to develop a long-term framework and strategy that meets the needs of the amateur service while addressing the requirements of a robust and growing industry of non-licensed devices authorized under FCC Part 15 Rules. Under a mixed use reallocation, the Federal allocation will be reduced to secondary, with the limited remaining Federal presence posing no impact on non-Federal use. This action provides the opportunity to have significant spectrum available for long-term development of non-licensed technologies. Furthermore it provides significant opportunities for innovators and small companies to make contributions to the overall mix of products and services available to the American public.

REGULATIONS AND STANDARDS

In the past, commercial interest in these frequencies has been somewhat tempered by the fact that national and international regulations specify that radio operations in the ISM bands must accept harmful interference that may result from ISM applications. Also, in order to promote ISM use of ISM designated bands, no U.S. or international ISM emission limits have been applied between 2400 and 2500 MHz, or, for that matter, within any of the ISM bands. Thus design of radio equipment to operate in the 2400-2500 MHz band represents a significant challenge.

Outside the ISM bands, emission limits have been established by the FCC, and adopted by the NTIA, to enhance compatibility between microwave ovens and radio services.[6] Though national and international regulations stipulate that ISM equipment must not cause interference outside the ISM bands, enforcement of this regulation for domestic microwave ovens could be both difficult and expensive due to the large number in the hands of the public. Furthermore, if interference to a radio service occurs, it may be caused by an aggregate of microwave oven sources, not a single oven. Therefore, since enforcement of this out-of-band emission regulation may be impractical, radio communications system developers designing equipment for near term implementation must design their equipment to be compatible with the existing RF emissions environment. Implementation of new services and technologies in the long term provides more flexibility since there may be time to update emission standards for microwave ovens. In order for applicable emission limits to continue to facilitate compatibility, spectrum management authorities must periodically review and revise them, consistent with the requirements of future radio systems.

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6 Emission standards and measurement approaches pertaining to radio interference and electromagnetic compatibility are distinct from those dealing with radiation hazards to people. Within the efforts addressed in this report, NTIA did not measure emissions in a manner applicable to evaluate bioeffects. Radiation hazard aspects are regulated by the Food and Drug Administration under *Title 21, Code of Federal Regulations*, Section 1030.10, "Performance Standards for Microwave and Radio Frequency Emitting Products".

The International Special Committee on Radio Interference (CISPR) Subcommittee B is currently developing international limits for ISM emissions above 1 GHz.[7] Subcommittee discussions have focused on the emission limits of domestic microwave ovens. The levels emitted by ovens currently in use, the manufacturers ability to limit emissions outside the ISM band (with associated costs), and the needs of radio users constitute the primary factors considered in establishing the limits. The outcome of CISPR discussions will potentially impact U.S. oven manufacturers by establishing the most widely used standard for microwave ovens sold outside the United States. If the FCC chooses to have its standards conform to CISPR, these discussions will impact equipment designed for the U.S. market as well. The lifespan of microwave ovens creates a situation where standards implemented today, and microwave ovens built to those standards, will affect the electromagnetic environment of radio systems to be placed in operation ten or more years in the future.

[7] CISPR is a body of the International Electrotechnical Committee (IEC) and develops industry standards for preventing radio interference. The American National Standards Institute (ANSI) provides U.S. representation.

SECTION 3

MEASUREMENTS AND ANALYSES

PROCEDURES

All data were collected utilizing the NTIA Radio Spectrum Measurement System (RSMS). The RSMS is a mobile, essentially self-contained computer-controlled radio receiving system capable of a wide variety of measurement scenarios over a frequency range of 50 MHz to 22 GHz. These measurements are usually conducted in an automatic mode with computer control of software algorithms that tailor the RSMS to detect and measure characteristics of the various radio emitters that occupy the observed spectral band.

Data collection using the RSMS was accomplished at several different geographic locations. The first site was in Denver, CO, and for that testing, the measurements were performed during the week of August 29 through September 1, 1994 both at a public parking lot located at the intersection of 16th and Sherman Streets in downtown Denver, and from a site on Genesee Mountain overlooking, and about 16 kilometers west of, Denver. Data were also collected in the vicinity of Los Angeles, CA, specifically from an IIT Gilfillan antenna test range located at an old Nike anti-aircraft missile site on top of a mountain near Valencia, CA. The location afforded an almost unobstructed view of Los Angeles, including the Burbank, Van Nuys and Los Angeles International Airports, and many residential, business, and light industrial neighborhoods. In addition, the site had the advantage of having virtually no nearby 2400-2500 MHz emitters, with the possible exception of microwave ovens at a Fire Station located approximately 400 meters to the east.

Two basic types of data were collected during the testing, conventional spectrum analyzer sweeps across the frequency band of 2300-2600 MHz (Frequency Domain data), and Time Waveform "zero-span" sweeps at selected frequencies within that same frequency band. In each case a variety of analyzer bandwidths were utilized, and sufficient data were collected to allow averaging and other types of statistical interpretation. The amount of data collected (about megabytes) necessitated the use of data reduction techniques in order to provide a workable set for analysis. In order to perform any data analysis however, the method of data detection must be well understood. For these tests the primary data collection devices were spectrum analyzers, so a brief discussion of the operation of those spectrum analyzers is warranted.

<u>The Spectrum Analyzer</u>

In simplest terms, the spectrum analyzers employed operate by tuning to a user-defined frequency and measuring the amount of energy present at that frequency in a user-defined measurement bandwidth. These measurements are performed such that 1001 points are recorded Within any set of user-defined scan limits --limits which could be, for example, start/stop frequencies for the frequency domain measurements, or start/stop times for time waveform measurements. The method utilized by the spectrum analyzer to determine the 100 I-point recorded data is integral to any analysis of the potential impact of the sampled RF environment on other equipments.

The algorithms of interest – *peak* and *sample* modes – are best explained through the use of an example. Suppose that the user requirement was that 20.02 milliseconds of time waveform data be collected on frequency 2450 MHz, with a measurement bandwidth of 300 kHz.

(20020 microseconds)÷(1001) recorded samples) = 20 microseconds per sample

The spectrum analyzers utilized in the measurement program incorporate analog detectors which determine the energy present in the selected measurement bandwidth. For +*peak mode,* the largest detected signal level during that 20 microsecond (µsec) period is used as the recorded sample. This results in a "worst case" snapshot of the time waveform. Conversely, in *sample mode,* the signal level registered on the detector at the end of the 20 µsec period is recorded. This methodology tends to present a more "averaged" view of the actual time waveform. Either or both of these characterizations of the RF environment could be of interest to an equipment manufacturer dependent on their particular design constraints.

For all tests, two spectrum analyzers were used simultaneously. This was accomplished such that direct comparisons could be made, either:

1. through the use of one analyzer as a "control" (i.e. two measurements using different test setups and separated in time could be compared as each would have a companion data set collected under a standard set of bandwidth, detector type, etc. conditions), or,

2. in the omnidirectional versus directional antenna, by ensuring that both antennas were measuring the same environment.

Once the data were collected, post-test processing was performed to derive sets sufficiently small to be workable. For the Frequency Domain testing, the reduction scheme used was min/mean/max processing, while the Time Waveform measurements were reduced through the use of amplitude probability distributions (APDs).

The min/mean/max processing was as follows. For each tested IF bandwidth, approximately thirty, 10-second sweeps were performed. In each sweep, 1001 measurements, on 1001 frequencies equally spaced across the 2300-2600 MHz band, were stored. Recall, as outlined above, the stored value was either the maximum (for +Peak) or last (for Sample) sampled value depending on the sampling mode selected. When all of the sweeps were completed the data collection software reviewed the data and for each of the 1001 frequencies recorded the minimum, mean and maximum values of the thirty stored samples. Post-test processing software allowed like-data sets (e.g. same IF bandwidth and sampling mode) to be further combined to construct min-of-mins, mean-of-means, and max-of-maxs curves.

For each IF bandwidth/center frequency combination, approximately 150,000 Time Waveform data samples were collected and stored. In order to analyze this pool of data, APDs were constructed to test the hypothesis that in the aggregate, the ISM signals combined so as to result in simply Gaussian noise at a level elevated above that of purely thermal noise. Plotting samples from a Gaussian distribution as the amplitude of the sample versus the percentage of samples which exceed that amplitude, results in the characteristic curve shown in Figure 1. If the APD of the aggregate ISM signals matched the shape of Figure 1, then the hypothesis would be supported.

RESULTS

Analyses of the data provided several interesting insights that should be useful to designers developing equipments for the 2400-2500 MHz ISM band. These observations are described below. As noted above, a considerable amount of data were collected during this effort. Though all of the data was examined, only a representative sample is reproduced in this report. Appendix A contains a complete listing of the tests performed.

a) General: Review of the data leads to several general observations. First, limited activity was noted in the frequency band from 2300 to 2400 MHz. This is not completely unexpected, as the band is allocated for amateur use and telemetry in flight testing of aircraft, spacecraft, and missiles at military and NASA centers.

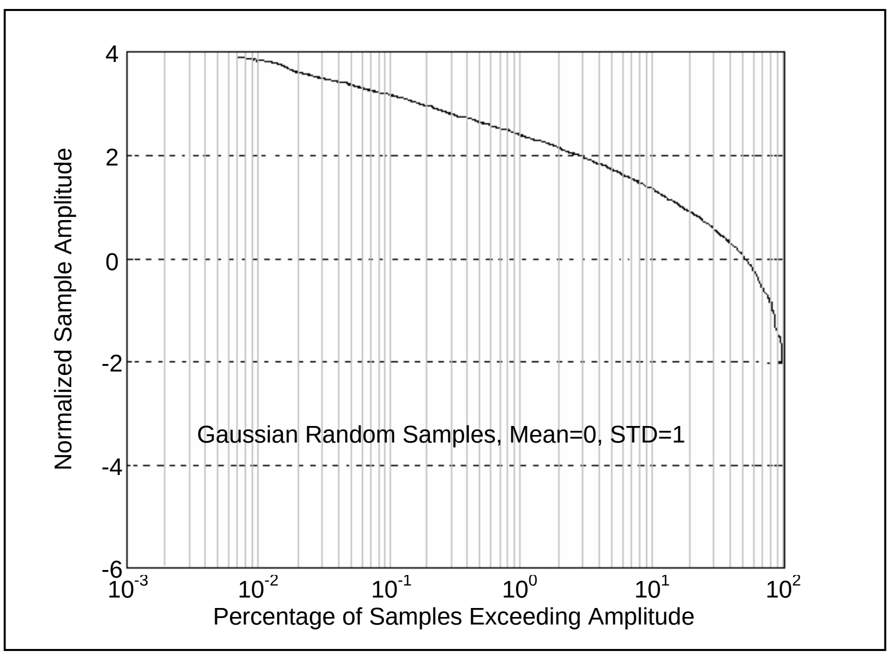

Figure 1: Amplitude Probability Distribution of a Sample of Gaussian-Distributed Random Amplitude Signals.

The relatively large signals noted in some spectra plots in the vicinity of2380 MHz were examined and found to be very narrowband, and therefore it is unlikely that they are artifacts of 2400-2500 MHz ISM equipment transmissions. Secondly, over the band of principal interest, 2400-2500 MHz, the primary usage was concentrated toward the upper part of the band (e.g. 2420-2500 MHz), and peak signals were generally noted in the 24502460 MHz region. In general, the shape of the aggregate signal spectrum was consistent with that noted in the single microwave oven tests described in reference 4. Finally, the upper part of the monitored band (2500-2600 MHz) shows significant activity, especially in the Los Angeles CA data. These frequencies are employed for '"wireless cable" entertainment programming in Multichannel Multipoint Distribution Service (MMDS), closed circuit educational TV transmissions in the Instructional Television Fixed Service (ITFS), and private video teleconferencing.

b) Background and Dominant Oven Environments: Two types of aggregate ISM environment were noted: background only, without dominant oven sources, and background with dominant oven sources. As described later in this report, the former environment had the characteristics of Gaussian noise, while the latter included a component identical to the signals observed during the single oven testing (reference 4).

c) Diurnal Variation: Data sets were collected hourly over a 24 hour period. The background ISM signal did not display any noticeable variation with time-of-day. As shown in Figures 2 through 5, the data collected at the Los Angeles location, away from any "dominant oven" sources reveals a 2400-2500 MHz usage that is fairly devoid of diurnal cycling. Although the case could be made that use of the band did decrease during the very early morning (e.g. 1-4 AM) hours, the reduction was not significant. This could be due to there being a variety of applications for domestic microwave ovens apart from just meal cooking; or the full time operations of industrial or commercial ISM equipment.

In the downtown location, spectrum monitoring did reveal an apparent diurnal cycle, where the signal peaked during the morning, noon and evening hours (see Figures 6 through 9). These periods coincide with the breakfast/lunch/dinner periods, and close scrutiny of the data revealed that the spectral amplitudes of the aggregate signal were being influenced by signals from nearby dominant oven sources. As most of these dominant oven sources were located in restaurants in the area, their usage obviously did follow a diurnal cycle, resulting in a cycling of the monitored aggregate signal.

d) Aggregate Signal Amplitude: Statistically, the aggregate signal at any given frequency is similar to Gaussian noise -- albeit at an elevated level. This assertion is supported both by the shape of the signal amplitude probability distributions (see Figures 10 and 11), and the approximately 10log (BW1/BW2) relationship evident between measurements performed with varied receiver bandwidths (see Figures 12-13 and Table 2). As with the diurnal variation data, this characterization is tempered somewhat when "dominant oven" signals are evident. As shown in Figure 14, signals from those dominant oven sources appear identical to those measured in the single-oven tests, though riding on an elevated noise floor. These dominant oven signals result in the "second hump" apparent in some APDs of the time waveform data (see Figure 15). This feature is not as evident in the APDs of data collected far from those dominant sources.

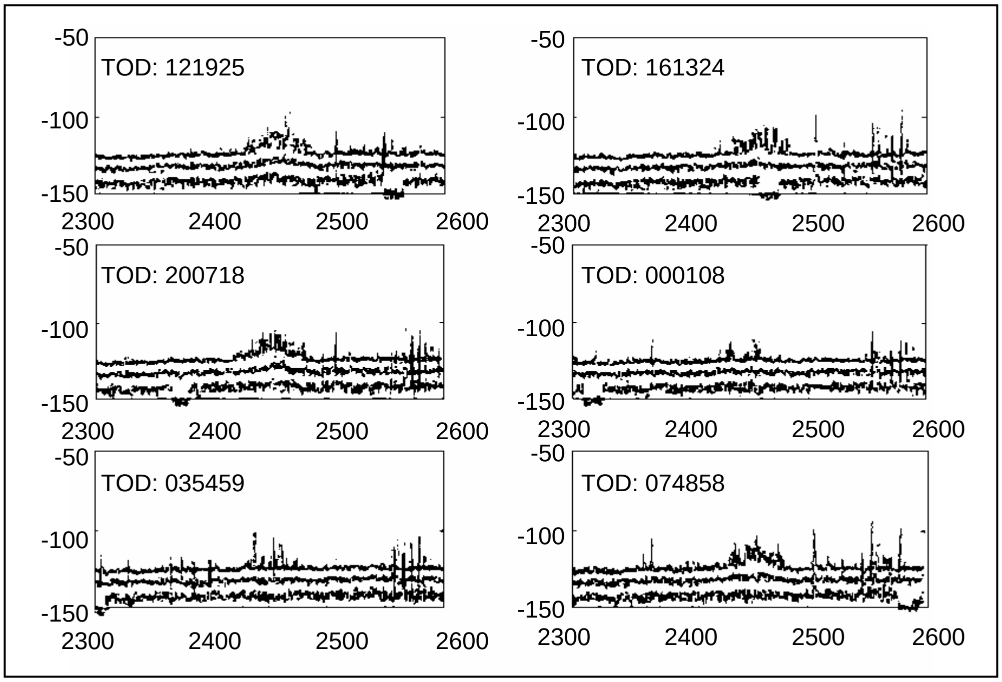

Figure 2: Diurnal Variation in 2300-2600 MHz Spectral Usage, Sample Mode, 30 kHz Receiver BW, Los Angeles CA Data, Amplitude(dBm) vs. Frequency(MHz)

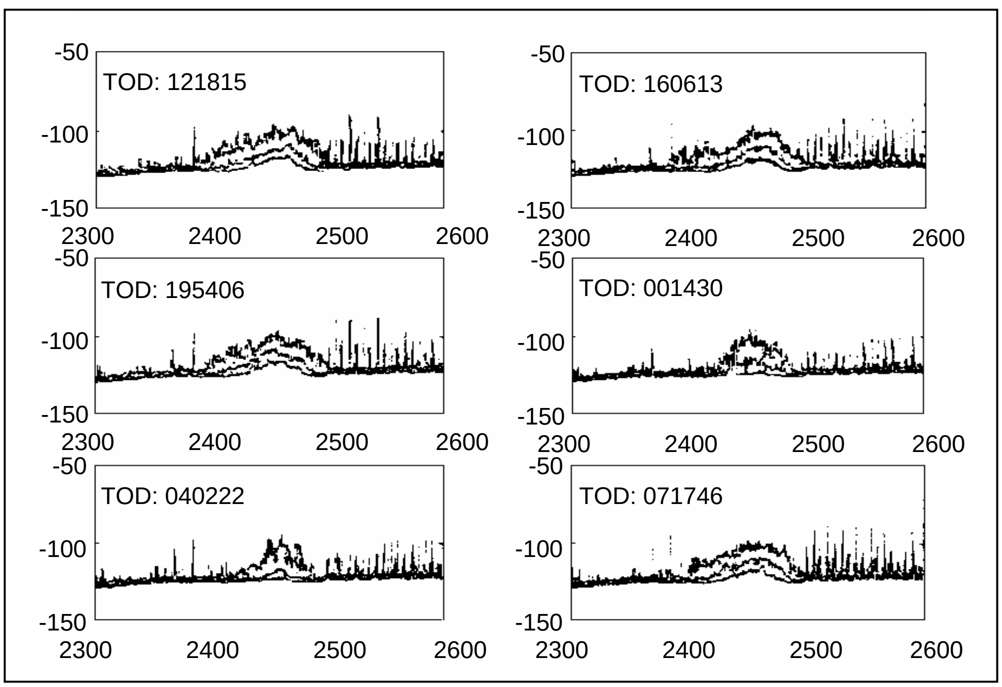

Figure 3: Diurnal Variation in 2300-2600 MHz Spectral Usage, +Peak Mode, 30 kHz Receiver BW, Los Angeles CA Data, Amplitude(dBm) vs. Frequency(MHz)

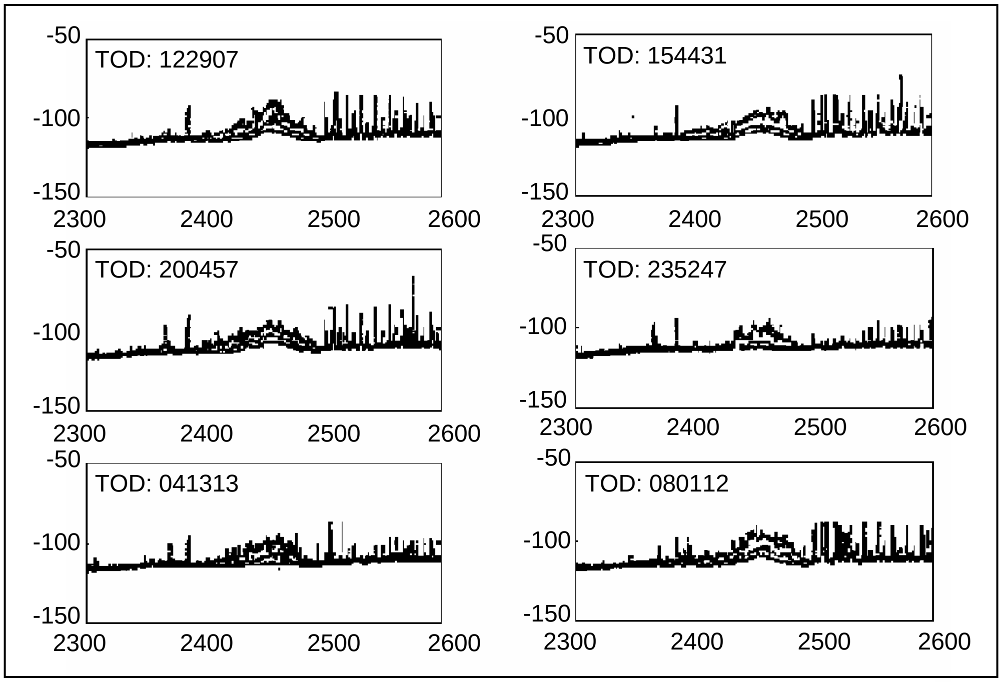

Figure 4: Diurnal Variation in 2300-2600 MHz Spectral Usage, +Peak Mode, 300 kHz Receiver BW, Los Angeles CA Data, Amplitude(dBm) vs. Frequency(MHz)

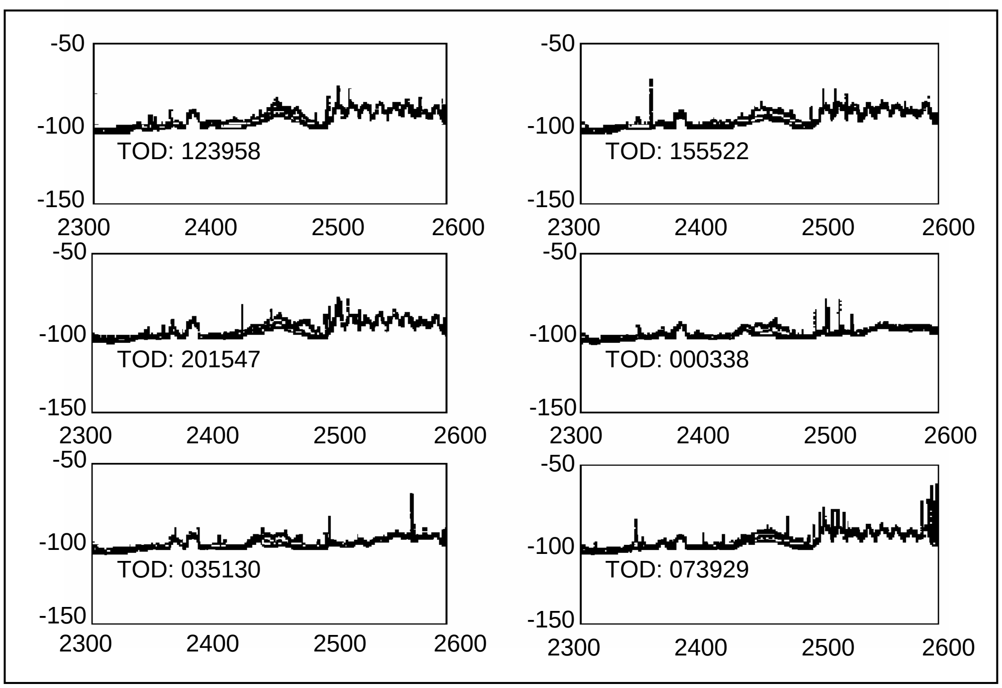

Figure 5: Diurnal Variation in 2300-2600 MHz Spectral Usage, +Peak Mode, 3 MHz Receiver BW, Los Angeles CA Data, Amplitude(dBm) vs. Frequency(MHz)

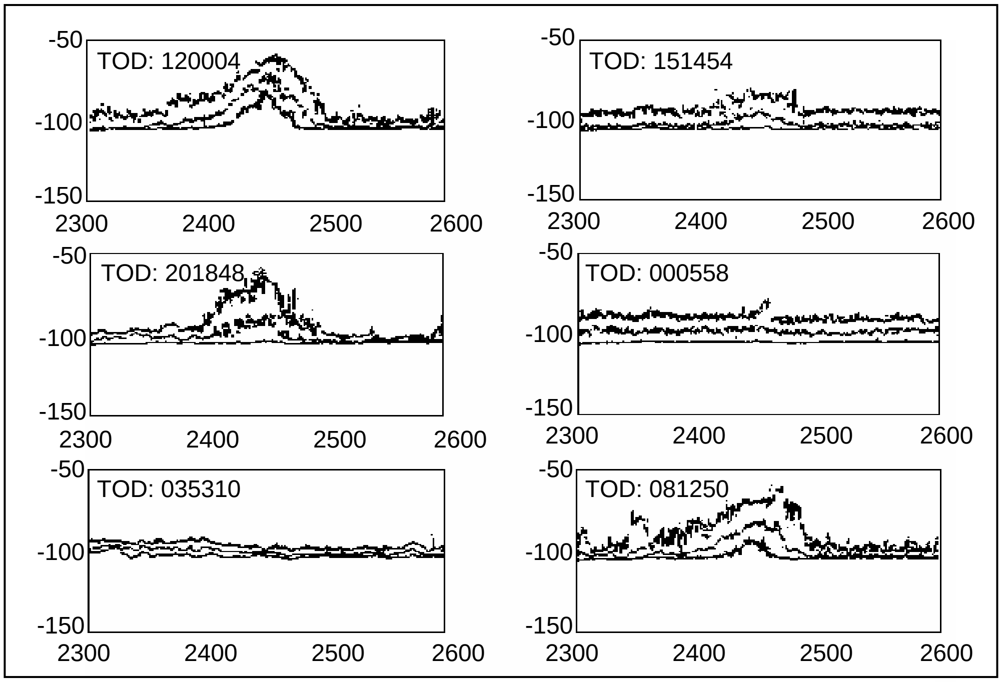

Figure 6: Diurnal Variation in 2300-2600 MHz Spectral Usage, +Peak Mode, 300 kHz Receiver BW, Downtown Denver CO Data, Amplitude(dBm) vs. Frequency(MHz)

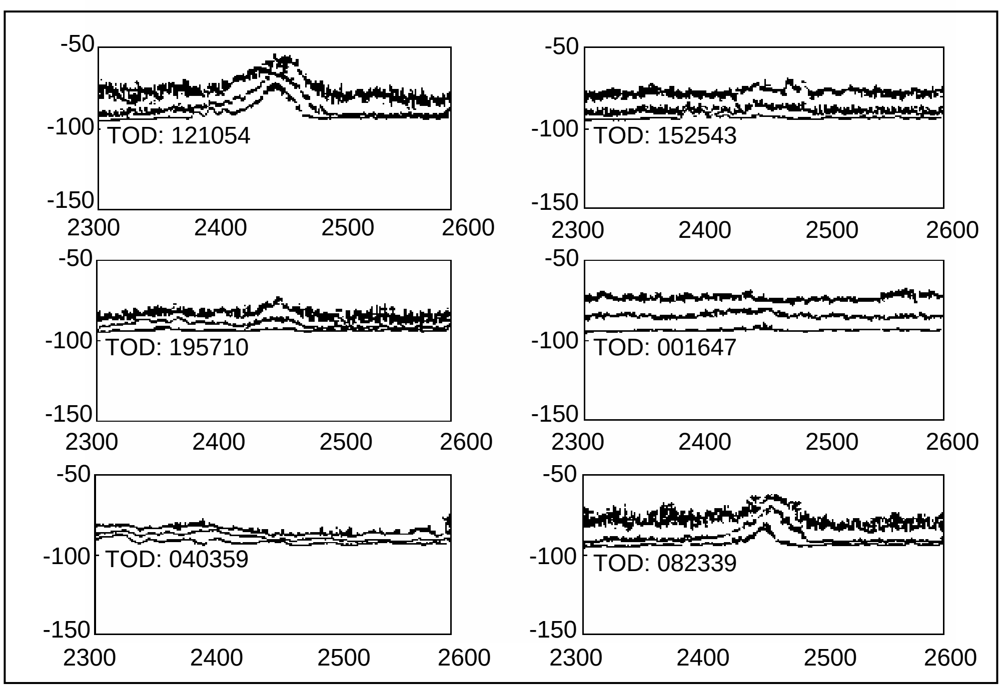

Figure 7: Diurnal Variation in 2300-2600 MHz Spectral Usage, +Peak Mode, 3 MHz Receiver BW, Downtown Denver CO Data, Amplitude(dBm) vs. Frequency(MHz)

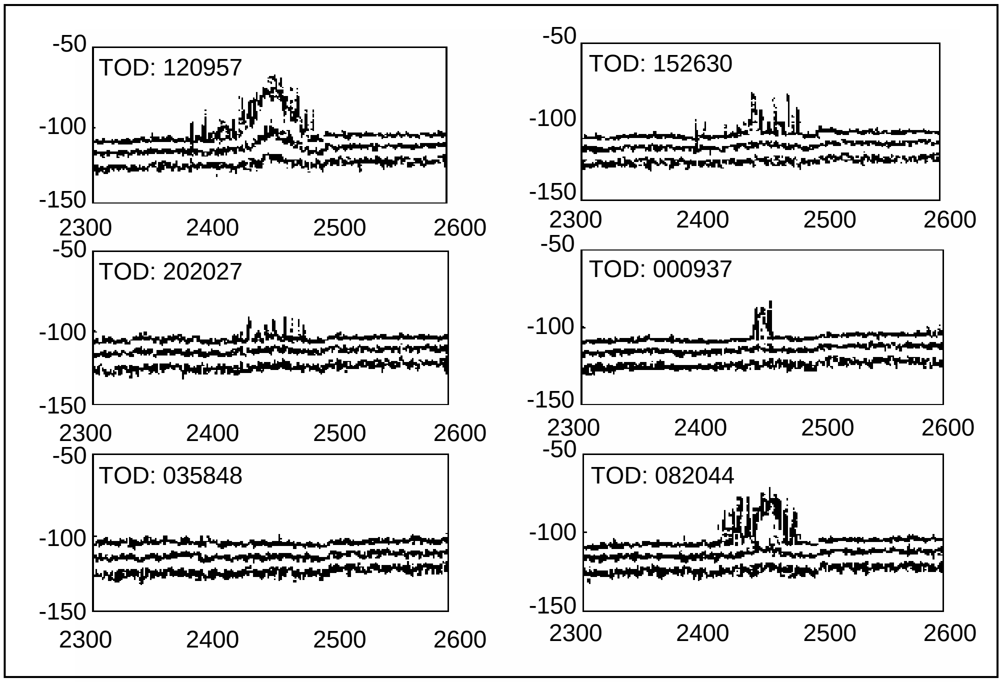

Figure 8: Diurnal Variation in 2300-2600 MHz Spectral Usage, Sample Mode, 300 kHz Receiver BW, Downtown Denver CO Data, Amplitude(dBm) vs. Frequency(MHz)

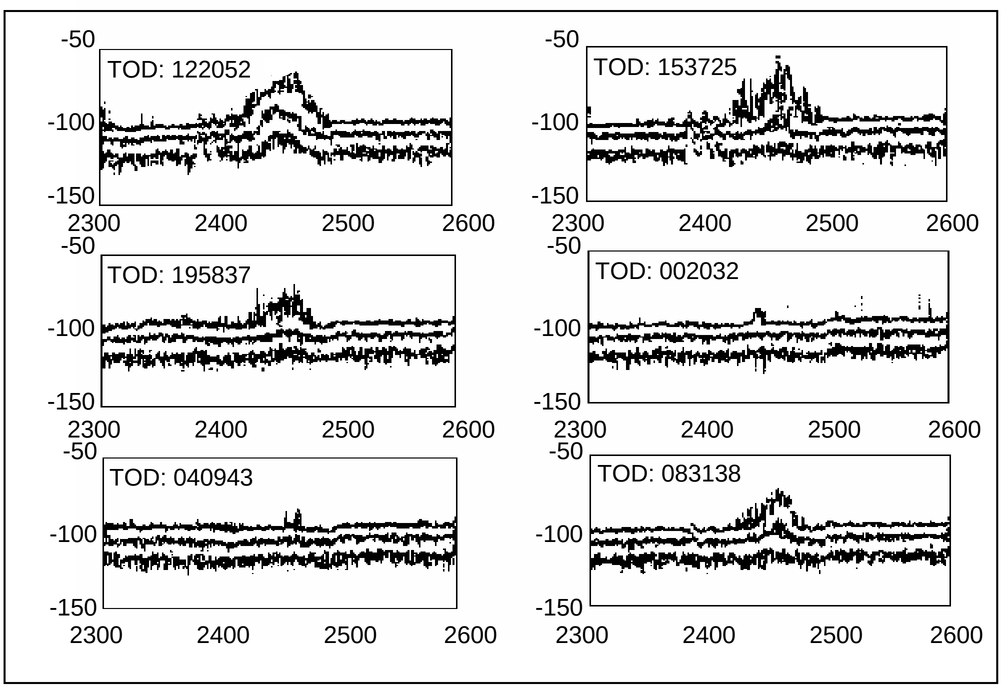

Figure 9: Diurnal Variation in 2300-2600 MHz Spectral Usage, Sample Mode, 3 MHz Receiver BW, Downtown Denver CO Data, Amplitude(dBm) vs. Frequency(MHz)

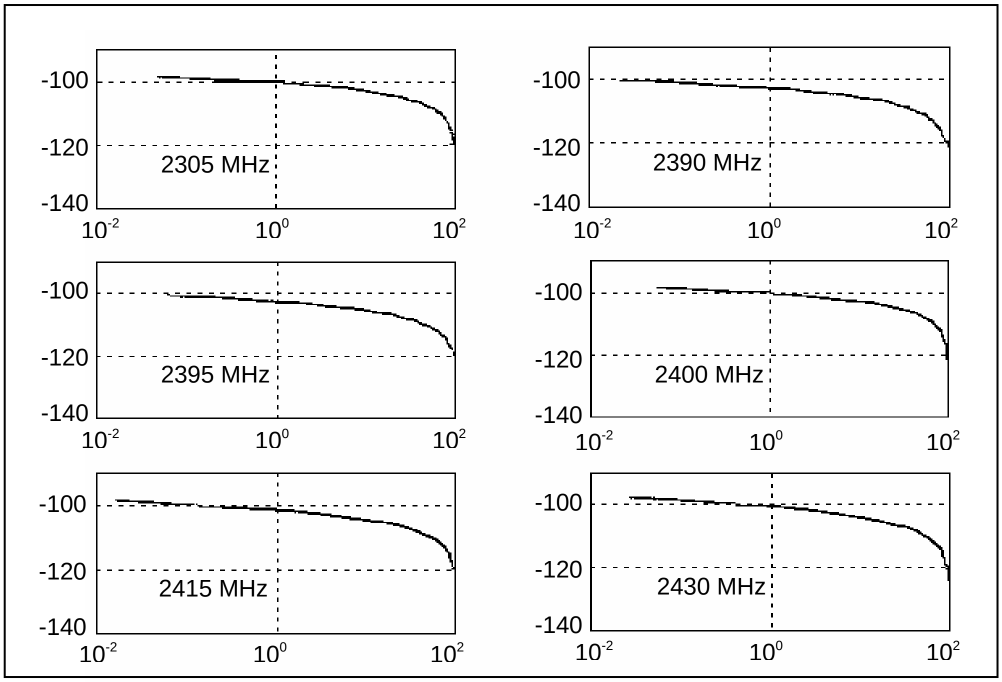

Figure 10: Amplitude Probability Distributions, Indicated Frequency, Sample Mode, 3MHz Receiver BW, Los Angeles CA Data, Amplitude(dBm) vs. Percentage of Samples Exceeding that Amplitude

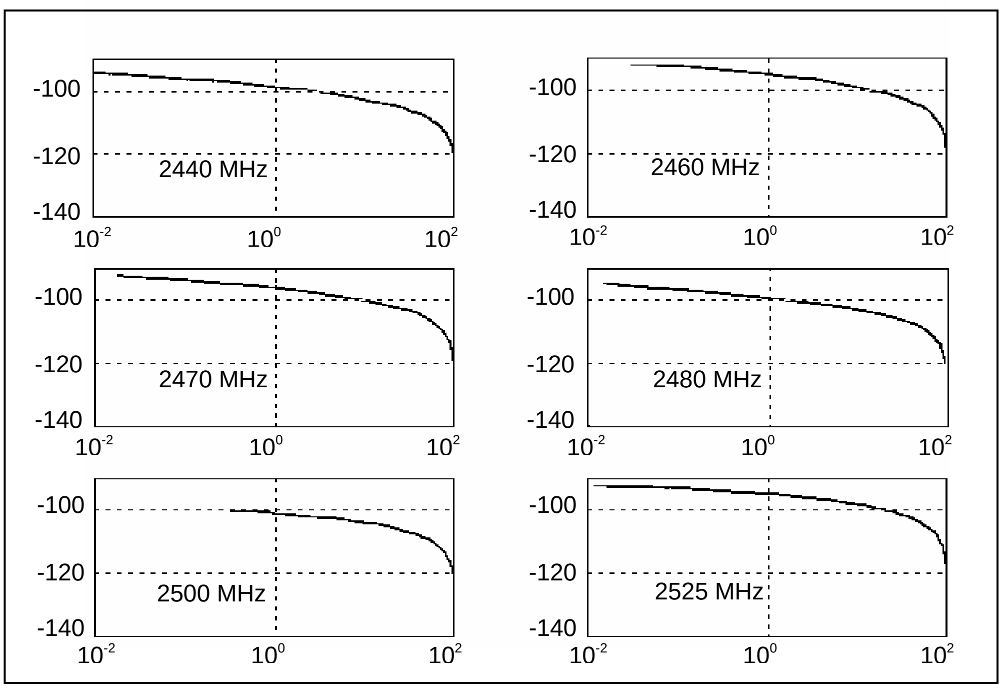

Figure 11: Amplitude Probability Distributions, Indicated Frequency, Sample Mode, 3MHz Receiver BW, Los Angeles CA Data, Amplitude(dBm) vs. Percentage of Samples Exceeding that Amplitude

Table 2: Measured Amplitude Probability Distribution Values, LA Data, Sample Mode, 2450 MHz

Receiver Bandwidth	Amplitude Exceeded in Indicated Percentage of Measurements (dBm)				
	90%	50%	10%	1%	0.01%
30 kHz	-136	-128	-122	-113	-100.5
100 kHz	-130	-122	-116	-108	-96
300 kHz	-124	-116	-108	-102	-94
1000 kHz	-118	-110	-104	-99	-94
3000 kHz	-114	-106	-100	-96	-91

e) Omni versus Directional Antennas: As described above, a limited amount of testing was performed to determine whether the aggregate ISM signal characteristics would be altered by the utilization of a directional receive antenna instead of an omni-directional antenna. Using two spectrum analyzers, one connected to a directional antenna and the other connected to an omni antenna, simultaneous measurements of the aggregate signal environment were made. For aggregate signal sources which are distributed uniformly within an area around the measurement system receiver and/or the desired signal source, there does not appear to be much of an advantage to utilizing a directional antenna (see Figures 16 through 18). This is a result of the fact that while the directional antenna allows for spatial discrimination of the aggregate signal, the increased directive gain of the antenna more than compensates for that spatial attenuation. If however the desired signal source is in a different direction from the sources comprising the aggregate signal, the directivity of the antenna could provide an advantage. Use of the directional antenna did not appear to result in any change in the number of "dominant oven" sources detected.

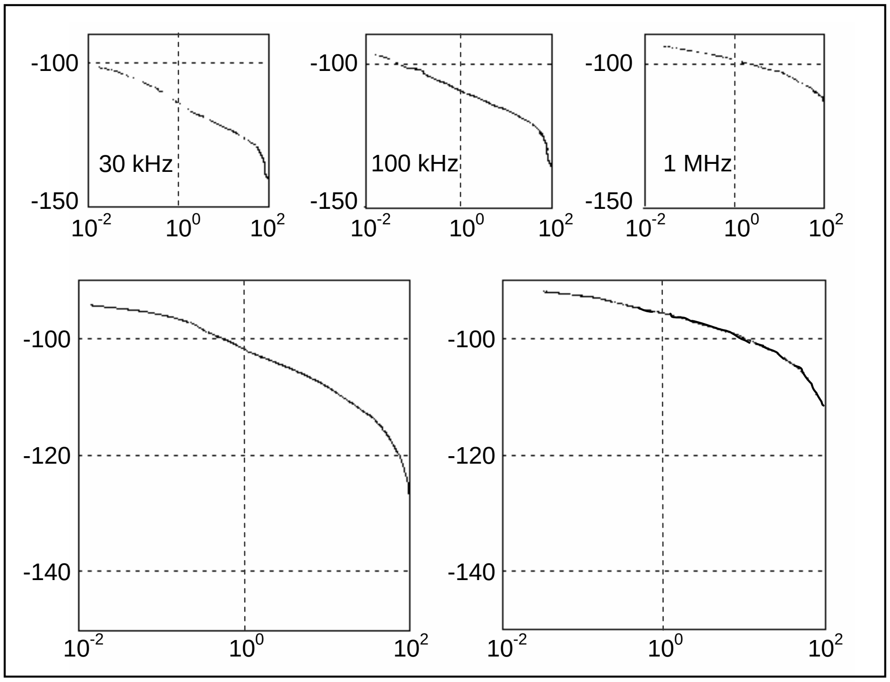

Figure 12: Amplitude Probability Distributions, 2450 MHz, Sample Mode, Indicated Receiver BW, Los Angeles CA Data, Amplitude(dBm) vs. Percentage of Samples Exceeding that Amplitude

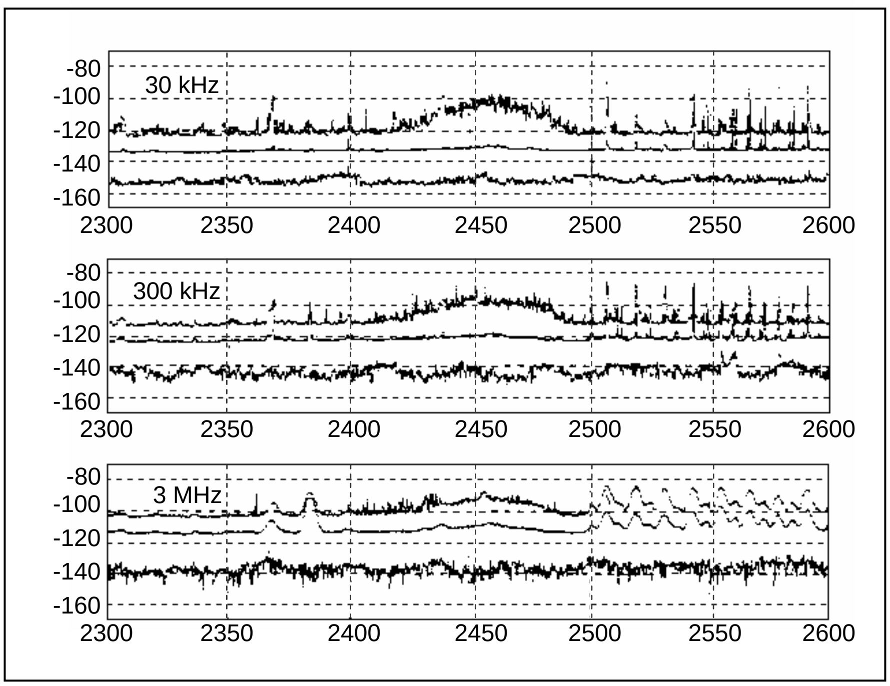

Figure 13: Cumulative Spectra Usage, Sample Mode, Indicated Receiver BW, Los Angeles CA Data, Min of mins, Mean of means, and Max of maxes, Amplitude(dBm) vs. Frequency(MHz)

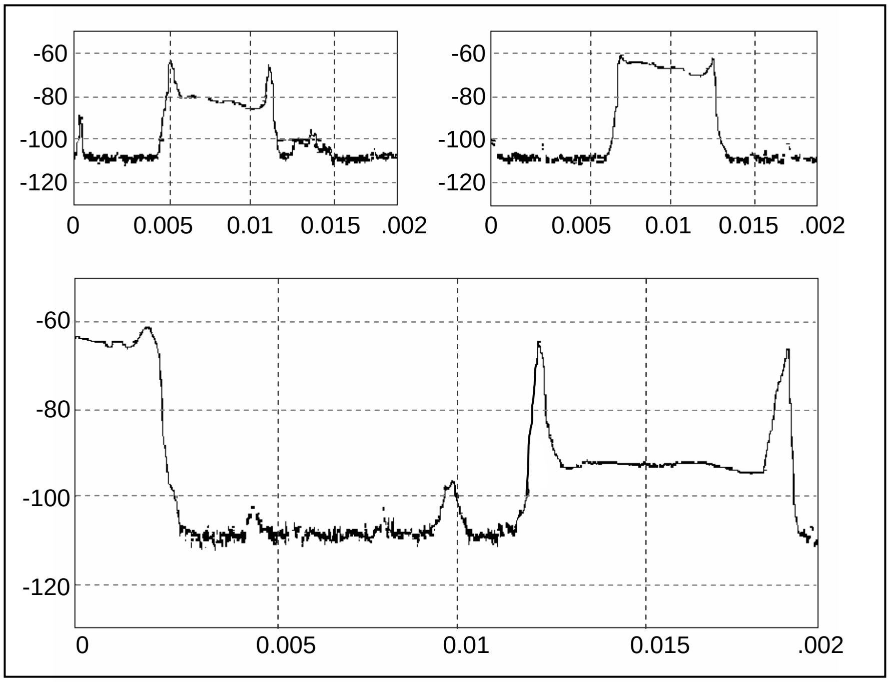

Figure 14: Sample “Dominant Oven” Time Waveforms, 2460 MHz, +Peak Mode, 300 kHz Receiver BW, Downtown Denver CO Data, Amplitude (dBm) vs. Time (sec).

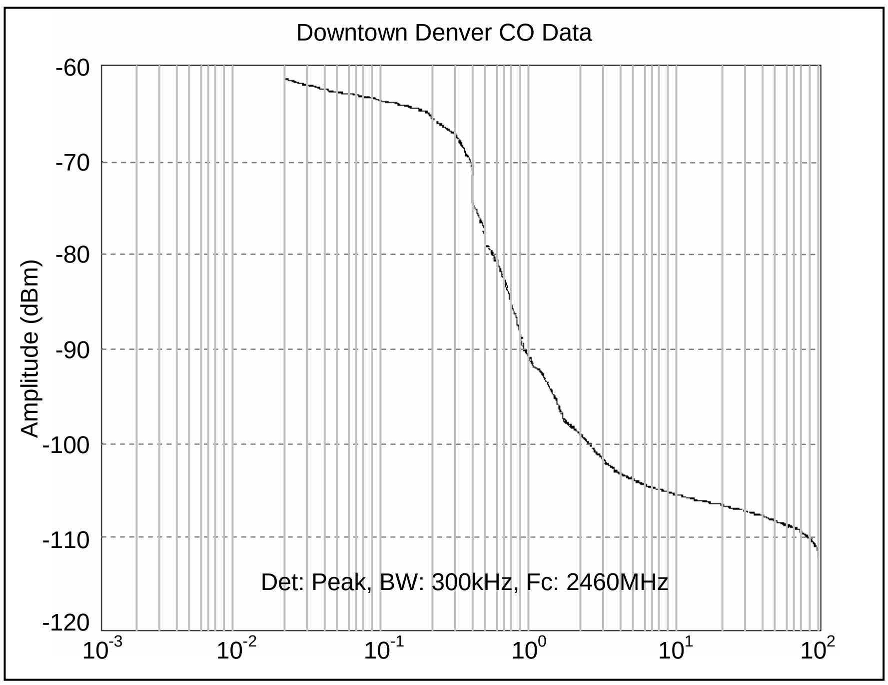

Figure 15: Example of “Dominant Oven” Effect on Signal Amplitude Probability Distribution

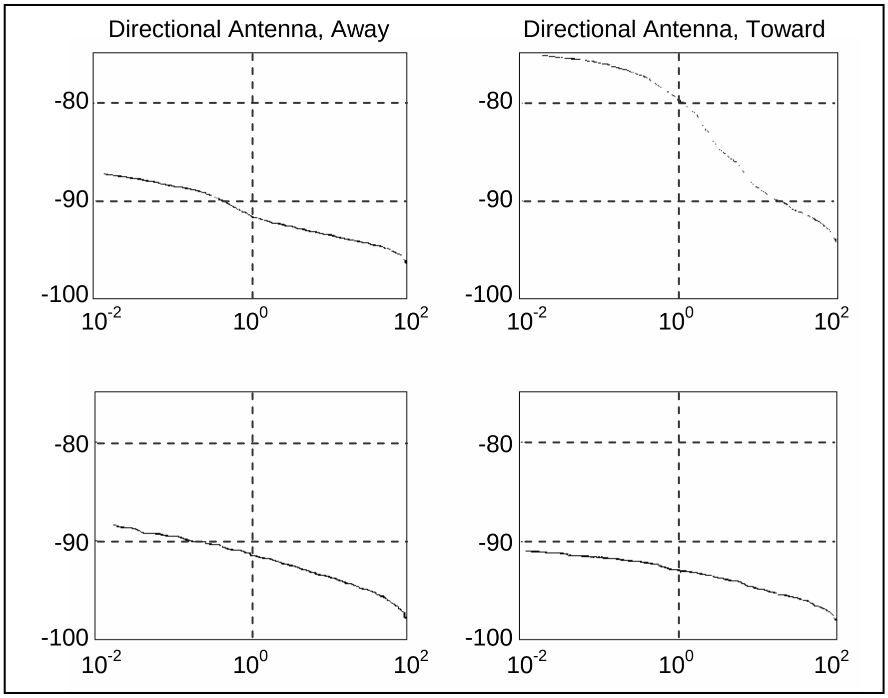

Figure 16: Los Angeles CA Data, 2450 MHz, +Peak Mode, 3 MHz Receiver BW, Amplitude(dBm) vs. Percentage of Samples Exceeding that Amplitude

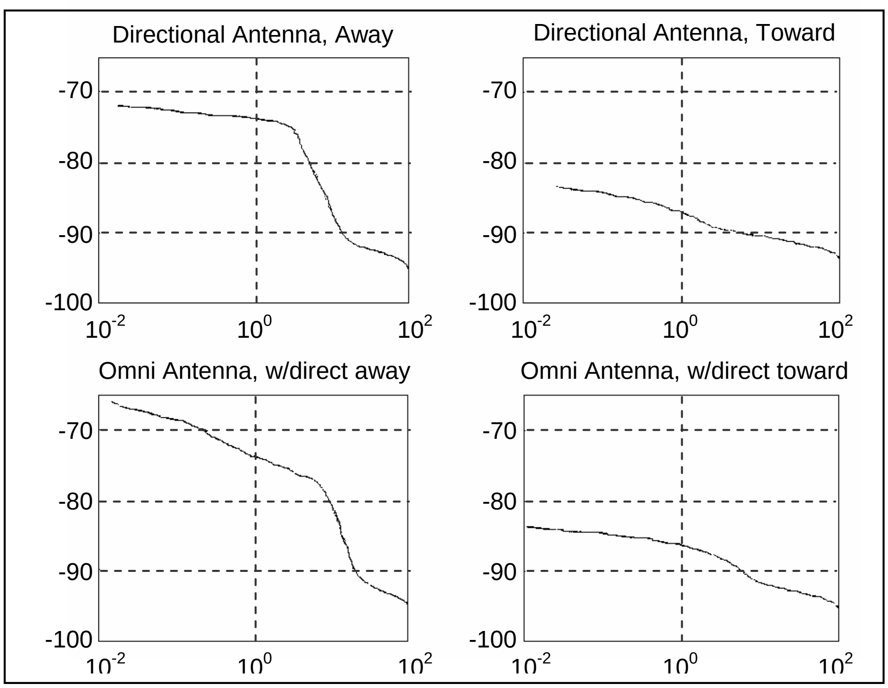

Figure 17: Downtown Denver CO Data, 2450 MHz, +Peak Mode, 3 MHz Receiver BW, Amplitude(dBm) vs. Percentage of Samples Exceeding that Amplitude

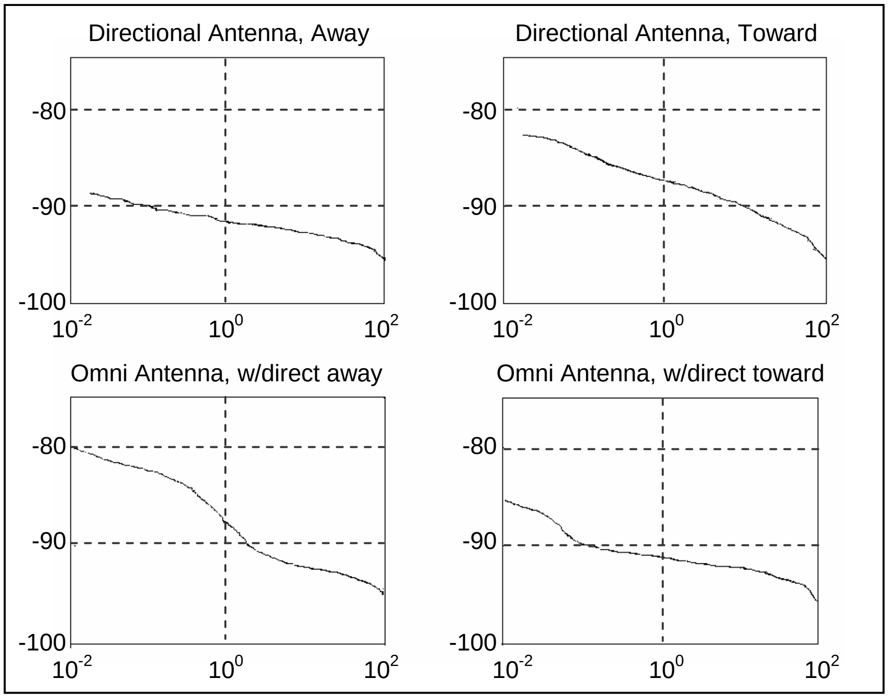

Figure 18: Genesee Mountain CO Data, 2450 MHz, +Peak Mode, 3 MHz Receiver BW, Amplitude(dBm) vs. Percentage of Samples Exceeding that Amplitude

SECTION 4

RESULTS

CONCLUSIONS

- The primary conclusion of the test effort is that the characteristics of the aggregate signal in the ISM band (2400-2500 MHz) are dependant on the receiver's location with respect to dominant oven sources. Away from those sources, the aggregate signal can be viewed statistically as elevated gaussian random noise. This is not unexpected, as the random spatial distribution of the domestic microwave ovens, and the attendant random start-phase nature of their magnetron signal sources intuitively rule out any kind of a "coherent addition" signal process. The amount of "elevation" is obviously frequency-dependent, with 3-10 dB being the norm over the band 2420-2480 MHz.

- In a downtown location, the aggregate emission environment was composed of a background composite signal similar to that described above, plus a component due to nearby dominant microwave oven sources. Characteristics of that dominant oven component are described in reference 4, and of particular note is that depending on the tuning of the victim receiver with respect to the oven transmission, the signals can be anywhere from 8 milliseconds to tens of microseconds or less in length. This is due to the fact that as the receiver is tuned farther and farther from the transmitted oven pulse frequency, only the Wideband energy present in the leading and trailing edges of that pulse are captured by the receiver. Excitation of the impulse response of the receiver (in our case the spectrum analyzer) intermediate frequency (IF) filter results in the characteristic "rabbit ears" time waveforms, degenerating as off-tuning progresses to simply two low-level narrow-in-time pulses. Note that on-tune the dominant oven signals can be 30 dB or more stronger than the background aggregate signal. For this reason it is important that designers of equipment to be used in the 2400-2500 MHz band consider the effects imposed by those dominant oven sources, especially if the equipment is to be used in a downtown location.

  The background aggregate signal measured away from dominant oven sources did not display any diurnal variation. This was not expected. If, as hypothesized, domestic microwave ovens were the primary contributors to the aggregate signal, then the levels should peak during the mealtime hours – a hypothesis supported by the diurnal variation evident when "dominant ovens" were present.

Appendix A

The tests summarized in this Appendix were performed in their entirety at both the downtown Denver CO, and Los Angeles CA test sites. At the Genesee Mountain CO site, only those tests denoted "test set F" were performed. The data collected was used to characterize the 2400-2500 MHz ISM band and adjacent frequency bands. In general, six types of measurements were performed:

A. Frequency Domain (versus measurement bandwidth and time of day),
B. Time Waveform (20 millisecond sweep, peak),
C. Time Waveform (20 millisecond sweep, sample),
D. Time Waveform (60 second sweep, peak),
E. Time Waveform (60 second sweep, sample), and
F. Omni vs. Directional Antenna tests,

and tables identifying specific test parameters are given below. In all cases, if the results from Test Set A indicated a diurnal variation in the measured data, then tests B through F were scheduled to be performed during hours of peak activity. The two spectrum analyzers used testing are denoted SpAn A and SpAn B.

A. Frequency Domain Measurements:

Test Setup

Frequency Range	2300-2600 MHZ
Receiver Algorithm	Swept/m3
IF Bandwidth (IFBW)	10, 30, 100, 1000, and 3000 kHz
Detector Type	SpAn A: +Peak Mode SpAn B: Sample Mode
Video Bandwidth (VBW)	Same as IFBW
Antenna Type	Omni
Preselection	Bandpass
Preamplifier	On
Sweep Time	10 seconds
Hold Time	5 minutes

Test Schedule: All data should be collected hourly over a 24 hour period (i.e. 0100 to 2400 hours local time), providing insight into spectrum use versus time of day.

B. Time Waveform Measurements, 20 millisecond sweep, peak:

Test Setup

Frequency Range	2305, 2390, 2395, 2400, 2415, 2430, 2440, 2450, 2460, 2470, 2480, 2500 and 2525 MHz
Receiver Algorithm	Zero Span Sweep
IF Bandwidth (IFBW)	SpAn A: 300 kHz SpAn B: 30, 100, 300, 1000, and 3000 kHz
Detector Type	SpAn A: +Peak Mode SpAn B: +Peak Mode except for the 300 kHz IFBW case. For that configuration the Sample Mode was used.
Video Bandwidth (VBW)	Same as IFBW
Antenna Type	Omni
Preselection	Bandpass
Preamplifier	On
Sweep Time	20 milliseconds
Sweeps per Freq/IFBW combo	150

C. Time Waveform Measurements. 20 millisecond sweep. sample:

Test Setup

Frequency Range	2305, 2390, 2395, 2400, 2415, 2430, 2440, 2450, 2460, 2470, 2480, 2500 and 2525 MHz
Receiver Algorithm	Zero Span Sweep
IF Bandwidth (IFBW)	SpAn A: 300 kHz SpAn B: 30, 100, 300, 1000, and 3000 kHz
Detector Type	SpAn: Sample Mode SpAn: Sample Mode except for the 300 kHz IFBW case. For that configuration the +Peak Mode was used.
Video Bandwidth (VBW)	Same as IFBW
Antenna Type	Omni
Preselection	Bandpass
Preamplifier	On
Sweep Time	20 milliseconds
Sweeps per Freq/IFBW combo	150

D. Time Waveform Measurements, 60 second sweep, peak:

Test Setup

Frequency Range	2305, 2395, 2400, 2440 and 2450 MHz
Receiver Algorithm	Zero Span Sweep
IF Bandwidth (IFBW)	SpAn A: 300 kHz SpAn B: 30, 300, and 3000 kHz
Detector Type	SpAn A: +Peak Mode SpAn B: +Peak Mode except for the 300 kHz IFBW case. For that configuration the Sample Mode was used.
Video Bandwidth (VBW)	Same as IFBW
Antenna Type	Omni
Preselection	Bandpass
Preamplifier	On
Sweep Time	60 seconds
Sweeps per Freq/IFBW combo	1

E. Time Waveform Measurements, 60 second sweep, sample:

Test Setup

Frequency Range	2305, 2395, 2400, 2440 and 2450 MHz
Receiver Algorithm	Zero Span Sweep
IF Bandwidth (IFBW)	SpAn A: 300 kHz SpAn B: 30, 300, and 3000 kHz
Detector Type	SpAn: Sample Mode SpAn: Sample Mode except for the 300 kHz IFBW case. For that configuration the +Peak Mode was used.
Video Bandwidth (VBW)	Same as IFBW
Antenna Type	Omni
Preselection	Bandpass
Preamplifier	On
Sweep Time	60 seconds
Sweeps per Freq/IFBW combo	1

F. Omni versus Directional Antenna Measurements:

These tests were intended to give insight into the signal environment as viewed through two different types of antennas – omni-directional, and directive. For these tests, one spectrum analyzer was connected to the omni antenna, and one to the directional antenna. For both antenna-to-spectrum analyzer chains, all components (cables, LNAs, etc) were as similar as possible. Settings for both spectrum analyzers were the same, and the analyzers were triggered manually as near the same time as possible.

Two Frequency Domain, and two Time Waveform tests were performed, where the distinction between the two tests for each set was the aiming direction of the directional antenna. With the measurement equipment sited at a high location overlooking the city, the first tests were performed with the directional antenna pointing at the city. The second tests were then performed with the directional antenna pointed away from the city.

Test Setup-Frequency Domain

Frequency Range	2300-2600 MHz
Receiver Algorithm	Swept/m3
IF Bandwidth (IFBW)	3000 kHz
Detector Type	SpAn A: +Peak Mode SpAn B: +Peak Mode
Video Bandwidth (VBW)	Same as IFBW
Antenna Type	SpAn A: Omni SpAn B: Directional
Preselection	Bandpass
Preamplifier	On
Sweep Time	10 seconds
Hold Time	5 minutes

F. Omni versus Directional Antenna Measurements (cont):

Test Setup – Time Waveform

Frequency Range	2450 MHz
Receiver Algorithm	Zero Span Sweep
IF Bandwidth (IFBW)	SpAn A: 3000 kHz SpAn B: 3000 kHz
Detector Type	SpAn A: +Peak Mode SpAn B: +Peak Mode
Video Bandwidth (VBW)	Same as IFBW
Antenna Type	SpAn A: Omni SpAn B: Directional
Preselection	Bandpass
Preamplifier	On
Sweep Time	20 milliseconds
Sweeps per Freq/IFBW combo	150