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Title: **Appendix E: Sharing Spectrum with Microwave Ovens of the NTIA Special Publication 94-27, Preliminary Spectrum Reallocation Report**

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Abstract: This submission is a reprint of Appendix E: Sharing Spectrum with Microwave Ovens of the NTIA Special Publication 94-27, Preliminary Spectrum Reallocation Report.

APPENDIX E

SHARING SPECTRUM WITH MICROWAVE OVENS

INTRODUCTION

In accordance with the International Radio Regulations, the frequency band 2400-2500 MHz is designated on a worldwide basis for industrial, scientific and medical (ISM) applications. Such applications are devices that intentionally generate radio frequency signals for non-radiocommunication purposes. A typical example is the generation of radio frequency energy for purposes of heating. While other radio services are also allocated on a primary basis within this same band; namely, fixed, mobile and radiolocation services, they must accept any harmful interference which may be caused by these ISM applications, as stipulated by international regulations. While a variety of ISM applications are used in this band, the predominate uses, by a wide margin, are microwave ovens. Although microwave ovens were originally developed for industrial applications and are regulated under the category of ISM, they have, of course, been widely accepted as a consumer appliance. Today, over 80 million microwave ovens are used in the United States. Microwave ovens are also widely used at work environments as an employee convenience. It is thus safe to assume that almost any indoor location, including motor homes, could include operation of a microwave oven.

Considering the increasing value of the radio spectrum and continuing demand for more spectrum allocations for certain services, an important question to consider is the ability to share spectrum between radiocommunication services and microwave ovens. While microwave ovens are closed devices, intended to confine the microwave signals for cooking purposes, they nevertheless radiate some level of radio emissions. The level of these emissions are considered safe from the standpoint of radiation hazard to persons; yet, the levels may be high enough to pose a significant source of interference to radio services sharing the same spectrum.

APPENDIX E SHARING SPECTRUM WITH MICROWAVE OVENS

Within the 2400 to 2500 MHz frequency range, there are no national or international limits on the levels of emissions other than limits due to radiation hazard to personnel. The following subsections describe measurements that have been made on microwave oven emissions, both individual ovens and aggregate effects, and assesses the suitability of this spectrum for use by radiocommunication purposes.

MEASUREMENTS ON INDIVIDUAL MICROWAVE OVENS

Various studies have been completed describing measured data of microwave emissions. As part of United States preparation for the 1992 World Administrative Radio Conference (WARC-92) in Geneva, Switzerland, NTIA completed a limited set of measurements of microwave ovens, both individual and aggregate, to help assess the potential for accommodation of certain radio services in the 2300-2450 MHz band.[1] Recently, NTIA completed a more extensive measurement program of microwave ovens and documented the results in a technical report.[2]

Two features of the emissions from microwave ovens are important - the variation in emission levels as a function of frequency (emission spectrum) and the variation as a function of time (time waveform). The recent measurement effort included measurements on 11 different microwave oven models under a variety of test conditions. Figures E-1 and E-2 provide representative measured data from these ovens showing a typical emission spectrum and sample time waveforms at three selected frequencies, 2400, 2425 and 2450 MHz.

While emissions showed variations depending on the conditions, such as amount and type of food being heated, orientation of measurement equipment, etc., certain trends are clear. In the center of the ISM band, around 2450 MHz, the peak level of the emissions were consistently high, on the order of 1/10 to 1 Watt[a], and the percentage of time that the signal is present (duty cycle) can approach 50%. The pulses of energy occur at a 60 Hertz rate, being triggered by the 60 Hertz of the input power line. Because of the inherent instability in the center frequency of the emissions, these high peak values drift over a wide range as much as ± 25 MHz around the frequency 2450 MHz. These characteristics were quite consistent among most ovens tested.

At the upper edge of the ISM band, i.e., 2500 MHz, all ovens tested showed consistently low levels of emissions, i.e., peak values within the 1 to 100 microwatt range. Although the 2483.5-2500 MHz band is within the total band designated for microwave ovens, it has been found suitable for reallocation for the mobile-satellite (space-to-Earth) services.[b]

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1. Cesar A. Filippi et al., U.S. Department of Commerce, NTIA TM-92-154, *Accommodation of Broadcast Satellite (Sound) and Mobile Satellite Services in the 2300-2450 MHz Band* (January 1992).
2. Philip Gawthrop et al., U.S. Department of Commerce, NTIA Report, *Radio Spectrum Measurements of Individual Microwave Ovens* (forthcoming 1994).

[a] The right-hand scale of each chart is given in logarithmic units of dB above a picowatt (dBpW). As a reference, a value of 120 dBpW is equal to 1 Watt and a value of 110 dBpW is equal to 1/10 Watt.

[b] At the recently concluded 1992 WARC, the band 2483.5-2500 MHz was allocated on a worldwide basis for the mobile-satellite service (space-to-Earth) service.

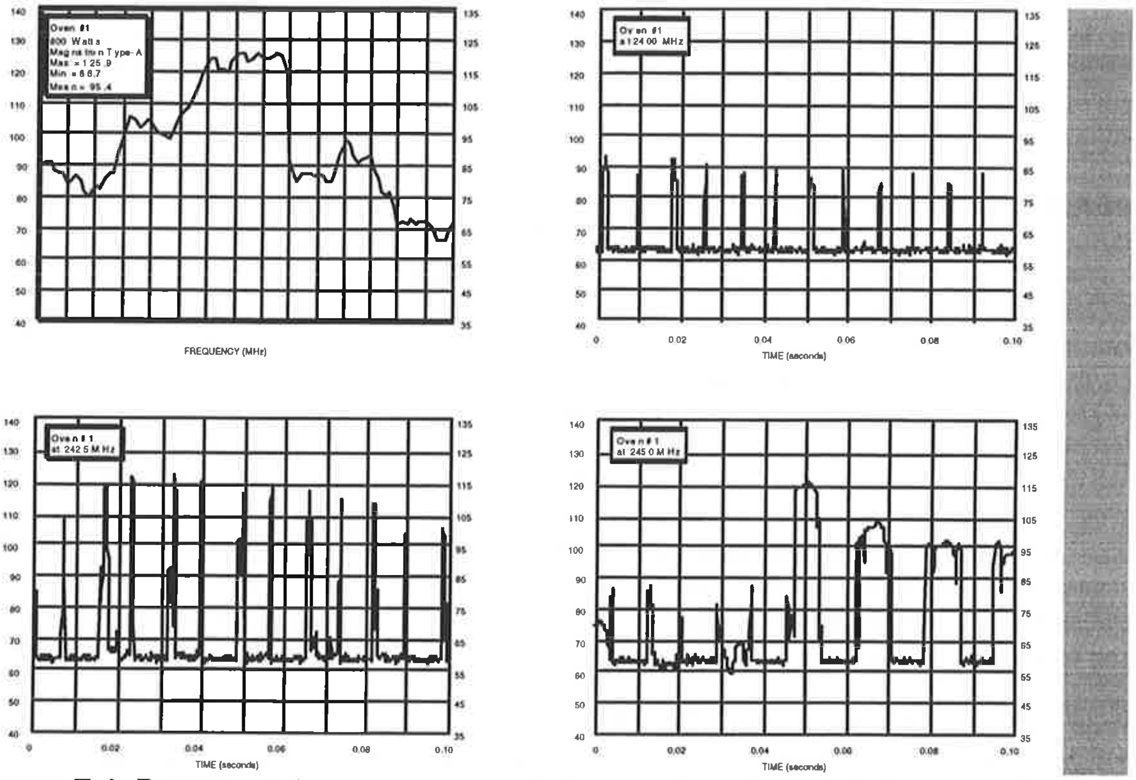

Figure E-1. Representative microwave emission spectra and sample time waveforms.

At the lower edge of the ISM band, i.e., 2400 MHz, the levels of emissions also showed low levels, albeit at a somewhat higher level than the upper band edge. At a frequency of 2400 MHz, the sample time waveform data indicated typical peak levels below 300 microwatts. The pulses of energy tend to be very short and impulse-like occurring at a 120 Hertz rate, corresponding to short bursts at the leading and trailing edges of the basic 60 Hertz pulses. All measured duty cycles of the emissions at 2400 MHz were consistently low, typically around 3 to 6%.

In summary, the measurements of emissions from individual microwave ovens showed high emission levels of up to 1/10 to 1 Watt at the center frequency of 2450 MHz. The duty cycle of these emissions were also high, approaching 50%. At 2400 MHz, the peak emission levels were consistently below 300 microwatts. At this frequency, the emissions were impulse-like with a typical duty cycle of about 3 to 6%.

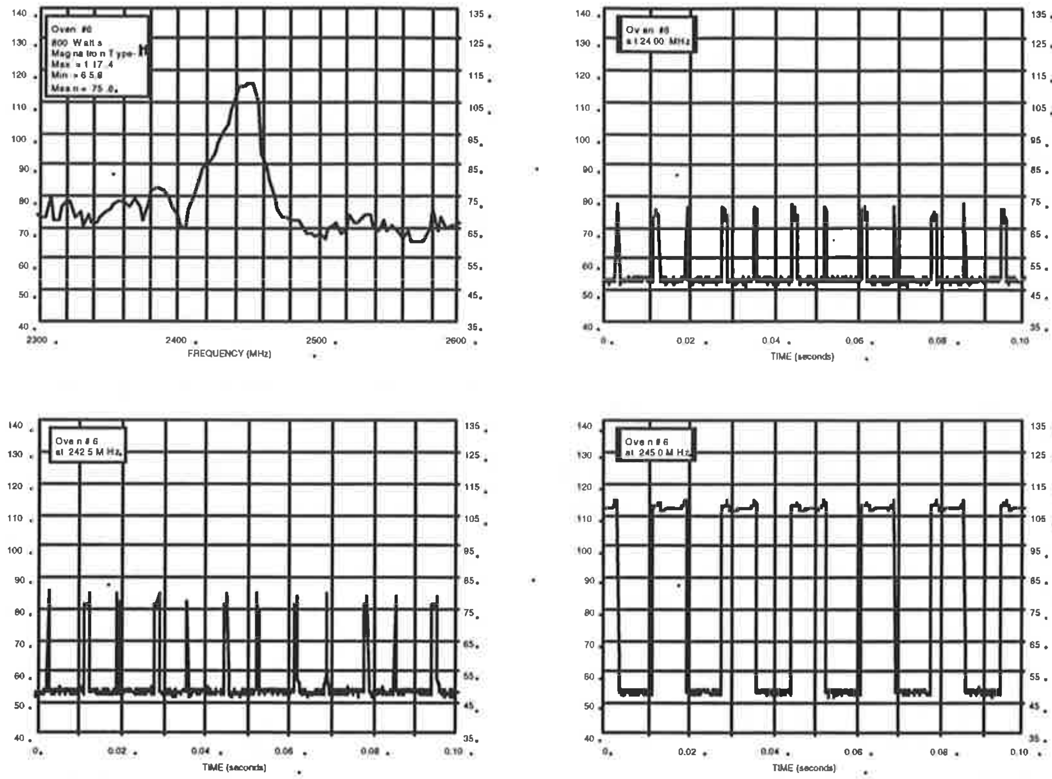

Figure E-2. Representative microwave emission spectra and sample time waveforms.

AGGREGATE MEASUREMENTS OF MICROWAVE OVENS

Measurements are also available that demonstrate the aggregate effects from many microwave ovens over a large area. NTIA has completed three sets of measurements at sites near or overlooking the cities of Boulder and Denver, Colorado and Chicago, Illinois. Extensive aggregate measurements were also made at over 180 sites distributed around three major U.S. cities.[3]

Representative measurement results are shown in Figures E-3 through E-5. The measurements near Boulder, at Green Mesa and Flagstaff, were taken 6 to 9 a.m. at approximately 150 and 610 meters above, and 2.3 and 3.5 km from significant populated areas, respectively. The measurements near Denver and Chicago were taken in a suburban area several kilometers from the downtown area. The measurement antennas used were either omnidirectional or low-gain, broad-beam antennas.

3. Jeffrey A. Wepman et al., U.S. Department of Commerce, NTIA Report 91-279, *Spectrum Usage Measurements in Potential PCS Frequency Bands* (September 1991).

APPENDIX E SHARING SPECTRUM WITH MICROWAVE OVENS

The resulting data in the spectrum plots shown in Figures E-3 through E-5 were used to determine the maximum peak, mean peak, and minimum peak signal levels received at each frequency. Therefore, the minimum levels shown in these figures are actually the minimum peaks taken during many scans (a scan consisting of many sweeps by the spectrum analyzer). The other curves could be referred to as the maximum peaks, and mean peaks.

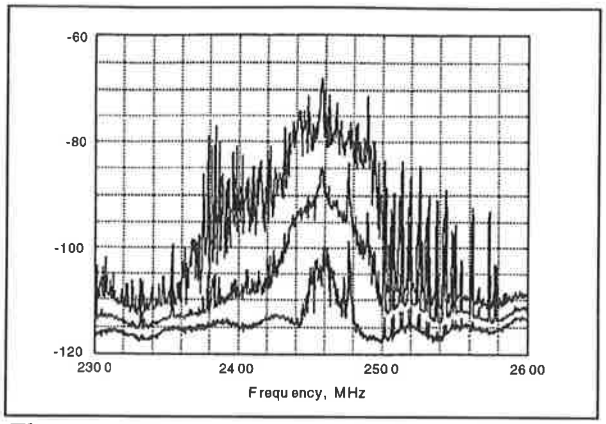

Figure E-3. Aggregate emission spectrum from Green Mesa.

Although slightly different measurement techniques were used among the three sites, all showed a consistent trend. For example, at the center of the band, 2450 MHz, all measured data showed peak received noise at about 20-40 dB higher than the receiver noise levels. At this frequency, the received microwave oven noise approximated Gaussian-type noise. As in the individual oven measurements, the level at the edges of the band, at 2400 and 2500 MHz, were consistently much lower. At these frequencies the received signals were impulse-like and had a very low transmission duty cycle. The point where the emissions transition from the low level, impulse-like emissions to thc high level, Gaussian-like noise cannot be precisely defined. However, at frequencies between about 2425 and 2475 MHz, the emissions are consistently high. Because of the ubiquitous use of microwave ovens, these measured ambient noise levels resulting from microwave ovens are likely to be similar to those measured in any urban/suburban area in the country.

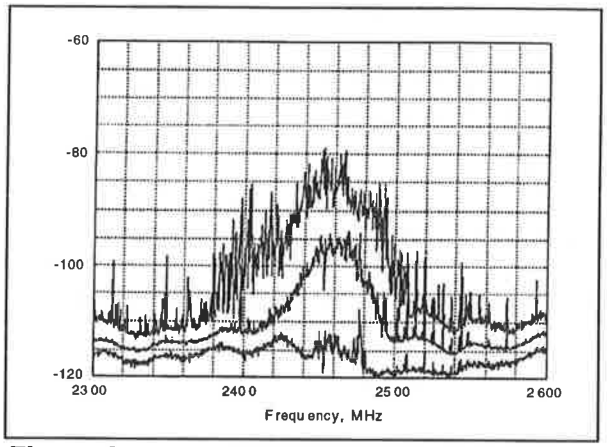

Figure E-4. Aggregate emission spectrum from Flagstaff.

CURRENT SPECTRUM SHARING WITH MICROWAVE OVENS

In examining the feasibility of sharing spectrum with microwave ovens, a first logical step is to review instances where such sharing is presently taking place. The band 2400-2450 MHz is allocated on a primary basis for Federal Government radiolocation. Before the 1980's this band was used extensively for air defense radars. In recent years, however, these radars have been retired and replaced with radars designed to operate in other bands. As a result, this band is now used only to a limited extent by the Federal Government. This current use is generally confined to the lower 15 MHz, i.e., in the range 2400-2415 MHz, with most use being experimental in nature.

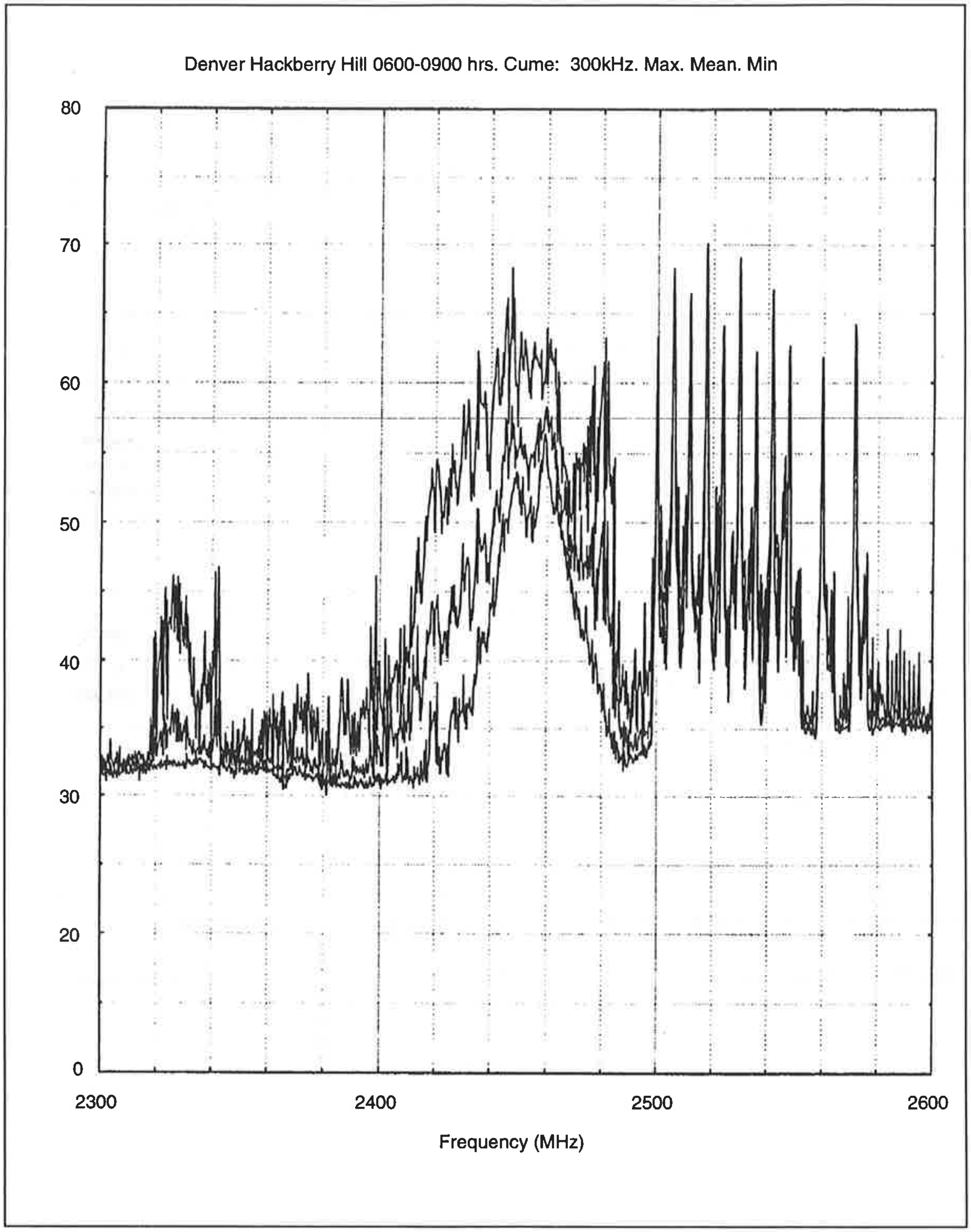

Figure E-5. Measurements showing the aggregate effects from many microwave ovens.

The upper adjacent 2450-2483.5 MHz band is allocated for use by non-Federal, private operational fixed stations, TV pickup mobile stations and intercity relay in accordance with Parts

94 and 74 of the FCC Regulations. These are licensed under the condition that any harmful interference from ISM equipment must be tolerated. A search of the FCC Master Frequency File of Frequency Assignments[a] for this frequency range indicates about 380 licenses for low capacity fixed stations and about 320 TV pickup mobile and intercity relay stations. All use analog radios and the FCC license data indicate that receivers are generally located in non-urban areas. Many of the low-capacity fixed links are for off-shore communications.

The amateur radio service is also allocated for the band on a secondary basis. Overall use by the amateur community cannot be easily determined; however, it is believed to be at a much lower activity level than at lower frequency bands. Several amateur-satellite downlinks in the OSCAR satellite series have been successfully used in the 2400-2402 MHz band.

Other uses are made of the 2400-2483.5 MHz band by non-licensed devices authorized under the FCC Part 15 Regulations. These include field disturbance sensors (Part 15.245), low power devices (Part 15.249) and spread spectrum systems (Part 15.247). The field disturbance sensors, authorized from 2435 to 2465 MHz, are the most extensive Part 15 application. These devices typically use continuous-wave doppler techniques to detect motion by persons in the radio beam due to motion. Although the band has been authorized for spread spectrum use since 1985, only four systems have been certified as of June 1993 by the FCC for operation. This contrasts to the similarly allocated band, 902-928 MHz, where over 120 systems have been certified and are marketed using spread spectrum techniques.

FEASIBILITY OF SPECTRUM SHARING WITH MICROWAVE OVENS

Spectrum sharing with microwave ovens is clearly possible, given the fact that it currently exists. However, the extent of effective sharing is a function of several factors including: the portion of the band being used, the type of service and the type of modulation used. Given the high level of ambient radio noise, operation of any radio service in the central portion of the band, i.e., 2425-2475 MHz, is significantly disadvantaged in and around urban areas. Measured ambient peak noise levels from microwave ovens are typically 20 to 40 dB above receiver noise. The microwave oven noise approaches a thermal noise characteristic similar to receiver noise, thus creating a harmful interference environment. To counter the microwave oven noise, a communication service using this spectrum would have to increase transmitter power by a considerable amount, i.e., 20 to 40 dB. Any licensed communication service located near urban areas requiring reliable operation is unlikely to succeed in this portion of the band.

Both individual and aggregate measurements of microwave oven emissions indicate emissions are significantly lower at the upper and lower band edges, and have impulsive noise characteristics. A number of technologies exists that perform well in an impulsive noise environment including advanced error correction, packet radio and spread spectrum. The mobile-satellite service (space-to-Earth) recently allocated by the FCC in the upper 16.5 MHz portion of the ISM band, i.e., 2483.5-2500 MHz, is expected to employ spread spectrum and industry clearly expects this application to be successful. Although the ambient noise levels at a similar 16.5 MHz portion at the low end of the band, i.e., 2400-2416.5 MHz, are somewhat higher than the upper band edge, use of a robust type of modulation such as spread spectrum could be

[a] A complete file of the FCC Master File of Frequency Assignments was provided to NTIA by the FCC in 1993. Data was taken from this source.

successful.