Interference Characteristics of Microwave Ovens in Indoor Radio Communications

J. Y. C. Cheah

Hughes Network Systems
San Diego

Abstract

The scarcity of suitable radio spectrum for indoor radio communications under the regulatory constraints has prompted endeavors to investigate means of utilizing the valuable channel bandwidths available within these constraints. The interference potential of the microwave oven is characterized in an attempt to render the ISM band it occupied useful for indoor radio communications. The characterization process included an in-depth power spectral measurement of the radiation. A theoretical model of the radiation characteristics is then proposed. The interference characterization results point to a possible valuable frequency bandwidth that may be available for high speed indoor communications usage in the "low cost" consumer product arena.

1 Introduction

The advent of the regulatory rulings regarding the much relaxed power emission levels and bandwidth occupancy requirements of the 2.4 Ghz ISM band using spread spectrum technique, has spurred interest in its exploitation for indoor communications. 2.4 Ghz is also well within the implementation realm of the low-cost, high-frequency silicon technology.

The ISM band of 2400-2483.5 Mhz is designated by FCC Part 15 Subpart C, 15.247 for spread spectrum usage. The similar lower band of 902-928 Mhz is extremely congested, and narrow for regular LAN operations. The higher band of 5725-5850 Mhz is currently limited by the cost of technology for consumer products. Unfortunately, the 2.4 Ghz band supports the wide spread use of microwave ovens. As a result of the omnipotence interference potential of microwave oven spurious radiations, as well as the ubiquity of its use that coincides with the indoor communications operation domains, utilization of this band for communications and other ISM purposes has been largely ignored. Moreover, the hardware cost to operate at this frequency band was perceived as beyond what a "low cost" market place could bear only a few years ago.

It is therefore appropriate to investigate the characteristics of microwave oven radiation so that this valuable ISM band can be reclaimed for suitable communications usage.

An interference power spectrum measurement effort was expended[1] in characterizing the radiation characteristics. The measurement was conducted with various resolution bandwidths equally distributed across the interference spectrum. The measurement results present a compact interference behaviour that can be readily identified. A theoretical model was formulated to describe the observed spectral phenomenon so as to facilitate designs to accommodate this interference source in the communications channel.

2 Measurement Setup

The measurement was conducted using a Hp 8566 spectrum analyzer calibrated using its internal automatic calibration procedure. A test antenna was designed to provide an overall return loss performance of better than 10 dB over the measurement frequency range. The performance of the test antenna was calibrated by a HP 8753 network analyzer coupled with a Hp 85046A S parameter test set. The intent was to prevent the test antenna in exerting a significant frequency response of its own onto the test results.

Figure 1 shows the calibration results of the test antenna used.

The measurement was conducted within the near field region at the bore-sight of the oven door. The following near field assumptions were made[2]:-

- The radiation near field region of the radiation is determined by the smallest dimension D of the oven using the following relationship.

$$d \leq \frac{2D^2}{\lambda} \tag{1}$$

$$\text{where} \begin{cases} d \text{ is the distance from the oven door.} \\ \lambda \text{ is the wavelength.} \end{cases}$$

- D represents the effective radiation antenna dimension of the oven.
- The effective radiation propagation is directed from the oven door.

The reason for conducting the measurements within the near field of the oven under test was to eliminate any possible radiation antenna effect that may be present from the oven. Precaution was also taken to select a constant load for the oven. It was determined arbitrarily that a 12 oz water load at an initial temperature of about 25 degree C was to be used. For "Max-hold" spectrum measurements, a fixed 10 second cooking time is used. The measurement time for "Zero frequency span" time domain measurements is one single sweep. The same test conditions were used to ensure the uniformity of the test environment. Several makes of ovens were tested using the measurement regime shown in Figure 2. This represents over 30 measurements per oven.

3 Measurement Results

Spectrum measurements with various resolution bandwidths and sweep times are necessary to determine the complicated interference characteristics as observed. Representative plots are shown in Figures 3a, 3b, 3c, 3d.

The following general observations were made:-

- The interference radiation emission is synchronous to the 60 Hz mains frequency and the interference energy exists only for half of the period.
- The interference power measured was approximately proportional to the measurement resolution bandwidth. This relationship held true from 30 Hz to 3 Mhz bandwidth.
- There were very rapid amplitude bursting characteristics which might have a rise time much shorter than 300 nsecs.
- There was no evidence of a detectable single frequency spectrum line during the measurement. The rapid and abrupt amplitude variation behaviour precluded this possibility.
- In the wide frequency span measurement, it could be seen that the detected signal levels in the measurement results were not exactly reduced by the same amount of the resolution bandwidth reduction. This phenomenon implied that the spectra measured was not really white. The small amount of error indicated the impulsive nature of the signal where the effective impulsive resolution bandwidth is related to the amplitude response $V(t)$ of the impulse [3]:-

$$BW_{impulse} = \frac{V_{pk}}{\int_{-\infty}^{\infty} V(t)dt} \tag{2}$$

Figure 3a shows a representative plot of this measurement.

- A typical plot for the narrow frequency span measurement is shown in Figure 3b. The need to limit the resolution bandwidth to 1 Khz in this case is governed by the resolution bandwidth filter shape factor K and frequency span F_{span} where[4],

$$T_{sweep-time} \geq \frac{KF_{span}}{BW_{res}^2} \tag{3}$$

- Figure 3c shows the fine grain structure of the impulse characteristics in a wide resolution bandwidth time domain measurement. An observation can be made that the interference can in fact exist for up to 8 milliseconds at any given frequency within the frequency range. The fine oscillatory power variations are most likely caused by an impulse that approaches a Delta function with respect to the filter bandwidth at 3 Mhz. The measured $|S(t)|^2$ is a result of an impulse such that,

$$S(t) = \frac{2A}{\pi(t-t_0)}\sin(\pi(f_2-f_1)(t-t_0)) \cdot \cos(\pi(f_2+f_1)(t-t_0)) \quad (4)$$

where f_1 and f_2 are the lower and the upper frequencies of the resolution filter.

- Narrow resolution bandwidth time domain measurement shows a near perfect impulse response of the 10 Hz resolution bandwidth as shown in Figure 3d.

4 An Interference Model

From the measurement effort described above, a theoretical model of the interference signal structure is proposed as shown in Figure 4a. Since the 60 Hz component is clear, it is only of interest to investigate the time window when the interference exists. A time series for this general basic structure can be written as,

$$S(t) = \sum_{k=-(m-1)}^{m-1} \delta(t-k\Delta t) + \sum_{k=m}^{m+n-1}\left(1-\frac{k-m+1}{n+1}\right) \cdot[\delta(t+k\Delta t)+\delta(t-k\Delta t)] \quad (5)$$

The corresponding Fourier Transform is,

$$S(\omega) = \frac{\sin[(\frac{2m-1}{2})\omega\Delta t]}{\sin[\frac{\omega\Delta t}{2}]} + \sum_{k=0}^{n-1}\left(1-\frac{k+1}{n+1}\right) \cdot[2\cos[(k+m)\omega\Delta t] \quad (6)$$

A more compact equation can be derived from Equation (6) without significantly affecting the accuracy from that of the proposed model. It can be obtained by making $n=1$. Then, the Fourier Transform is simplified to,

$$S(\omega) = \cot[\frac{\omega\Delta t}{2}]\sin[m\omega\Delta t] \quad (7)$$

There are two derivatives of this general basic model. If one takes Δt =0 at some interval between $-m$ and m, the resultant wave shape will represent most of the interference structures observed, as depicted in Figure 4b. One can also expect a break in the impulse train for a few multiples of Δts. This is shown in Figure 4c. The value of Δt was determined to be approximately 3 μsecs, and n is between 1 to 10. There is also a low frequency amplitude envelope function which is omitted. This interference structure has a carrier frequency of 2.45 Ghz.

The study of this interference model will hopefully point to a number of solutions that can result in efficient use of this band.

5 Conclusion

A detailed study of the interference characteristics of microwave ovens is presented. A theoretical representation of the interference structure is also proposed. The aim is to stimulate efforts in reclaiming this valuable spectrum resource for indoor communications use.

References

[1] J. Y. C. Cheah, "IEEE 802.4L submission on microwave oven interference measurement", *IEEE p802.4L/90-08a.*, Feb. 1990.

[2] J. Appel-Hansen, "Seminar on Electromagnetic antenna and scattering measurements", Part I, *CSIRO Division of Applied Physics, National Measurement Laboratory, Australia*, Nov., 1982.

[3] F. Ball, "Measure the real impulse bandwidth", *Microwaves & RF*, Jan. 1987, pp.93-96.

[4] New England Microwave Corp, "Power spectral analysed in PIN-diode switching transients", Application Note, *MSN*, Dec. 1986, pp. 101-105.

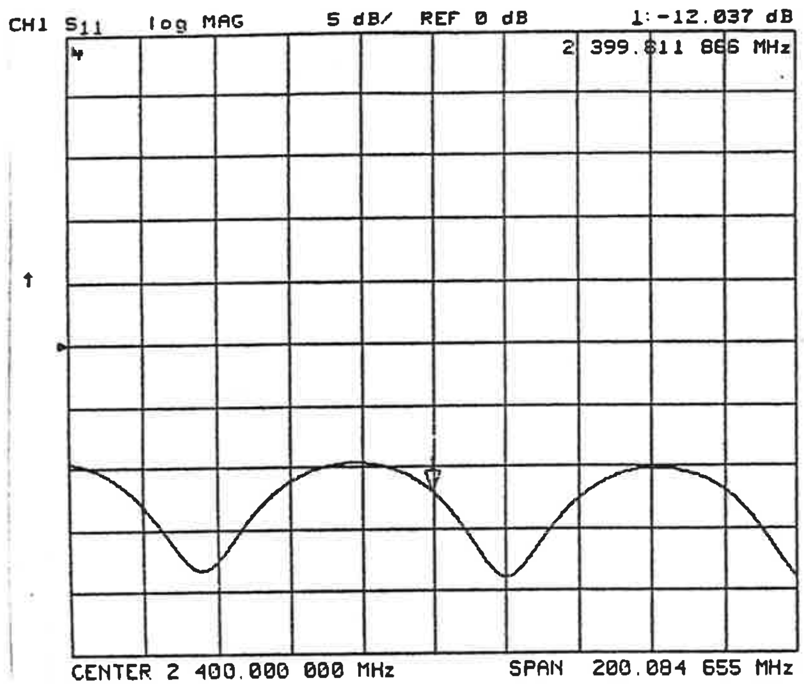

Figure 1: The frequency response of the specially designed antenna in terms of return loss.

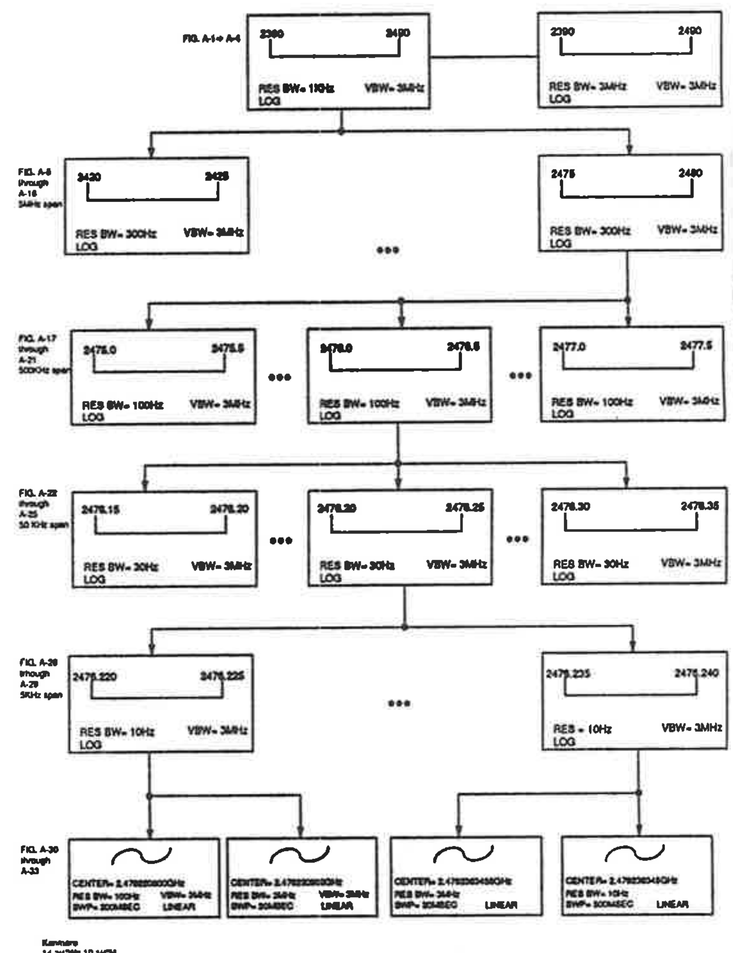

Figure 2: The spectrum measurement regime over the measurement frequency range.

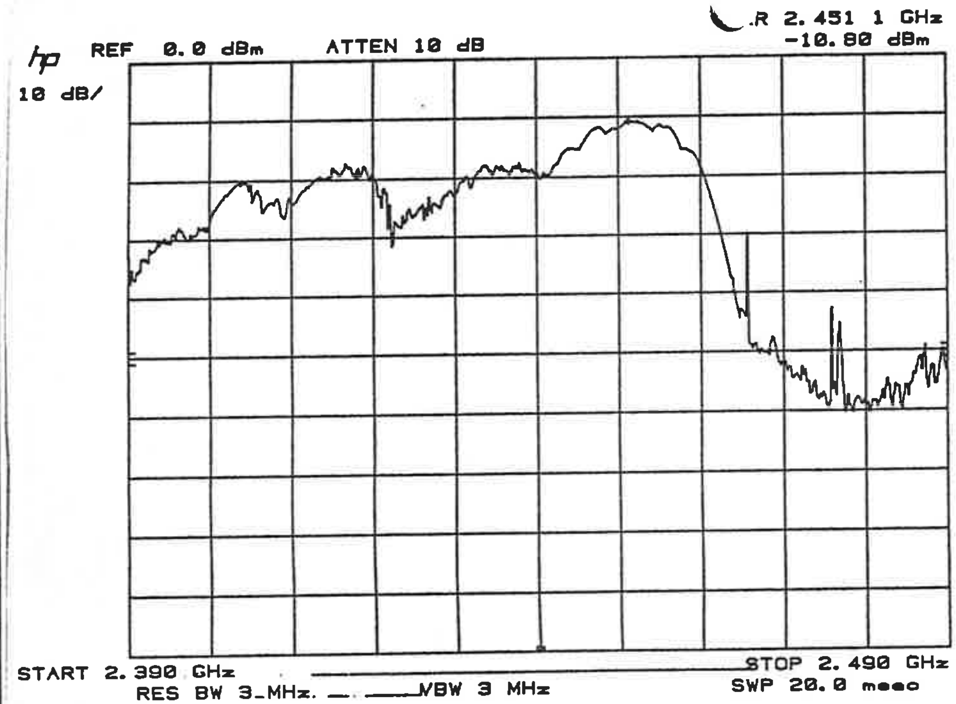

Figure 3a: A representative plot for the wide frequency span measurement.

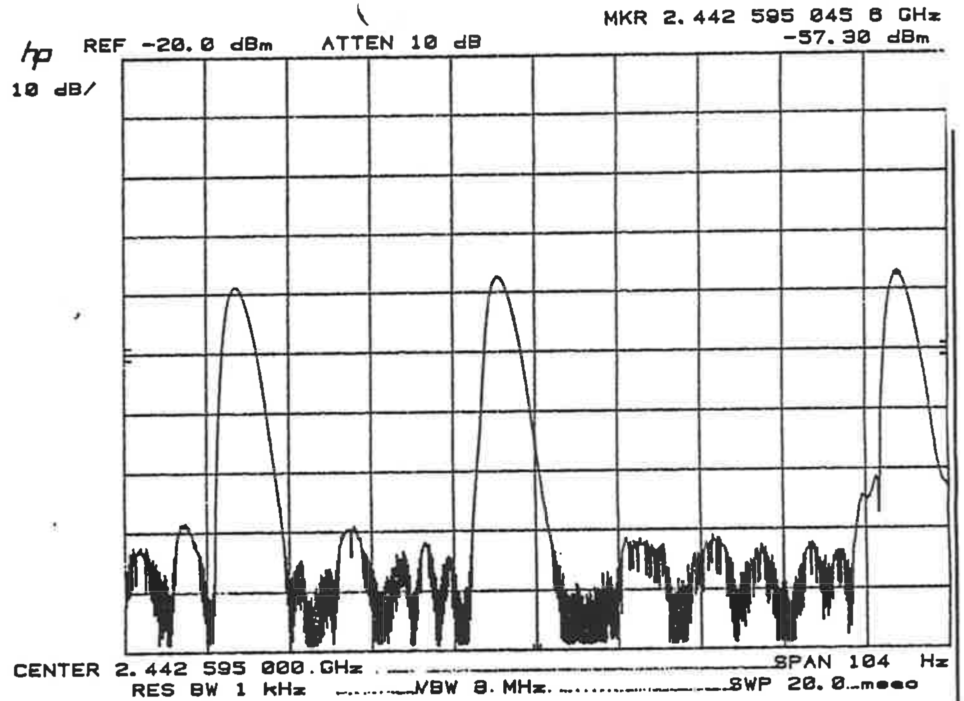

Figure 3b: A representative plot for the narrow frequency span measurement.

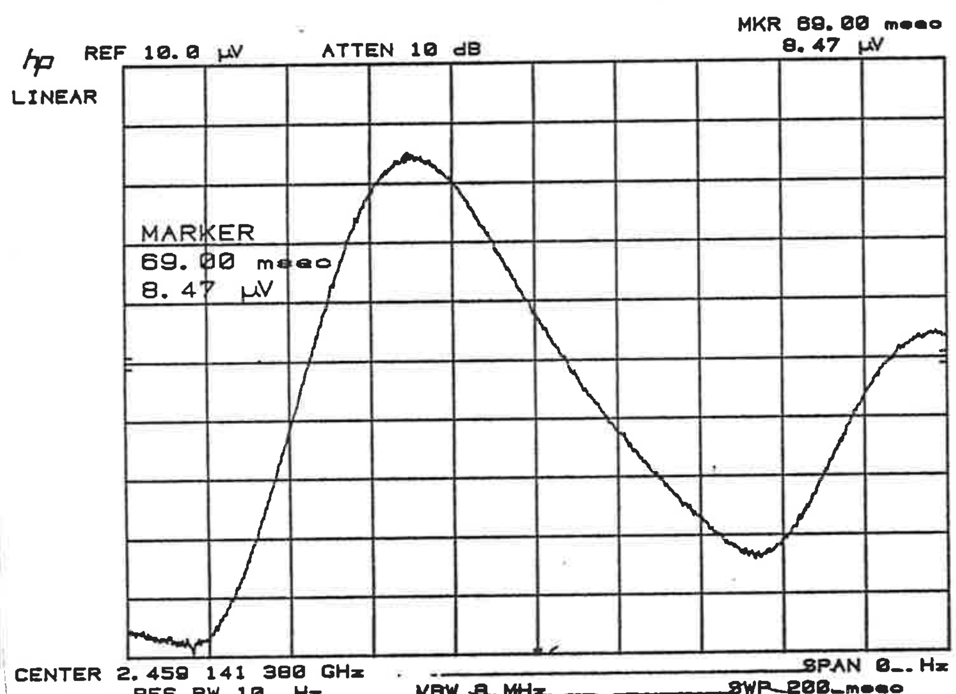

Figure 3d: A representative plot for the narrow resolution bandwidth time domain measurement.

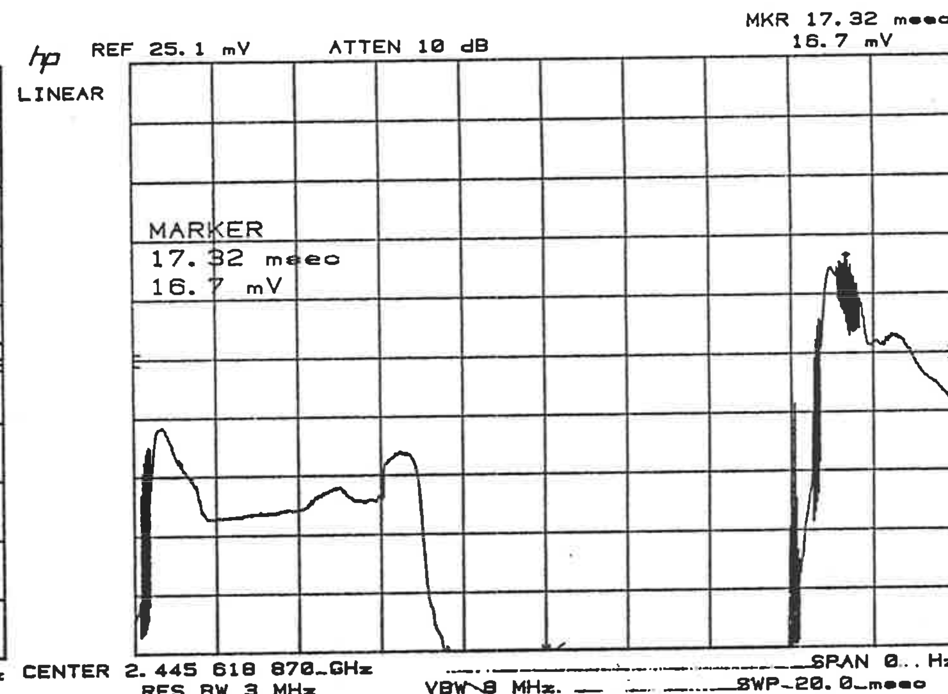

Figure 3c: A representative plot for the wide resolution bandwidth time domain measurement.

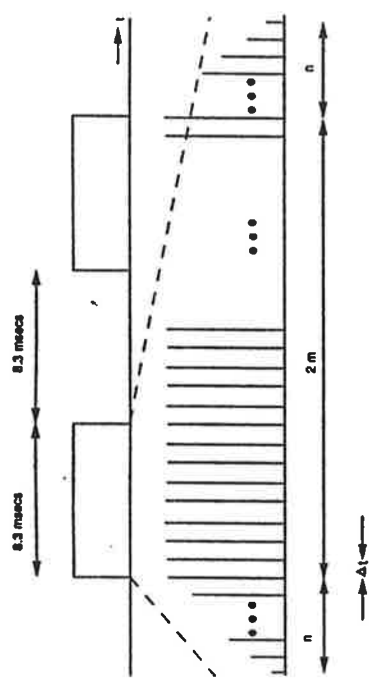

Figure 4a : The general microwave oven interference model.

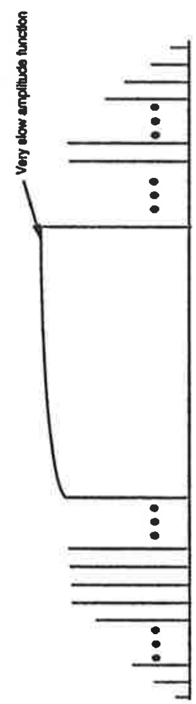

Figure 4b: The pulse interval collapses to form a contiguous radiation pattern.

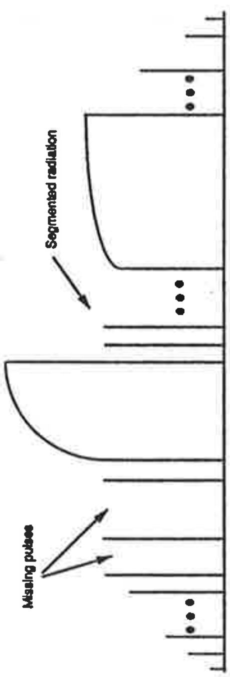

Figure 4c: The pulse train may have missing pulses, and the contiguous radiation patterns may also be segmented.