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RADIO SPECTRUM MEASUREMENTS OF INDIVIDUAL MICROWAVE OVENS

VOLUME 1

Philip E. Gawthrop
Frank H. Sanders
Karl B. Nebbia
John J. Sell

U.S. DEPARTMENT OF COMMERCE
Ronald H. Brown, Secretary

Larry Irving, Assistant Secretary
for Communications and Information, and
Administrator, National Telecommunications
and Information Administration

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ABSTRACT

This report provides results of radio spectrum measurements of 13 individual microwave ovens performed at the National Telecommunications and Information Administration (NTIA) Institute for Telecommunication Sciences (ITS). Measurements include emission characteristics and time waveforms covering the frequency range 2300-2600 MHz, oven emission characteristics of harmonic frequency ranges up to the 7th harmonic. Test parameters were varied to identify their impact on test results. These parameter variations include such factors as cooking load, start temperature, oven orientation, and receiver bandwidth. Test procedures of the Federal Communications Commission (FCC), the International Special Committee on Radio Interference (CISPR), and additional procedures developed by NTIA and ITS are also discussed.

KEY WORDS

INDUSTRIAL, SCIENTIFIC, AND MEDICAL (ISM) EQUIPMENT
MICROWAVE OVENS
2300-2600 MHz

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SECTION 1
INTRODUCTION

BACKGROUND

Increased demand for spectrum for mobile services has focused attention within the national and international radiocommunications community on the frequency bands between 1 and 3 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 other uses must be known.

Some service providers and manufacturers have considered development of new systems near or in the 2400-2500 MHz band. The International Telecommunication Union (ITU) designates 2450 MHz ± 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 ovens within the United States and 200 million worldwide operating nominally at 2450 MHz, and the investment in terms of industry costs and public outlays, make microwave ovens a major factor in considering options for the future radio use of 2400-2500 MHz and surrounding bands.[2/] Some radio services may operate in an environment where emissions from individual ovens are the primary concern. For other radio services, aggregate microwave oven sources may have a greater impact. Therefore, emission characteristics from individual microwave ovens and aggregate microwave oven sources must be determined. The potential economic impact of these radio-based technologies makes resolution of issues related to compatibility with microwave ovens essential.

National and international radio 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 within the ISM bands, and specifically between 2400 and 2500 MHz.

1/ *ITU Radio Regulations* #752, International Telecommunication Union, Geneva Switzerland, 1990, p. RR8-105.

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 their impact on use of radio systems near the 2400-2500 MHz band. Therefore, ensuring compatible radio operations with these ISM uses requires a separate set of considerations. The presence of these systems should be reflected in measurements of aggregate signal levels. NTIA will perform aggregate measurements as part of a subsequent task.

Thus, design of radio equipment to operate in the 2400-2500 MHz band presents a significant challenge.

Outside the ISM bands, ISM emission limits have been established by the Federal Communications Commission (FCC), and adopted by the National Telecommunications and Information Administration (NTIA), to enhance compatibility between microwave ovens and radio services.[3/] National and international regulations stipulate that ISM equipment must not cause interference outside the ISM band. However, in the case of domestic microwave ovens, enforcement of this regulation could be both difficult and expensive because of the large number of ovens 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. Since enforcement of this regulation may be impractical, radiocommunications system developers designing equipment for near term implementation must design their equipment to be compatible with the current RF emission 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. If applicable emission limits are to continue to facilitate compatibility, spectrum management authorities must periodically review and revise them, based on the characteristics of those future radio requirements.

The International Special Committee on Radio Interference (CISPR) Subcommittee B is currently developing international limits for ISM emissions above 1 GHz.[4/] Subcommittee discussions have focused on the emission levels 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 negotiating the limits. The outcome of CISPR discussions will impact U.S. oven manufacturers by potentially establishing the most widely used standard for microwave ovens sold outside the United States. If the FCC chooses to have its standards conform with CISPR, these discussions will impact equipment designed for U.S. markets also. The lifespan of microwave ovens necessitates that agreement be reached on these issues relatively soon. Standards implemented today, and microwave ovens built to those standards, will affect the radio environment of systems to be placed in operation ten or more years in the future.

In 1991, NTIA determined that, for the Broadcast Satellite Service (Sound) to be accommodated between 2300 and 2400 MHz, microwave oven emissions must be taken into account in system design through sophisticated signal processing techniques, such as time

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3/ Emission standards and measurement approaches pertaining to radio interference and electromagnetic compatibility are distinct from those dealing with radiation hazards to people. Within this effort, 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".

4/ CISPR is an 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.

and frequency interleaving and forward error correction.[5] Measurements performed by the Institute for Telecommunication Sciences (ITS) showed that the ovens emit RF energy across a wide spectrum, with high peak levels outside the frequency band designated for ISM use.

The results of the 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

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, formulate appropriate emission limits and methods of measurement, and identify services that can compatibly operate in the 2400-2500 MHz ISM band and adjacent bands.

This report represents the results of the first of those three tasks. The measurement results described here provide useful information for evaluating the potential impact of microwave ovens on radio systems. <u>However, the results must be considered as a whole.</u> For example, the pulsed nature of oven emissions make peak measurements useful. Nevertheless, the use of a peak envelope measured over a period of time without recognizing the pulse duty cycle and frequency shifts characteristic of microwave ovens will lead to erroneous interference predictions. Furthermore, the aggregate measurements planned as the second task will be helpful for determining the impact of large numbers of microwave ovens on systems, such as spaceborne receivers, which are more susceptible to aggregate microwave oven emissions. Taken as a whole, the spectral emission characteristics, time waveforms, and statistical summaries provide a more complete and valuable picture. No attempt has been made by NTIA, within this first task, to specifically analyze the potential impact of the oven emissions.

OBJECTIVES

The objectives of these microwave oven measurements are to

5/ 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. identify and evaluate the measurement procedures specified by the FCC and by CISPR and investigate alternate measurement techniques,

2. characterize microwave oven emissions in the 2400-2500 MHz ISM band and adjacent bands (2300-2400 MHz and 2500-2600 MHz) on a frequency and time basis,

3. characterize microwave oven harmonic emissions up to the 7^{th} harmonic,

4. identify microwave oven designs that minimize emissions outside the ISM band.

APPROACH

The following approach was taken to meet the objectives of this task.

1. Fourteen microwave ovens were identified for testing, twelve supplied directly by manufacturers and two purchased by ITS. One of the manufacturer-supplied ovens was not tested due to its use of an unusual electrical connector.

2. Preliminary measurements were performed to

   a) determine the difference in test results using the FCC, CISPR, and an NTIA/ITS-specified test procedure,

   b) identify the impact of test parameter variations on test results in order to determine the best parameters to use during further testing,

   c) determine the 2300-2600 MHz spectral emission characteristics of the ovens in order to identify ovens for detailed tests.

3. Detailed measurements were performed on selected ovens to

   a) determine oven spectral emission characteristics from 2300-2600 MHz using predetermined receiver bandwidths and test parameters,

   b) characterize oven time waveform characteristics at a number of specific frequencies,

   c) determine oven emission characteristics in harmonic bands up to the 7^{th} harmonic using predetermined receiver bandwidths and test parameters.

4. Based on measured data, amplitude probability distributions and frequency stability were determined.

SECTION 2
STANDARD AND MEASUREMENT PROCEDURES

INTRODUCTION

Whenever the emission spectra of microwave ovens are measured, individuals reviewing the results invariably want to compare the data against the requirements set out in national and international standards. Those standards and associated measurement procedures reasonably serve as a starting point for evaluating techniques for performing measurements of microwave ovens.

National spectrum management authorities establish emission limits for radio-based technologies, such as ISM, to protect radio services. Therefore, the selection of an emission limit should ultimately be linked to the kind of protection desired and the nature of radio devices being protected. The standards compliance testing procedures and measurement results should be reasonably applicable for evaluating compatibility in situations common to a particular radio environment. As radio technologies evolve, spectrum regulatory authorities must update their standards to ensure that limits continue to be appropriate and adequate, without being unnecessarily restrictive. However, an emission limit is defined not only by the limit value but by the method of measurement. Therefore, any limit must include an associated measurement procedure. The method of measurement must enable the recording of emitter levels in a manner that is meaningful in the context of radio services to be protected. In fact, the terms in which a limit is stated (peak or average detector and measurement bandwidth) must be settled before considering a limit value. Furthermore, the measurement procedure needs to be sufficiently detailed to ensure consistent application and repeatable results. Procedural variations alter the result of any measurement, and thus the record of emission levels and compliance with emission limits. In the case of microwave ovens, the method of measurement may need to specify the test instrumentation, and parameters related to oven operation.

When designing microwave oven equipment, manufacturers face a variety of requirements from national and international regulatory and standards organizations. For ovens operated within U.S. borders, the FCC bears responsibility for regulating emissions from privately owned microwave ovens. The FCC regulates the operation of microwave ovens as ISM equipment via Part 18 of its Rules.[6] Associated measurement procedures are included in a separate document, FCC/OST MP-5 (hereinafter referred to as MP-5).[7] Ovens owned and operated by agencies of the Federal Government are regulated by NTIA. However, maintaining separate emission standards for private sector and federally owned ovens is not practical, since ISM equipment operated by the private sector far outnumber those of the

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6/ *Title 47, Code of Federal Regulations*, Part 18, October 1992, pp. 595-602.

7/ *FCC/OST MP-5 (1986)*, "FCC Methods of Measurements of Radio Noise Emissions From Industrial, Scientific, and Medical Equipment," Federal Communications Commission, Office of Science and Technology, February 1986.

Federal Government. Therefore, NTIA has chosen to draw its standard from the FCC standard. Federal Government standards are stated in Chapter 7 of the Manual of Regulations and Procedures for Federal Radio Frequency Management.[8]

The situation with respect to international standards is less clear. The ITU does not have standards or regulations governing the level of emissions of ISM equipment. Task Group 1/2 of the ITU Radiocommunication Sector recently completed a recommendation on ISM standards. The task group recommends that administrations consider using the CISPR standard for ISM. CISPR sets standards for ISM devices within CISPR Publication 11 (hereinafter referred to as CISPR 11).[9] However, with the exception of a limit for the range 11.7-12.7 GHz, CISPR 11 has no standards for ISM that apply to radiated emissions above 1 GHz. CISPR Subcommittee B is currently developing limits covering 1-18 GHz. Many national administrations have their own standard, and microwave oven manufacturers must identify and meet these national requirements, creating a difficult task for international marketing. If the members of the European Economic Community (EEC) eliminate their individual standards in favor of a unified standard, the variety of requirements will be cut significantly. Decision-makers within the European standards process have determined that the EEC will follow CISPR standards where such standards exist. Due to the lack of CISPR standards above 1 GHz, the future requirements remain unclear. Therefore, emission limits and related compliance measurement procedures for microwave ovens continue to vary from country to country.

The following discussion describes the national and international standards that apply to microwave ovens and considers the associated methods of measurement.

FCC STANDARD AND MEASUREMENT PROCEDURES

Via Part 18, the FCC applies a field strength limit of 25 μV/m at 300 meters for ISM equipment that operate in the 2450 MHz $\pm$50 band if the equipment generates less than 500 Watts. For equipment generating 500 Watts or more, as most microwave ovens do, the Part 18 field strength limit (in μV/m) at 300 meters is:

$$25\sqrt{power/500}$$

8/ *Manual of Regulations and Procedures for Federal Radio Frequency Management*, National Telecommunications and Information Administration, Department of Commerce, May 1992 Edition (Revisions through May 1993), Paragraph 7.10.1, pp. 7-7 through 7-8.

9/ *CISPR Publication 11*, "Limits and Methods of Measurement of Electromagnetic Disturbance Characteristics of Industrial, Scientific and Medical (ISM) Radio Frequency Equipment", Second Edition, International Special Committee on Radio Interference, International Electrotechnical Committee, Geneva, Switzerland, 1990.

However, the emissions from higher-powered devices may not exceed 10 μV/m at 1600 meters.[10] Even though these limits apply to equipment with operating frequencies in an ISM designated band, they apply only to emissions that occur outside the ISM bands. Within the ISM bands themselves, no limit applies.

Part 18 criteria requires that microwave oven emissions, outside the ISM bands, must not exceed the specified amplitude at a distance of 300 meters from the oven. However, within the Part 18 text, the FCC does not specify test procedures, such as the type of detection, the measurement bandwidth, the length of the test, or the test load, to be used in assessing oven emissions. Instead, Part 18 § 18.311 references MP-5 as its guidance for performing measurements of ISM. While noting that the use of those procedures is not mandated, Part 18 encourages manufacturers to use the MP-5 procedures as that which the FCC uses.

MP-5 § 2.2 specifies measuring ISM equipment with a field intensity meter (in MP-5, referred to as a radio noise meter) that conforms with the American National Standard Specifications for Electromagnetic Interference and Field Strength Instrumentation 10 kHz to 1 GHz, ANSI C63.2-1980.[11] It permits measurements to be made at a distance closer than that specified for the limit, such as 3 meters, provided the results are extrapolated to 300 meters. The procedure stipulates that the measurement bandwidth be 1 MHz, and that the detector be linear and set to read average levels. However, field intensity meters for measurements above 1 GHz are very expensive. Today, when spectrum analyzers are often used instead of such meters, particularly above 1 GHz, a procedure specific to those spectrum analyzers is needed. Recognizing that field intensity meters may not be readily available or are prohibitively expensive, the FCC allows (see MP-5 § 2.2) that "[a]lternatively, a spectrum analyzer may be used, provided the results obtained can be accurately reproduced with a suitable radio noise meter. . . ." The FCC has verbally conveyed to some test labs a set of test procedures facilitating the use of a spectrum analyzer. These procedures, though not altering the stated limit, do alter the process used by those test facilities to determine oven compliance. Of the two major U.S. manufacturers of microwave ovens, one uses this procedure while the other uses the field intensity meter. The unofficial spectrum analyzer procedures are summarized in Appendix A. Furthermore, the FCC permits other instruments

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10/ Part 18 of the FCC Rules does not specify whether the field strength limit values are peak or average. However, measurement procedures recommended by the FCC indicate the values represent a type of average.

11/ ANSI C63.2-1980, *American National Standard for Instrumentation - Electromagnetic Noise and Field Strength 10 kHz to 1 GHz - Specification*, American National Standards Institute, The Institute of Electrical and Electronics Engineers, Inc., New York, NY, 1980. This document was updated in 1987 to cover up to 40 GHz; however, no specifications are provided for the use of spectrum analyzers. Spectrum analyzers specifications are said to be under consideration. See ANSI C63.2-1987, *American National Standard for Instrumentation - Electromagnetic Noise and Field Strength 10 kHz to 40 GHz - Specification*, American National Standards Institute, The Institute of Electrical and Electronics Engineers, Inc., New York, NY, February 1987.

to be used for "certain restricted and specialized measurements when data so measured are correlatable to that achieved by C63.2 instrumentation" but provides no guidance as to what cases this applies. The official field intensity meter procedure and the unofficial spectrum analyzer procedure are clouded by the statement in MP-5 § 2.2 that, "No specific standard will be required for instrumentation used to perform measurements above 1 GHz," and by the fact that the version of the ANSI specification referred to by MP-5 covers field-strength instrumentation only from 10 kHz to 1 GHz. Procedures for microwave oven measurements for ranges above 1 GHz are probably the most important. The updated ANSI C63.2-1987 still leaves a void, stating that "[a] separate document covering spectrum analyzers for use from 20 Hz to 40 GHz is in preparation. . . ."

Regardless of the instrumentation, MP-5 § 2.2.2 specifies that the detector function shall be set to average, and shall be linear. Both of these detector characteristics can create difficulties depending on the emission characteristics of the ISM equipment and the receivers that the standard intends to protect.

"Average" is a mathematically defined quantity, and many different averaging functions exist. These include, but are not limited to, linear average, log average, and root-mean-square (RMS) average. Because each type of average provides different measurement results, the specific averaging function must be defined in a measurement procedure.

Linear average power of a pulsed emitter, for example, is the total energy emitted by the device during a pulse repetition interval and divided by that interval. Equivalently, average power may be obtained by measuring the peak power and multiplying by the duty cycle of the device, assuming that pulse time waveforms are roughly rectangular. Strictly defined, the measured peak power should include all energy emitted by the device. As a measurement bandwidth sufficiently wide to include most or all energy in the spectrum might be unobtainable, the total power value could also be obtained by measuring power in a narrower bandwidth and taking a series of such measurements across the emission spectrum in such a way as to integrate most or all power in the emitted spectrum within that series of measured points.

Another type of averaging, often referred to as "video averaging," is included in the unofficial FCC procedures. It is performed by using a relatively wide IF bandwidth (typically about 1 MHz) and a narrow post-detector video bandwidth (as narrow as a few hertz).[12/] The idea behind this technique is to utilize an IF bandwidth and an envelope detector that are sufficiently wideband to follow fluctuations of the signal in the pre-detector stages, and then to obtain an average value by smoothing the signal with a narrow post-detection low-pass filter (the video bandwidth). A linear amplitude display is required on the spectrum analyzer

12/ "Spectrum Analysis," Application Note 150, pp. 16-17, Hewlett-Packard Company, November 1989; "Automatic CISPR EMI Testing," Application Note 331-1, pp. 26-27, Hewlett-Packard Company, 1986; "Performing CISPR-Required Average Measurements Using a Spectrum Analyzer," Hewlett-Packard Company; S. Linkwitz, "Measurement of Narrowband and Broadband Emissions Using Peak and Average Detection," IEEE/EMC Symposium 1987.

for this type of measurement. In effect, this average suppresses the broadband content of the measured signal, allowing measurement of its narrowband, continuous-wave-like (CW) component, if any.

Video averaging works well as long as the dynamic range of the signal being measured can be accommodated within the dynamic range of the linear amplifier in the measurement system. However, if the dynamic range of the measured signal exceeds the dynamic range of the linear amplifier, the video average will no longer reflect the true average of the signal. In cases where the dynamic range of the linear amplifier is sufficient, the video average is still only a single data point, which does not indicate the RMS average, the peak value of the signal, or the percentage of time over which the signal exceeds any given threshold, including the average value itself.

For spectrum analyzers, the FCC has unofficially recommended a 1 MHz intermediate frequency (IF - often referred to as the resolution bandwidth) measurement bandwidth coupled with a narrow (3 Hz) post-detector video bandwidth. The choice of 3 Hz video bandwidth eliminates from observation impulsive, low duty cycle components of an oven's emissions. The only emissions that will be observed under these procedures will be high duty cycle, almost CW components of an oven signal. These procedures may be useful for making measurements of line structure in the spectra of a repetitive and structured pulsed wave form; however, microwave ovens do not exhibit this line structure characteristic because of the rapidly shifting frequency.

The unofficial FCC measurement procedures may indicate emission levels which are tens of decibels lower than would be indicated by wide bandwidth, peak-detected measurements. Figure 2-1 shows three time waveforms taken at the same frequency with a wide IF bandwidth (3 MHz) and video bandwidths of 1 MHz, 10 Hz, and 3 Hz. The data shown in Figure 2-1 were acquired at a frequency of 2365 MHz. This frequency was selected because the oven tested (Oven #1)[13/] showed, during emission spectrum measurements, a high emission level at that frequency. Measured oven emissions decrease with decreasing video bandwidth, and drop off most markedly at bandwidths less than about 1 kHz. When a video bandwidth of 3 Hz is reached, the variations in the oven emissions are no longer observable. The measured values give no indication of the peak amplitudes that occur, nor do they indicate the percentage of time that the signal exceeds any given threshold. Thus, the measurement procedure itself eliminates the record of the existing signal, potentially crucial for the interference prediction on which a limit might be based, and certainly important to standards compliance testing. The dynamic range of the signals measured in this case was such that linear amplification could not be used to get an accurate measurement, a problem cited above for the video averaging technique. Because ITS did not have a field intensity meter for making measurements above 1 GHz, they could not determine whether the video bandwidth procedure meets the FCC's own requirement that it reproduce accurately measurements performed with a field intensity meter.

13/ The microwave ovens tested and the associated numbering scheme is described in detail in Section 3.

In light of increasing use of wideband receivers, the value of protecting radio systems by basing limits on average values which generally reflect narrow bandwidth, high duty-cycle components is unclear (whether using a field intensity meter or a spectrum analyzer). Such techniques will produce results that do not reflect peaks and tend to lessen the differences between emission characteristics of pulsed emitters. The use of linear detectors also may not be adequate to record the large range of microwave ovens emission levels. The FCC documents referenced herein do not indicate the rationale behind the selection of their official or unofficial procedures. However, Part 18 was developed in the late 1970s, and most radio receivers designed in that period would have used analogue techniques with relatively narrow bandwidths. Average emission levels and averaging measurement techniques would be appropriate to protect such systems.

The use of a field intensity meter to accurately record the maximum emissions outside the ISM band is further complicated by the difficulty of identifying at which frequency the device should be set. The FCC, as a matter of procedure, measures the field strength at the ISM band edge at 2400 MHz, where the highest emissions outside the band might be expected, assuming that field strength decreases with frequency separation from the primary operating frequency. However, higher levels may be emitted at lower frequencies. Some ovens have a characteristic secondary peak somewhere between 2300 and 2400 MHz.

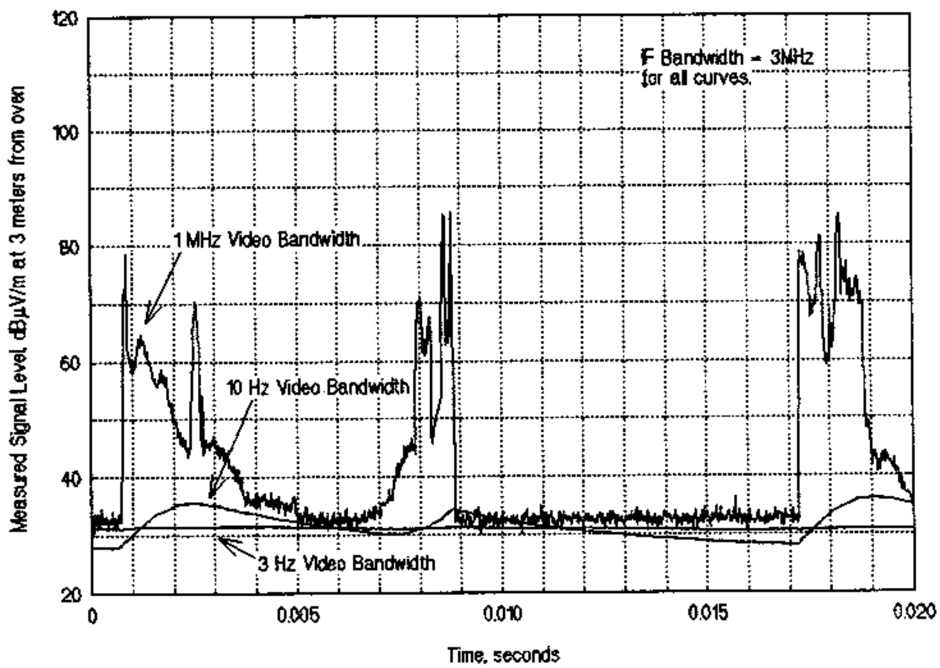

Figure 2-1. Emissions in decreasing video bandwidth.

CISPR STANDARD AND MEASUREMENT PROCEDURES

CISPR limits and methods of measurement for ISM equipment, including microwave ovens, are stated in CISPR 11. As noted above, CISPR has not yet specified limits above 1 GHz with the exception of the 11.7-12.7 GHz band. In that range, Paragraph 5.2.3 specifies a limit of 57 dBpW effective radiated power (referred to a half-wave dipole). CISPR Publication 16 (hereinafter referred to as CISPR 16), a guide for performing ISM measurements, gives information on making measurements up to 1 GHz and does not define detection functions above that frequency.[14/] CISPR 11 § 9 provides some indication as to possible procedures for measurements above 1 GHz. Manufacturers must currently assume that these procedures apply only to oven tests in the 11.7-12.7 GHz range. Yet, without more detail in the measurement technique, variations in application exist and will continue to exist between administrations. CISPR Subcommittee B is currently developing limits to apply above 1 GHz; however, the subcommittee rejected its most recent proposal, CISPR/B(Secretariat)84, because participants could not yet agree on the limit values.[15/] That proposal, although formally rejected, represents the closest thing to an agreement reached so far. Application of a standard based on CISPR/B(Secretariat)84 would have been difficult had agreement been reached. The proposal recommended use of a peak detector, a method not defined in CISPR 16.

The CISPR 16 guidelines specify the use of a quasi-peak detector (including charging, discharging, and display time constants for the detector), as well as the measurement bandwidths to be used with the detector in four frequency bands between 0.01 GHz and 1 GHz. The 6 dB bandwidths specified in CISPR Publication 16 are listed in TABLE 2-1.

TABLE 2-1
CISPR PUBLICATION 16 MEASUREMENT BANDWIDTHS

Frequencies (MHz)	6 dB IF Filter Bandwidth (kHz)
0.01-0.15	0.2
0.15-30.0	9
30-300	120
300-1000	120

14/ *CISPR Publication 16*, "Specification for Radio Interference Measuring Apparatus and Measurement Methods," Second Edition, International Special Committee on Radio Interference, International Electrotechnical Committee, Geneva, Switzerland, 1987.

15/ CISPR/B(Secretariat)84, "Limits and Methods of Measurement for Electromagnetic Radiation in the Frequency Band 1 to 18 GHz," International Special Committee on Radio Interference, International Electrotechnical Committee, Geneva, Switzerland, May 1992.

The quasi-peak bandwidths and detector response specified by CISPR 16, if applied above 1 GHz, will provide measurements results that, like those under the video averaging tests, tend to discriminate against broadband emissions. If a device under test emits high duty cycle signals (i.e., CW or slowly varying spectral components), then the quasi-peak detector is well-suited to determining the characteristics of those emissions. If an emission is strongly impulsive, the response of the quasi-peak detector to such emissions is reduced at a rate that is roughly proportional to the decrease in the emitter's duty cycle.

CONSIDERATIONS IN SELECTING A MEASUREMENT METHOD

In selecting a measurement method on which a standard can be based, regulatory authorities must consider the radio systems to be protected. Where receivers are susceptible to narrowband components in an emitted signal, a quasi-peak detector response or some other type of average may be desirable. Use of quasi-peak detection is justifiable for interference measurements below 1 GHz, where potential incompatibility between devices often results from the existence of high duty-cycle components. It is also justifiable where the emitter characteristically emits high duty-cycle signals. However, above 1 GHz, receivers often utilize receiver bandwidths of 1 MHz or more. Receivers using such wide bandwidths may be more susceptible to interference from impulsive emissions. If the purpose of measurement procedures is to realistically assess this potential or to measure standards compliance for a limit based on this potential, then such procedures should include detection techniques more responsive to impulsive emissions than quasi-peak detection.

For interference assessments above 1 GHz, and especially for wide bandwidth receivers above that frequency, the use of positive peak detection and wider measurement bandwidths may provide a better indication of the potential for interference. Positive peak detection incorporates a peak-hold latch which retains the highest value sampled from an envelope detector in a specified period.[16/] This approach allows the recording of the emission spectrum over whatever range is necessary, and the frequencies and amplitude of the highest emissions outside the microwave oven band can then be determined. However, peak envelope levels reflect a worst case which can mislead, especially when measuring pulsed emitters that shift in frequency. Emissions at the peak levels may seldom occur. Therefore, some sort of time-oriented measurement is also important. Centering on frequencies of high emissions, time waveforms can be measured, and, using computer generated output, amplitude probability distributions can be produced. These outputs provide data with respect to other aspects of the potential interference problem, specifically the amount of time that receiver threshold levels may be exceeded. Further manipulation of the data can provide pulse-width statistics, or, inversely, clear interval statistics. These statistics,

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16/ Positive peak detection should not be confused with the maximum-hold function, in which the maximum value obtained in each display bin over successive sweeps is retained. Positive peak is a detector function, while maximum-hold refers to a display function. A maximum hold display can be used to portray maximum values for any detector over a measured period, for example, the maximum of an RMS average.

though difficult to incorporate in a standard, can provide information useful to spectrum system planners in determining the compatibility of microwave ovens with planned uses.

Should further research reveal that there are a variety of receiver types that must be considered in emission standards for microwave ovens, then measurements of both average and peak signals and measurements in a variety of bandwidths may be required. If a decibel relationship can be determined between emissions levels recorded in different measurement bandwidths, then measurements could be made in one bandwidth and the results converted to other bandwidths. This approach assumes that, though oven characteristics differ, a reasonably similar wide-to-narrow bandwidth relationship exists between all ovens, and at all frequencies.

SUMMARY

In light of the evolving radiocommunications environment, the FCC needs to review its method of measurement and consequently the related limit value applying to microwave ovens and revise Part 18 as necessary. Satisfactory limits can be set only after having established the general characteristics of the radio uses to be protected and devising the measurement methods to reflect their requirements. The growing demand for systems incorporating wideband digital techniques, places in question whether the current measurement techniques are appropriate for protecting radio systems in the future. Considering that digital technologies above 1 GHz, often use bandwidths of 1 MHz or more and never use bandwidths as narrow as 3 Hz, measurements employing such averaging techniques seem inappropriate. The FCC should not rely on evidence of interference to initiate such a review, but must recognize the growing demand for spectrum and the changing nature of the predominant radio systems if the measurement procedure is to continue to be appropriate.[17/]

If the FCC is to continue authorizing the use of spectrum analyzers for Part 18 compliance testing above 1 GHz, it needs to formalize its procedures for those measurements. The allowance within MP-5 that no specific standard for instrumentation applies above 1 GHz and the acceptance by the FCC of a variety of measurement approaches without verifying the consistency of results nullifies the limit's value. Cost and availability of field intensity meters make use of the MP-5 procedures difficult. Nevertheless, neither the field intensity meter nor the spectrum analyzer video averaging approaches are probably adequate to conduct tests of microwave ovens for the purpose of evaluating the potential for interference to wideband systems.

Positive peak detection in a wide measurement bandwidth is desired if the extended spectral characteristics of an impulsive emitter are to be measured, or if interference is expected to result from broadband emissions. Quasi-peak detection or other averaging

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17/ NTIA has in no way attempted here to evaluate the effectiveness of the Part 18 standard to date. In fact, the limits above 1 GHz based on a narrowband averaging technique cannot be meaningfully assessed with respect to protection of digital systems.

techniques are desirable if the characteristics of a high duty-cycle and narrowband signal are to be measured. Microwave ovens are impulsive, broadband emitters, and it is therefore possible that interference due to oven operation, if it should occur, will be due to broadband emissions. If this is the case, then above 1 GHz peak detection in a wide measurement bandwidth will be a more effective method of measurement than an average or quasi-peak based procedure for assessing the interference potential from microwave ovens. The spectrum analyzer video averaging approach recommended by the FCC makes it particularly difficult to discriminate between different broadband emissions and shows little differences between ovens. Peak based measurements of microwave ovens show significant peak power levels and large variations from one oven to another. It is possible that both types of measurements (narrowband/averaged and wideband/peak) should be performed on devices, and that the appropriate set of test results be applied in assessments of interference potential.[18/] This could be done on the basis of the characteristics of receivers potentially operating in the microwave oven environment.

18/ Wideband measurements employing a peak detector will probably require log amplification due to the range of the emission levels produced by a microwave oven.

SECTION 3
NTIA MEASUREMENT PROCEDURES

INTRODUCTION

Desiring to perform measurements that would reveal more information about the emission characteristics of microwave ovens, NTIA investigated measurement techniques other than those specified by the FCC and CISPR, selected a test procedure and measurement equipment configuration, and measured the characteristics of the ovens. Also, as a lead-in to the testing of the individual ovens, it was necessary to perform tests identifying the impact of variation of the test parameters. The basic test procedure and measurement equipment configuration is discussed in this section. Results of the parameter variation tests are provided in Section 4. Results of the oven measurements are provided in Section 5 and Appendices B, C, and D.

UNITS FOR TEST

In order to simulate tests that would reflect compliance procedures that a manufacturer might have to perform, NTIA determined to test new ovens.[19/] The microwave ovens used in this measurement program were provided to NTIA by three microwave oven manufacturers. In accepting these ovens, NTIA agreed not to identify the manufacturer of each individual oven. For this reason, ovens are referred to by an arbitrarily assigned number 1 through 12. Though the manufacturers did not guarantee the ovens to be new (in some cases, the ovens had been used for test purposes), none of the ovens had been sold to the public or used extensively. The ovens supplied by the manufacturers were understood to be recently produced, unmodified units which were taken at random from the production inventory. The oven units were representative of the equipment that is available at the present time on the consumer market. Though only 12 models from three manufacturers were measured, they are sold under a variety of brand names and associated model numbers and therefore represent a significant portion of the microwave oven models on the market.

Near the end of the measurements, NTIA chose to purchase two ovens from retail outlets in the Boulder area. It selected one to match the manufacturer and model number of Oven #7, which during initial testing showed a relatively good emission spectrum. This purchase was intended to help determine whether the performance of the oven was characteristic of others of its model. This additional oven was numbered #7DUP (for #7 duplicate). NTIA selected Oven #13 to match the manufacturer of Oven #7 but to have a different model number, choosing to evaluate whether the characteristics of Oven #7 were consistent with other models of the manufacturer. ITS limited tests of these additional ovens to spectral emission characteristics, considering those results sufficient to confirm similarities or differences with Oven #7.

19/ The previous NTIA measurement effort (see note 3) tested older, used ovens available in or near the ITS facility.

All of the ovens operated at 2450 MHz[20/] and were manufactured during 1991 or 1992. They varied in size from 0.023 to 0.042 m^3 (0.8 to 1.5 ft^3). They varied in rated power from 700 to 1000 Watts. Some had turntables or browning elements and some did not.

Operational Checkout

ITS received the manufacturers' ovens at its laboratory in Boulder, CO. ITS personnel unpacked the units and configured them as indicated in each unit's instruction manual, including the installation of turntables. All of the ovens except one, Oven #3, operated from 110 volt commercial power on three-prong plugs. Oven #3 used 220 volt power on an industrial plug, and was incompatible with the sockets available at the ITS lab. Therefore, Oven# 3 was eliminated from the tests.

Each oven was turned on with a 1-liter water load and observed for unusual behavior. All ovens appeared to operate properly. Each oven was also operated intermittently for a total of about one hour, so as to eliminate any behavior which might be peculiar to the first few minutes of operation with all-new, never-powered components.

Oven Fundamental Power Test

Each oven comes with a manufacturer-specified rating for power output. The manufacturer confirms this power output rating using Procedure IEC-705. NTIA tested the units, not to verify this procedure, but rather to ascertain the typical, average power coupling between each oven and a 1-liter water load. The results of the measurements are presented in TABLE 3-1.

The measurement procedure used for each oven was as follows: 1 liter of water was poured into a cylindrical container, and its initial temperature (°C) was measured with a thermocouple thermometer. The water was then placed in the oven under test and heated at full power for 4 minutes or 240 seconds (longer heating caused evaporation). The water was then removed and its temperature immediately measured. The average power was then calculated under the assumption that 1 calorie will raise the temperature of 1 ml of water by 1 °C. A 40°C rise in the temperature of 1000 ml of water implies 40,000 calories of heat energy coupled into the water. This caloric output was then multiplied by a conversion factor of 4.187 joules/calorie to get the energy, in joules, coupled into the water. Dividing that quantity by the heating time in seconds yields the average power coupled into the water in joules/second, or Watts. To summarize, if the temperatures are measured in degrees

20/ This is a nominal operating frequency. All microwave ovens shift in frequency during operation, and most do not emit their highest levels of emissions at 2450 MHz. Peak levels are generally seen between 2450 and 2480 MHz.

centigrade, the time is measured in seconds, and the water load is a constant 1 liter = 1000 ml, then the calculation is:

$$\text{Power into load (Watts)} = ((T_f - T_i) * 4187)/(\text{cooking time}).$$

As can be seen in TABLE 3-1, the measured power levels are typically about 16% or about .8 dB less than the labelled power levels. There could be several reasons for this; for one, the energy being lost in vaporization could not be ascertained. Also, the procedure used at ITS did not try to replicate the IEC-705 procedures, thereby decreasing the probability of identical results. In many cases on the microwave oven units, the manufacturers indicated the IEC-705 power and their own manufacturer's determined values. In each case, the IEC-705 value indicated a higher power level than the manufacturer rating. Nonetheless, the measured values were sufficiently close to the indicated output values to consider the units to be operating at their nominal power output levels.

TABLE 3-1
MEASURED VS. LABELLED POWER OUTPUT OF MICROWAVE OVENS

Oven #	T_i (°C)	T_f (°C)	Time (s)	ΔT (°C)	Energy (Joules)	Measured Power(W)	Labelled Power(W)	Diff. (%)	Diff. (dB)
1	22.2	49.9	180	27.7	115980	644	800	−20	−0.9
2	15.2	59.4	240	44.2	185065	771	900	−14	−0.7
3	(Incompatible power plug--no tests performed)								
4	17.0	46.8	240	29.8	124772	520	700	−26	−1.3
5	12.9	54.1	240	41.2	172504	719	800	−10	−0.5
6	15.8	55.8	240	40.0	167480	698	800	−13	−0.6
7	17.0	55.3	240	38.3	160362	668	750/850	−21	−1.0
8	14.2	60.3	240	46.1	193020	804	1000	−20	−0.9
9	17.1	60.8	240	43.7	182972	762	800	−4.8	−0.2
10	16.3	54.1	240	37.8	158269	659	800	−18	−0.8
11	15.9	56.8	240	40.9	171248	714	800	−11	−0.5
12	17.1	56.7	240	39.6	165805	691	900	−23	−1.1
7DUP	18.7	58.7	240	40.0	167480	698	750/850	−18	−0.8
13	18.6	57.7	240	39.1	163712	682	750/850	−20	−0.9

Measurement Configuration

The arrangement of equipment for the NTIA microwave oven tests is shown in Figure 3-1. The measurements were all performed indoors in a non-anechoic laboratory room, since tests performed in association with NTIA Technical Memorandum 92-154 (note 3) showed no significant differences between data obtained at an outdoor test range with a ground plane and the indoor, non-anechoic lab.

Each oven was mounted on a wooden table, with the base of the oven 1 meter above the floor. A 1.7-2.6 GHz, National Institute of Standards and Technology (NIST)-calibrated, standard gain horn was mounted at a height of 1.1 meter at a distance of 3 meter from the front face of the oven.

A short (approximately 1 meter long), low-loss (approximately 1 dB at 3 GHz) RF line connected the horn to the front end of the measurement system. The front end was a custom-designed and constructed 2-18 GHz preselector which combined the features of noise diode calibration, 0 to 70 dB of interactive RF attenuation, automatic tracking YIG preselection, and 2-18 GHz low noise amplification.

A longer, higher-loss section of RF line connected the front end box to a second low noise amplifier (LNA) at the front end of a Hewlett-Packard 8566B spectrum analyzer. Fixed attenuation was introduced into the line, both ahead of and after the second LNA, so as to maximize the measurement system's instantaneous dynamic range while simultaneously providing just enough gain to overdrive the noise figure of the RF path and the spectrum analyzer (see Calibration, below).

The spectrum analyzer video output was directed to a Tektronix 2430A digital oscilloscope, where time waveforms could be measured and recorded (see Time Domain Measurements, below). All system components were operated via an 80486-based PC controller, which was in turn operated under a custom-designed and written, general-purpose program named DA (data acquisition). Measurements were recorded on magnetic mass storage disks for subsequent analysis.

To monitor frequency drift of microwave ovens, a Hewlett-Packard 53310A modulation domain analyzer was operated. The modulation domain analyzer was operated manually.

Calibration

All system calibrations were performed with noise diodes. The measurement system could be calibrated with a noise diode at the horn antenna output, or at the front of the preselector box. A calibration was performed once a day at the horn output, and at more frequent intervals with the built-in diode in the preselector box. The horn-position calibration was used to automatically correct measurement values prior to recording those values. The preselector box calibrations were performed to check that the sensitivity and gain of the system had not changed, and to verify that the YIG was tracking properly.

The noise diode calibrations utilized the Y-factor method, and are accurate to within ±1 dB if the overall noise figure exceeds about 2 dB. Typically, the noise figure of the measurement system was 9 dB, and the gain for the entire signal path, excluding the measurement antenna, was about 30 dB. To minimize noise figure while maximizing instantaneous dynamic range, fixed attenuators were introduced into the signal path until the excess noise observed from the LNAs ahead of the spectrum analyzer was observed to overdrive the spectrum analyzer noise figure by about 3 dB.

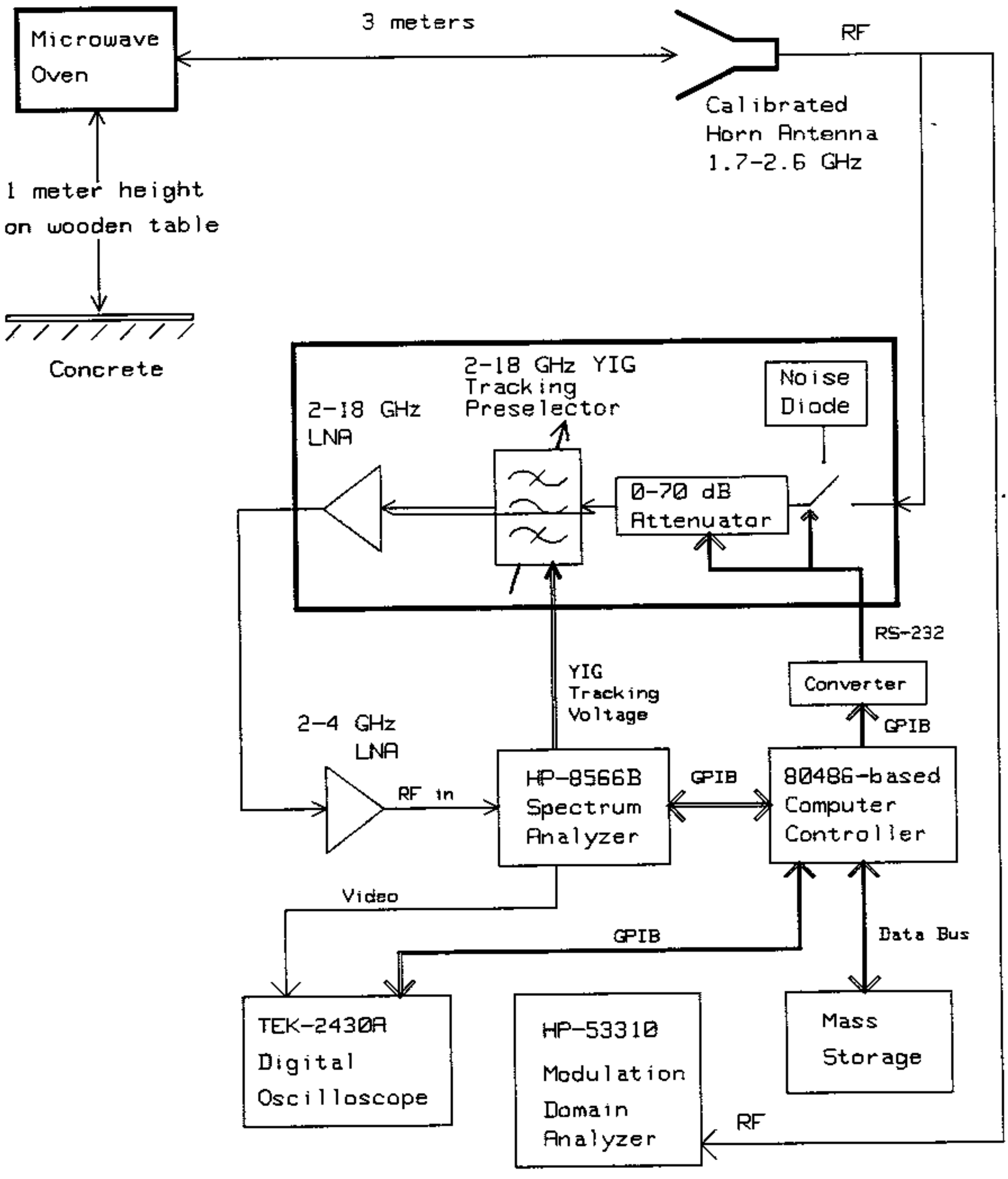

Figure 3-1. Measurement configuration.

TYPES OF MEASUREMENTS

Frequency Domain Measurements

All ovens were measured in the frequency domain to ascertain their spectral emission characteristics. Power received in a bandwidth was measured as a function of frequency for each oven. The fundamental unit of these measurements is power, in dBm, measured in 50 ohms in bandwidths of 30 kHz to 3 MHz.

Although the units of the measurement are absolute in the 50 ohm measurement circuit, they do not take into account the antenna correction factor (ACF) of the broadband horn, and thus indicate only emission levels in free space if no corrections are made to the recorded dBm values. If the ACF is factored into the recorded dBm values, then the field strength in dBμV/m, which is incident at the receiving antenna, can be determined. Also, the ACF can be combined with the recorded dBm values, and the 3 meter path loss can be factored in to yield the effective isotropic radiated power (EIRP) from the ovens under test, in dBpW.[21/]

An example of a spectral emission characteristics measurement is provided in Figure 3-2. Samples of spectral emission characteristics of individual ovens are presented in Section 5 while the rest of the results are provided in Appendix B.

For high duty cycle emitters (CW or nearly CW), the measurement of emitted power as a function of frequency involves sweeping a spectrum analyzer across the frequency range of interest, putting it in a maximum-hold mode, and waiting long enough to fill in a spectral envelope. For pulsed emitters (radars in general, and microwave ovens in particular), the choice of measurement algorithm is non-trivial and has an enormous effect on the

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21/ Field strength at 3 meters and EIRP were calculated from measured values of dBm in 50 ohms (assuming free space propagation and no near-field effects) via the following two equations:

$$\text{Field Strength in dB}\mu\text{V/m (at 3 meters)} = P_{meas} + (77.2\text{ dB}) + 20\log(f) - G_{dBi}$$

and

$$\text{EIRP in dBpW} = P_{meas} + (72\text{ dB}) + 20\log(f) - G_{dBi}$$

where

P_{meas} = Power, dBm, measured in 50 ohms;
f = frequency in megahertz;
G_{dBi} = gain in decibels relative to isotropic of measurement antenna at frequency f.

To convert EIRP to effective radiated power relative to a dipole (ERP), subtract 2.14 dB from the EIRP value.

measurement results. Selection of a technique to measure microwave ovens is exacerbated by the fact that the ovens do not generally operate at a single, stable center frequency. ITS examined two basic algorithms for measuring emission spectra: swept and stepped.

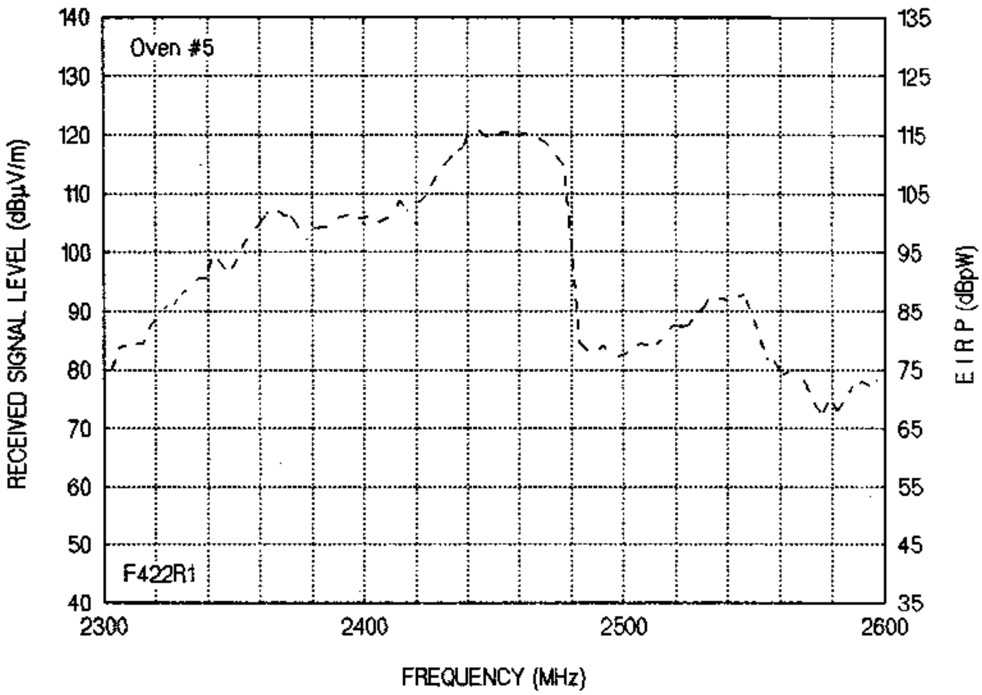


Figure 3-2. Example of emission spectrum.

Swept Spectrum Measurements. In swept measurements, the spectrum analyzer is sweep-tuned continuously across a desired frequency range. With respect to the method of making peak measurements, the simplest approach is to utilize an off-the-shelf spectrum analyzer which is swept across the spectrum of interest with a peak detector and a maximum-hold display. The bandwidth should be as wide as possible to capture the impulsive characteristics of the microwave oven emissions.

One problem with swept measurements, however, is that the time required to perform them can add to the difficulty of the tests. The emissions from the oven at any given frequency can vary by as much as 30-40 dB during a period of about one second, and it was observed during the measurements that the behavior at any given frequency also tends to repeat within about one second. This means that, to record the highest emission that can occur at any given frequency, the measurement must look at each of the spectrum analyzer bins for about one second. If the analyzer has 1001 measurement bins, and each bin must be monitored for a total of one second, then the total time which must be spent sweeping to get a reasonable peak occupancy envelope is about 1001 seconds, or about 17 minutes. This could be accomplished by running a single 17-minute sweep, or by running 60 sweeps at 17 seconds each, etc. It is crucial that on any given sweep, the time spent measuring at each bin within each sweep should not be less than the pulse interval of 1/60 of a second (17 ms), so that at least one pulse can be sampled at each bin on each sweep. Therefore, 17 ms/bin = 17 seconds/sweep would be the minimum adequate sweep time, and 60 such sweeps would be required to complete the measurement. This technique takes so long (17 minutes minimum) that the water load in the oven may boil before the test is completed causing variations in the results. Thus the test must be halted two or three times while the load is changed.

A more serious problem is that system dynamic range is limited to the instantaneous dynamic range of the spectrum analyzer. ITS usually tries to achieve a goal of a 100 dB dynamic range, but instantaneous dynamic range of the spectrum analyzer is likely to be only about 60 to 70 dB. This may not be enough to show both the spurious emission sidebands and the center-frequency amplitude accurately. If additional sensitivity is desired and an LNA is placed ahead of the analyzer, then instantaneous dynamic range is restricted even further. Thus, an experimenter doing this measurement may have to decide between measuring the sidebands while the center frequency is saturating (thus rendering the entire measurement questionable) or else using enough RF attenuation to get a good reading of center-frequency amplitude while losing the extended spectrum in system noise. The only way around that problem with an off-the-shelf measurement approach would be to do the spectrum in segments, and to use tunable bandpass/highpass/lowpass and notch filters to keep the system linear. This further complicates and slows the measurement process, not to mention creating calibration difficulties.

The ITS measurement system solves the tracking problem by utilizing a YIG filter at the front end and tracking the filter with the spectrum analyzer sweep voltage. But the dynamic range problem cannot be eliminated with a sweeping measurement algorithm.

An additional difficulty occurs in the measurement of average levels in a swept mode. The sampling required to derive averages tends to be inherently biased toward either the pulse peaks from the oven or toward the measurement system noise floor, depending upon the sweep rate which is used. The bimodal nature of the average (either it tends to be the same value as the peak emissions, or else it tends to be down at system noise) occurs because the ovens are pulsed emitters.

The oven emits pulses at the rate of 60 Hz, or once every 17 ms. If the analyzer sweeps slowly enough that a pulse is sure to occur at each bin in the sweep (sweep time is at least as long as 17 ms x number of bins/sweep), and if positive peak detection is used, then the single point which the analyzer selects for display in each bin will usually be the peak amplitude of a pulse. If average statistics are derived from such data, then the average will be almost as high as the peak data. If sample detection is used instead of peak detection, then the biasing in favor of peaks is removed, but the maximum emission envelope (which must be gathered simultaneously in swept/m3 algorithm) cannot be obtained.

If, on the other hand, sweeps are run at a high rate (20 ms/sweep, for example, which translates into 20 μs/bin), then the analyzer almost always samples on its own noise floor, and the average data look like the measurement system noise. Neither solution works very well.

Stepped Spectrum Measurements. ITS has developed an alternative that overcomes these problems, stepping instead of sweeping. If a measurement steps from one frequency to the next in increments of the measurement bandwidth, then it is only necessary to measure N steps, where N = (measurement range)/(measurement bandwidth), instead of the 600 or 1000 points that most analyzers display. For example, if we want to measure 300 MHz of spectrum (2300-2600 MHz) in a 3 MHz bandwidth, then only 100 steps are required. At 1 second per step plus 20% data transfer overhead, the measurement period comes out to just 2 minutes instead of the 17 minutes required by the swept measurement. The water does not have to be changed in that interval. Furthermore, it is possible to change the front-end RF attenuation while the measurement progresses across the band, and thus the measurement's available dynamic range can be extended by the additional 70 dB available in the preselector front end. However, this process requires a computer-controlled spectrum analyzer and tracking preselector so that stepping can be performed. The RF front end must track the stepped-tuned frequencies, which is performed by the analog tracking voltage available from the spectrum analyzer, just as with the swept algorithm. But the stepped technique allows the measurement to take full advantage of the dynamic range extension from the RF attenuation, and that in turn allows the maximum exploitation of the sensitivity afforded by the front end LNAs.

For these reasons, it makes more sense from both a theoretical and a practical standpoint to make measurements of microwave ovens in a stepped, rather than swept, mode.

Selected Parameters. For the NTIA measurements, stepped measurements were performed on each oven tested. The measurement parameters are displayed in TABLE 3-2.

Time Domain Measurements

Time domain measurements at single frequencies are an important method for obtaining non-spectral data, including time waveforms and amplitude-probability distributions (APDs). Time scans were taken in two phases. During Phase 1, time waveforms were measured at 2300, 2325, 2350, 2375, 2400, 2425, 2450, 2475, 2500, 2525, 2550, 2575, and 2600 MHz for all ovens. Because time waveform measurements are very time-consuming, it was not possible to acquire an exhaustive set of data on each oven. Therefore, for detailed time domain measurements, NTIA selected a subset of five ovens having the best and worst spectral emission characteristics (Ovens #1, #5, #7, #10, and #11). For each oven in this set (Phase 2), time waveforms were collected for each of the six measurement bandwidths and seven frequencies (2300, 2350, 2400, 2450, 2500, 2550, and 2600 MHz).

TABLE 3-2
PARAMETERS USED FOR STEPPED SPECTRUM MEASUREMENTS

Parameter Description	Value(s) Used for Measurements
Detection	Positive Peak
Time/Step	0.9 seconds
IF Bandwidths	30 kHz, 100 kHz, 300 kHz, 1 MHz, 3 MHz
Frequency Range	2300-2600 MHz (wider in a few cases)
Steps/Spectrum	As required to fill in spectrum without gaps (e.g., 100 steps for 3 MHz bandwidth, 300 steps for 1 MHz bandwidth, etc.)

During Phase 1, the period scan was .1 seconds and no LNA was used. This approach provided sequences of approximately six oven pulses, thereby revealing variation in the recorded pulse shapes, but limited the dynamic range of the measurements. An example of a raw time waveform scan is shown in Figure 3-3. During Phase 2, ITS performed 100 scans at each frequency and bandwidth. Each time scan was composed of 1001 points acquired in 20 ms using the sample detector and added the LNA to the measurement configuration. Thus, at each frequency and bandwidth combination, a total of 100,000 points, at 20 μs/point were accumulated. A total of 2 seconds of time waveform data were acquired with 20 μs resolution at each combination of bandwidth and frequency for each of the five ovens. Though this approach limited the number of pulses recorded in each scan, it increased the resolution of the recorded signals and the associated APDs. Samples of time waveforms for individual ovens are presented in Section 5, while the rest of the results are provided in Appendix C.

From the time domain data of the Phase 2 measurements, APDs were produced. The APDs show the percentage of acquired points (x-axis) which exceed an amplitude (y-axis). APD plots are useful for determining the total percentage of time that oven emissions exceed given amplitudes. As noted previously, the APD plots are based on 100,000 points over a 2-second period, allowing calculation of percentages to one thousandth of a percent or 10^{-5}. This level of resolution is particularly crucial for evaluation of impact to digital systems. At the oven operating frequency, an APD should show a near vertical increase in pulse amplitude near 50%, representing the oven duty cycle. As the measurement system is tuned off of the oven operating frequency, as is the case in Figure 3-4, less of the pulse will be recorded and the break point should move toward a lower percentage. In that example, pulses exceeded 60 dBμV/m about 6% of the time. The graph levels at the higher amplitudes, where the levels are less frequently reached.

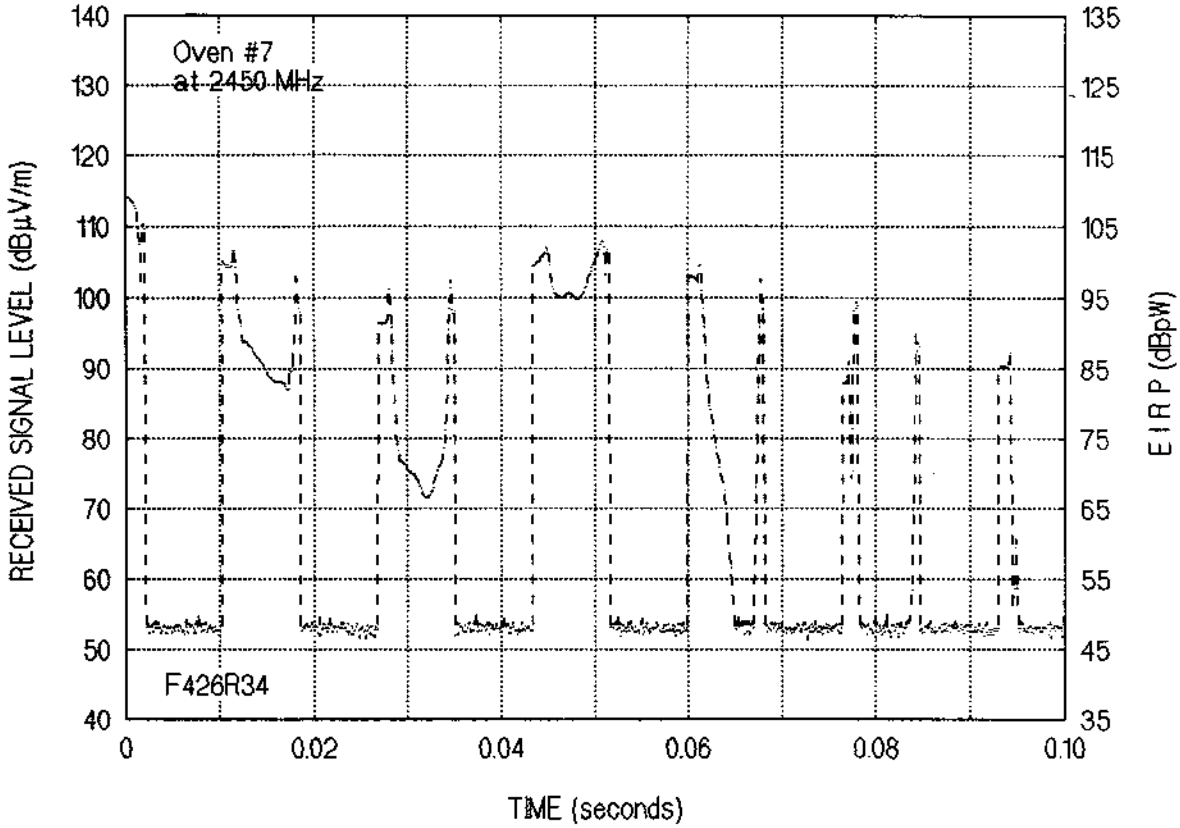


Figure 3-3. Example time waveform.

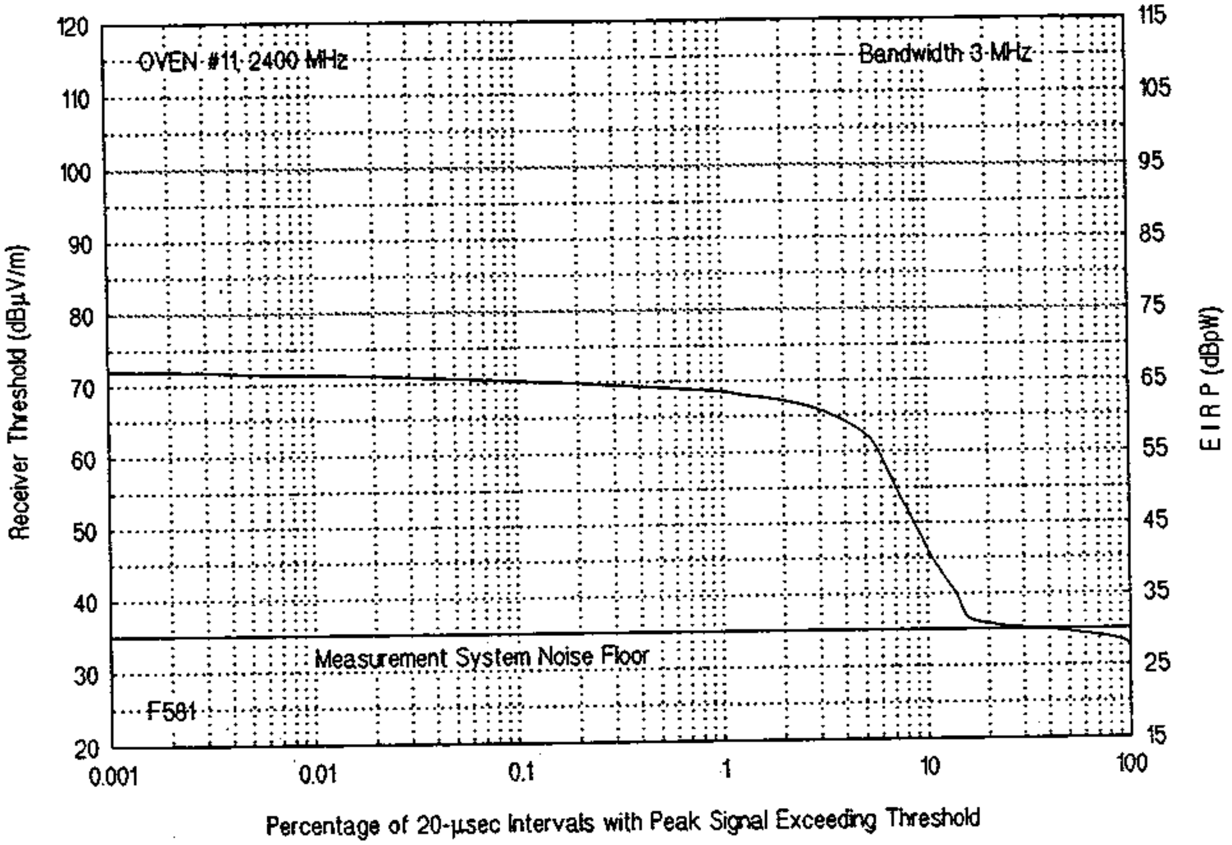


Figure 3-4. Example amplitude probability distribution.

SECTION 4
PARAMETER VARIATION MEASUREMENTS

INTRODUCTION

ITS performed measurements to determine the influence of external conditions and measurement system parameters on spectral emission characteristics from microwave ovens. These parameter variation measurements are described in this section. Examples of external conditions include start temperature, orientation, oven load, and oven power setting.[22/] Measurement system parameters include antenna polarization, measurement bandwidth and measurement period.[23/] Since there potentially exists the requirement to know the oven spectral emission characteristics measured in a variety of bandwidths, the measurement bandwidth parameter was not studied as part of the parameter variation tests, but was dealt with as part of the main body of spectral emission and time waveform measurements. All spectral emission data presented here were obtained using the procedures for stepped measurements discussed in Section 3.

The tabular and graphic data displays in this section illustrate points of discussion. A constant scale has been used in graphical displays of like parameters to allow easy comparison of results obtained for different conditions. The data presented here represents a sample of the total amount that was accumulated during the parameter variation tests. Additional data has been provided in Appendix D.

Information presented in this section concerning differences between results under varied conditions is based to a great extent on visual comparisons of graphical displays of data and examination of the statistics associated with the data. Pearson's correlation coefficient is used to quantify the differences between results. It is defined by the equation below.

$$r_{AB} = \sum_{i=1}^{n} (a_i\, b_i)/(n\, S_A\, S_B)$$

22/ All oven magnetrons operate at their rated power regardless of the oven power setting. The power setting on the oven regulates the percentage of time that the magnetron is operating, by switching the magnetron on or off. Thus, the emission spectrum characteristic of any oven is created by the periods in which the magnetron is turned on and is the same for any power setting. Therefore, no tests were performed varying the power setting.

23/ ITS did not perform tests of varying periods because the stepped procedure required time to step through the frequency range. All tests were run for approximately 5 minutes.

Where:

	A_i	=	the dependant variable for a specific data set
	B_i	=	the dependant variable for another data set
	a_i	=	$(A_i - \mu_A)$
	b_i	=	$(B_i - \mu_B)$
	μ_A	=	mean of the set represented by A
	μ_B	=	mean of the set represented by B
	n	=	number of data points
	S_A	=	standard deviation of the set represented by A
	S_B	=	standard deviation of the set represented by B

The correlation coefficient for two sets of data can be calculated to obtain an estimate of the degree of association. The coefficient ranges from -1 to $+1$, with 0 meaning the two distributions are independent of each other. The degree of association of the two distributions is indicated by the magnitude of the correlation coefficient such as 0.914. If a set of distribution data were correlated with itself, the coefficient would be equal to 1. A negative value for the coefficient means that the two distributions are inversely related.[24/]

Various schemes have been used to interpret values of correlation coefficients. A common approach is to classify correlation coefficients as "very high" (for example $\mathbf{r} \geq 0.90$), "high" ($0.90 < \mathbf{r} \geq 0.70$), "medium" ($0.70 > \mathbf{r} \geq 0.30$), or "low" ($\mathbf{r} < 0.30$). However, what constitutes a high or low correlation depends on what is being correlated and what use is made of the correlation coefficients once it has been computed. One type of test for reliability is called "test-retest reliability" and is determined by administering a test, waiting and then readministering the test. The test's reliability or the consistency of the measurement is the correlation between the two sets. A "test-retest reliability" coefficient below 0.80 would raise serious doubts about the reliability of that test.[25/] The "very high" and "high" correlation appears applicable for the microwave oven test-retest reliability as is shown below in the control tests.

PARAMETER TESTS

Control Tests

ITS ran several units through a control test to determine whether the ovens produced a repeatable spectrum output from test to test. The test parameters were standardized as follows.

24/ Hogg & Craig, *Introduction To Mathematical Statistics*, 2nd Edition, The Macmillan Company, 1965.

25/ Kirk, Roger E., Baylor University, *Introductory Statistics*, The Brook/Cole Publishing Co., a Division of Wadsworth Publishing Co., Monterey, CA, 1978, pp. 100-108.

Start Temperature	-	Warm oven (5 minute warm-up)
Measurement Period	-	Approximately 5 minutes
Measurement Bandwidth	-	1 MHz
Oven Orientation	-	Antenna Aimed at the Oven Door
Antenna Polarization	-	Vertical
Oven Load	-	1 liter of water

Figure 4-1 shows five identical tests of each oven performed at different times within a 15 minute time span. Tests of the same oven yield highly correlated results. The correlation coefficients shown in TABLE 4-1 range between 0.89 and 0.99. Variations occurring during the following parameter tests producing correlation coefficients below the lower values in TABLE 4-1, can be attributed to the changes in parameters induced during the tests.

TABLE 4-1
CORRELATION COEFFICIENT RESULTS OF CONTROL TESTS[26/]

DATA SETS BEING COMPARED	PEARSON'S CORRELATION COEFFICIENT
Oven #1 (F515R7-R11)	0.974 to 0.986
Oven #2 (F667R1-R5)	0.885 to 0.981
Oven #4 (F669R1-R5)	0.929 to 0.956
Oven #5 (F492R8-R12)	0.932 to 0.982
Oven #7 (F536R6-R10)	0.983 to 0.990
Oven #8 (F668R1-R5)	0.976 to 0.993
Oven #10 (F621R6-R11)	0.962 to 0.992
Oven #11 (F578R6-R11)	0.948 to 0.990

26/ All possible combinations of records were evaluated. As an example, for File 515 records 7 through 11, all ten possible combinations of records were used. Record 7 was correlated against records 8, 9, 10, and 11; record 8 was correlated against records 9, 10, and 11; record 9 was correlated against records 10 and 11; and record 10 was correlated against record 11. Then the best and the worst correlation coefficient values were listed in TABLE 4-1.

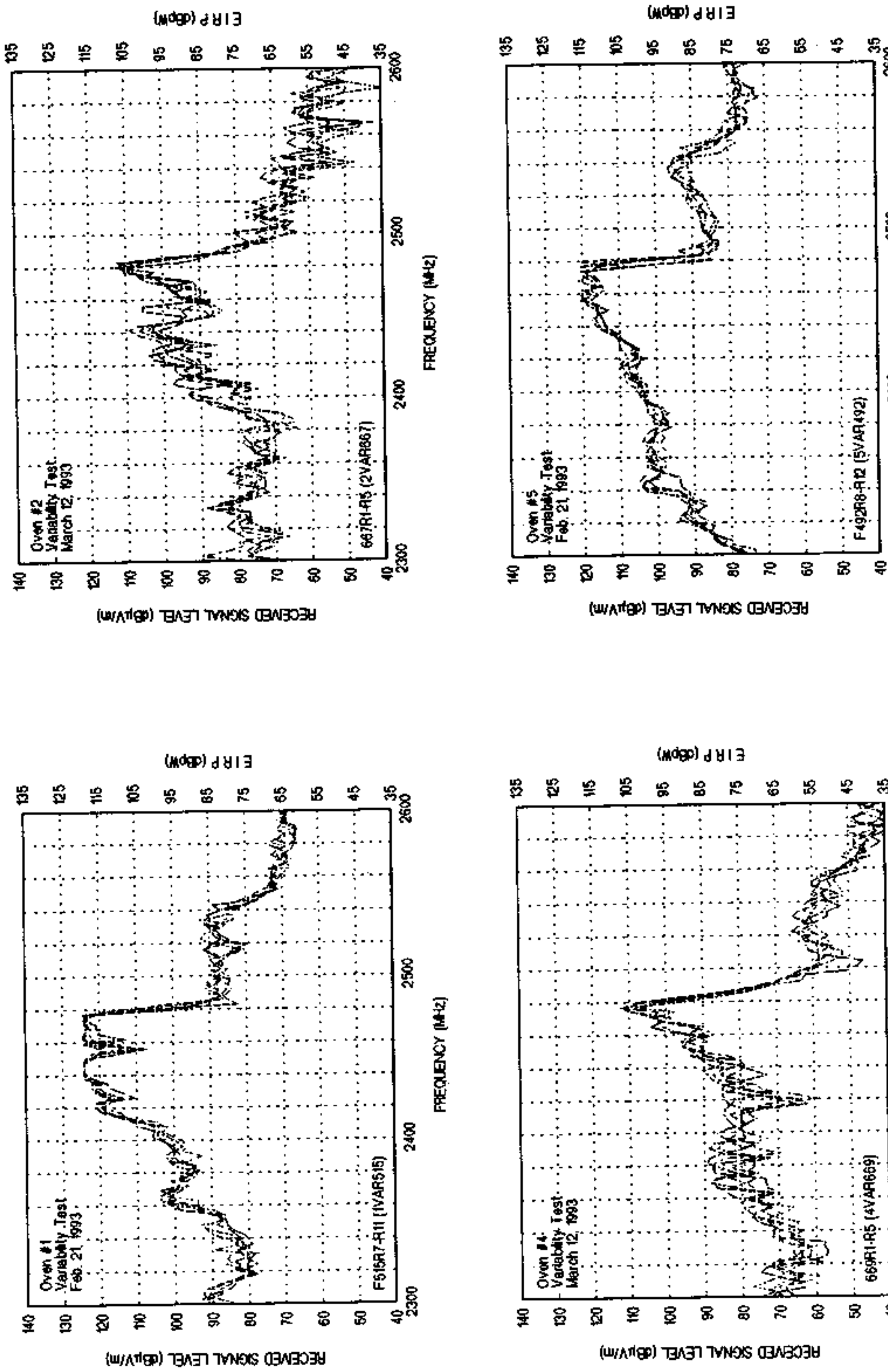


Figure 4-1. Control tests for Ovens #1, #2, #4, and #5.

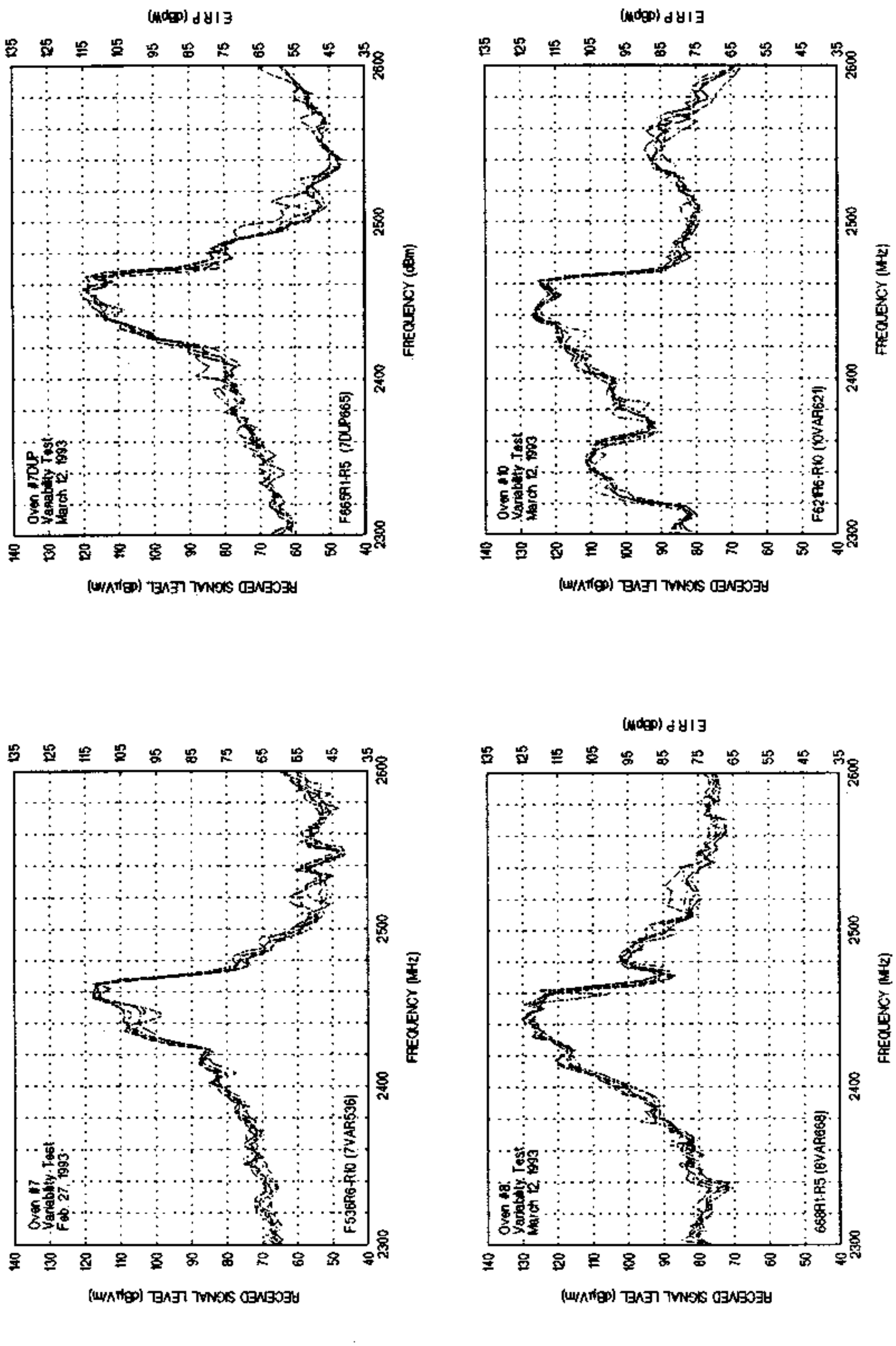
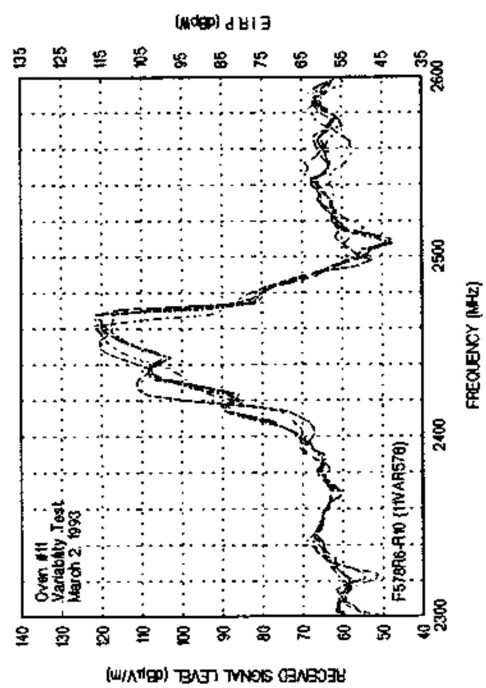


Figure 4-1 cont. Control test for Ovens #7, #7DUP, #8, and #10.



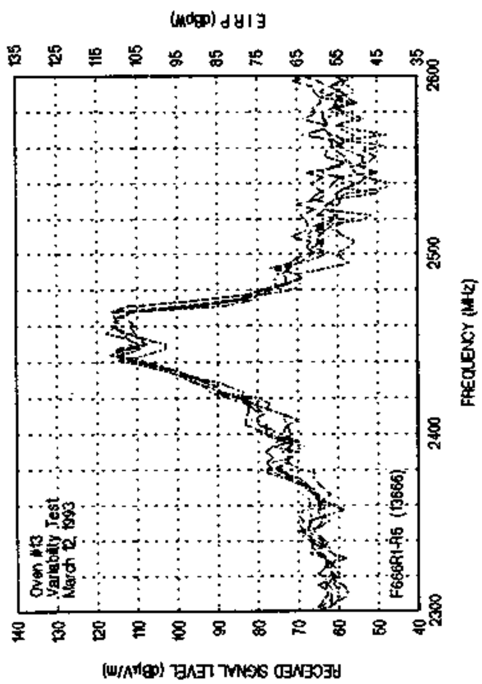


Figure 4-1 cont. Control tests for Ovens #11 and #13.

Start Temperature

Start temperature refers to the temperature of the oven at the start of particular set of measurements. A cold start means that the oven is at room temperature, not having been operated for a period of time. Warm start indicates that the oven is warm due to prior usage.

The investigation of start temperature consisted of measuring the spectral emission characteristics of Oven #2 immediately after turn-on and at 5 minute intervals up to 30 minutes. This was the maximum time available before the 1 liter of water, being used as the oven load, completely boiled away.

Figure 4-2 shows plots of the spectral emission characteristics obtained during each time interval. The measurement bandwidths of 1 MHz contributes to the difference between these and other graphs of similar data that are presented within the majority of spectral emission characteristics measurements in Section 5 and Appendix B.

TABLE 4-2 shows the results in terms of the correlation coefficient quantifying differences in successive measurements. A slight change is evident between the oven start measurement and those at other times. Once warm, the ovens consistently show high correlation.

TABLE 4-2
RESULTS OF TEMPERATURE INVESTIGATION FOR OVEN #2

DATA SETS BEING COMPARED	CORRELATION COEFFICIENT	DATA SETS BEING COMPARED	CORRELATION COEFFICIENT
Cold Start vs. 5 Minutes	0.891	Cold Start vs. 5 Minutes	0.891
Cold Start vs. 10 Minutes	0.904	5 vs. 10 Minutes	0.957
Cold Start vs. 15 Minutes	0.890	10 vs. 15 Minutes	0.952
Cold Start vs. 20 Minutes	0.861	15 vs. 20 Minutes	0.957
Cold Start vs. 25 Minutes	0.870	20 vs. 25 Minutes	0.951
Cold Start vs. 30 Minutes	0.859	25 vs. 30 Minutes	0.948

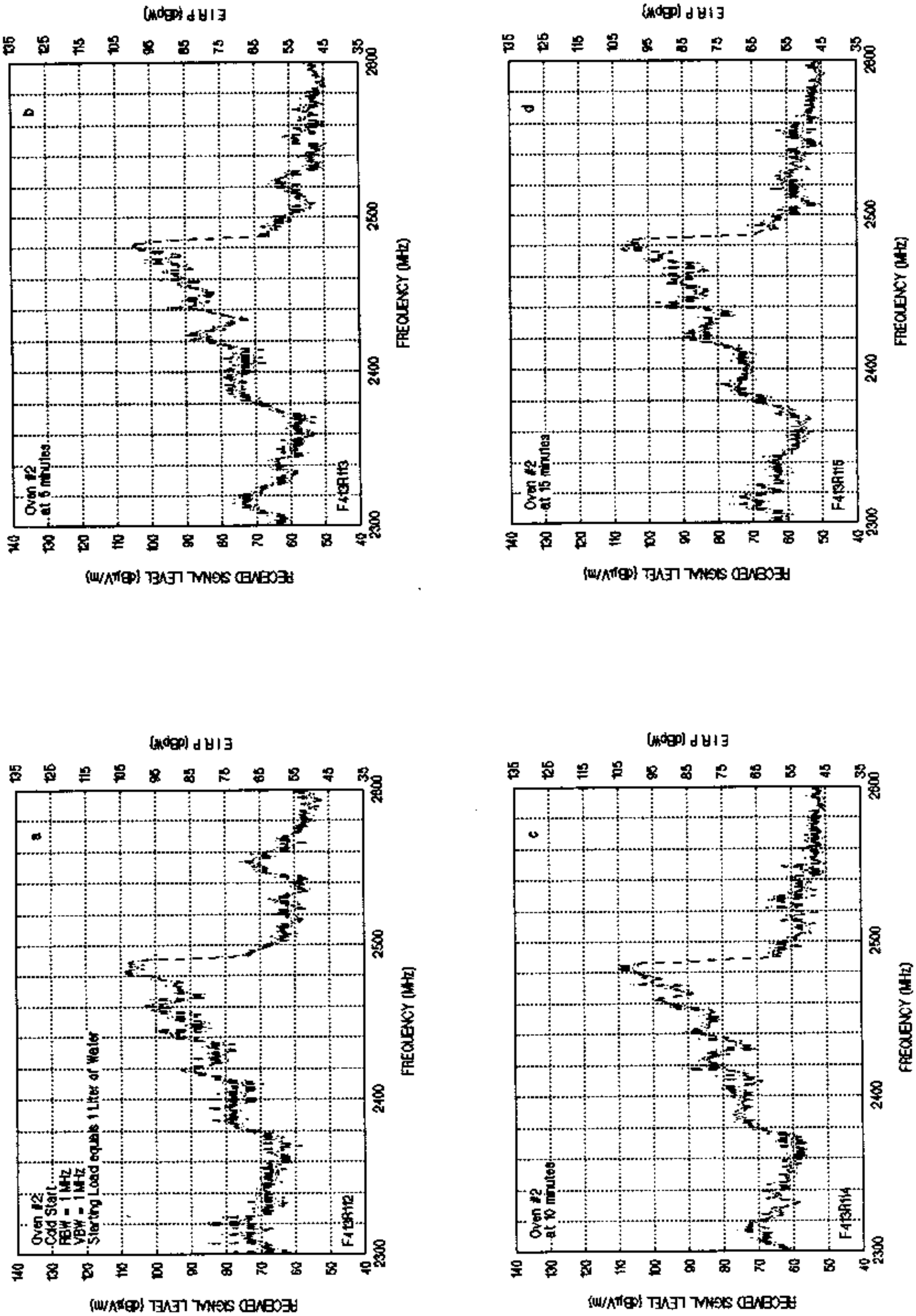
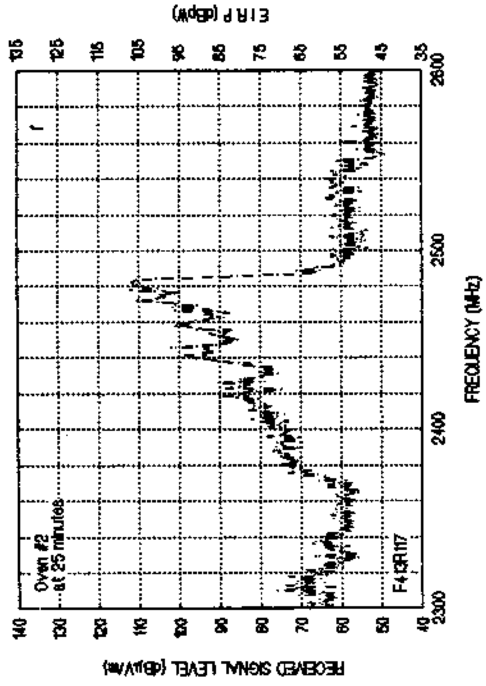
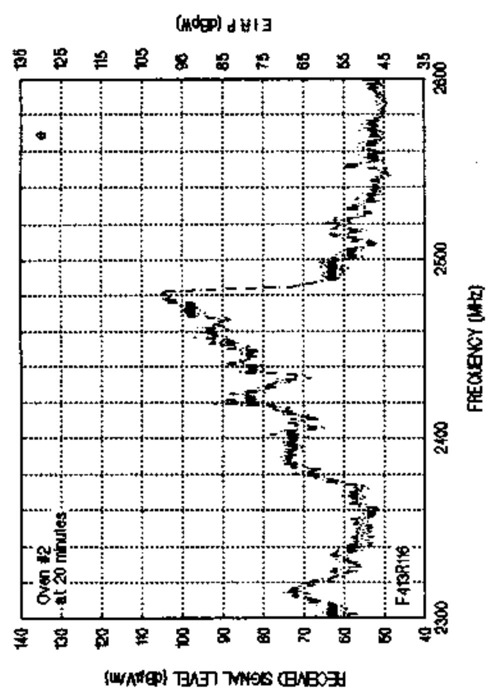


Figure 4-2. Temperature variation test of Oven #2.





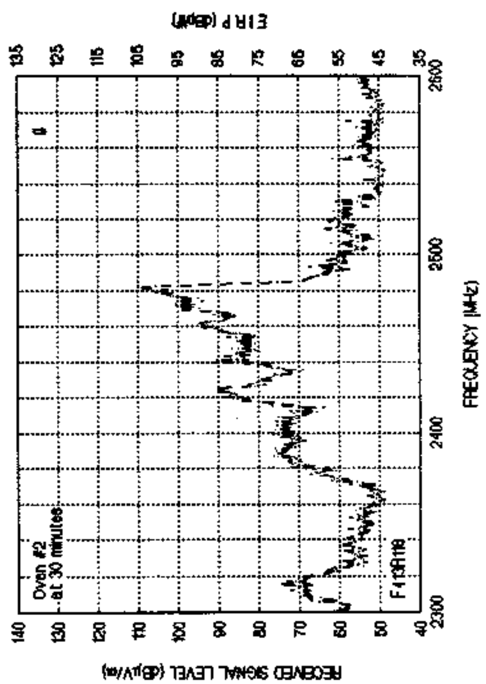


Figure 4-2 cont. Temperature variation test of Oven #2.

Oven Orientation

ITS tested whether performing measurements with the antenna pointed at the oven's door were sufficient for determining the spectral emission characteristics. During measurements in conjunction with its 1992 effort (see note 3), NTIA determined that emitted power from an oven varied by as much as 20 to 25 dB when measured from locations covering 360° in the three planes around the unit, but as shown in Figure 4-3, the horizontal radiation pattern was predominantly omnidirectional. Additional information was sought in these tests to determine whether the overall spectral emission characteristics varied with oven orientation. These tests were accomplished by measuring Oven #8 several times, changing the orientation of the oven between measurements. In separate tests, the measurement system antenna pointed at both sides, the front, and the rear of the oven.

The results obtained for the oven orientations of 0°, 90°, 180° and 270° are presented in Figure 4-4. The corresponding correlation coefficients are listed in TABLE 4-3.[27/] The magnitude of the coefficients indicate that changes as a function of oven orientation are small. Also, the graphs confirm that the maximum signal at any frequency is obtained generally at the front of the oven, 0° orientation.

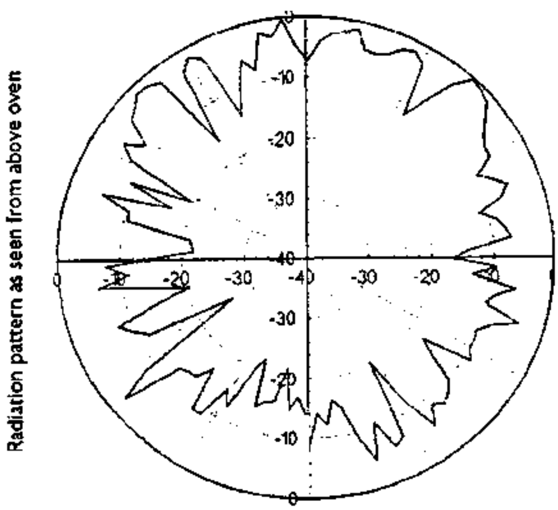


Figure 4-3. Representative microwave oven radiation pattern.

27/ Oven #8, vertical polarization, measured at 0°, had 5 different records (see TABLE 4-1). Ten possible combinations were evaluated with the most conservative correlation coefficient listed in TABLE 4-3 under 0°. A mean of those 5 different records was correlated against each of the measurement at 90°, 180°, and 270°; hence, 0° (Avg.) vs. 90°, etc. in TABLE 4-3.

TABLE 4-3
PEARSON'S CORRELATION COEFFICIENTS FOR OVEN #8
WITH RESPECT TO OVEN ORIENTATION

0°	0° (Avg.) vs. 90°	0° (Avg.) vs. 180°	0° (Avg.) vs. 270°
0.976	0.914	0.865	0.945

Antenna Polarization

The ITS team altered the antenna polarization of the measurement system antenna between vertical (VP) and horizontal (HP). The tests were performed using Ovens #4 and #8. Two sets of data were taken for each oven: one set for the antenna in a vertical polarized plane and another set for the antenna in a horizontal polarized plane. Figures 4-5 and 4-6 show the spectral emission characteristics of each oven with vertical and horizontal polarization, using video and resolution measurement bandwidths of 1 MHz.

The figures indicate that both polarizations produce similar results. TABLE 4-4 shows the results of the Pearson's correlation coefficient for varied antenna polarization using Ovens #4 and #8. An examination of TABLE 4-4 reveals a high correlation.

TABLE 4-4
CORRELATION RESULTS FOR OVENS #4 AND #8
FOR VERTICAL AND HORIZONTAL POLARIZATIONS

DATA SETS BEING COMPARED	PEARSON'S CORRELATION COEFFICIENT
Oven #4 VP vs. Oven #4 HP	0.885
Oven #8 VP vs. Oven #8 HP	0.897

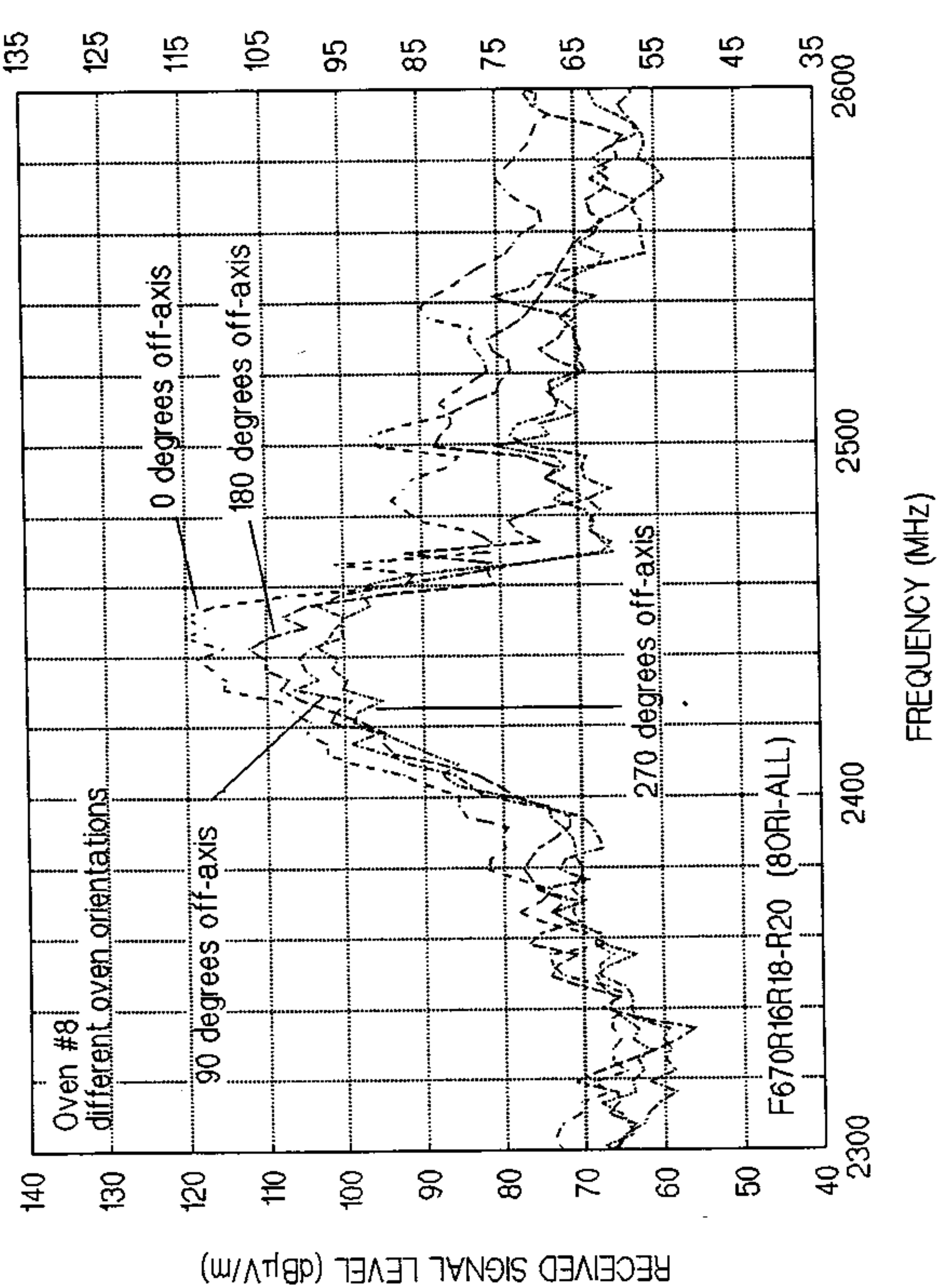


Figure 4-4. Orientation variation of Oven #8.

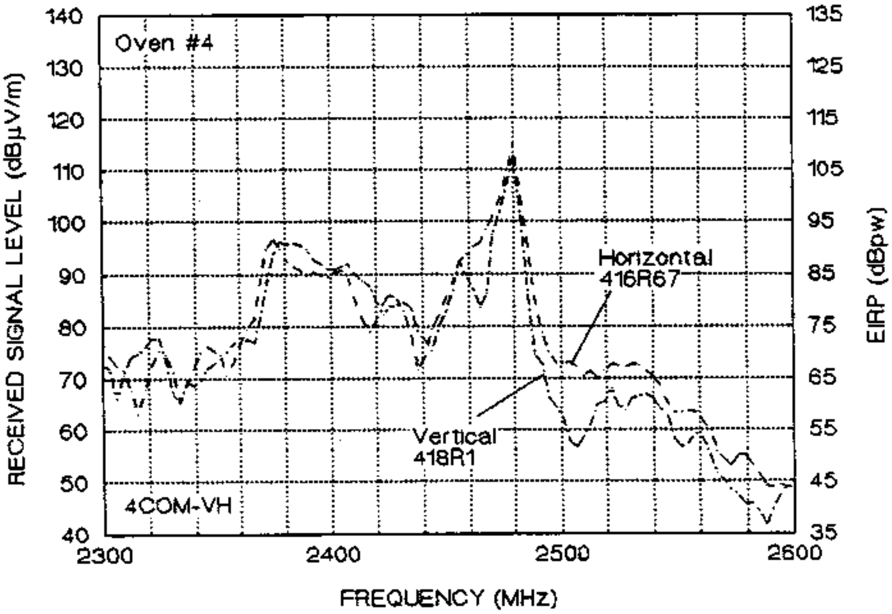


Figure 4-5. Antenna polarization variation with Oven #4.

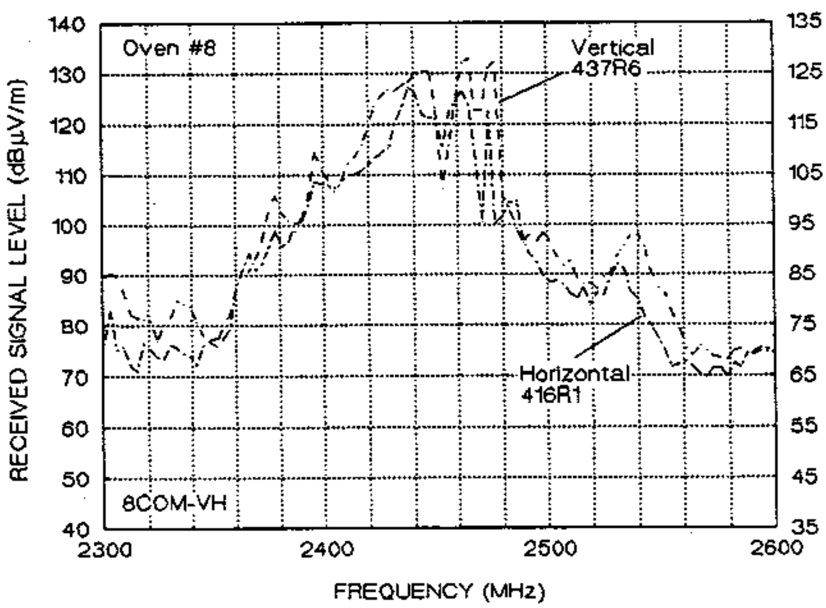


Figure 4-6. Antenna polarization variation with Oven #8.

Oven Load

ITS tested the impact of the load by measuring emission spectra while varying the substance or volume of the material being cooked with the oven. Two ovens, #2 and #8, were selected for testing. The first two load investigation graphs, Figures 4-7 and 4-8, show the results operating the ovens with tap water loads varying from 0.2 to 1.0 liters in 0.2 liter increments. The next two load investigation graphs, Figures 4-9 and 4-10, show the results of tests involving consumer loads, a TV Dinner, a frozen burrito, and microwave popcorn. TABLE 4-5 provides the correlation coefficients obtained for each oven with the varying water and consumer loads.

Figures 4-7 and 4-8 show a similarity of the emission spectra regardless of the amount of water. However, at specific frequencies, the signal level varies by up to 25 dB. Though the changing of the load does not appear to greatly distort the emission spectra, the results of compliance testing, when based on peak values could be affected by the load used. The correlation coefficient range is from 0.793 to 0.957.

Figures 4-9 and 4-10 show that regardless of consumer load the spectral emission characteristics followed a similar pattern for all tests. Again at specific frequencies, the signal level varies by up to 16 dB. The correlation coefficients range is from 0.760 to 0.964.

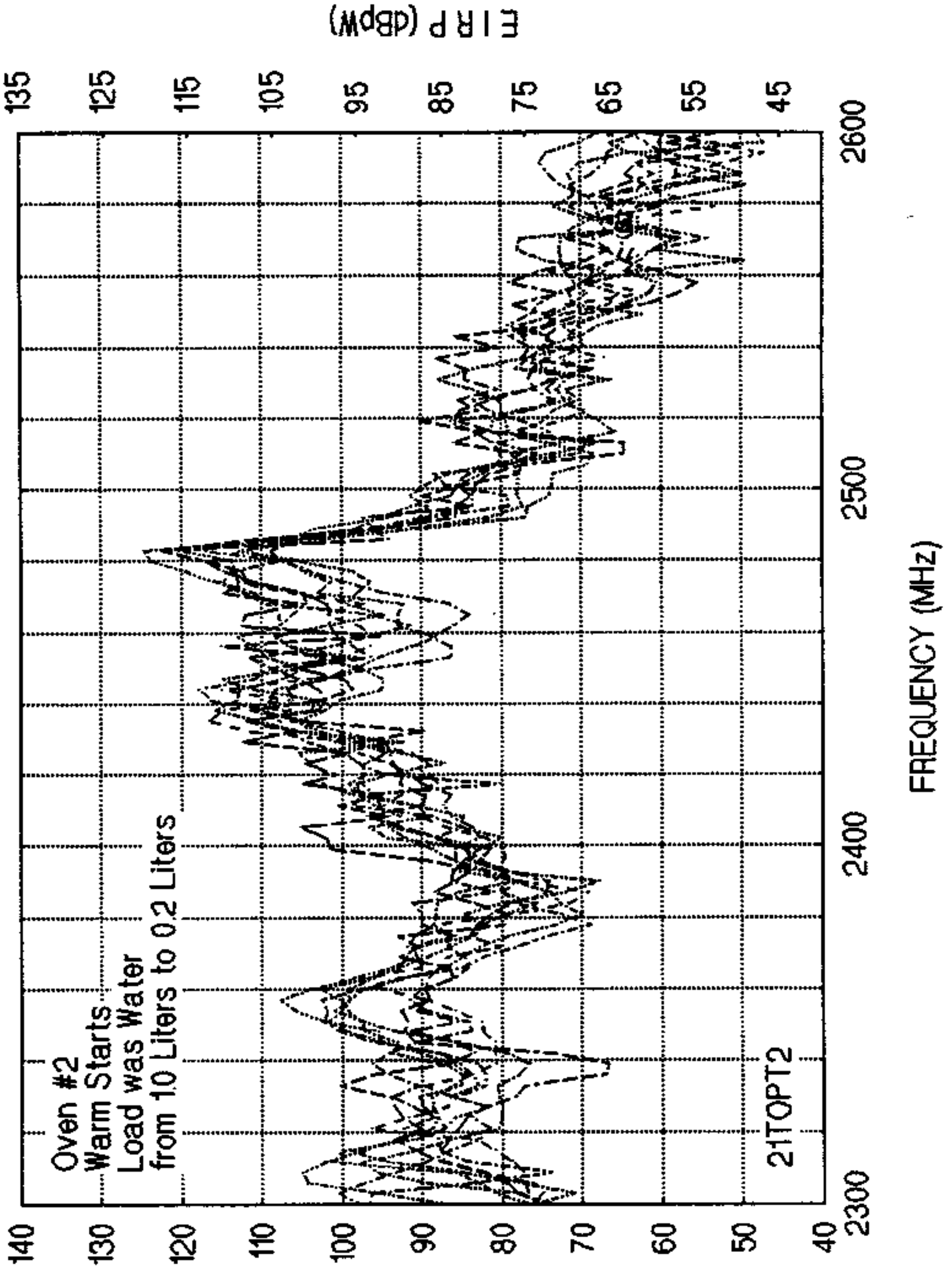


Figure 4-7. Oven #2 with varied water loads.

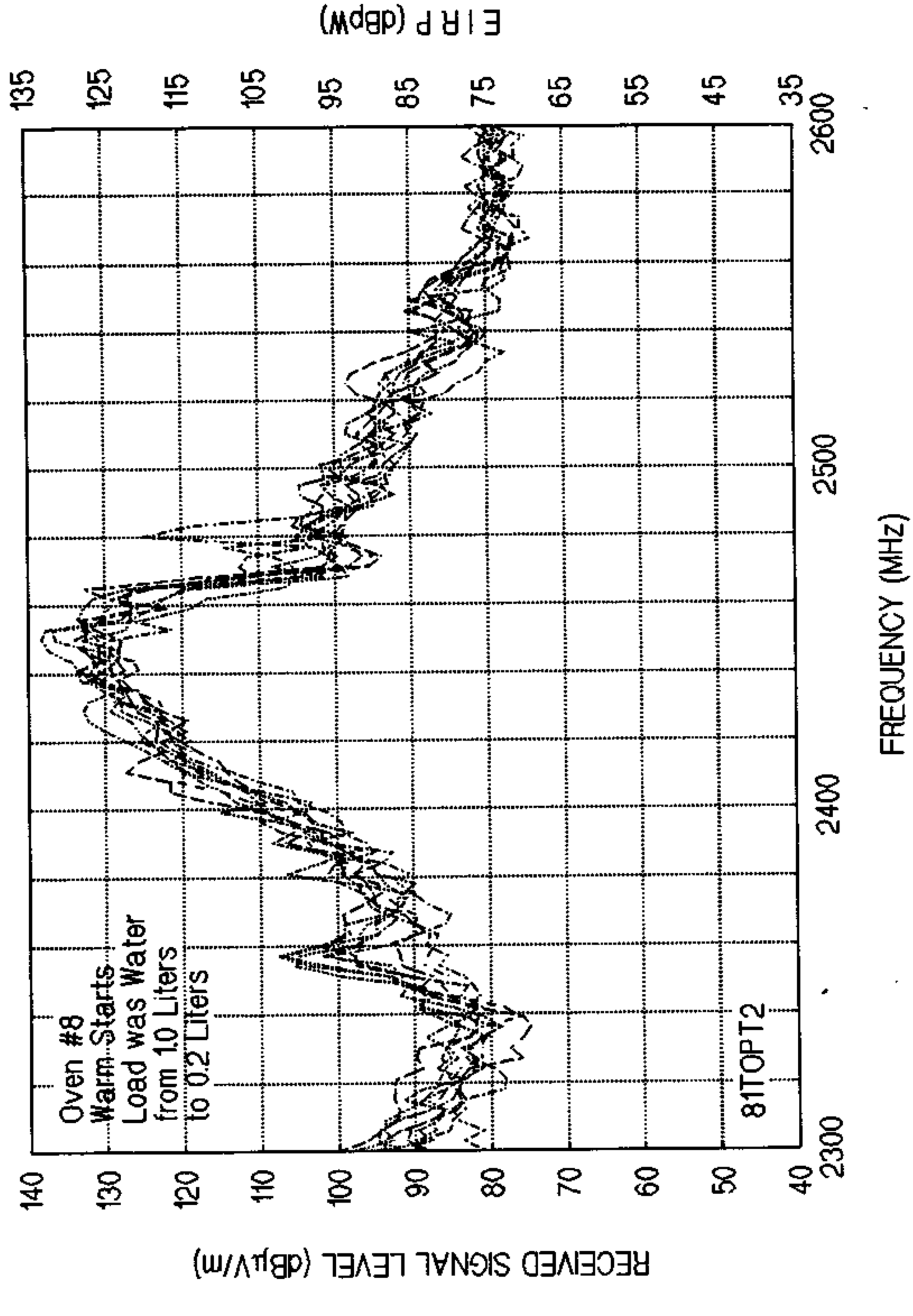


Figure 4-8. Oven #8 with varied water loads.

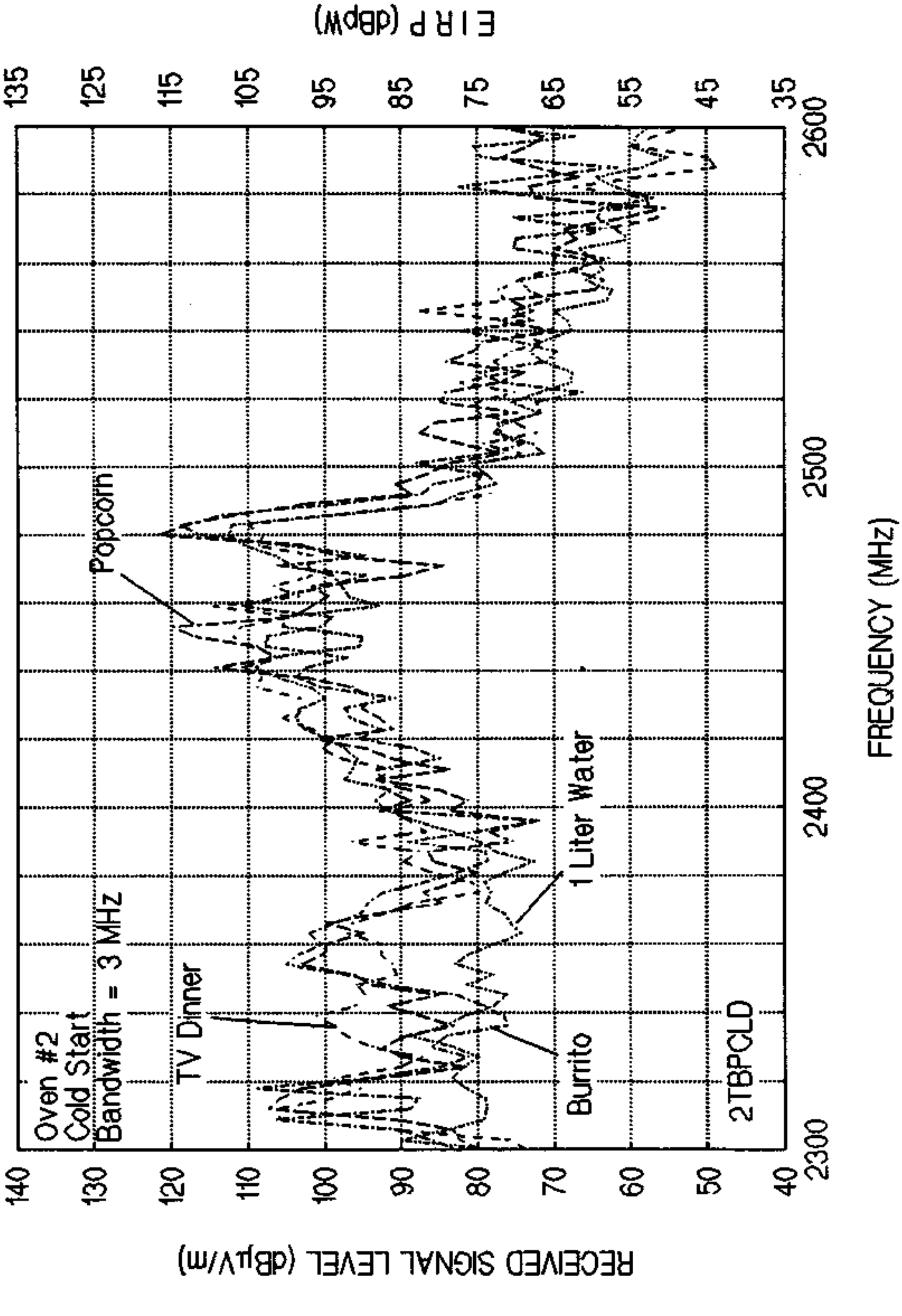


Figure 4-9. Oven #2 with varied consumer loads.

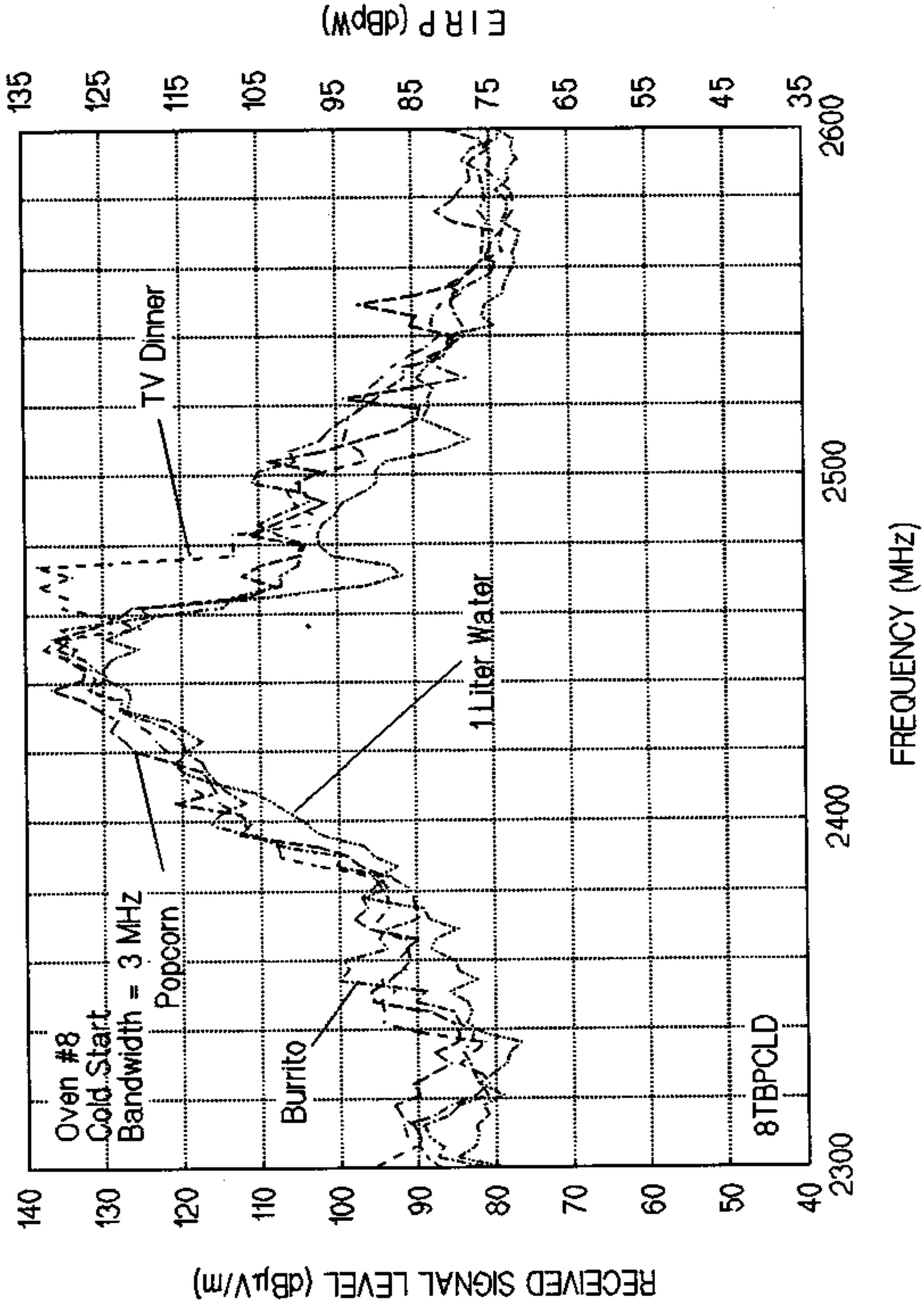


Figure 4-10. Oven #8 with varied consumer loads.

TABLE 4-5
PEARSON'S CORRELATION COEFFICIENT RESULTS
OF OVEN #2 AND #8 WITH VARIED LOADS

COMPARISON	OVEN #2	OVEN #8
1 Liter H_2O vs. 1 Liter H_2O	0.899	0.959
1 Liter H_2O vs. 0.8 Liters H_2O	0.884	0.957
1 Liter H_2O vs. 0.6 Liters H_2O	0.874	0.956
1 Liter H_2O vs. 0.4 Liters H_2O	0.880	0.952
1 Liter H_2O vs. 0.2 Liters H_2O	0.793	0.956
1 Liter H_2O vs. Frozen TV Dinner	0.851	0.903
1 Liter H_2O vs. Frozen Burrito	0.760	0.951
1 Liter H_2O vs. Microwave Popcorn	0.762	0.964

SUMMARY

Although the variation of parameters does alter the results of spectral emission measurements of microwave ovens and therefore also alters any results of compliance testing that are based on such procedures, the impact was limited to changes of about 20 dB at some frequencies. As indicated by the control tests, a portion of this variation can be attributed to the natural variation of each magnetron. Furthermore, the parameter driven variations occur at a variety of frequencies. Therefore, where a number of parameters may simultaneously be different than those used as part of a standard test procedure, as occurs during home use, the impact may not be additive.

The variation of load represented a particularly significant concern since the MP-5 load specification of 1000 ml of water does not coincide with real-life oven home use. However, the results of the load testing showed only slightly greater variation than, for example, from changes in the oven orientation. The use of 1000 ml of water has the added benefit of being convenient in that the water does not have to be continually replaced during the test, as might be the case with smaller water loads. The results of the consumer load tests did not contradict the validity of the 1000 ml of water test.

Oven orientation can be dealt with in one of two ways. Either all tests can be performed with the antenna aimed at the front of the oven, where levels are generally felt to be higher, or a radiation pattern can be measured to determine the point where the emissions are highest.

Neither the antenna polarization nor the start temperature had much impact. Both horizontal and vertical polarization should be permitted with compliance testing. The most significant emission level fluctuations due to start temperature occurred during the first seconds of operation. Therefore, test procedures should specify that emissions should be measured after an oven has been operated for at least 5 minutes.

Since all variations common to home use cannot be accounted for in compliance testing, spectrum managers must consider the application of a single set or a small number of parameters. NTIA believes that the variations reflected in these tests are not sufficient to require a variety of test configurations, but, in fact, support the specification of a single set of test parameters to obtain a reasonably consistent set of results.[28/] Based on this finding, the following set of parameters seems reasonable:

Start Temperature:	Oven Warm[29/]
Oven Load:	1 Liter Tap Water
Oven Orientation:	Antenna Aimed at the Oven Door

28/ Radio system designers will have to be cautious in evaluating the level of protection granted by an oven emission limit. Even in cases where an oven complies with specified limit using a standard set of measurement procedures, the possibility still exists that emissions will at times exceed the limit.

29/ A warm start indicates that the oven is warm due to prior usage, typically 5 minutes.

SECTION 5
MEASUREMENT RESULTS

INTRODUCTION

Based on the results of the parameter variation tests, NTIA selected a set of parameters that provided ease of testing for the general measurement of the characteristics of the ovens. TABLE 5-1 indicates the parameters used in the general testing (Phase I).

TABLE 5-1
MEASUREMENT PARAMETERS

PARAMETER	DESCRIPTION
START TEMPERATURE	OVEN WARM
OVEN LOAD	1 LITER TAP WATER
RESOLUTION BANDWIDTH	3 MHz
VIDEO BANDWIDTH	3 MHz
ANTENNA HEIGHT	OVEN CENTER
OVEN ORIENTATION	ANTENNA AIMED AT DOOR

All ovens were tested during Phase I. The tests consisted of runs of spectral emission characteristics from 2300-2600 MHz, and time waveform measurements at 25 MHz intervals, starting at 2300 MHz. A limited set of the measurement results has been presented in this section along with the text. Also, only emission spectra were recorded for Ovens #7DUP and #13, since the intent of those measurements was only to determine the similarities or differences of those ovens with Oven #7. For the presentation of these results, the ovens are grouped according to magnetron.

NTIA selected five ovens having the best and worst spectral emission characteristics for a more detailed phase of testing (Phase II). Additional emission spectra were recorded and time waveform measurements were taken at 50 MHz intervals, starting at 2300 MHz using measurement bandwidths of 30 kHz, 300 kHz and 3 MHz. From this data, APDs were produced. Spectral emission levels were also measured at harmonics up to the 7^{th}. During the Phase II measurements, a pre-selector and pre-amplifier were used ahead of the spectrum analyzer to increase the spectrum analyzer sensitivity thus permitting detailed time waveform measurements at lower noise levels than those recorded during Phase I.

Phase I data is presented in this section. Phase II, the more detailed data, is presented in Appendices B and C. Following the presentation of measurements of individual ovens are discussions of trigger jitter, the results of experiments in which oven components were switched from one oven to another, and information on simultaneous operation of several ovens.

OVEN DATA

General

The spectrum graphs, for each oven, represent the peak signal obtained while monitoring each of 100 frequency bins in sequence over the 2300-2600 MHz frequency range. In collecting the data, the analyzer was stepped in increments of 3 MHz from 2300-2600 MHz with a dwell time of 0.9 seconds at each frequency. During each dwell period, the level of the strongest received signal was stored. The microwave ovens all operate at a 60 Hz rate, their magnetrons being triggered by the resident electric line signal. Therefore, each of the 100 points comprising the emission spectrum is derived from 54 oven pulses. All tests were conducted in the full power mode.

Immediately following the spectral emission measurement for each oven, a series of time waveform measurements were made at 25 MHz intervals, starting at 2300 MHz. To obtain these data, the analyzer was tuned to the frequency of interest and placed in the zero span mode. Thus the analyzer display is level versus time. For the Phase 1 time waveforms, no LNA was used. Therefore, the signal level at the base of the individual traces represents receiver noise not the lowest amplitude of the microwave oven signal. In most cases, this level was approximately 52 dBμV/m. However, in some cases, ITS staff added additional attenuation to avoid measurement system front end overload. In these cases, the noise level is approximately 62 dBμV/m. The main purpose for acquiring these data was to show general pulse period and received pulse characteristics, however, the data can also give some indication of carrier frequency stability, particularly near the fundamental frequency. Where the magnetron tubes were more stable, the time waveforms show consistent pulse shapes within a series of pulses. The time waveforms of less stable magnetron tubes vary in shape from pulse to pulse.

Each oven produced a unique set of characteristics. TABLE 5-2 provides the specifications of the ovens. Figure 5-1a shows the measured emission spectra for each of the 13 ovens. Figure 5-1b, a composite display of the results obtained for 13 ovens, presents the highest, mean, and lowest amplitudes measured at each frequency. This display indicates the magnitude of the differences between spectral emission characteristics.

To identify microwave ovens for Phase II measurements and to quantify oven emission levels in the adjacent bands as well as in the ISM band, the receiver signal levels, using a peak detector and the step analyzer receiver algorithm as previously described, were averaged over each of the adjacent bands (2300-2400 MHz and 2500-2600 MHz) as well as the operating ISM band (2400-2500 MHz). The mean received signal level (dBμV/m) and the EIRP (dBpW) in the sub-bands for each of the microwave ovens are shown in Figures 5-2 and 5-4 in order of the highest mean emission level to the lowest mean emission level. The mean received signal level for each oven in the operating band is shown in Figure 5-3 using the same highest to lowest mean emission level scheme.

TABLE 5-2
OVEN SPECIFICATIONS

Oven #	Rated Power (Watts)	Measured Power (Watts)	Magnetron Tube	Date Manufactured	Additional Information
1	800	644	Type-A	July 1991	120V/60Hz/1500W
2	900	771	Type-D	June 1992	120V/60Hz/1520W single phase
4	700	520	Type-E	June 1992	120V/60Hz/1140W single phase
5	800	719	Type-A	May 1991	120V/60Hz/1500W
6	800	698	Type-H	June 1991	120V/60Hz/1500W
7	750/850	668	Type-G	July 1992	120V/60Hz/1500W
8	1000	804	Type-B	August 1991	120V/60Hz/1800W
9	800	762	Type-C	August 1991	120V/60Hz/1500W
10	800	659	Type-A	February 1992	120V/60Hz/1500W
11	800	714	Type-F	July 1992	120V/60Hz/12amp
12	900	691	Type-D	July 1992	120V/60Hz/13amp
7DUP	750/850	698	Type-G	July 1992	120V/60Hz/1500W
13	750/850	682	Type-G	July 1992	120V/60Hz/1500W

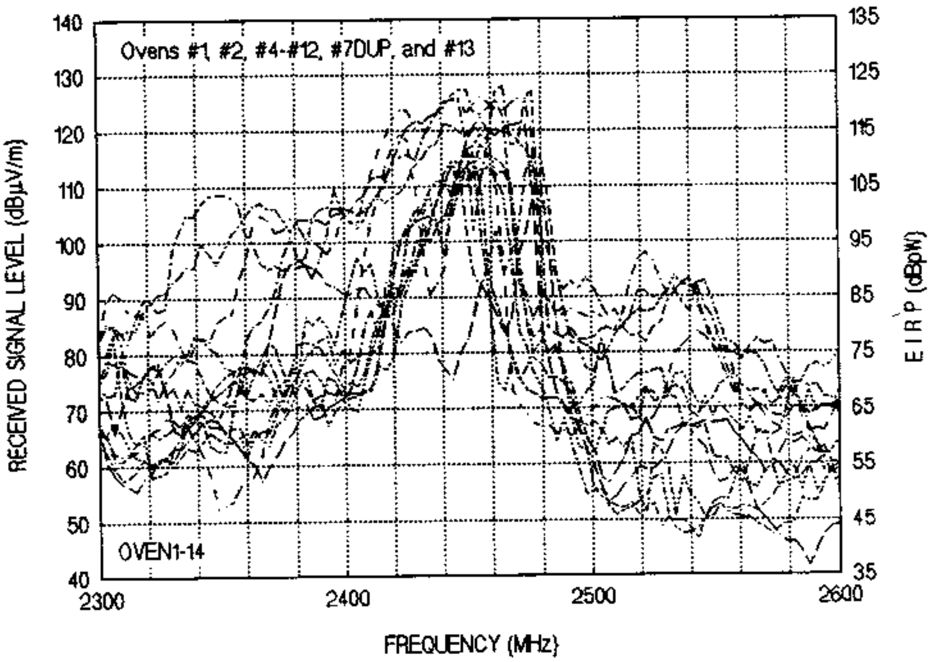


Figure 5-1a. Measurements of Ovens #1, #2, #4 through #12, #7DUP, and #13.

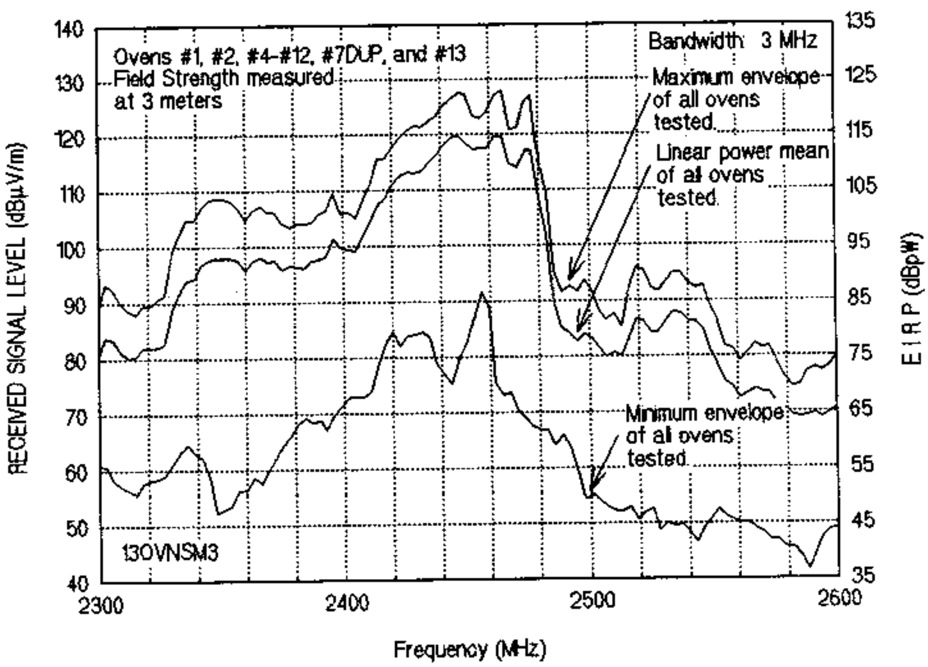


Figure 5-1b. A composite display of the results obtained for 13 ovens.

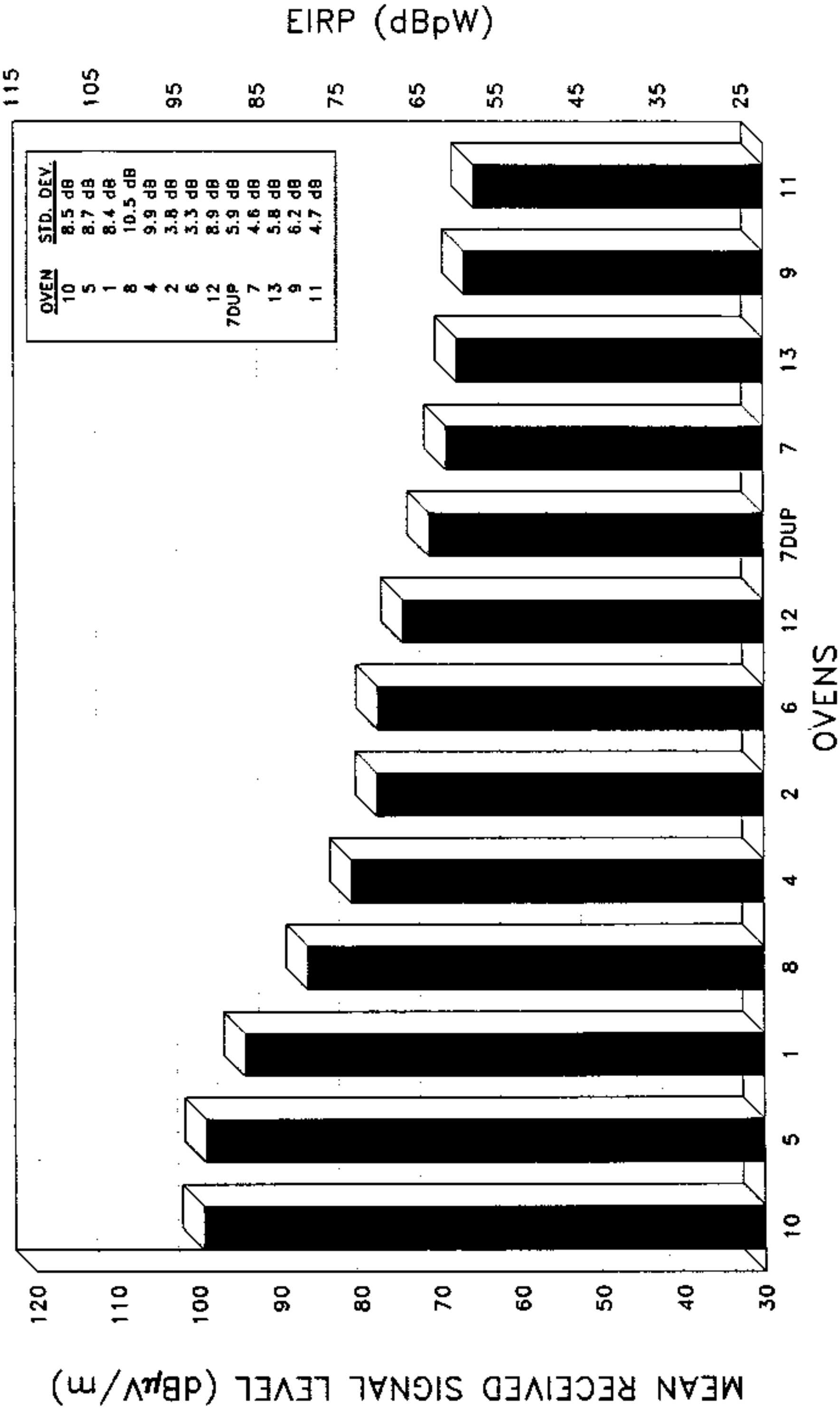


Figure 5-2. Mean signal level for each microwave oven in the lower adjacent band, 2300-2400 MHz.

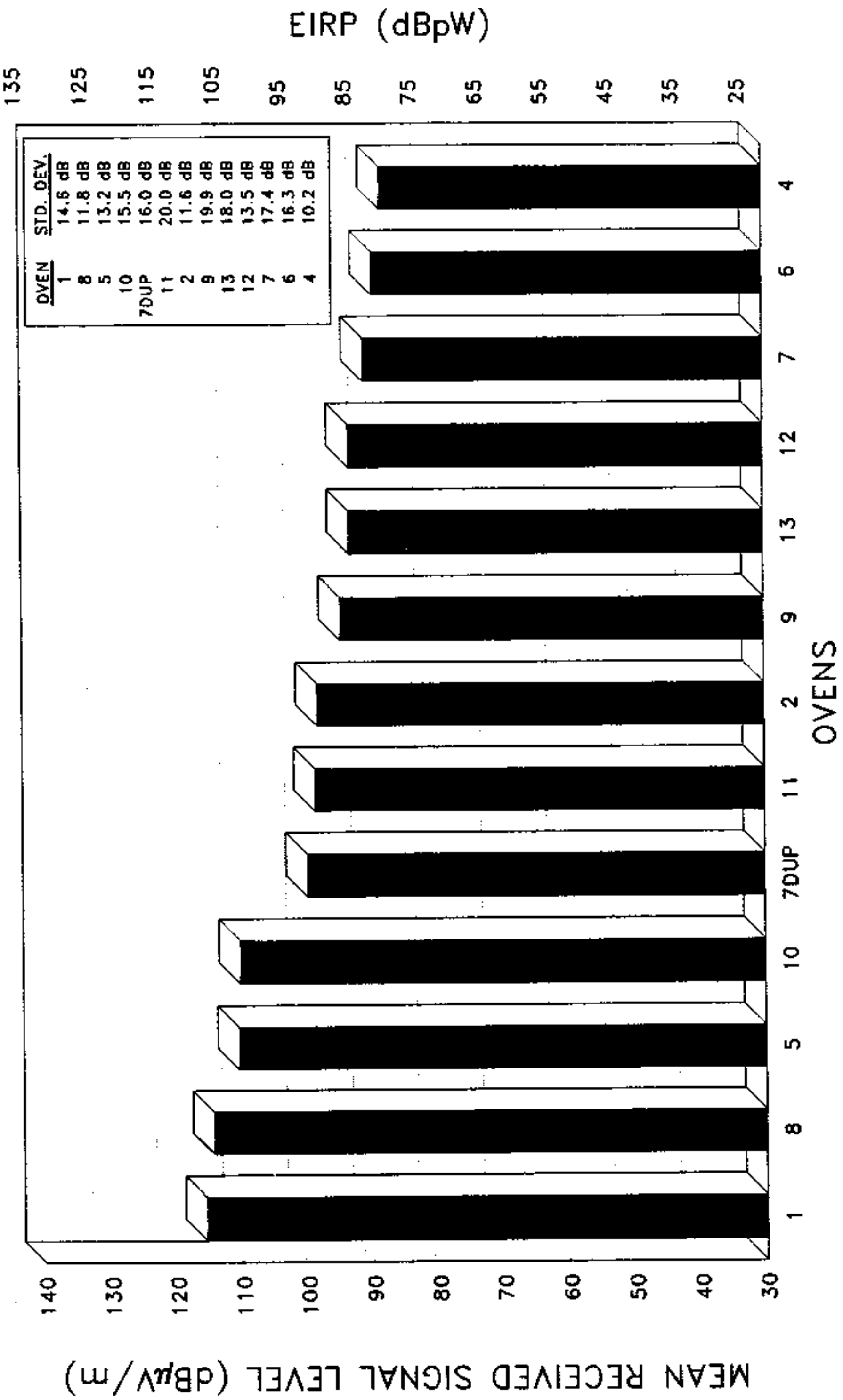


Figure 5-3. Mean signal level for each microwave oven in the assigned operating band, 2400-2500 MHz.

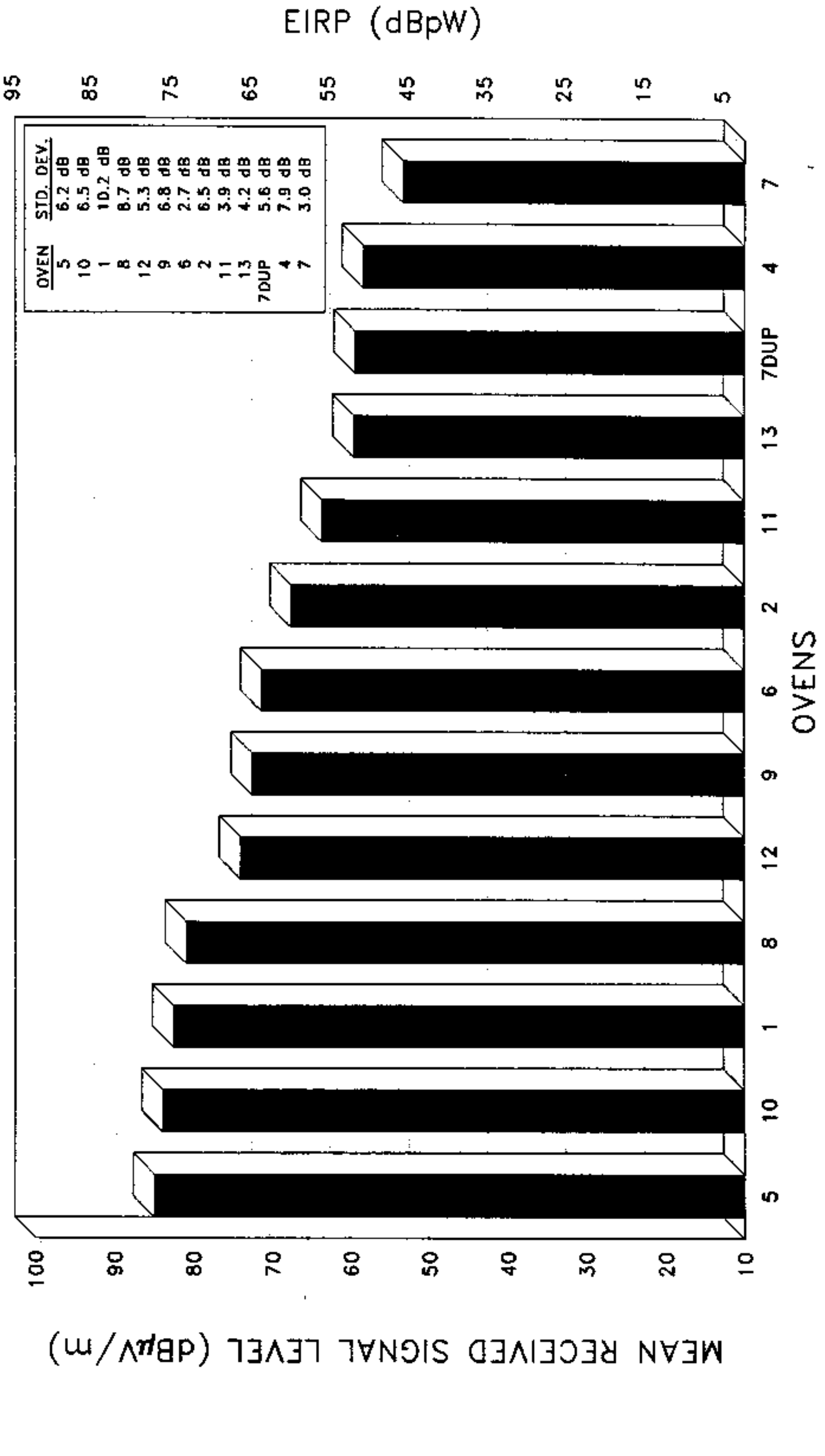


Figure 5-4. Mean signal level for each microwave oven in the upper adjacent band, 2500-2600 MHz.

Ovens #1, #5 and #10

The spectral emission characteristic plots, and the selected time waveforms obtained for Ovens #1, #5, and #10 are presented Figures 5-5 through 5-7. Each of these ovens use magnetron tube designated Type-A. Spectrum plots for these ovens, do not display a well defined carrier because of the shifting of the fundamental frequency. Further evidence of this shifting can be seen by changes in the time waveforms which occur on a pulse-to-pulse basis. Time waveforms are measured with the analyzer set to a fixed frequency. The changes manifest in these time waveforms are due to frequency shifting.

Another notable characteristic in the spectrum plots for these ovens is that they all produce detectable signals out to the extremes of the measured frequency range of 2300-2600 MHz. This is most likely due to the rise and fall times and the transient behavior occurring for the duration of the pulse. Figures 5-5b and 5-6b show examples of changes taking place within the pulse.

Statistics for Ovens #1, #5 and #10 are given in TABLE 5-3. The statistical results reveal a high degree of similarity between the three ovens. Ovens #1, #5 and #10 were among the highest emitters for the 3 sub-bands. In the lower and upper adjacent bands, Ovens #1, #5, and #10 are the highest emitters (see Figure 5-2 and 5-4).

TABLE 5-3
STATISTICS for OVEN #1, #5, and #10

Sub-band	Oven #1	Oven #5	Oven #10
2300-2400 MHz			
Mean (dBμV/m)	92.4	97.2	97.5
Maximum (dBμV/m)	104.8	107.3	108.8
Minimum (dBμV/m)	79.2	80.0	82.2
Standard Deviation	8.4	8.7	8.5
2400-2500 MHz			
Mean (dBμV/m)	113.7	108.6	108.4
Maximum (dBμV/m)	125.9	121.1	127.4
Minimum (dBμV/m)	84.7	82.2	81.1
Standard Deviation	14.6	13.2	15.4
2500-2600 MHz			
Mean (dBμV/m)	80.8	83.1	83.1
Maximum (dBμV/m)	98.0	96.2	95.9
Minimum (dBμV/m)	65.7	72.4	68.7
Standard Deviation	10.2	6.2	6.5

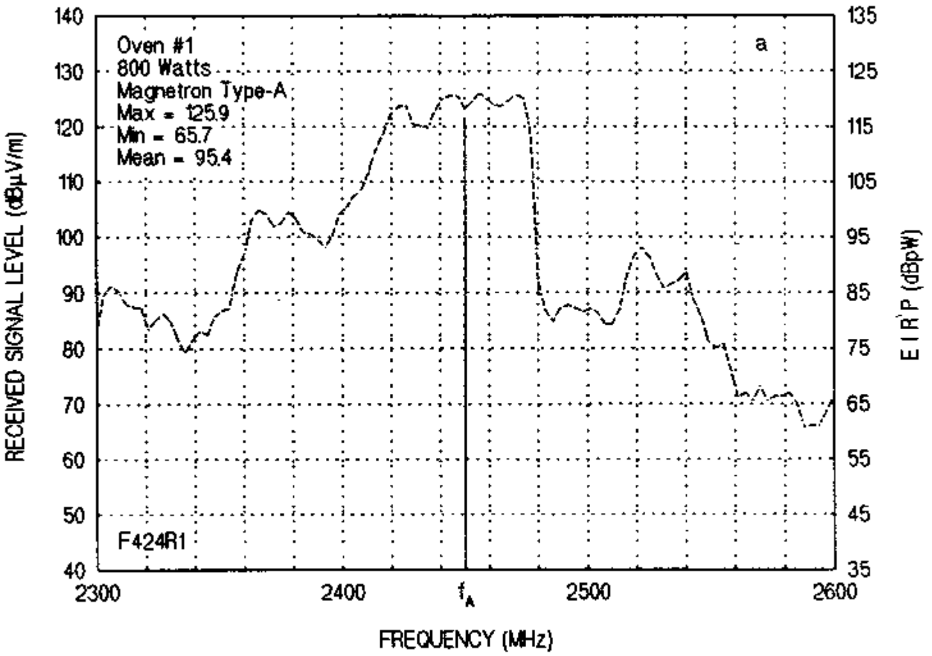


Figure 5-5a. Oven #1, Frequency vs. Amplitude.

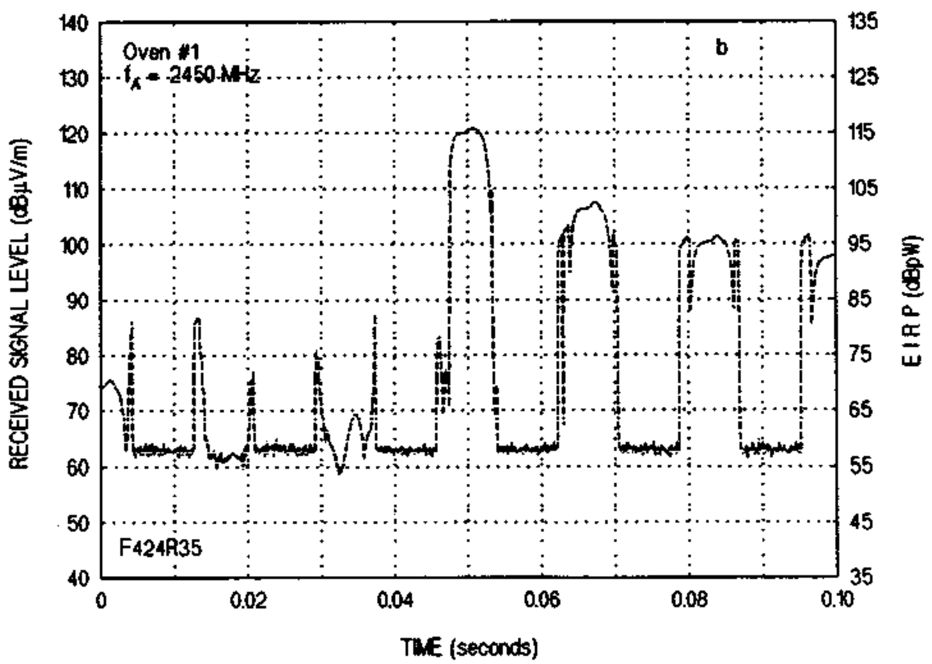


Figure 5-5b. Oven #1, Time vs. Amplitude at 2450 MHz.

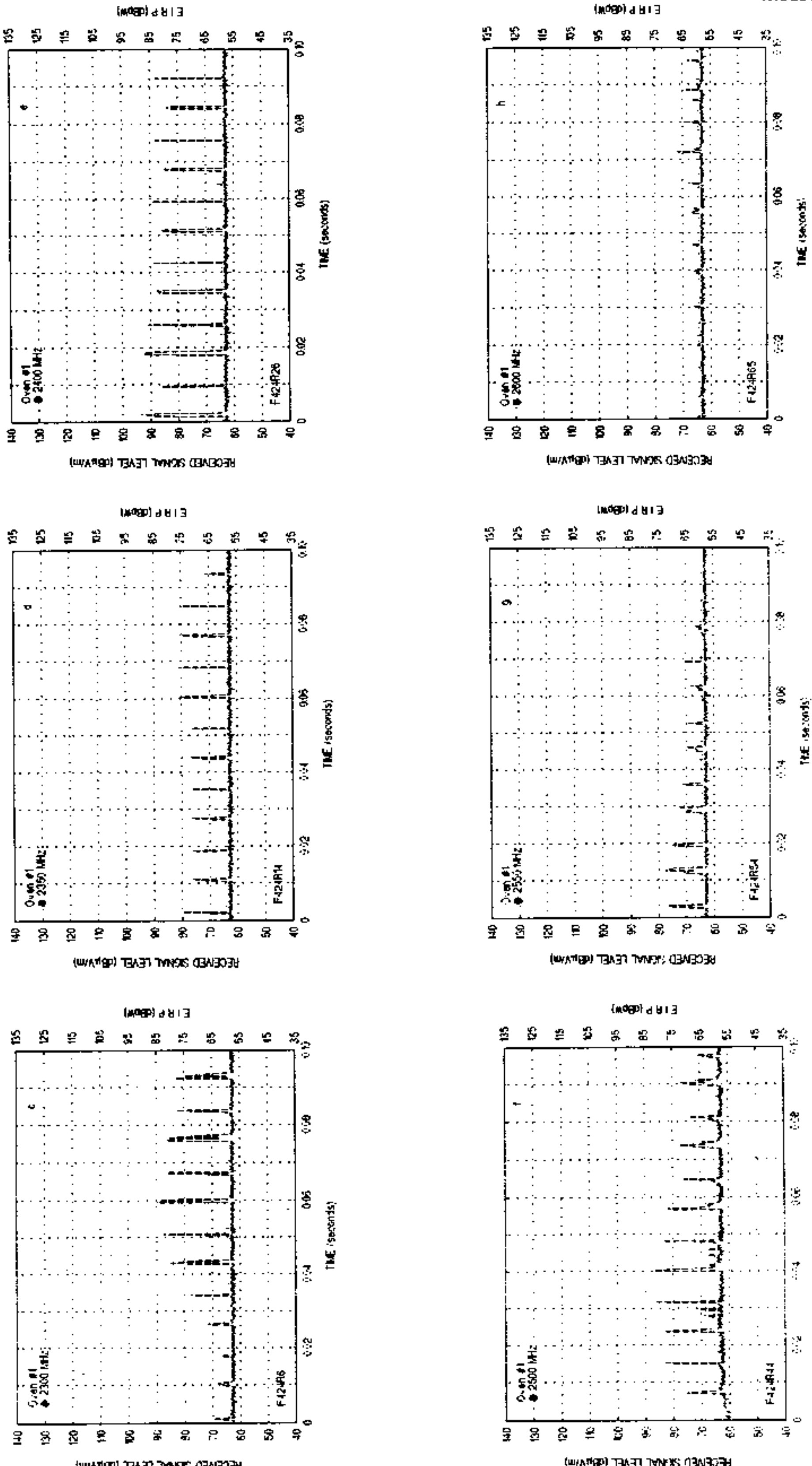


Figure 5-5c through 5-5h. Oven #1, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

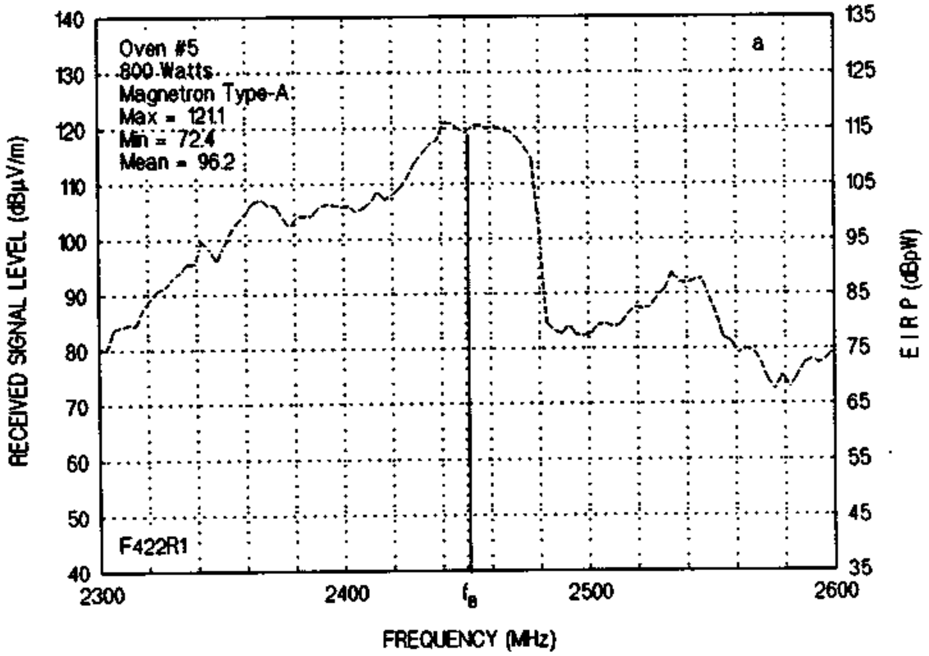


Figure 5-6a. Oven #5, Frequency vs. Amplitude.

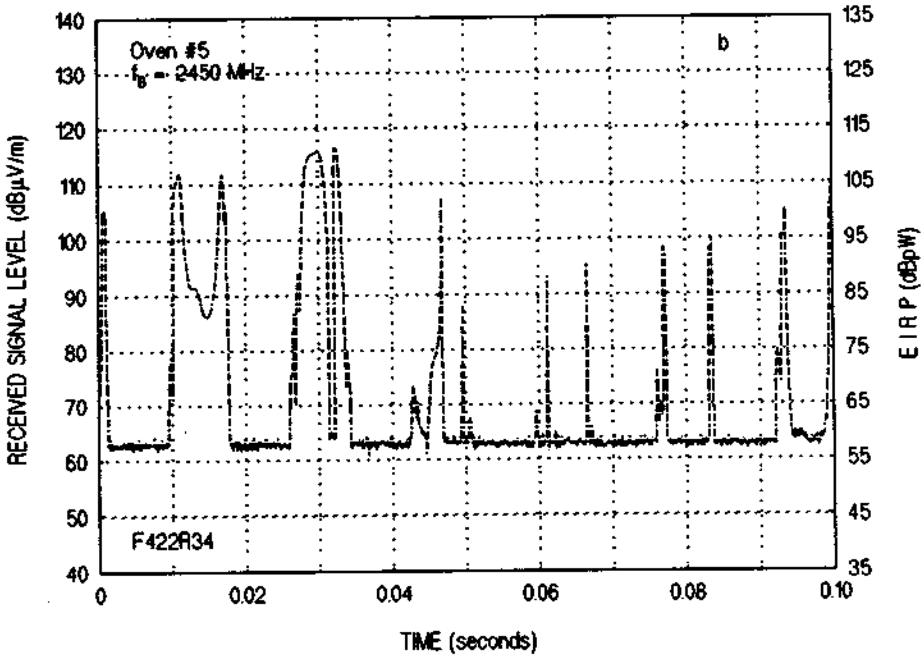


Figure 5-6b. Oven #5, Time vs. Amplitude at 2450 MHz.

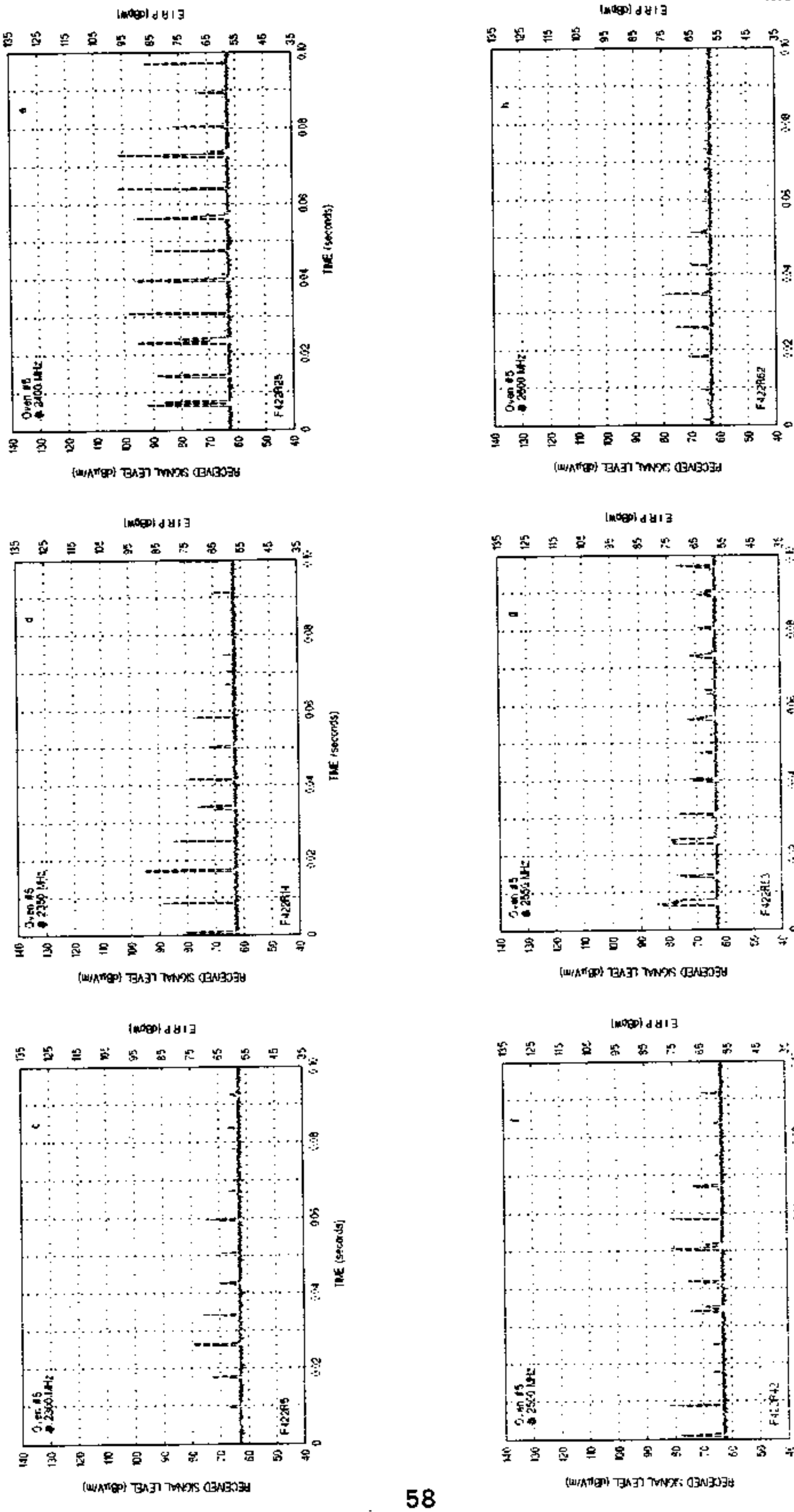


Figure 5-6c through 5-6h. Oven #5, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

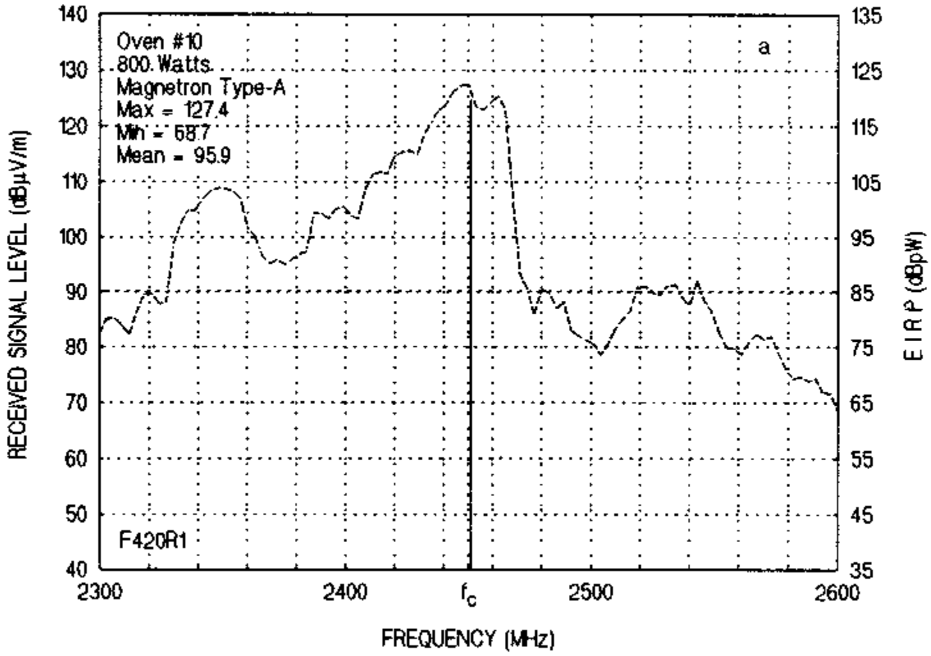


Figure 5-7a. Oven #10, Frequency vs. Amplitude.

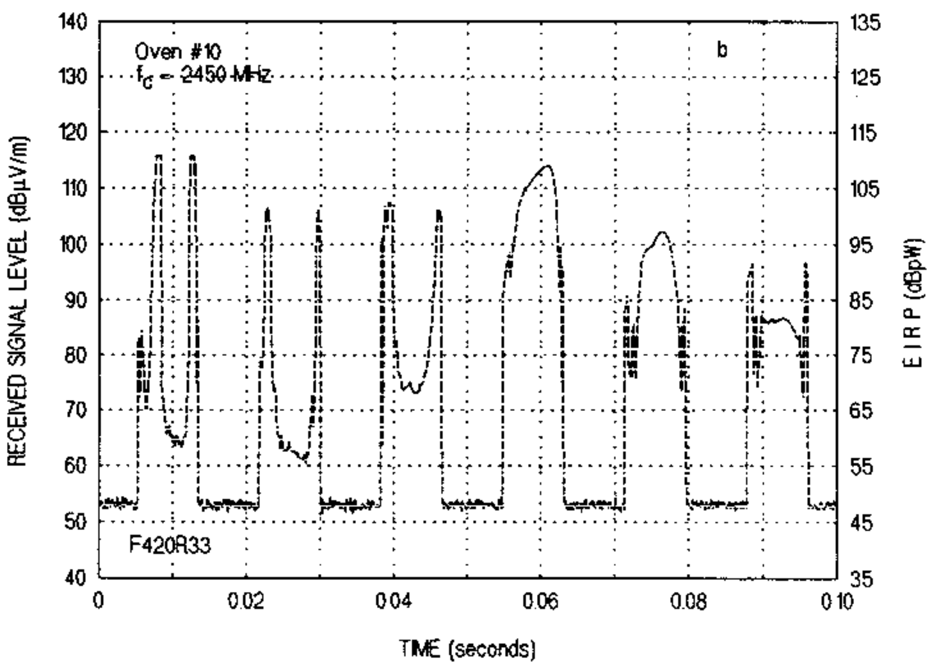


Figure 5-7b. Oven #10, Time vs. Amplitude at 2450 MHz.

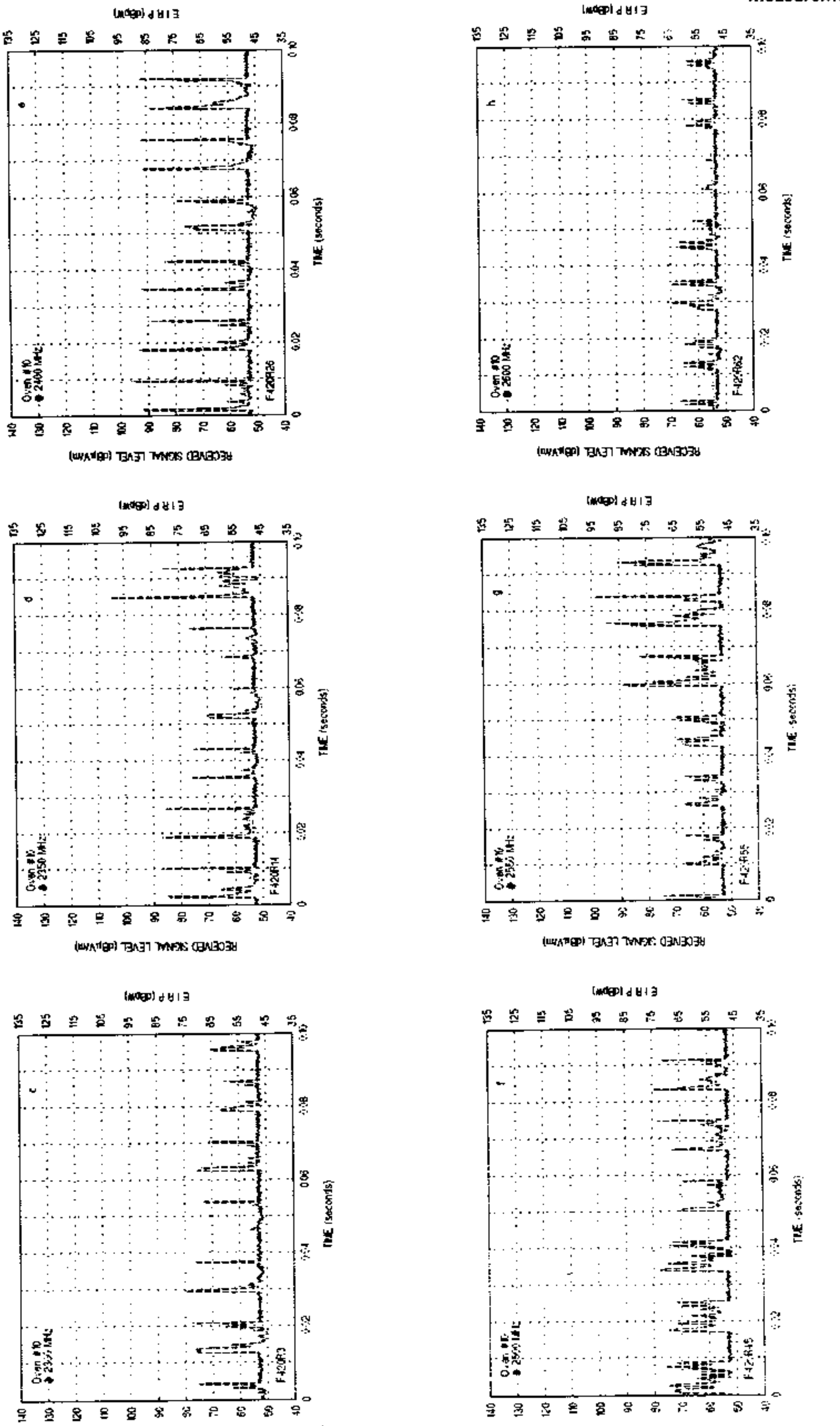


Figure 5-7c through 5-7h. Oven #10, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

Oven #8

Referring to TABLE 5-2, Oven #8 uses magnetron tube Type-B. No other oven tested used this magnetron. The spectrum plots and time waveforms are shown in Figure 5-8. Like Ovens #1, #5, and #10, Oven #8 also shows no defined peak at the designated operating frequency of 2450 MHz. In Figure 5-8b, very little change is manifest in the two pulses in the middle of the display which shows that the carrier was stable for at least two periods.

Comparison of the time waveforms for Oven #8 with those of Ovens #1, #5, and #10 indicates that Oven #8 may be changing frequency at a slower rate. Changes in adjacent pulses appear to be more gradual. Oven #8 detectable signals also extend out to the extremes of the upper and lower adjacent bands.

The statistics for Oven #8 are given in TABLE 5-4. They are similar to those given for Ovens #1, #5, and #10. Based on comparisons of ovens in Figure 5-2 through 5-4, Oven #8 was the 4th highest emitter in the first sub-band and the third sub-band, and 2nd highest in the second sub-band.

TABLE 5-4
STATISTICS for OVEN #8

Oven #8	2300-2400 MHz	2400-2500 MHz	2500-2600 MHz
Mean (dBμV/m)	84.7	112.5	78.1
Maximum (dBμV/m)	108.5	128.0	93.1
Minimum (dBμV/m)	71.0	91.5	68.3
Standard Deviation	10.5	11.8	8.7

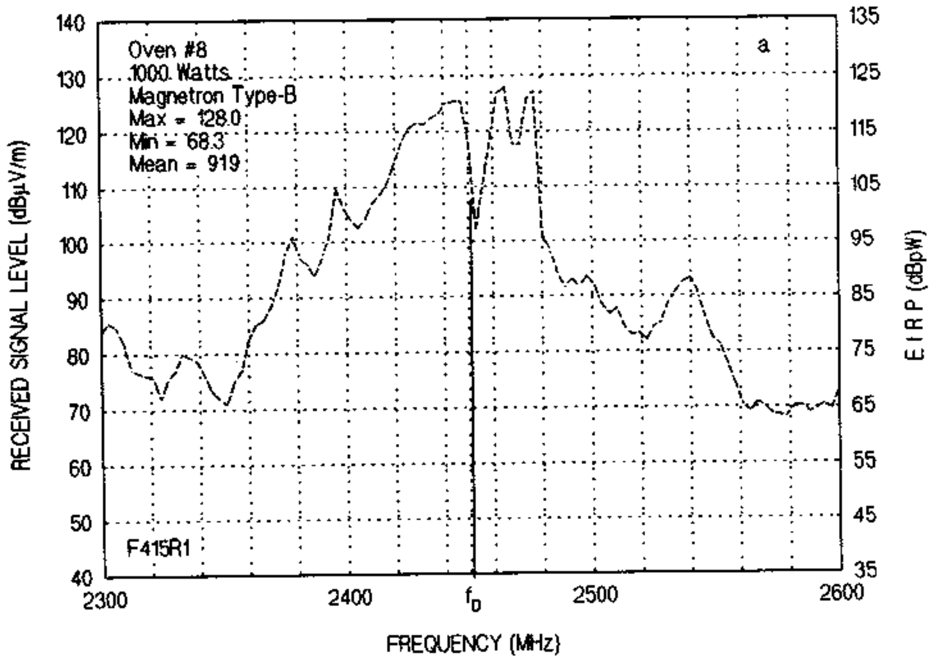


Figure 5-8a. Oven #8, Frequency vs. Amplitude.

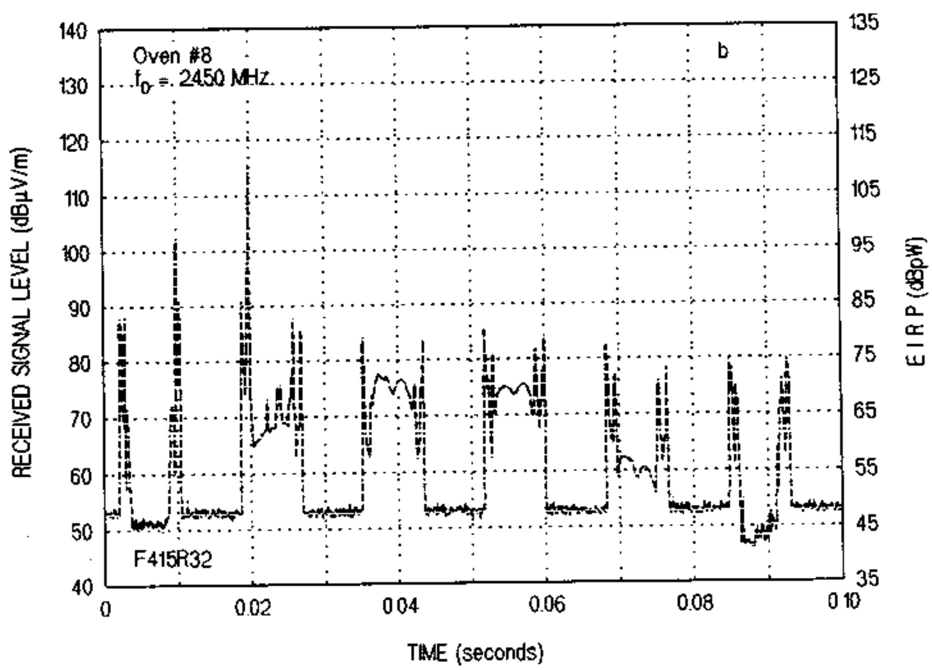


Figure 5-8b. Oven #8, Time vs. Amplitude at 2450 MHz.

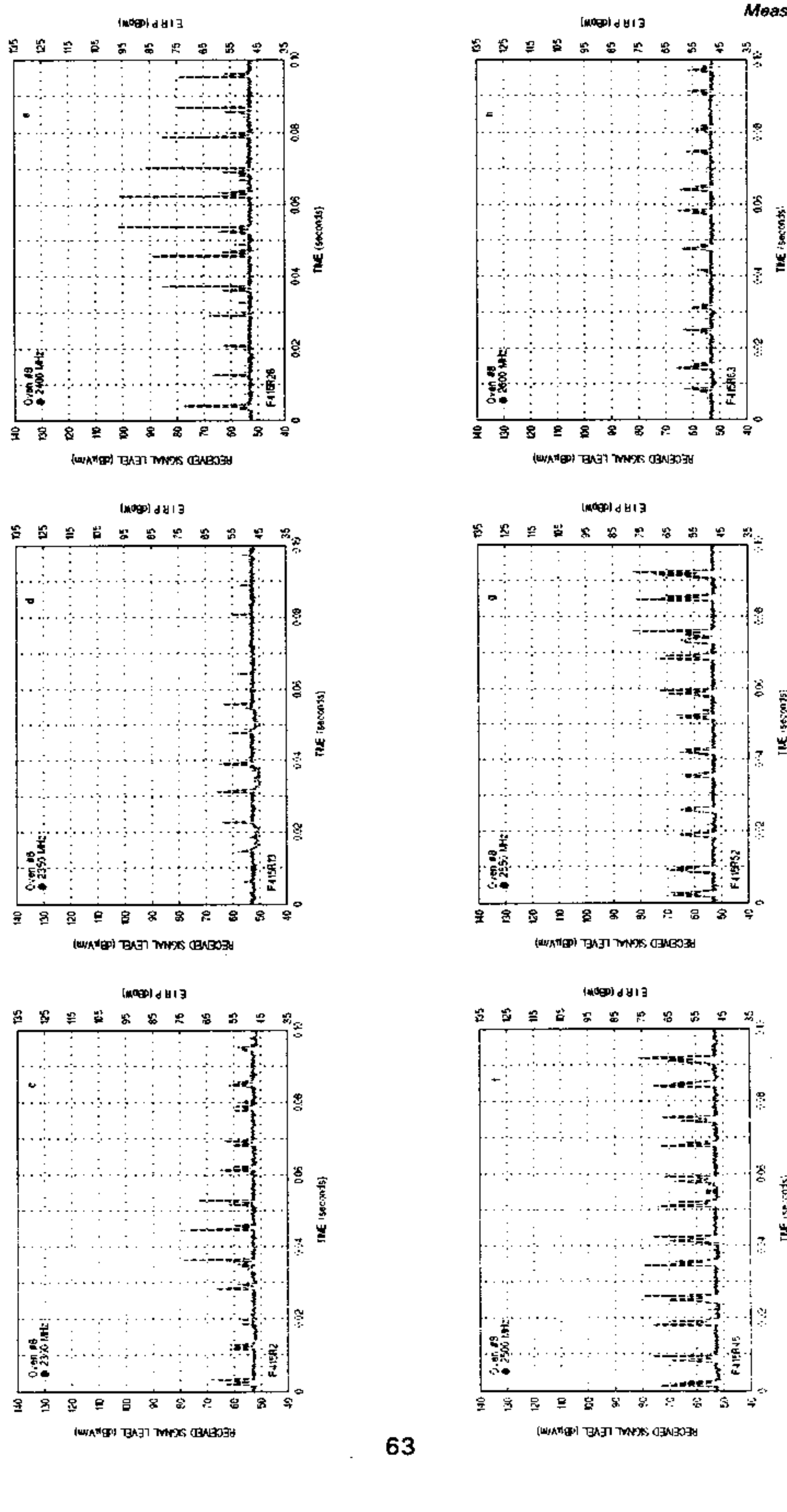


Figure 5-8c through 5-8h. Oven #8, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

Ovens #2 and #12

These two ovens use the Type-D magnetron tube. The spectrum plots and time waveforms are shown in Figures 5-9 and 5-10. These ovens display similar characteristics. The pulses in the time waveforms at 2450 MHz for these ovens appear particularly stable, which indicates that the carrier is fixed for more than several periods.

A unique feature of Oven #12 is the "fill-in" of the pulses out to the extremes of upper and lower adjacent bands. Though this characteristic is more pronounced due to the lower system noise level used in these measurements, the amplitudes exceed the 62 dBμV/m used for most of the previously discussed ovens. Ovens #2 and #12 occupied a middle position in the hierarchy of emitters (see Figures 5-2 through 5-4). Statistics for these ovens are listed in TABLE 5-5.

TABLE 5-5
STATISTICS for OVEN #2 and #12

Sub-band	Oven #2	Oven #12
2300-2400 MHz		
Mean (dBμV/m) Maximum (dBμV/m) Minimum (dBμV/m) Standard Deviation	77.0 83.3 67.0 3.8	72.8 87.9 58.1 8.9
2400-2500 MHz		
Mean (dBμV/m) Maximum (dBμV/m) Minimum (dBμV/m) Standard Deviation	96.4 115.3 73.5 11.6	91.4 116.2 70.3 13.5
2500-2600 MHz		
Mean (dBμV/m) Maximum (dBμV/m) Minimum (dBμV/m) Standard Deviation	65.8 79.9 54.7 6.5	72.3 82.4 58.5 5.3

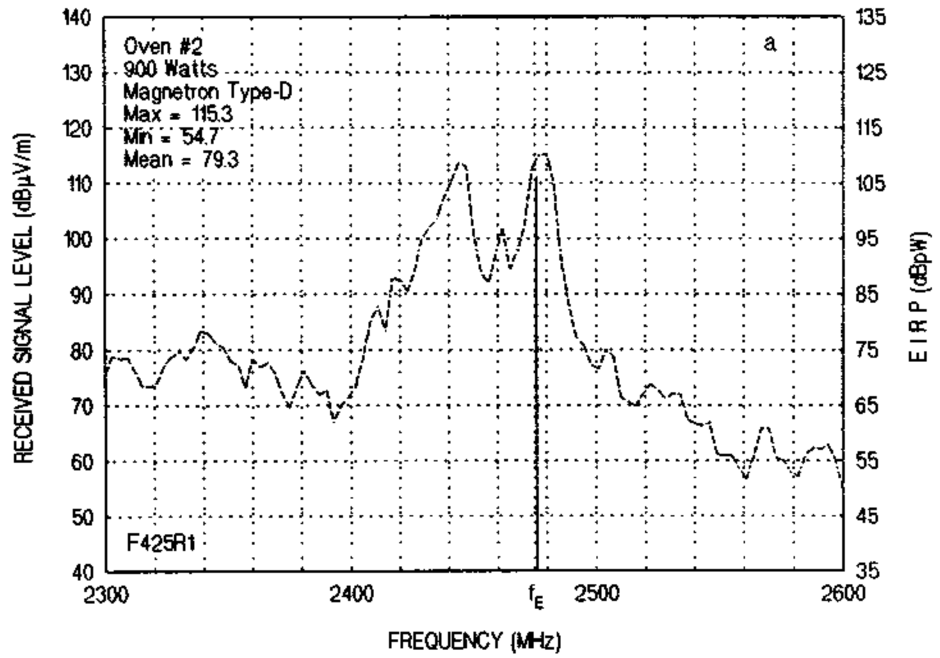


Figure 5-9a. Oven #2, Frequency vs. Amplitude.

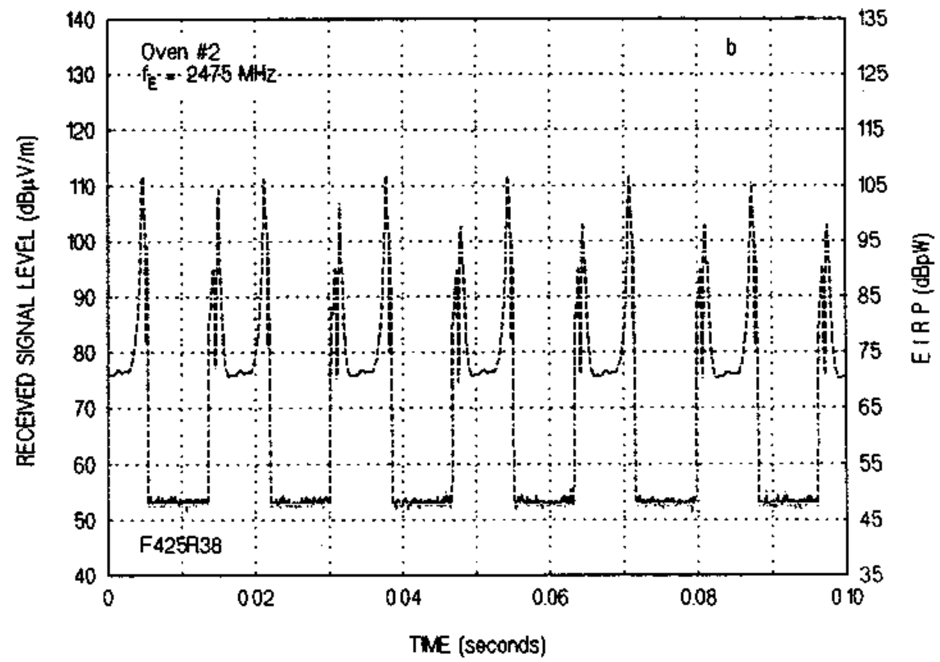


Figure 5-9b. Oven #2, Time vs. Amplitude at 2475 MHz.

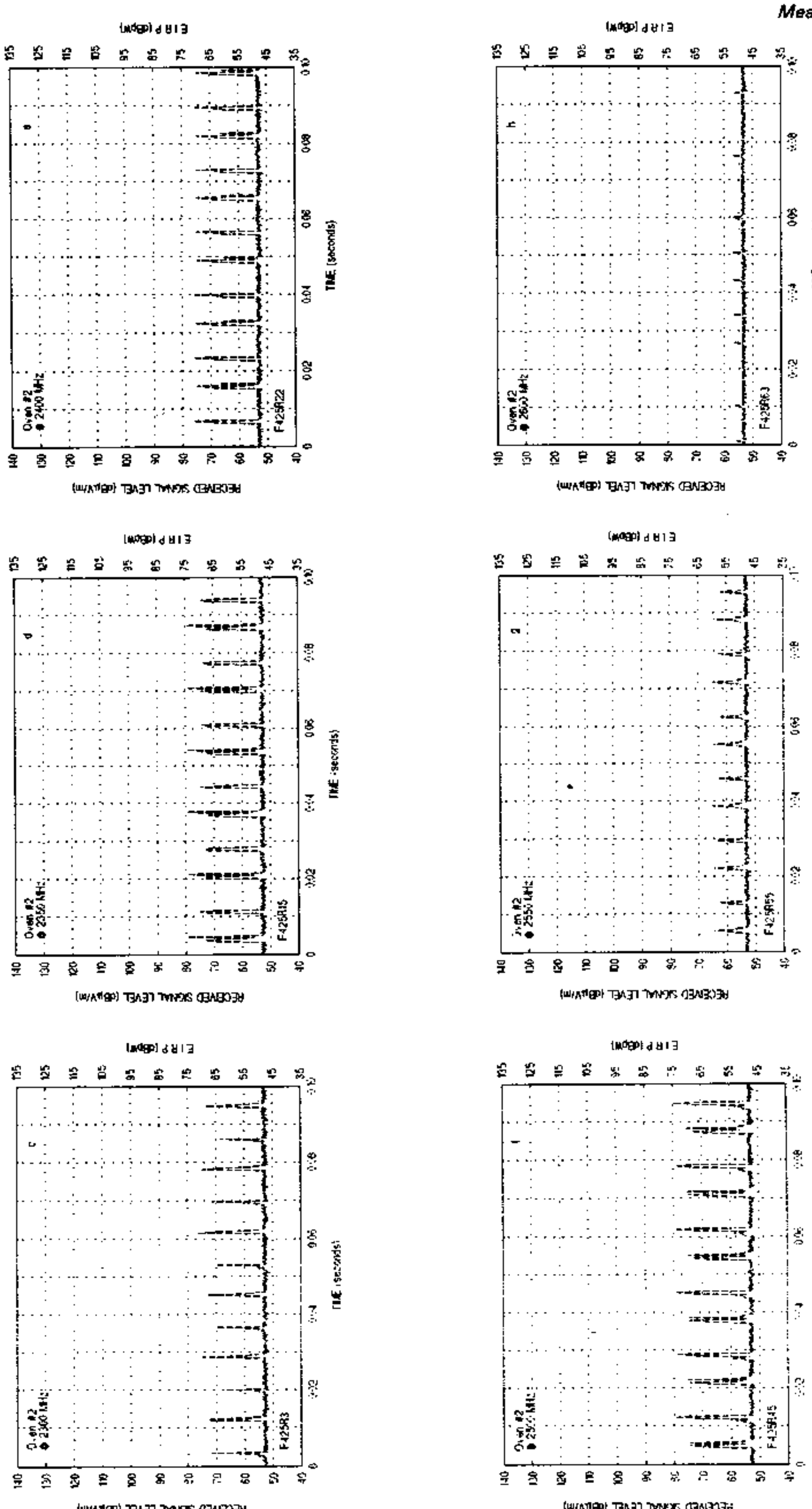


Figure 5-9c through 5-9h. Oven #2, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

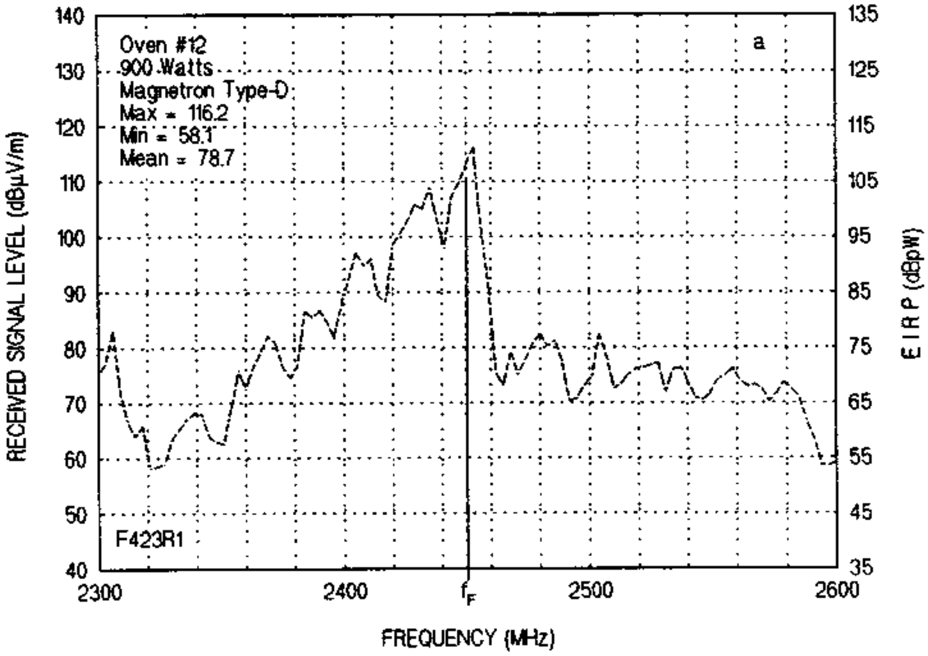


Figure 5-10a. Oven #12, Frequency vs. Amplitude.

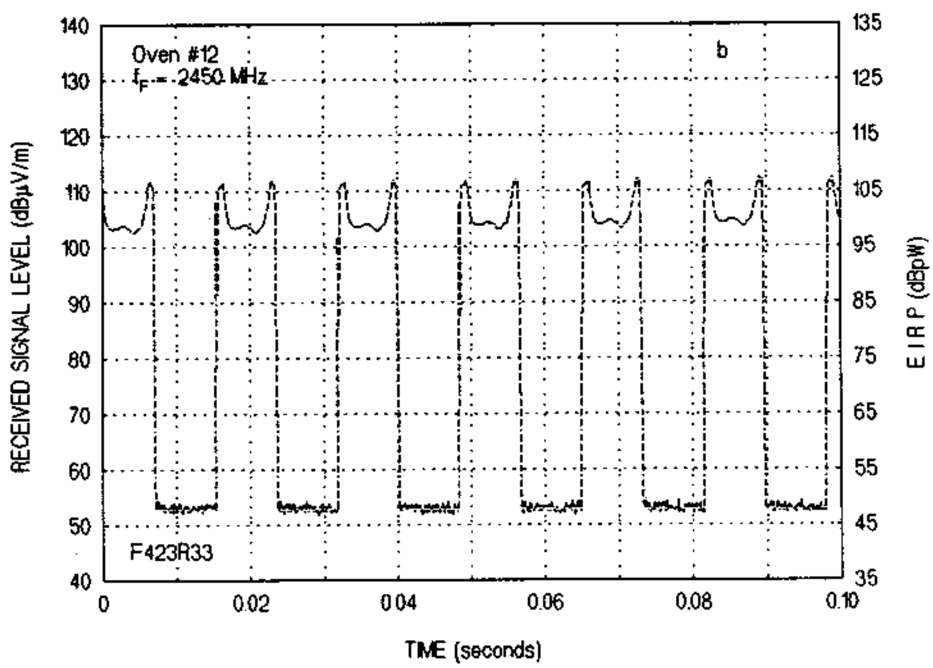


Figure 5-10b. Oven #12, Time vs. Amplitude at 2450 MHz.

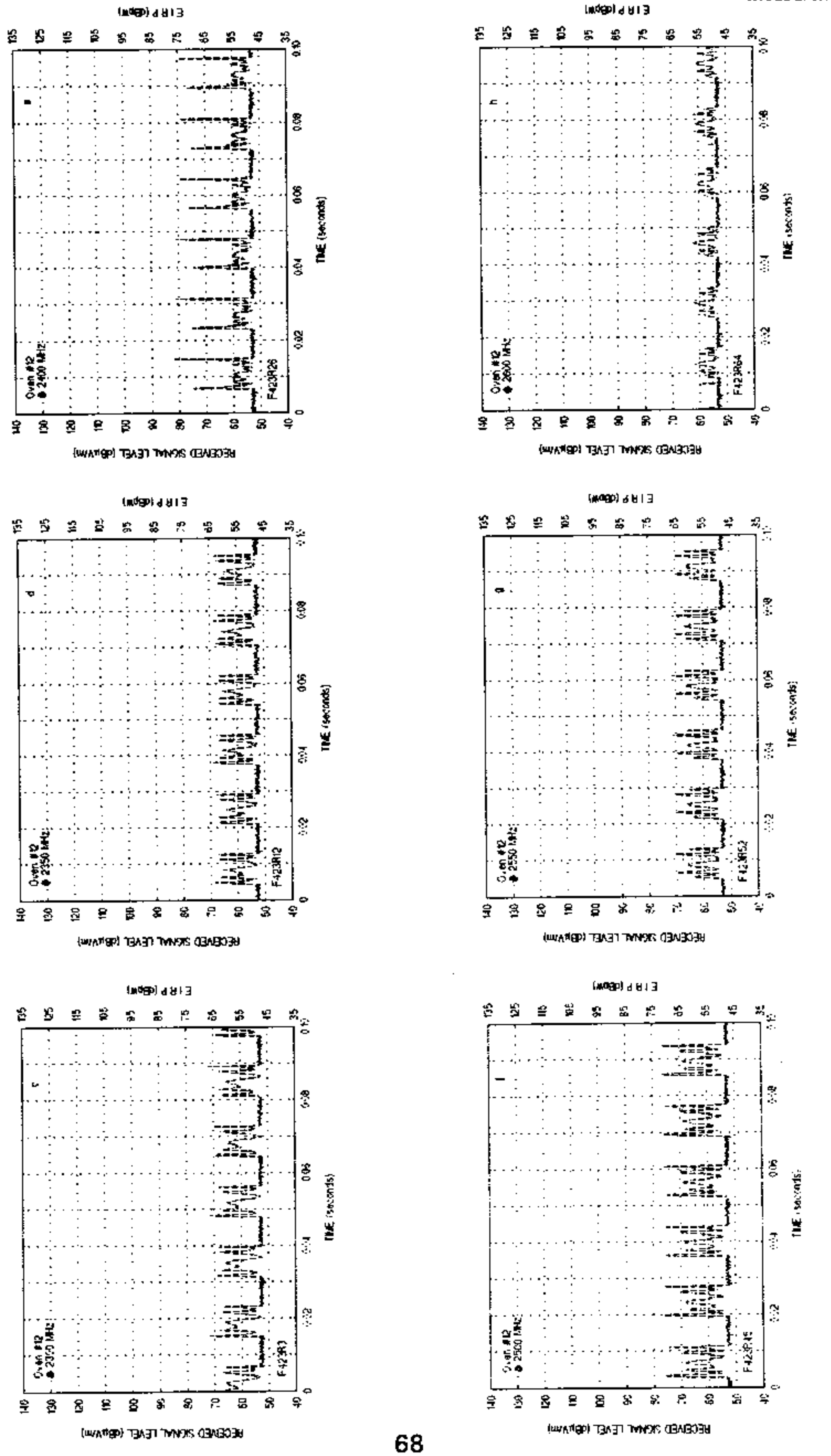


Figure 5-10c through 5-10h. Oven #12, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

Oven #9

Oven #9 characteristics are similar to those of Ovens #2 in that there are two distinct peaks in Figure 5-11a. Like Oven #2, there is little evidence of "fill-in" in the signals measured in the adjacent bands down to 52 dBµV/m, at least not at the discrete frequencies measured. This phenomena may occur at frequencies not included in the set that was measured.

TABLE 5-6 shows statistics for Oven #9. Referring to the bar graph of Figure 5-2, Oven #9 is the 2nd lowest emitter for the first sub-band; however, the bar graphs of Figures 5-3 and 5-4 shows that Oven #9 is to the middle position in the hierarchy of emitters.

TABLE 5-6
STATISTICS for OVEN #9

Oven #9	2300-2400 MHz	2400-2500 MHz	2500-2600 MHz
Mean (dBµV/m)	65.1	92.7	70.8
Maximum (dBµV/m)	78.1	119.4	83.6
Minimum (dBµV/m)	52.4	65.2	56.0
Standard Deviation	6.2	19.8	6.8

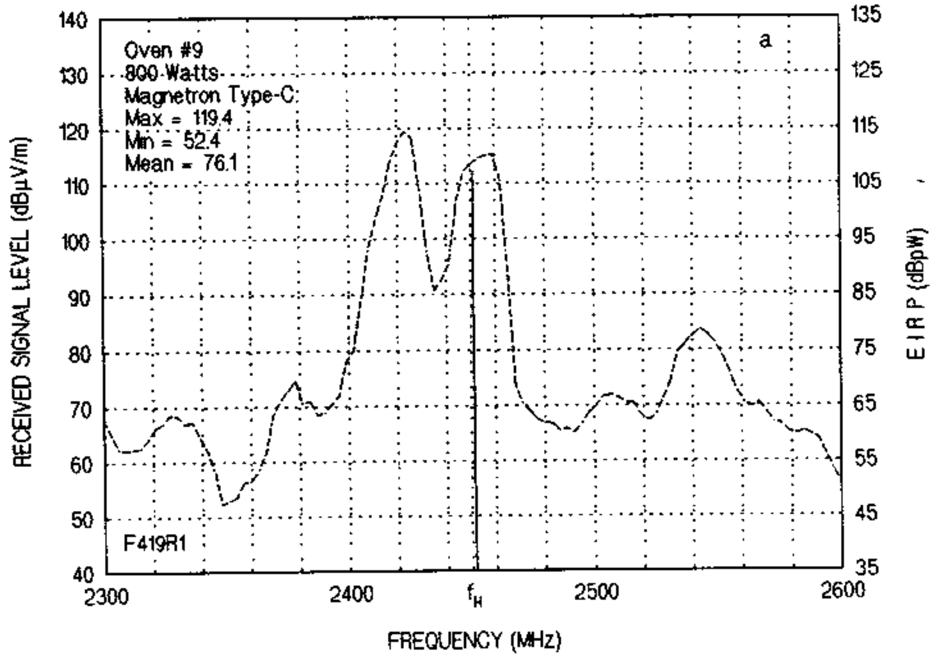


Figure 5-11a. Oven #9, Frequency vs. Amplitude.

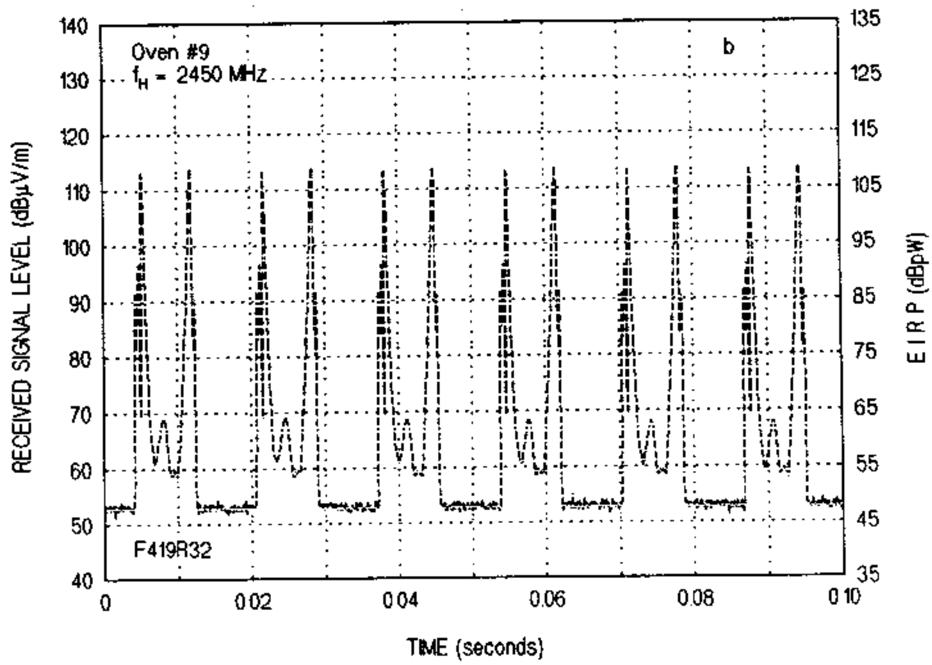


Figure 5-11b. Oven #9, Time vs. Amplitude at 2450 MHz.

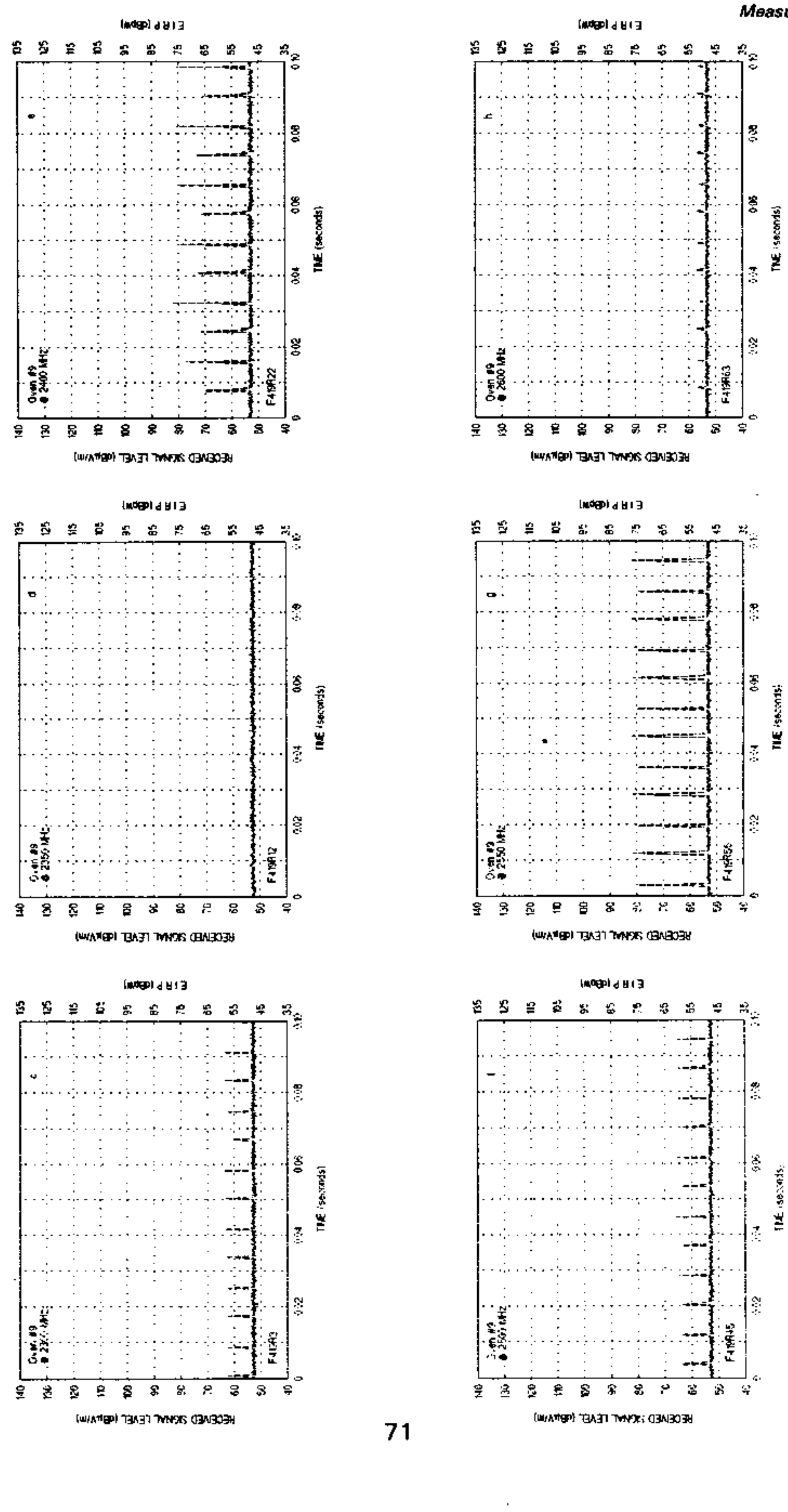


Figure 5-11c through 5-11h. Oven #9, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

Ovens #7, #7DUP and #13

Ovens #7, #7DUP and #13 use magnetron tube Type-G. The spectrum plots and time waveforms are shown in Figures 5-12 through 5-14. Each of these ovens has a well defined fundamental frequency. There is some shifting of Oven #7's carrier as indicated by changes in waveform shown in Figure 5-12b.

TABLE 5-7 shows the statistics for Ovens #7, #7DUP and #13, respectively. Referring to the bar graph of Figure 5-2 and 5-4, Ovens #7 is one of the lowest emitters. Oven #7DUP and Oven #13 had limited testing with the intent to verify the oven performance of Oven #7. The frequency domain characteristics showed a close resemblance to Oven #7.

TABLE 5-7
STATISTICS for OVEN #7, #7 DUP and #13

Sub-band	Oven #7	Oven #7 DUP	Oven #13
2300-2400 MHz			
Mean (dBμV/m)	67.3	69.5	66.0
Maximum (dBμV/m)	77.2	78.9	77.7
Minimum (dBμV/m)	60.5	60.8	57.7
Standard Deviation	4.6	5.9	5.8
2400-2500 MHz			
Mean (dBμV/m)	89.1	98.0	91.4
Maximum (dBμV/m)	113.5	120.9	117.5
Minimum (dBμV/m)	54.4	74.4	64.8
Standard Deviation	17.4	16.0	18.0
2500-2600 MHz			
Mean (dBμV/m)	51.5	57.7	57.8
Maximum (dBμV/m)	68.1	69.2	66.3
Minimum (dBμV/m)	46.6	49.3	50.1
Standard Deviation	3.0	5.6	4.2

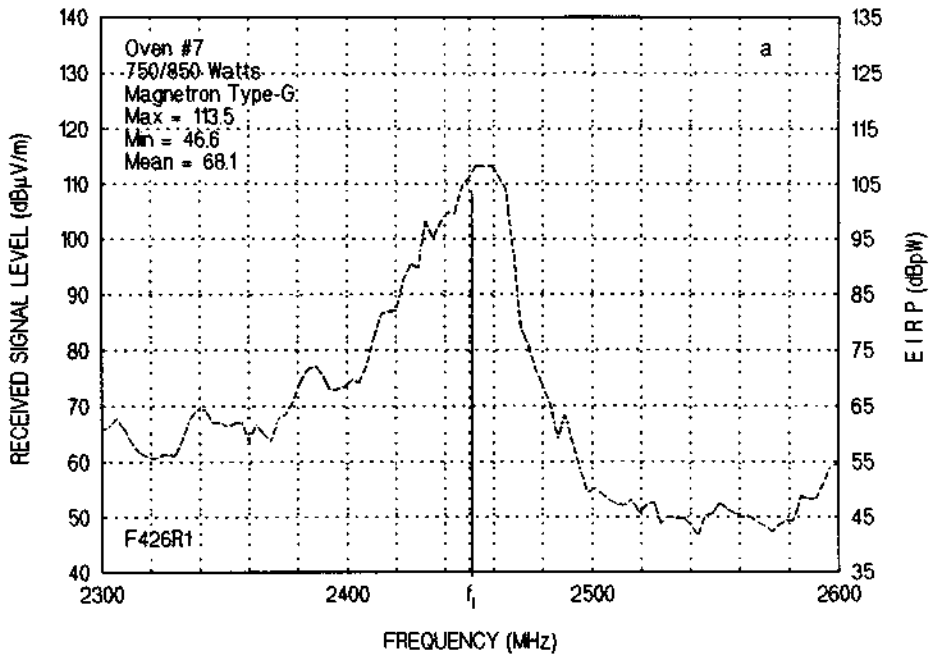


Figure 5-12a. Oven #7, Frequency vs. Amplitude.

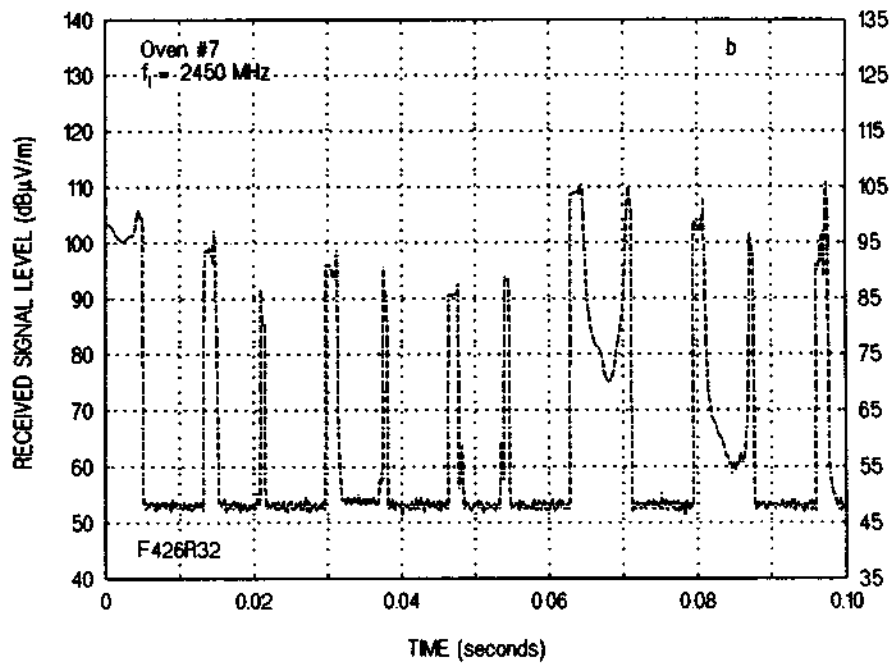


Figure 5-12b. Oven #7, Time vs. Amplitude at 2450 MHz.

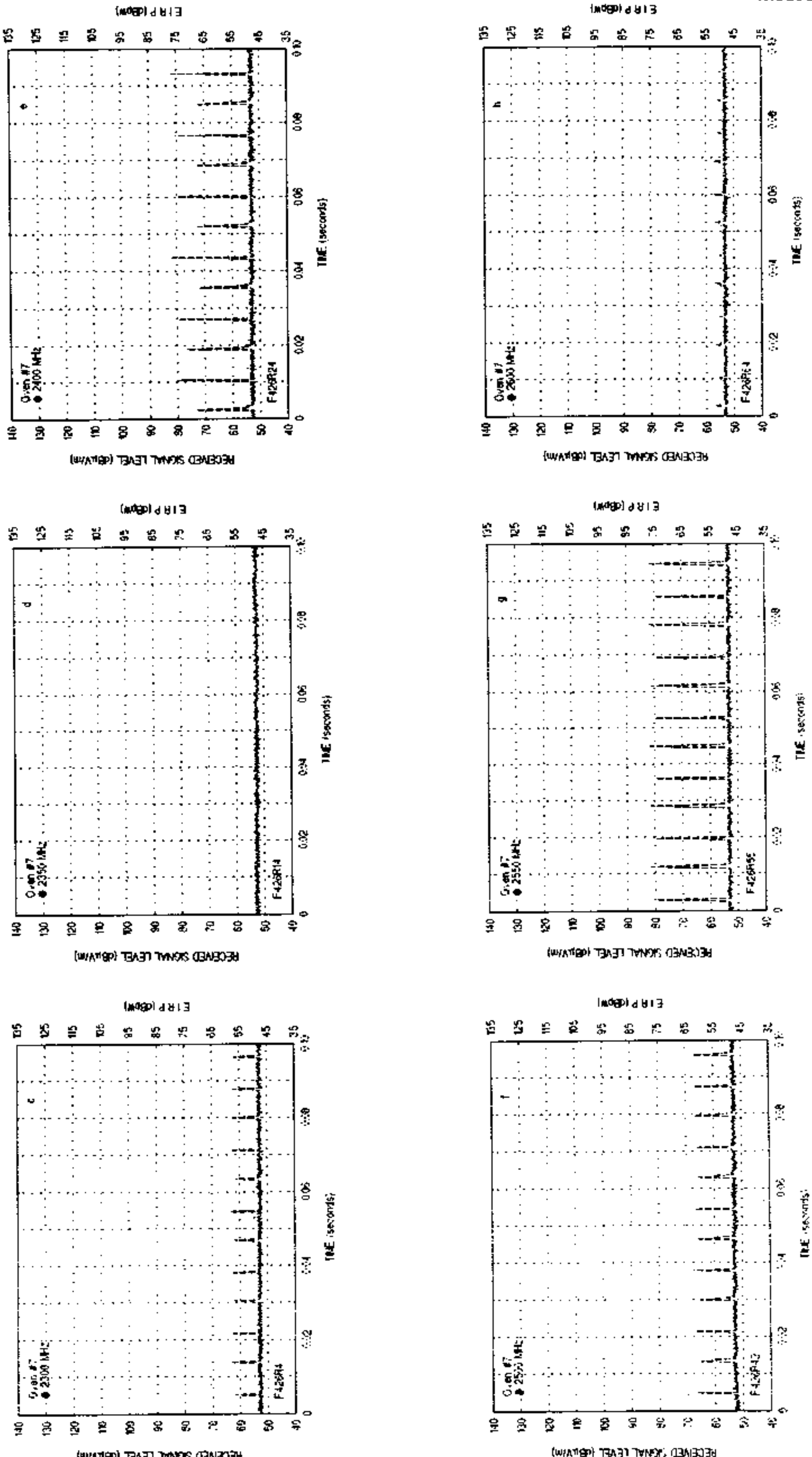


Figure 5-12c through 5-12h. Oven #7, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

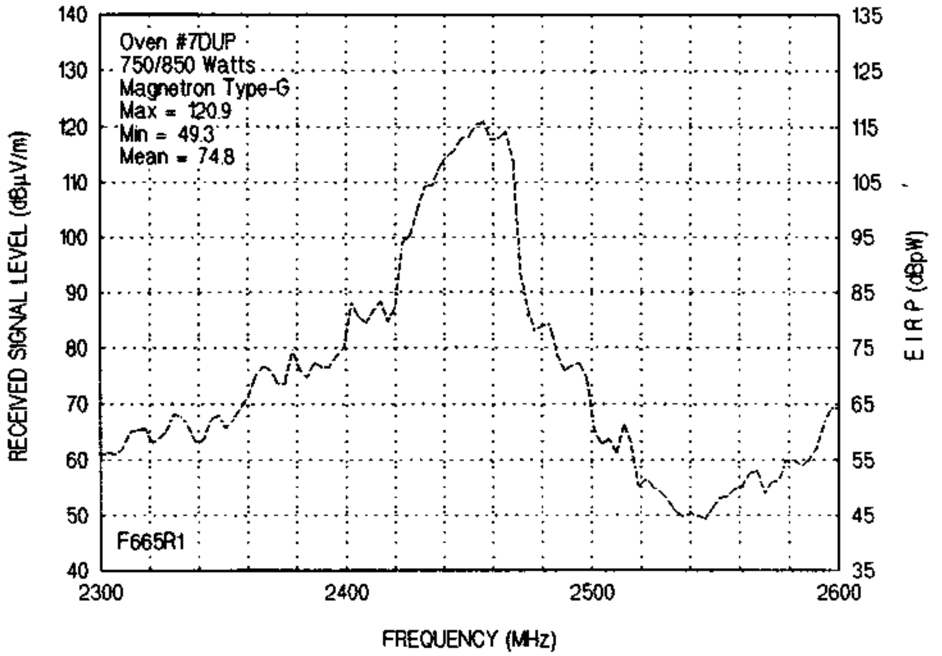


Figure 5-13. Oven #7DUP, Frequency vs. Amplitude.

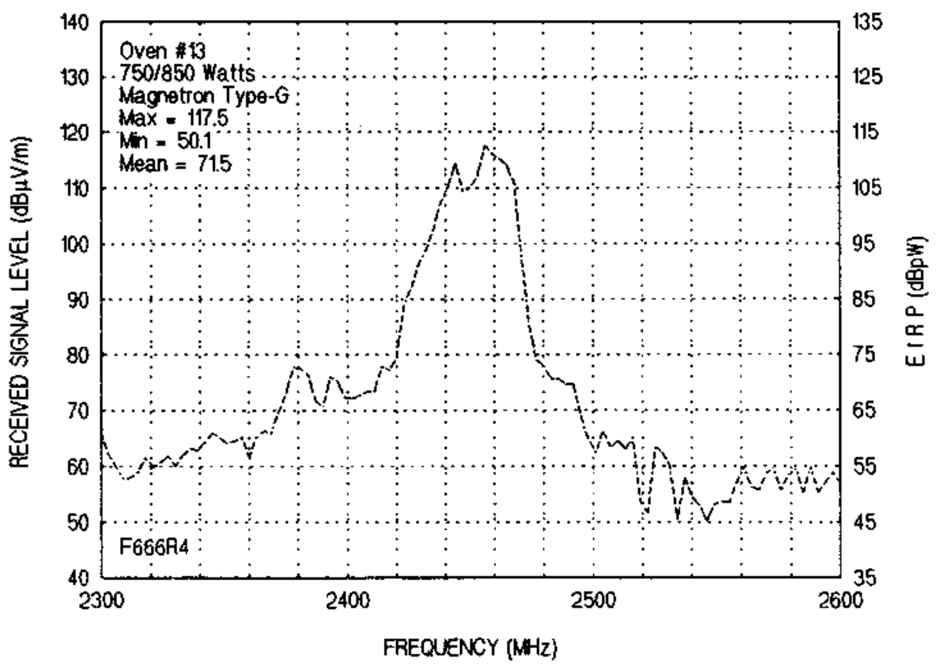


Figure 5-14. Oven #13, Frequency vs. Amplitude.

Oven #4

Referring to TABLE 5-2, Oven #4 uses magnetron tube Type-E. No other oven tested used this magnetron. The spectrum and time waveform plots are shown in Figure 5-15. Oven #4 exhibits a well defined fundamental frequency and a high carrier stability by the sharp peak in Figure 5-15a. It should be noted that this fundamental frequency is 2480 MHz. This oven also had very little frequency drift as is shown with the consistency of signals in the time waveform in Figures 5-15b.

TABLE 5-8 shows the statistics for Ovens #4. Referring to the bar graphs of Figures 5-3 and 5-4, Oven #4 was one of the two lowest emitters. Referring to the time waveform of Figure 5-15a, there is a secondary peak centered about 2380 MHz that may accounts for the fact that in Figure 5-2 the mean received signal level of Oven #4 was the fifth highest emitter.

TABLE 5-8
STATISTICS for OVEN #4

Oven #4	2300-2400 MHz	2400-2500 MHz	2500-2600 MHz
Mean (dBμV/m)	79.3	86.3	56.6
Maximum (dBμV/m)	96.2	112.7	74.0
Minimum (dBμV/m)	65.5	64.4	41.6
Standard Deviation	9.9	10.2	7.9

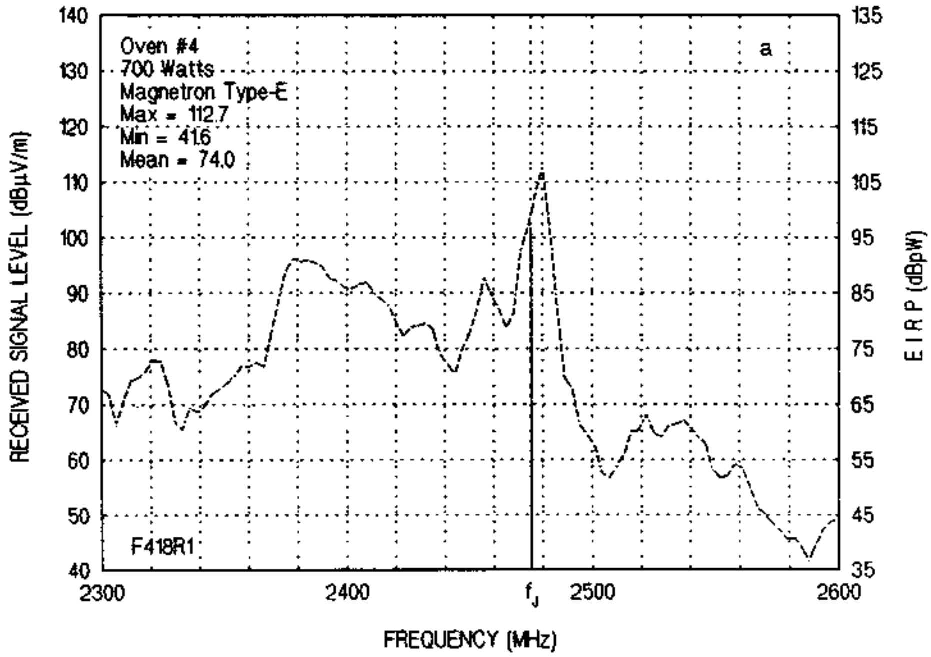


Figure 5-15a. Oven #4, Frequency vs. Amplitude.

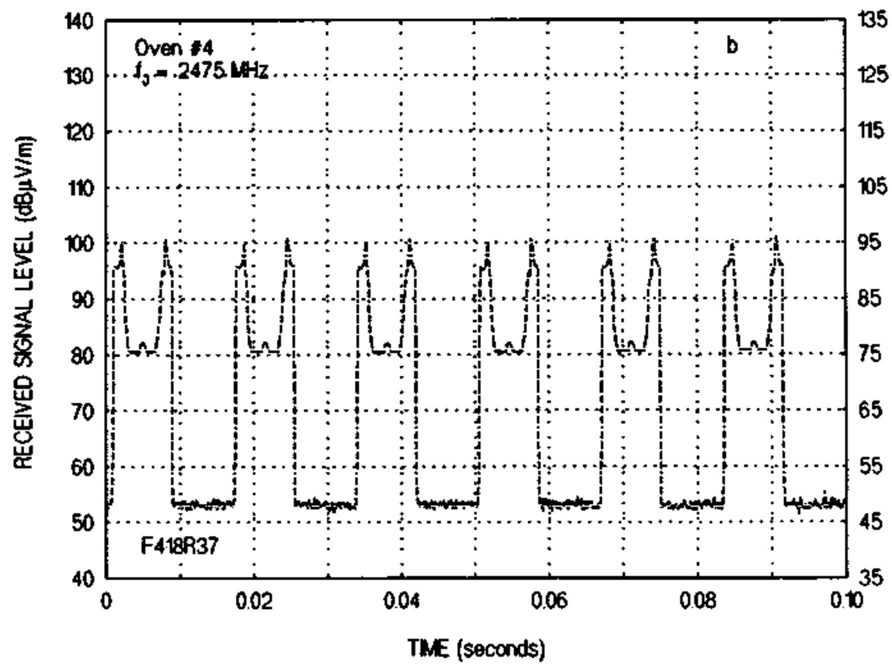


Figure 5-15b. Oven #4, Time vs. Amplitude at 2475 MHz.

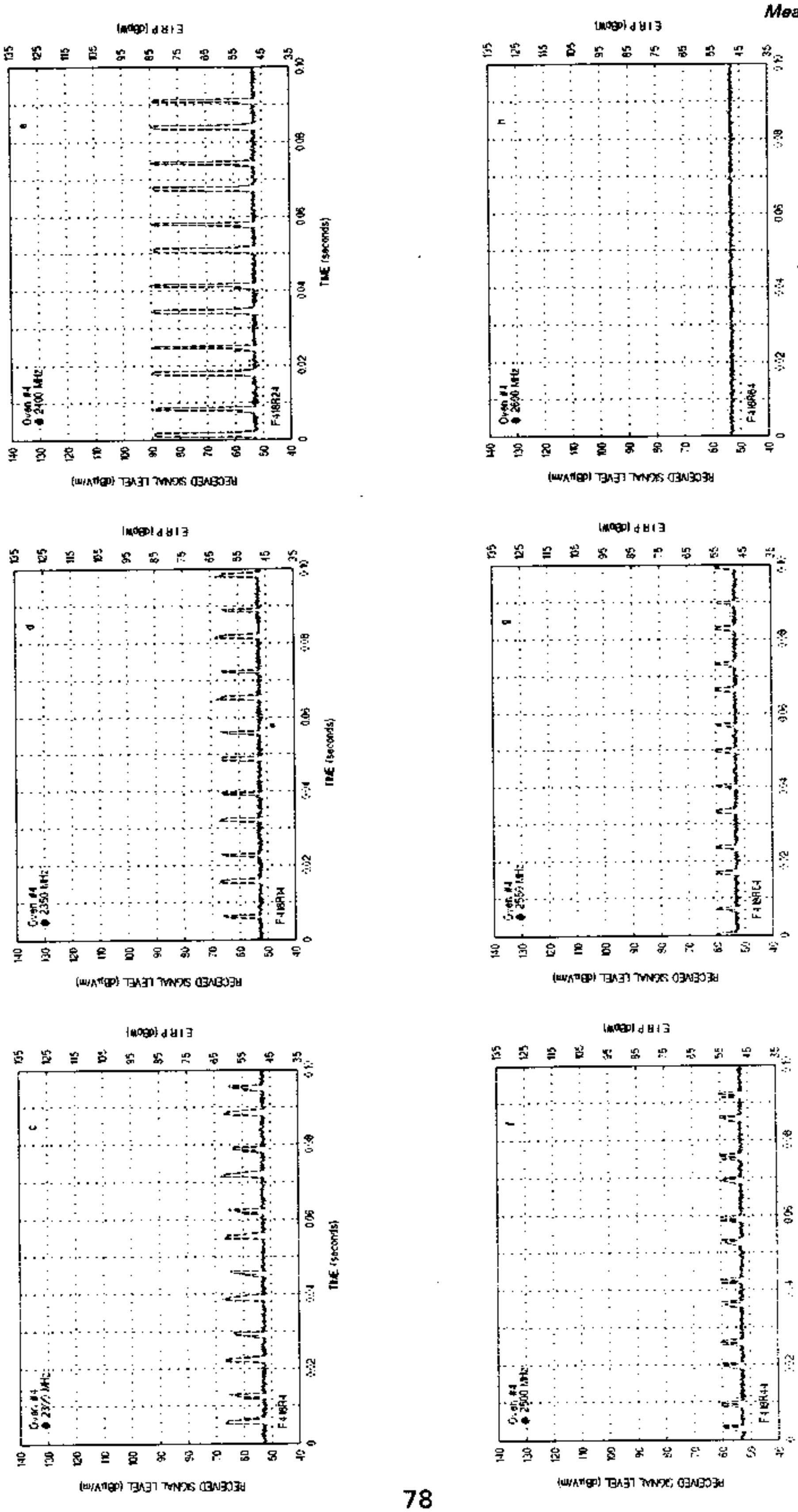


Figure 5-15c through 5-15h. Oven #4, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

Ovens #6 and #11

The spectrum and time waveform plots are shown in Figure 5-16 and 5-17. Both ovens had well defined fundamentals. Both ovens exhibited well defined fundamental frequency and a high carrier stability by the sharp peak in Figure 5-16a and 5-17a. These ovens also had very little frequency drift as is shown by the consistency of pulse shapes in the time waveforms in Figures 5-16b and 5-17b.

TABLES 5-9 and 5-10 show the statistics for Oven #6 and Oven #11, respectively. Referring to the bar graphs of Figures 5-2 to 5-4, Oven #6 and #11 are located in the lower or middle positions in the hierarchy of emitters.

TABLE 5-9
STATISTICS for OVEN #6

Oven #6	2300-2400 MHz	2400-2500 MHz	2500-2600 MHz
Mean (dBμV/m)	75.9	87.6	68.6
Maximum (dBμV/m)	82.1	115.8	77.6
Minimum (dBμV/m)	70.6	66.8	65.0
Standard Deviation	3.3	16.3	2.7

TABLE 5-10
STATISTICS for OVEN #11

Oven #11	2300-2400 MHz	2400-2500 MHz	2500-2600 MHz
Mean (dBμV/m)	64.0	96.8	61.9
Maximum (dBμV/m)	72.2	122.2	74.0
Minimum (dBμV/m)	55.6	62.5	53.4
Standard Deviation	4.7	20.0	3.9

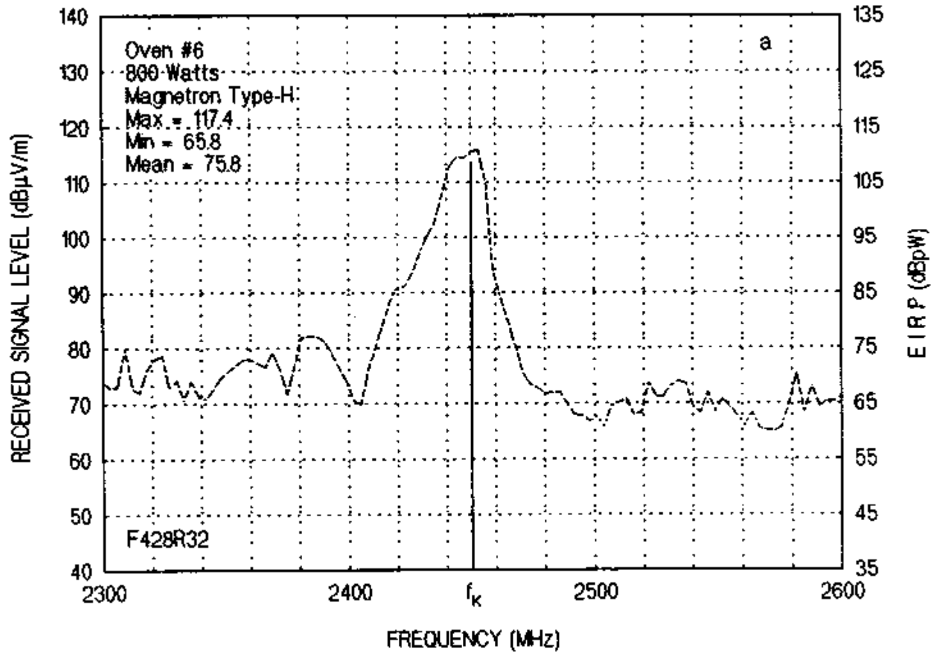


Figure 5-16a. Oven #6, Frequency vs. Amplitude.

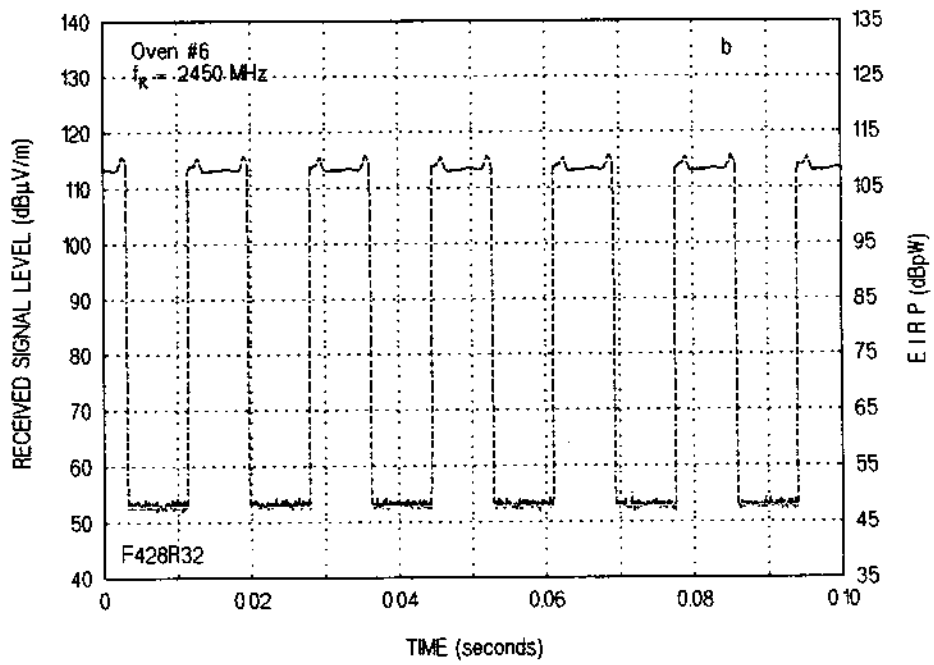


Figure 5-16b. Oven #6, Time vs. Amplitude at 2450 MHz.

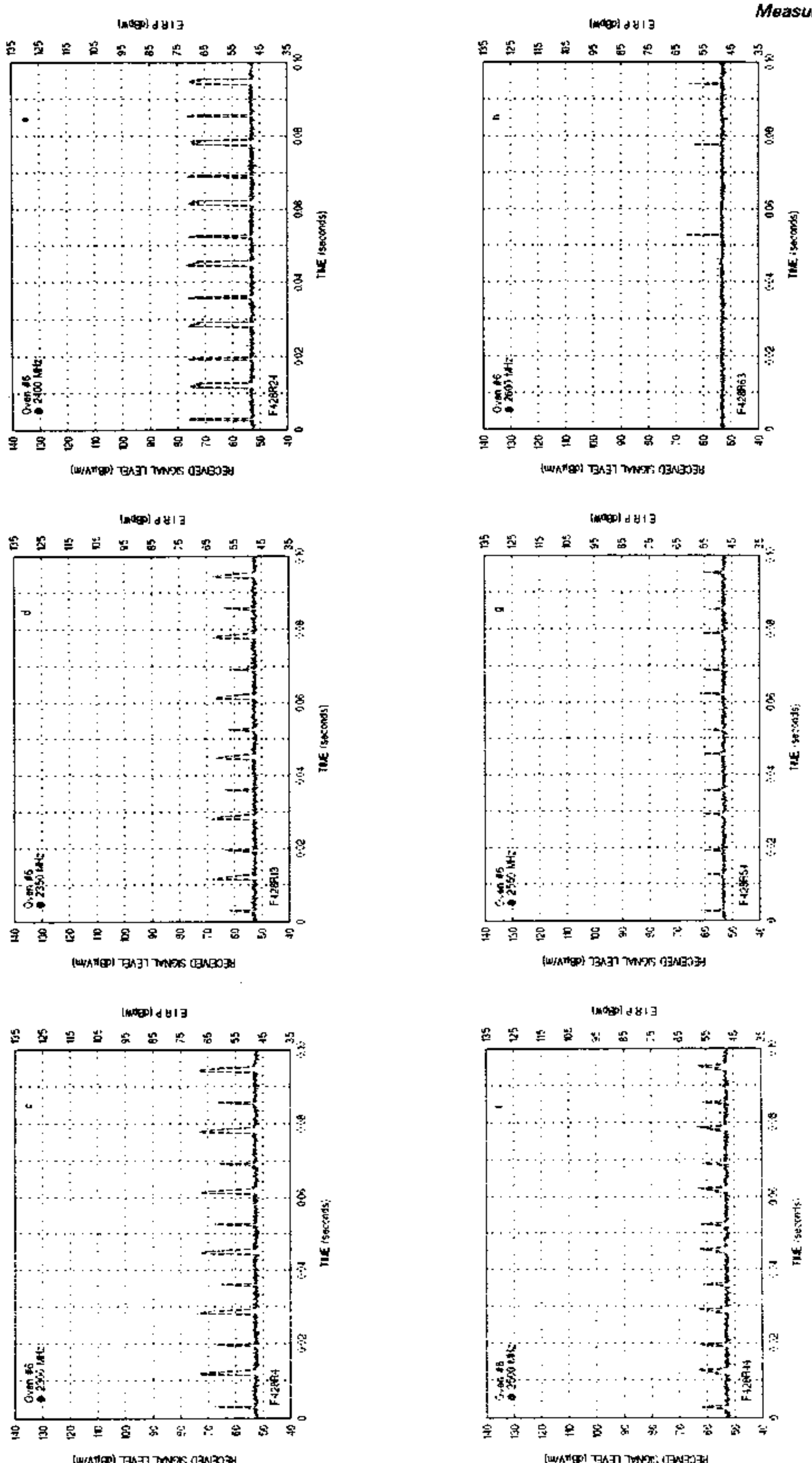


Figure 5-16c through 5-16h. Oven #6, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

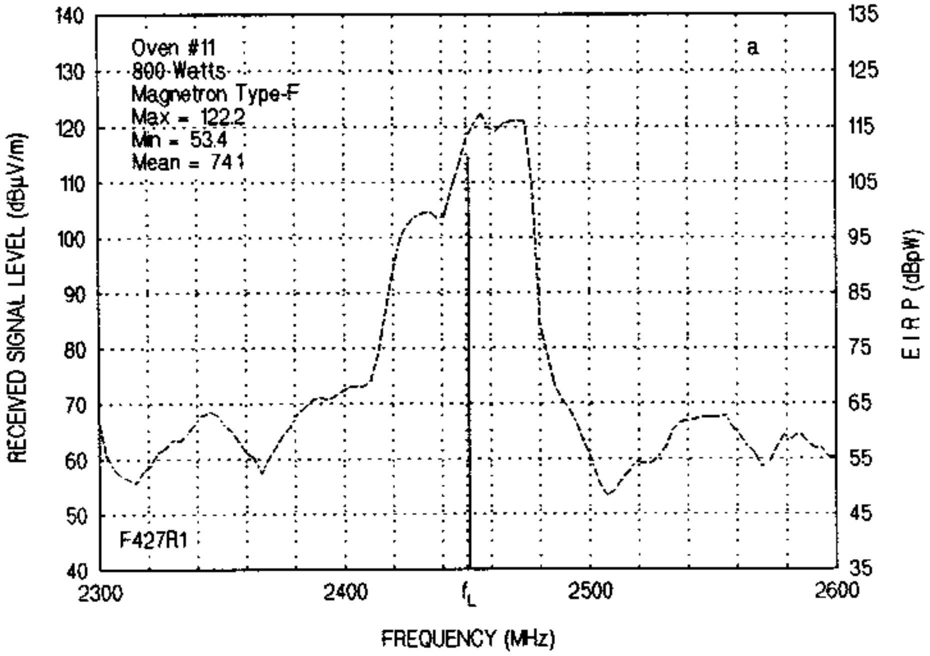


Figure 5-17a. Oven #11, Frequency vs. Amplitude.

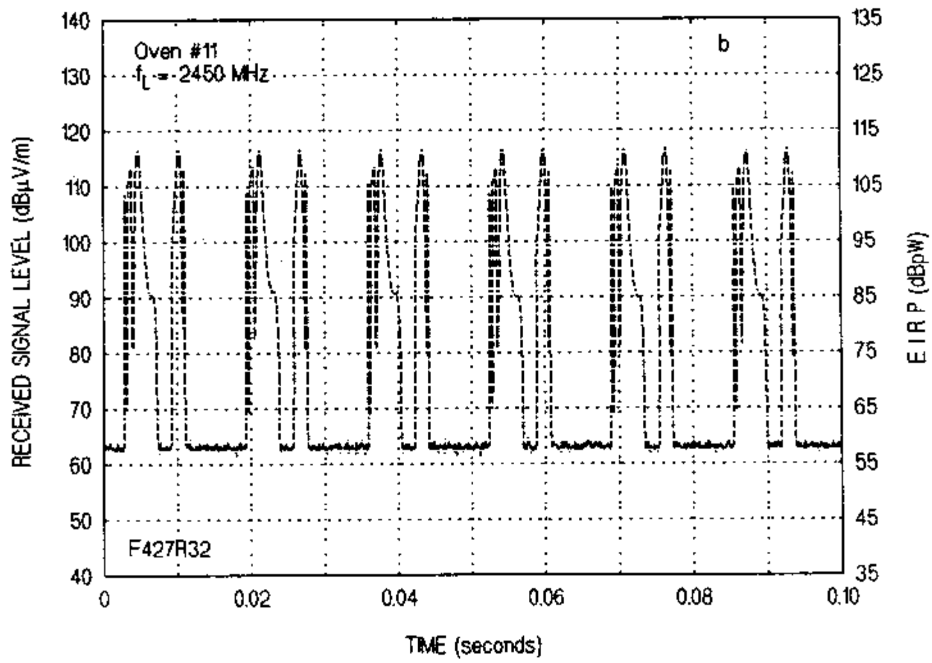


Figure 5-17b. Oven #11, Time vs. Amplitude at 2450 MHz.

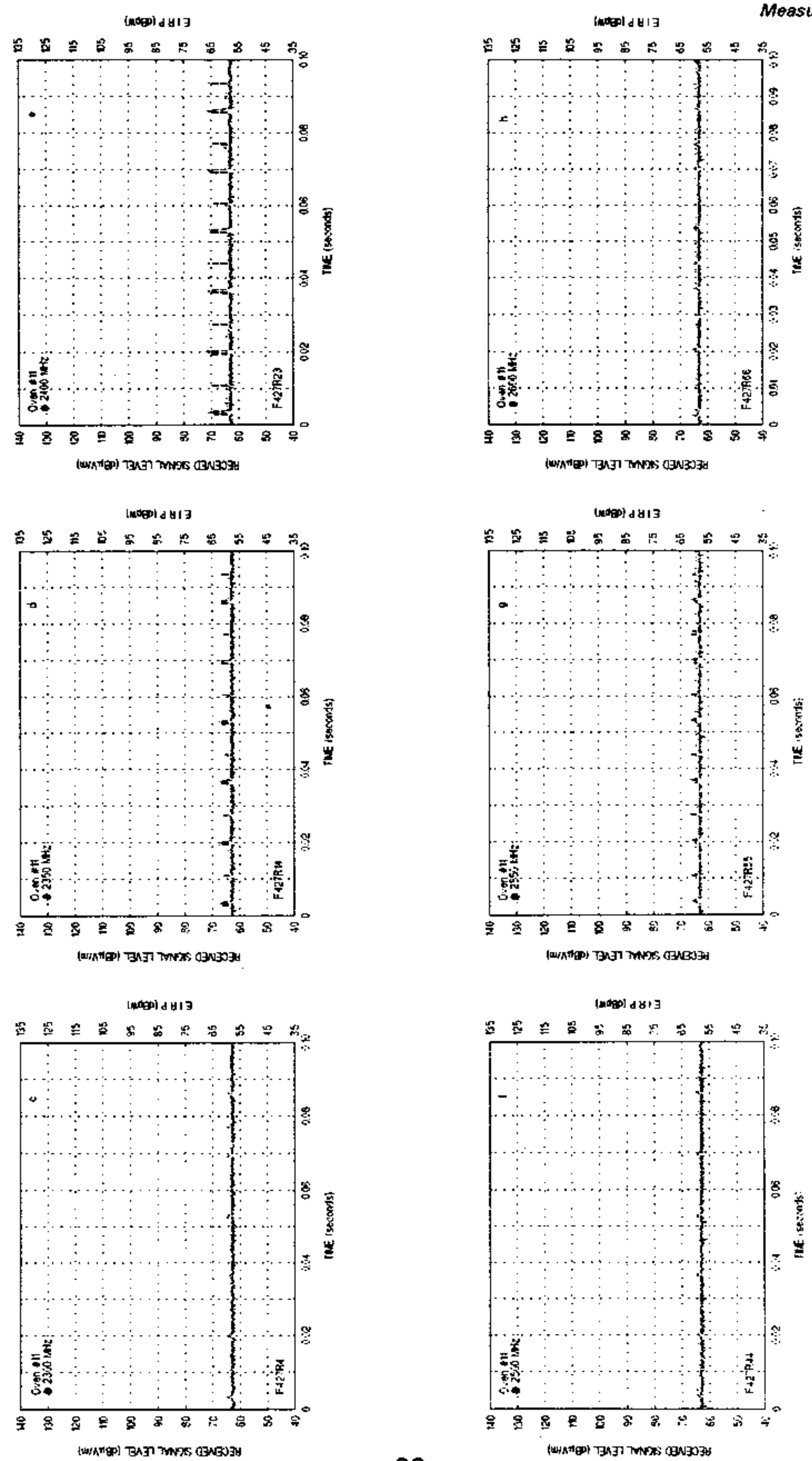


Figure 5-17c through 5-17h. Oven #11, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

TRIGGERING JITTER

According to the oven manufacturers, ovens are designed to trigger the magnetron at the peak of the 60 Hertz power cycle, a point of zero slope, to minimize inductive effects of the triggering circuit. Variations from this point would result in a mismatch between the triggering circuit and the magnetron. A check was made of the oven data for evidence of jitter in oven triggering by superimposing a 60 Hz signal on a time waveform display. This was done mathematically in the plot program and bears no relation to the actual triggering point. The results are shown in Figure 5-18. All ovens appear to fire consistent with the 60 cycle signal.

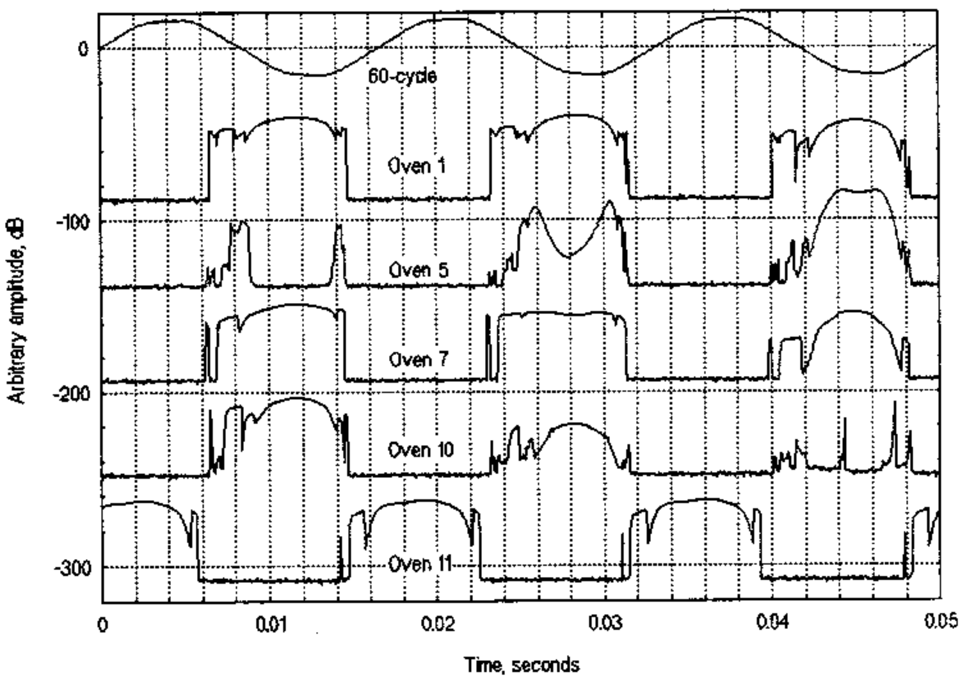


Figure 5-18. Results of trigger point examination.

HARDWARE EXCHANGE

Several experiments were performed to determine the effects of switching components from one test oven to another. The purpose of this test was to see if the oven retained its original characteristics or took on those of the oven from which the components were removed. The same procedures used to obtain the original emission spectra were repeated for these tests. Figure 5-19 shows a schematic of the oven components consistent in all the ovens.

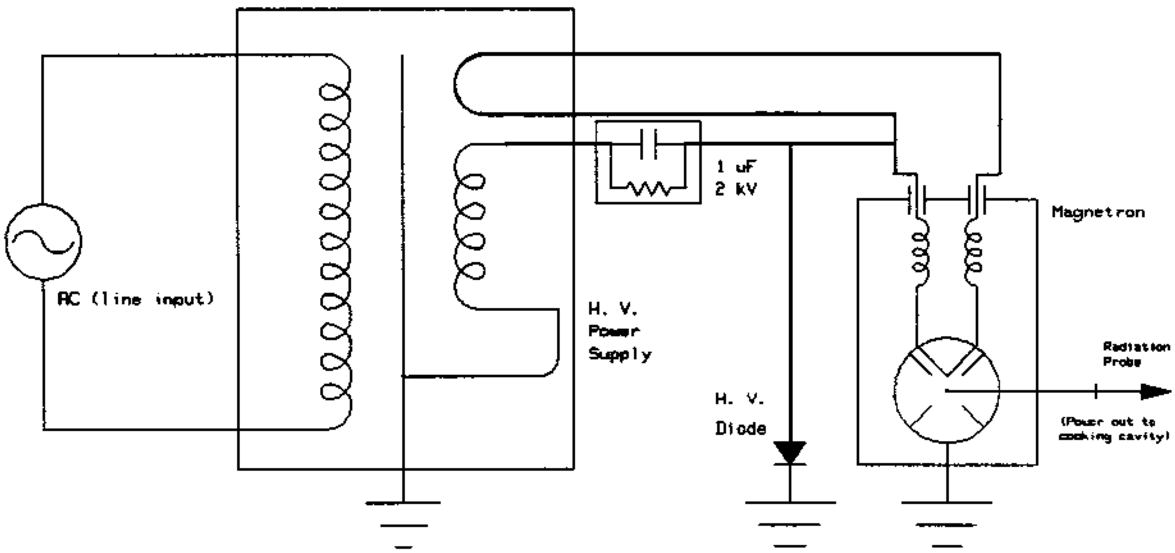


Figure 5-19. Schematic of a typical microwave oven. This diagram is representative of all ovens used in the NTIA tests described in this report.

Figure 5-20 (same as Figure 5-7a) shows the emission spectrum of the unmodified Oven #10, which had exhibited a relatively poor spectrum signature with high spurious emissions on both the low and high ends of the spectrum. The emission spectrum of Oven #7 in Figure 5-21 (same as Figure 5-12a) had a relatively good signature. The duplicate oven in Figure 5-22 (same as Figure 5-13) exhibited similar characteristics to that of Oven #7. The units of like model and like components produced nearly identical spectra.

In the first experiment the magnetron in Oven #10 was replaced with the one used in Oven #7DUP. Figure 5-23 shows what the effect of changing the magnetron tube had on the overall emission characteristics. The results indicate that Oven #10 has now taken on Oven #7DUP's characteristics to a large extent. With the exchanged magnetron, the levels in the adjacent bands have also improved by 10 to 24 dB. This demonstrates that the magnetron is a major determinant in the spectral emission characteristics of a microwave oven, and that out-of-band characteristics can be altered by changing magnetrons.

In the second experiment, the magnetron and capacitor in Oven #10 were replaced with those from Oven #7DUP. The results in Figure 5-24 show only slightly changed characteristics over the previous experiment. In this case, there is an additional 1 to 3 dB improvement on the lower end, near 2300 MHz (2300-2330 MHz), and 2 to 9 dB improvement at the upper end, near 2600 MHz (2580-2600 MHz). The spectrum levels from 2490-2570 MHz appeared to increase by 2 to 10 dB.

In the third experiment, the diode and the high voltage supply from Oven #7DUP were added to the previous exchange. In this case (Figure 5-25), the emission levels from 2500-2570 MHz showed a slight improvement by 5 to 10 dB over the first experiment and 10 to 15 dB over the second experiment. No improvement was demonstrated below 2400 MHz.

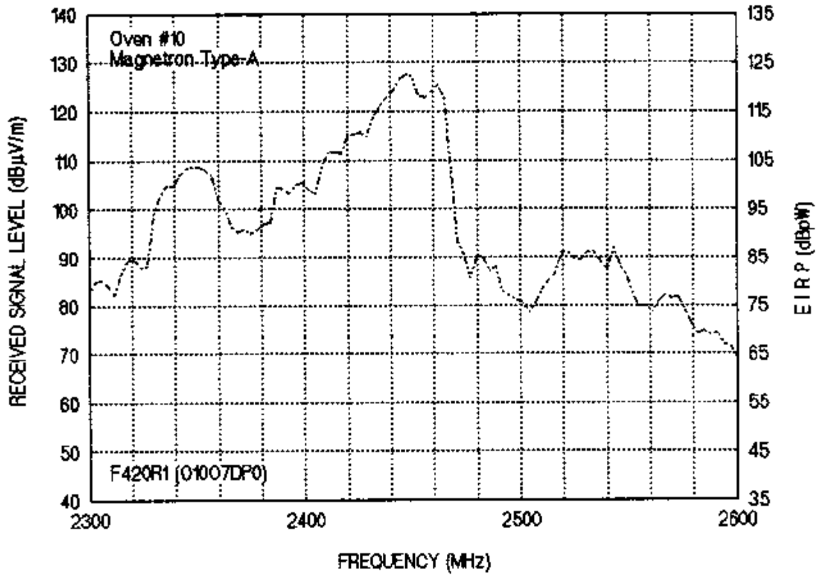


Figure 5-20. Frequency vs. Amplitude for Oven #10.

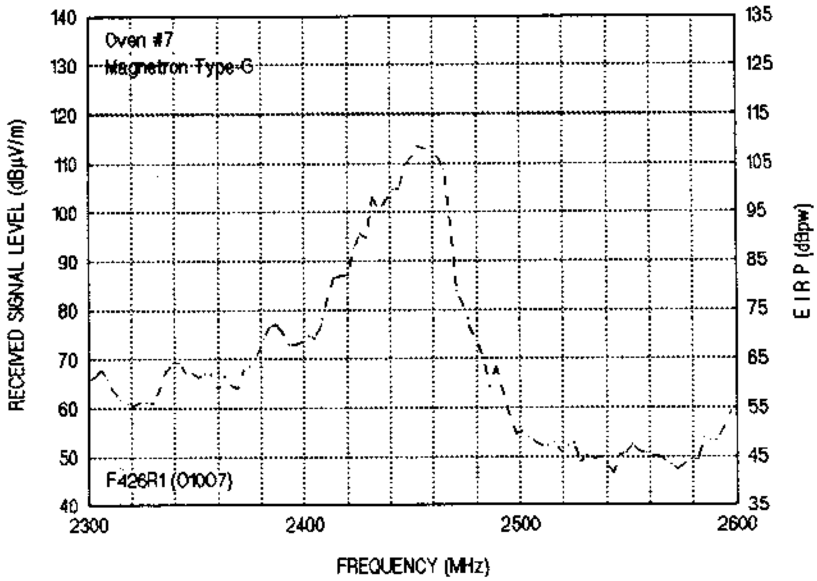


Figure 5-21. Frequency vs. Amplitude for Oven #7.

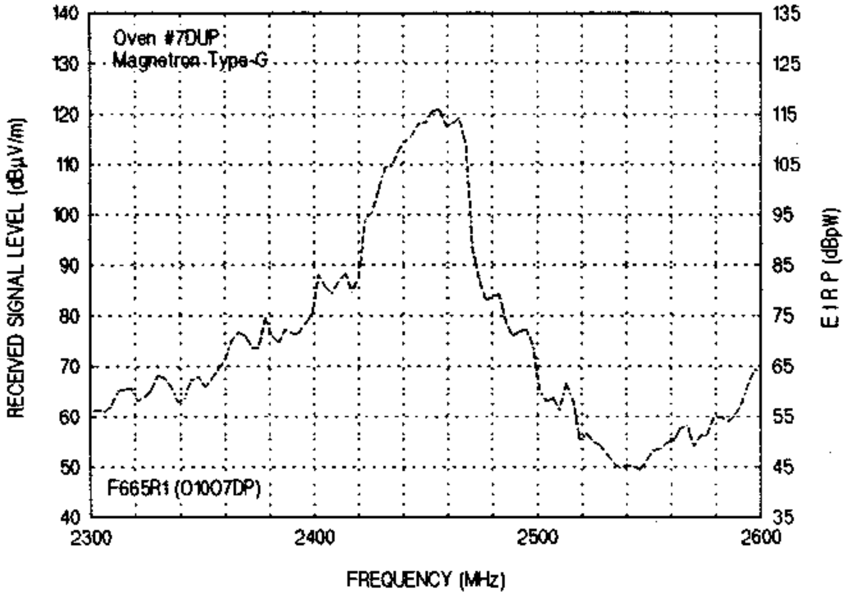


Figure 5-22. Frequency vs. Amplitude for Oven #7 DUP.

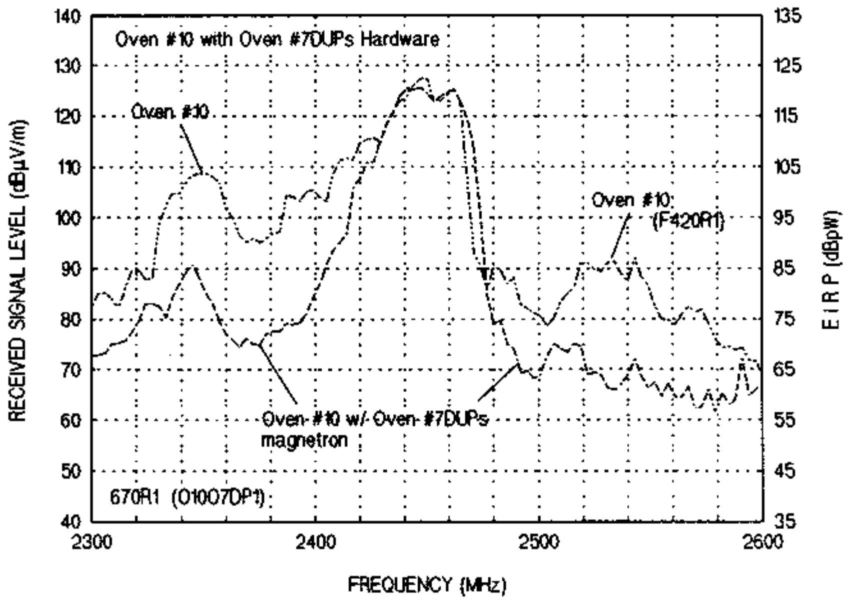


Figure 5-23. Frequency vs. Amplitude for Oven #10 and Oven #10 with Oven #7 DUP magnetron tube type installed.

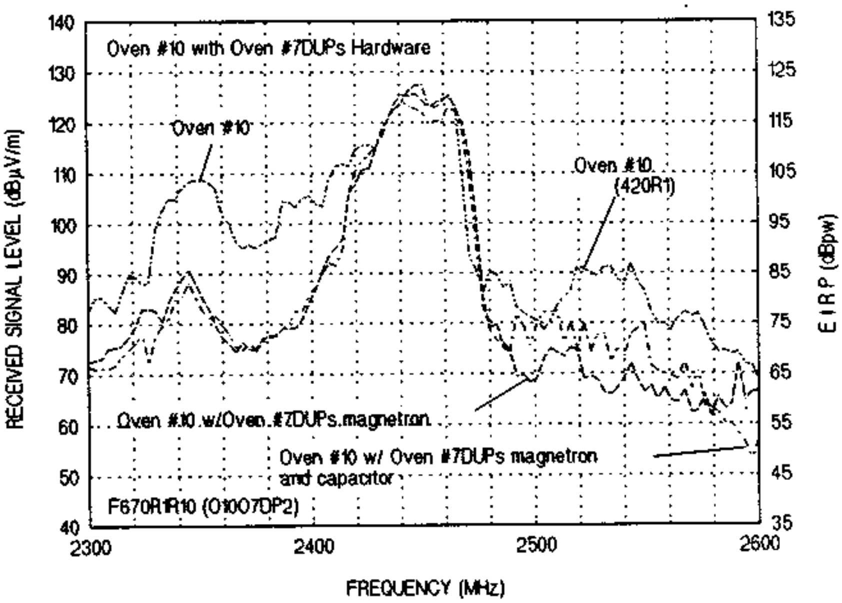


Figure 5-24. Frequency vs. Amplitude for Oven #10; for Oven #10 with Oven #7 DUPs magnetron tube type installed; and Oven #10 with Oven #7 DUPs magnetron tube type and capacitor installed.

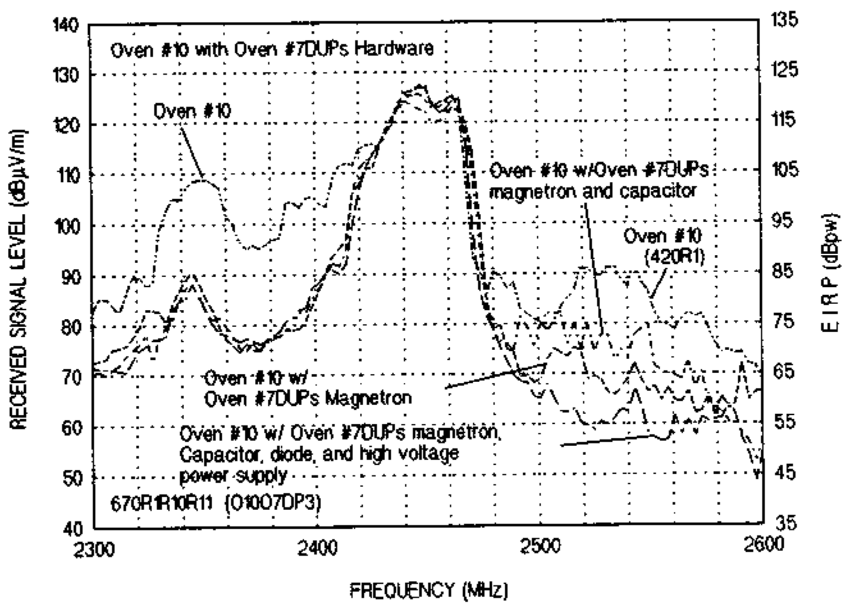


Figure 5-25. Frequency vs. Amplitude for Oven #10; for Oven #10 with Oven #7 DUPs magnetron; for Oven #10 with Oven #7 DUPs magnetron & capacitor installed; and for Oven #10 with Oven #7 DUPs magnetron, capacitor, and high voltage power supply installed.

HARMONIC EMISSION LEVELS

MP-5, Part 2.3, specifies that frequencies out to the 10th harmonic or the highest detectable emission level, must be measured. In the NTIA tests, the highest detectable level that could be measured was out to the seventh harmonic emission level.

The harmonic emission levels for Oven #1, #2, #6, #7 and #8 were measured to the 7th harmonic. Each of the five ovens was measured in bandwidth of 3 MHz over frequency ranges that included the discrete harmonic frequencies. The measurement was stepped with a peak detector and the number of steps was adjusted as the measurement span increased. Those harmonic frequency ranges were 4800-5000 MHz, 7200-7500 MHz, 9600-10000 MHz, 12000-12500 MHz, 14400-15000 MHz, and 16800-17500 MHz. The measured fundamental and harmonic frequency data for each oven tested is included in Appendix E. Figure 5-26 shows the harmonic measurement set-up for the harmonic measurements. All measurements were made using a 1-18 GHz vertically polarized calibrated horn, and TABLE 5-11 contains the manfacturer's specification for the antenna used during the test. Linear interpolation was used to obtain the proper gains for the discrete frequencies of each harmonic in TABLE 5-12. TABLE 5-13 shows the measured peak values in dBpW for all the ovens tested. Figure 5-27 shows the maximum harmonic emission levels including the fundamental frequencies in a single bar graph.

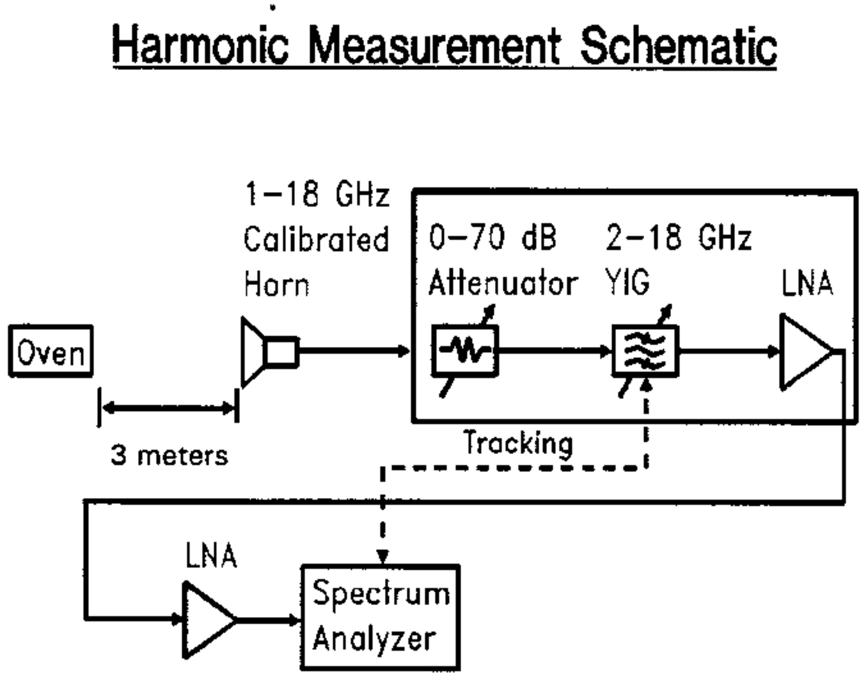


Figure 5-26. Harmonic measurement set-up for the tested microwave ovens.

TABLE 5-11
ELECTRO-MECHANICS CO. DOUBLE RIDGE GUIDE HORN ANTENNA MODEL NUMBER 3115, SERIAL NUMBER 3646 CALIBRATED 4/23/91 per ARP958 METHODOLOGY
1 Meter Calibration

Frequency (GHz)	Gain (dBi)
2.0	9.1
2.5	9.1
3.0	9.1
3.5	9.3
4.0	10.3
4.5	10.2
5.0	10.2
5.5	10.4
6.0	10.8
6.5	11.5
7.0	11.1
7.5	10.5
8.0	10.9
8.5	11.3
9.0	11.4
9.5	11.5
10.0	11.6
10.5	12.3
11.0	12.4
11.5	12.2
12.0	13.3
12.5	13.4
13.0	12.4
13.5	12.1
14.0	12.0
14.5	12.7
15.0	14.1
15.5	15.9
16.0	15.7
16.5	14.0
17.0	13.0
17.5	10.7
18.0	9.4

TABLE 5-12
HARMONIC GAINS USING
DOUBLE RIDGE 1-18 GHz HORN ANTENNA

Frequency (MHz)	Gain (dBi)
4900	10.25
7350	10.65
9800	11.65
12250	13.35
14700	13.20
17150	12.50

TABLE 5-13
MAXIMUM HARMONIC AMPLITUDE LEVELS

	Oven #1 (dBpW)	Oven #2 (dBpW)	Oven #6 (dBpW)	Oven #7 (dBpW)	Oven #8 (dBpW)
Fundamental	122 (2445 MHz)	99 (2480 MHz)	115 (2452 MHz)	105 (2466 MHz)	116 (2441 MHz)
2nd-Harmonic	73	48	76	53	73
3rd-Harmonic	71	47	66	48	41
4th-Harmonic	53	48	63	80	45
5th-Harmonic	83	50	47	41	44
6th-Harmonic	61	49	50	51	43
7th-Harmonic	65	46	55	44	51

All ovens tested were above the 500 watts of actual RF power generated. Oven #7, as previously shown, has good adjacent band characteristics (see Figure 5-12a) but shows a high peak of harmonic emissions at the 4^{th} harmonic.

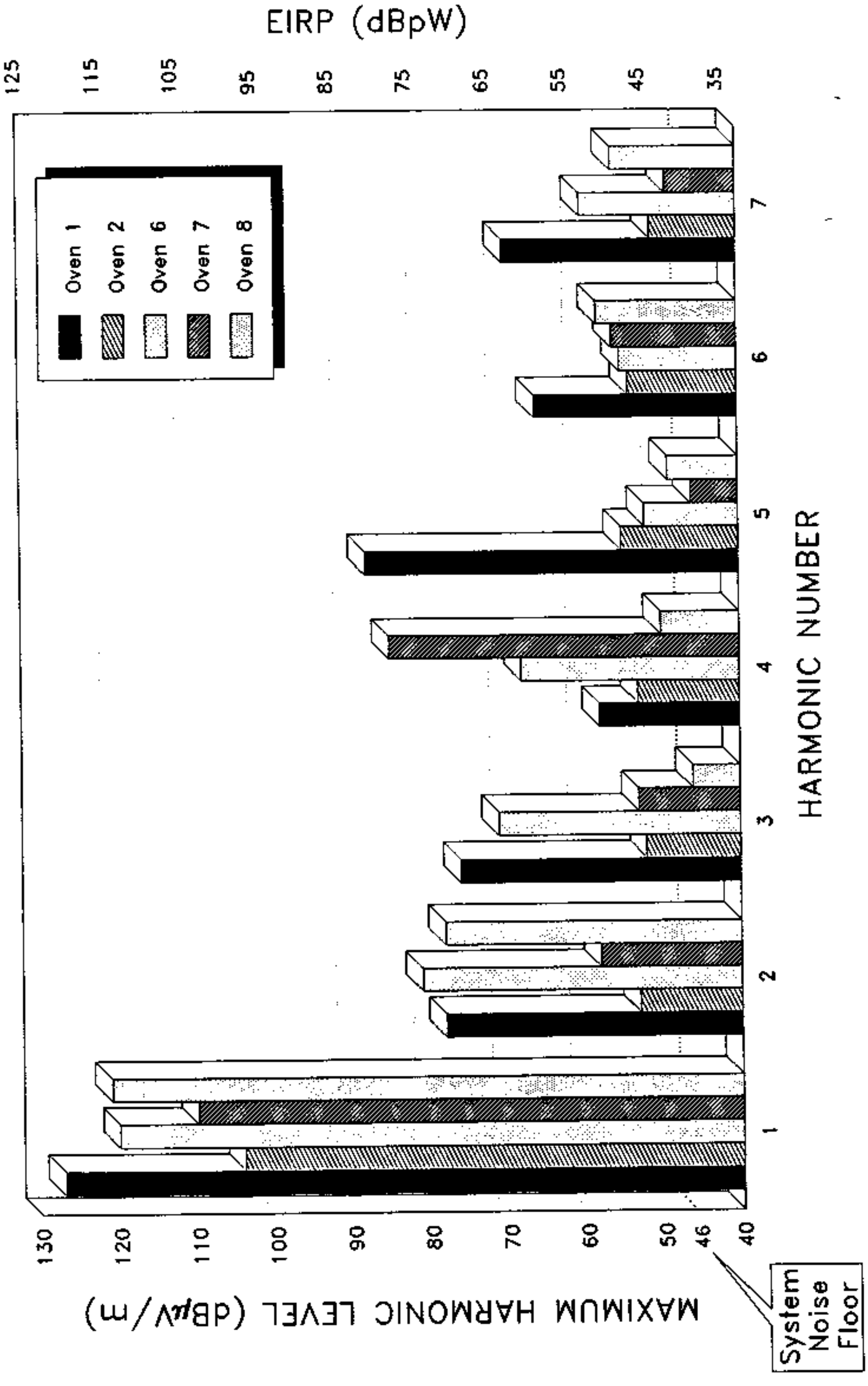


Figure 5-27. Harmonic emission levels of Ovens #1, #2, #6, #7, and #8.

MULTIPLE OVEN OPERATION

ITS performed a test in which five ovens (ovens #1, #5, #6, #8, #10) were operated simultaneously. The ovens were operated on three different power circuits at three different phases. Because the power phase determines the moment of oven triggering, the time waveforms are triggered at different times for ovens on each supply circuit. This is observed in Figure 5-28.

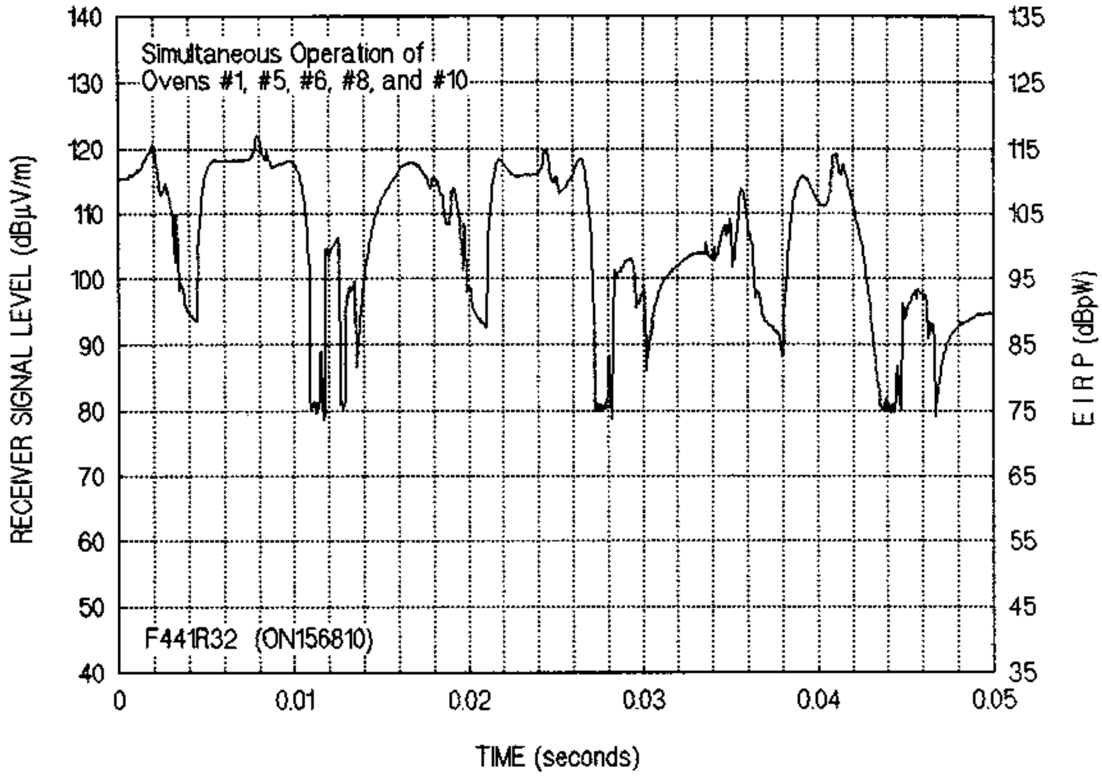


Figure 5-28. Multiple operation of ovens #1, #5, #6, #8, and #10.

SUMMARY

Each oven has a unique emission spectrum. The fundamental frequency on most of the ovens drifts. However, the rate and extent of that drift varies from oven to oven. The mean EIRP for all ovens (over the bands listed) measured with a peak detector was:

2300-2400 MHz	74 dBpW
2400-2500 MHz	95 dBpW
2500-2600 MHz	65 dBpW

The range of mean EIRP for all ovens (over the bands listed) measured with a peak detector was:

2300-2400 MHz	61 - 94 dBpW	(see Figure 5-2)
2400-2500 MHz	83 - 111 dBpW	(see Figure 5-3)
2500-2600 MHz	48 - 80 dBpW	(see Figure 5-4)

The range of maximum EIRP for all ovens[30/] (over the bands listed) measured with a peak detector was:

2300-2400 MHz	67 - 105 dBpW
2400-2500 MHz	106 - 123 dBpW
2500-2600 MHz	55 - 93 dBpW

The maximum EIRP at the harmonics measured with a peak detector, averaged for the five ovens tested, was (see TABLE 5-13):

fundamental	111 dBpW
2nd harmonic	65 dBpW
3rd harmonic	55 dBpW
4th harmonic	58 dBpW
5th harmonic	55 dBpW
6th harmonic	51 dBpW
7th harmonic	52 dBpW

Microwave ovens produce 60 pulses per second. Nominally, the pulse widths are 7 to 8 ms and the interval between pulses is about 8 to 9 ms. However, the rapidly changing fundamental frequency exhibited by most ovens results in a pulse-to-pulse time waveform sequence (as measured with a spectrum analyzer) which does not reflect those nominal 7 to 8 ms values, even at or near the nominal center frequency of 2450 MHz. Rather, using a spectrum analyzer with a 3 MHz measurement bandwidth and a fixed tuned frequency, the measured time waveform for most microwave ovens at almost any measured frequency is a series of much shorter pulse pairs commonly referred to as "rabbit ears." The fixed tuned frequency and finite bandwidth of the spectrum analyzer are analogous to the characteristics of most communications receivers. Thus a receiver that might share this frequency band would see similar time waveforms.

The typical interval within each pair of "rabbit ears" is about 6 to 8 ms (slightly less than the nominal pulsewidth), and the interval between each pair being about 8 to 9 ms. A "rabbit ear" pulse itself (½ of the pair) usually has a width of about 500 μs to 2 ms at the 3 dB points. Energy may be measured in the interval within a pair as little as a few dB below the peak amplitude, or may not be measured at amplitudes tens of decibels below the peak amplitude. Amplitudes may vary greatly, even at a single frequency for a single oven. See,

30/ Each frequency vs. amplitude graph in this section was examined to determine the maximum levels; Figures 5-5a, 5-6a, 5-7a, 5-8a, 5-9a, 5-10a, 5-11a, 5-12a, 5-13, 5-14, 5-15a, 5-16a, and 5-17a.

for example, Figure 5-12b. More sensitive receivers will see much more of the "fill-in" of the pulse, as revealed by the Phase II time waveforms in Appendix C.

The APDs in Appendix C also reflect the low duty cycle, "rabbit ear" characteristic of oven time waveforms. This is indicated by the fact that the 50% point on most of the APD curves falls at or close to the measurement system noise floor, indicating that the duty cycle of the measured pulses was much lower than the 50% duty cycle that would be predicted from the nominal oven pulse characteristics. (If the ovens had been measured at close to 50% duty cycle, then the 50% point on the APD curves would have been substantially higher than the measurement system noise floor.)

The magnetron tube type appears to be the significant factor in formulating an oven's emission spectrum. Changing the magnetron tube type from one oven to another can significantly alter the oven's characteristics. Three of the four ovens comprising the highest emitters for all sub-bands used the same magnetron tube type. Microwave oven manufacturers can lower the emission levels in the bands adjacent to the 2400-2500 MHz band through judicious selection of the better magnetron tubes already available. As shown by the NTIA measurement results, some manufacturers already incorporate in their designs magnetron tubes that have better adjacent band characteristics and that adjacent band emissions of other ovens can be improved by installing those magnetron tube types. It seems reasonable to assume that such an improvement could be made without increased cost or magnetron tube development. However, the emission characteristics in the 2300-2400 MHz and 2500-2600 MHz frequency ranges probably cannot be the sole determining factor in the selection of a magnetron. The fact that Oven #7 had good adjacent band characteristics, but high levels at the 4th harmonic raises a question as to the relationship, if any, between adjacent band characteristics and harmonic characteristics that result from the magnetron tube type in oven design.

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SECTION 6
FINDINGS AND RECOMMENDATIONS

FINDINGS

Methods of Measurement

1. Because emission limits and methods of measuring radio emission characteristics are most meaningful when linked to the characteristics of receivers operating or planned to operate in the environment, microwave oven emission limits and methods of measurement must take into consideration the evolution of radio systems above 1 GHz toward digital technologies, often using receiver bandwidths of 1 MHz or more.

2. Measurements based on techniques producing average values are not appropriate for evaluating a radio emitter's impact on broadband receivers.

3. The usefulness of emission standards, such as the FCC's Part 18, based on averaging measurement techniques will decrease as the radio environment continues to shift toward digital systems.

4. Averaging of the measured signal, particularly through the video averaging approach recommended unofficially by the FCC for spectrum analyzer-based measurements, makes it difficult to show the variation between microwave oven emission characteristics, while peak measurements show significant differences in the emission levels from one microwave oven to another.

5. Positive peak detection in a wide measurement bandwidth is useful for recording impulsive, broadband emission types, and therefore might be a more effective method of measurement than an average or quasi-peak based procedure for assessing the interference potential from microwave ovens.

6. The authorization of several different measurement procedures (MP-5, unofficial spectrum analyzer techniques, or others) decreases the likelihood of consistent Part 18 compliance testing results unless each procedure is carefully tested to demonstrate that it produces a result equal to the primary or recommended procedure.

7. Spectrum analyzers are readily available and commonly used for measurements above 1 GHz.

8. Though it is impossible to characterize the emissions of microwave ovens under all of the operating conditions found in common use, a single set of test parameters (possibly with the exception of a single measurement bandwidth) provides an adequate reflection of oven characteristics for standards setting. The parameters that were found to be useful in the NTIA testing procedures are given in the recommendations below.

Microwave Oven Spectral Emission Characteristics

9. Each oven has a unique emission spectrum. The fundamental frequency, nominally 2450 MHz, drifts. The rate and extent of the drift, and the dominant operating frequency vary from oven to oven.

10. The results of oven measurements are presented in Sections 4 and 5 as well as in Appendices B, C, and D. The mean EIRP for all ovens (over the bands listed) measured with peak detector was:

2300-2400 MHz	74 dBpW
2400-2500 MHz	95 dBpW
2500-2600 MHz	65 dBpW

The range of mean EIRP for all ovens (over the bands listed) measured with a peak detector was:

2300-2400 MHz	61 - 94 dBpW
2400-2500 MHz	83 - 111 dBpW
2500-2600 MHz	48 - 80 dBpW

The range of maximum EIRP for all ovens (over the bands listed) measured with a peak detector was:

2300-2400 MHz	67 - 105 dBpW
2400-2500 MHz	106 - 123 dBpW
2500-2600 MHz	55 - 93 dBpW

11. The amplitude and probability of occurrence of microwave oven pulses generally decrease as the frequency of separation from 2450 MHz increases. The ovens produce receiver responses of a pulse-like (pulsewidth approximately 7-8 ms) nature near the oven operating frequency, becoming increasingly impulsive (pulsewidth approximately the inverse of receiver bandwidth) as the frequency separation from the oven operating frequency increases.

12. The maximum EIRP at the harmonics measured with a peak detector, averaged for the five ovens selected for harmonic testing, was:

fundamental	111 dBpW
2nd harmonic	65 dBpW
3rd harmonic	55 dBpW
4th harmonic	58 dBpW
5th harmonic	55 dBpW
6th harmonic	51 dBpW
7th harmonic	52 dBpW

Microwave Oven Designs Which Minimize Emissions in the Bands Adjacent to 2400-2500 MHz

13. Manufacturers of microwave ovens can reduce the level of emissions in the bands adjacent to the 2400-2500 MHz band, without increased costs, by selecting magnetron tube types already available that emit lower levels in these frequency ranges.[31/]

RECOMMENDATIONS

1. The FCC should review the method of measurement and consequently the emission limit that it applies to microwave ovens, and should revise these aspects of Part 18 as necessary to ensure they are appropriate and adequate to protect of radio services present or envisioned for the environment.[32/] Due to the lifespan of microwave ovens, a review must consider the requirements of radio systems to be envisioned to be operating in 10 years or beyond.[33/] In determining the specifics of its measurement procedures, the FCC should link the measurement procedures to the types of receivers to be protected.

2. The FCC should consider requiring peak measurements for microwave ovens, possibly including measurements in a variety of bandwidths, but as a minimum, should abandon the 3 Hz video bandwidth approach.

3. Measurement procedures should be based on readily available measurement equipment such as spectrum analyzers. The procedures should be sufficiently detailed to ensure repeatable results.

4. Measurement procedures should include a single set of test parameters for microwave oven measurements (multiple measurement bandwidths may possibly be needed). The following parameters were found to be useful within the NTIA tests:

31/ NTIA recognizes that the emission characteristics in the 2300-2400 MHz and 2500-2600 MHz frequency ranges will probably not be the sole determining factor in the selection of a magnetron.

32/ NTIA has in no way attempted here to evaluate the effectiveness of the Part 18 standard to date. In fact with respect to microwave ovens, the limits above 1 GHz based on a narrowband averaging technique cannot be meaningfully assessed with respect to protection of digital systems.

33/ As indicated in Section 1 of this report, NTIA plans to conduct two additional tasks within this effort. The third part will look at future receiver requirements.

Oven Load	1 liter of water
Antenna Polarization	Both horizontal and vertical polarization should be authorized
Oven Orientation	Measurement antenna should be aimed at the oven door
Antenna Height	Antenna should be set at the height of the center of the oven
Oven Temperature	Oven should be warmed-up by operation for a few minutes

5. Considering the demand for radio frequencies, manufacturers of microwave ovens should place great significance on magnetron emission characteristics outside the bands the 2400-2500 MHz band when selecting a magnetron tube.

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