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 $r \geq 0.90$), "high" ($0.90 < r \geq 0.70$), "medium" ($0.70 > r \geq 0.30$), or "low" ($r < 0.30$). 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.

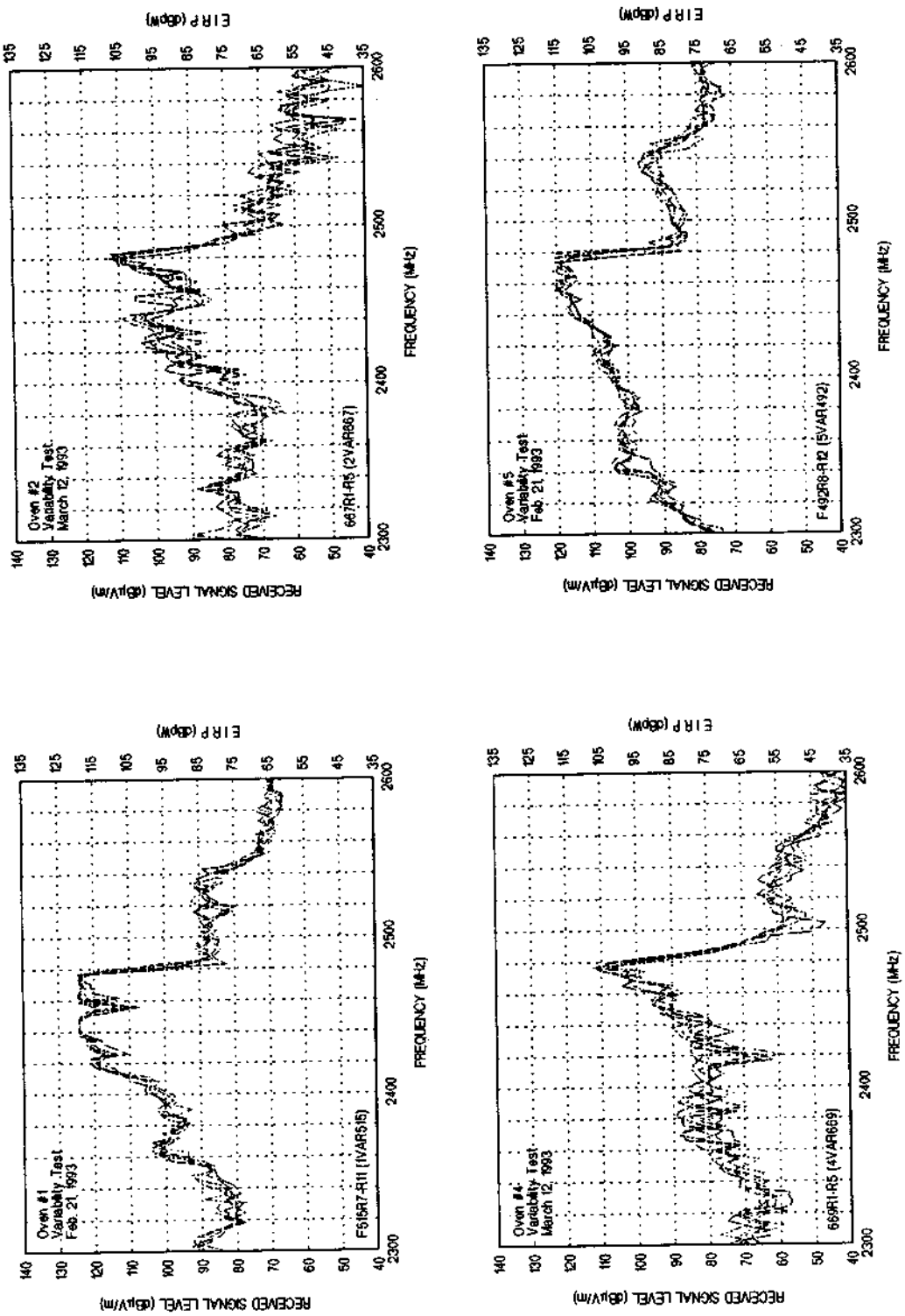


Figure 4-1. Control tests for Ovens #1, #2, #4, and #5.

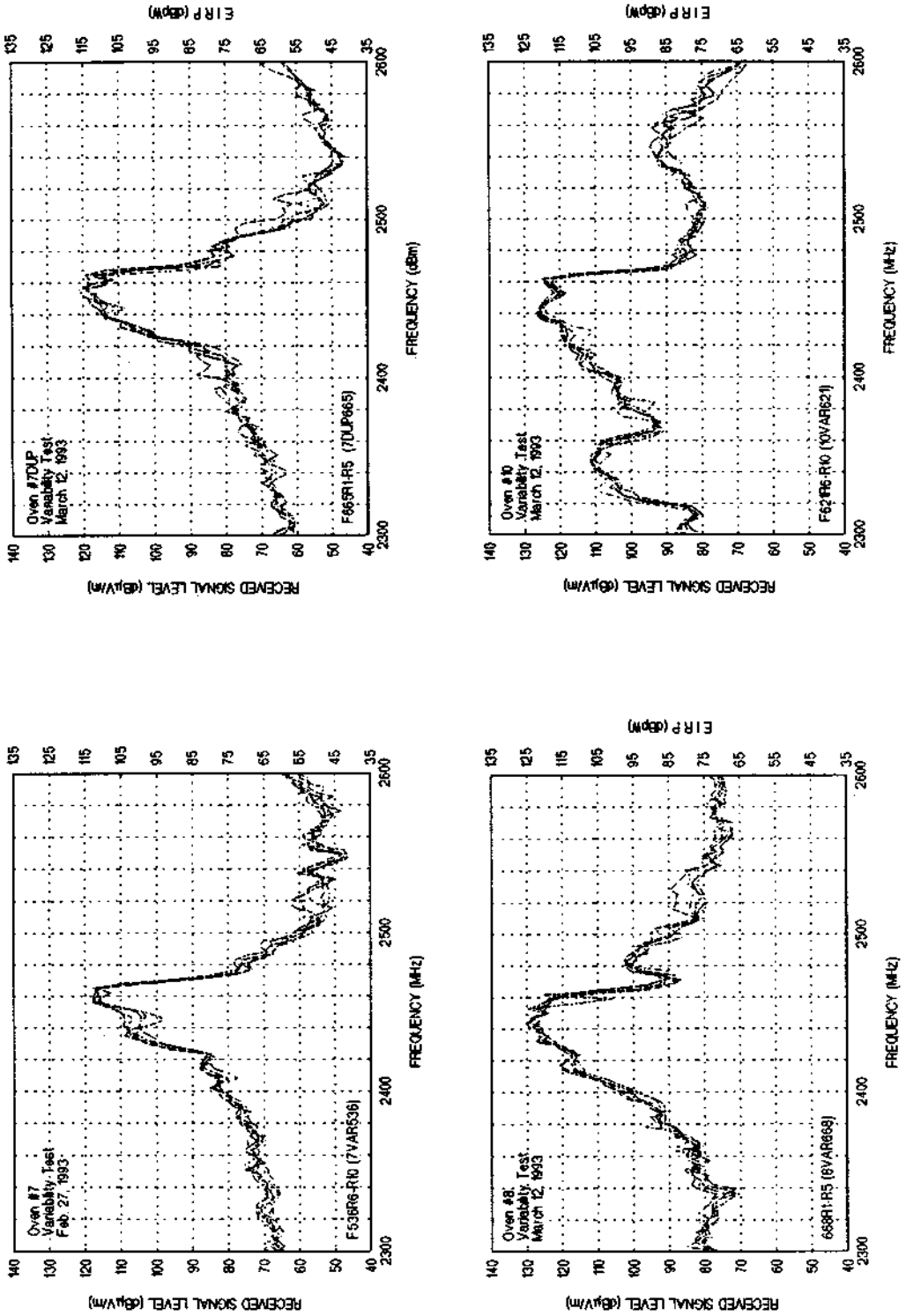
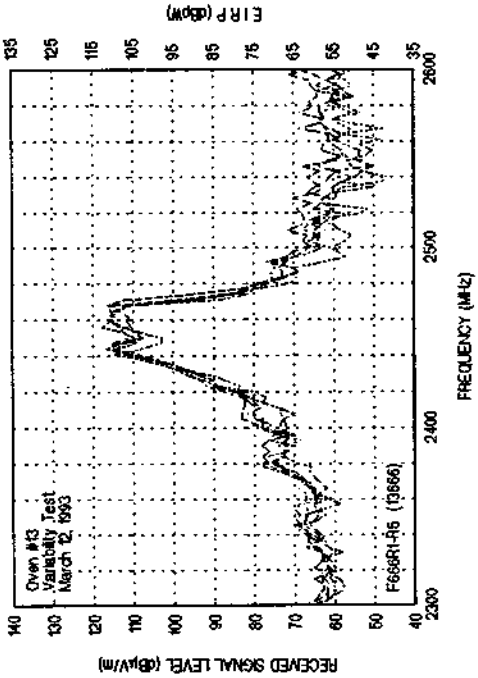


Figure 4-1 cont. Control test for Ovens #7, #7DUP, #8, and #10.



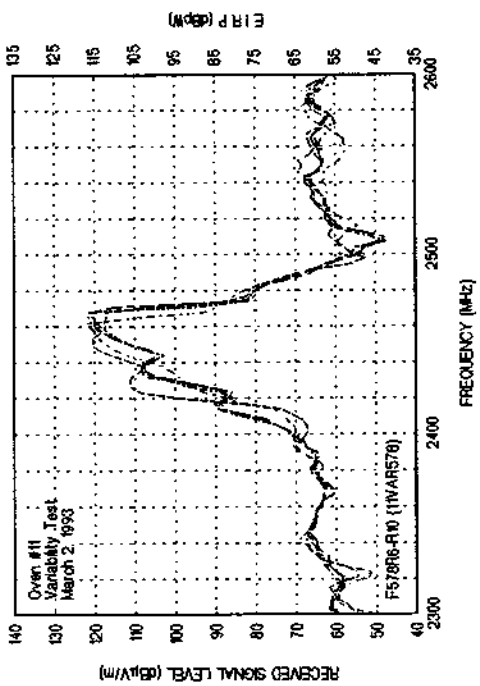


Figure 4-1 cont. Control tests for Ovens #11 and #13.

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.

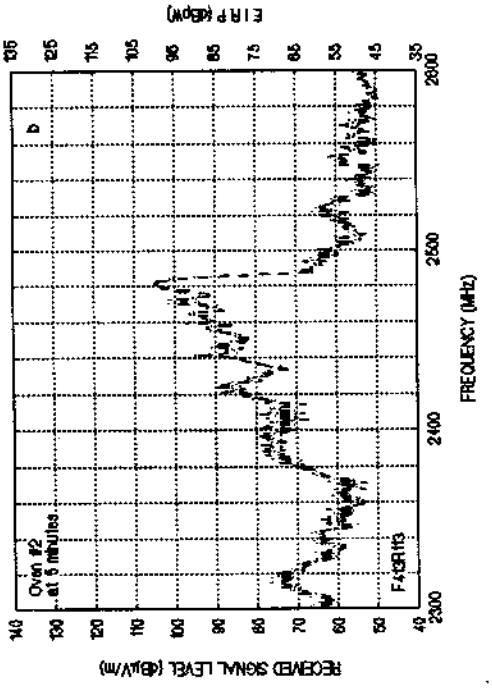
The investigation of start temperature consisted of measuring the spectral emission characteristics of Oven #2 immediately after turn-on and at 5 minute intervals up to 30 minutes. This was the maximum time available before the 1 liter of water, being used as the oven load, completely boiled away.

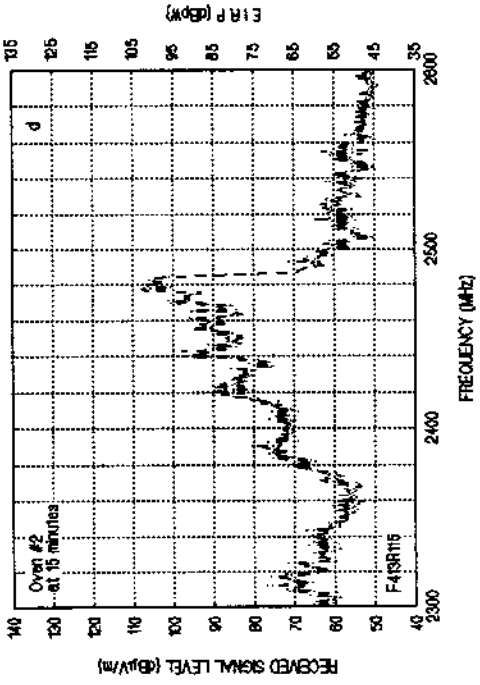
Figure 4-2 shows plots of the spectral emission characteristics obtained during each time interval. The measurement bandwidths of 1 MHz contributes to the difference between these and other graphs of similar data that are presented within the majority of spectral emission characteristics measurements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

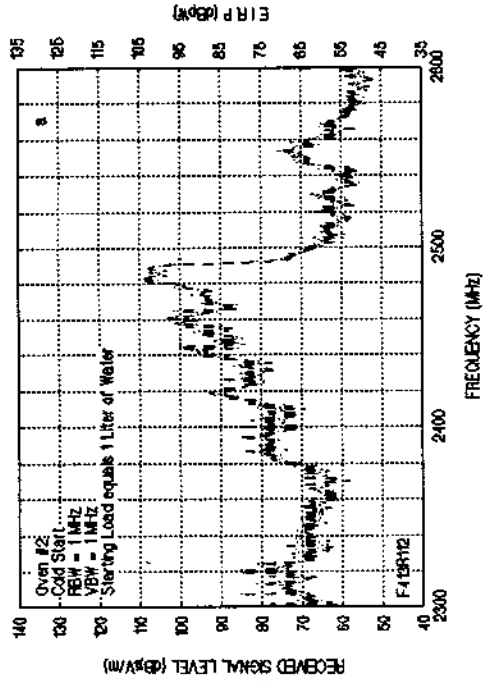
TABLE 4-2 shows the results in terms of the correlation coefficient quantifying differences in successive measurements. A slight change is evident between the oven start measurement and those at other times. Once warm, the ovens consistently show high correlation.

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







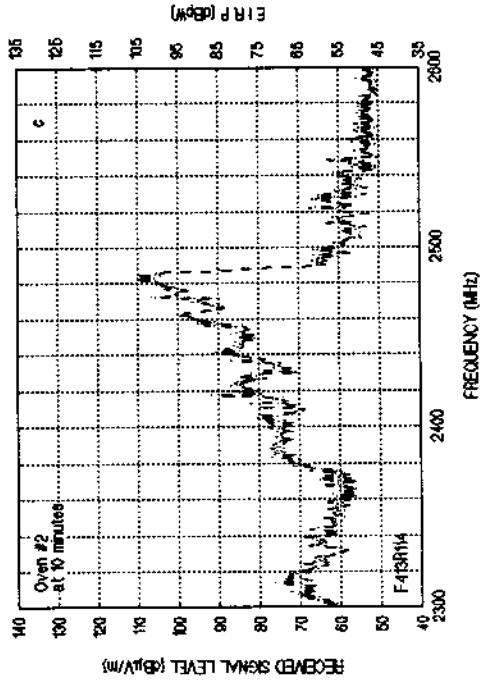
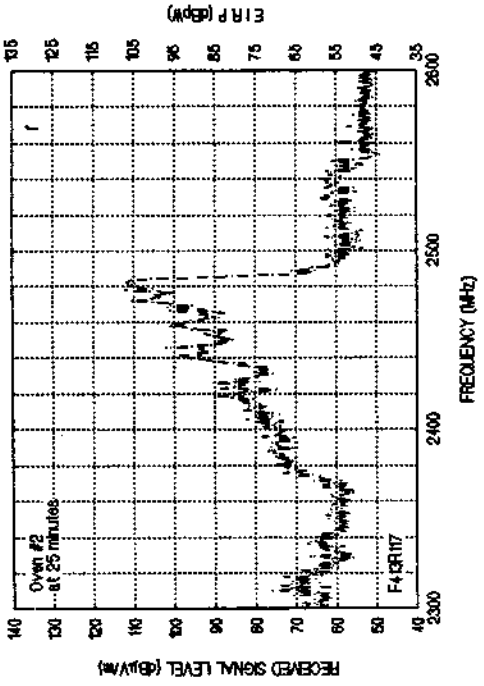
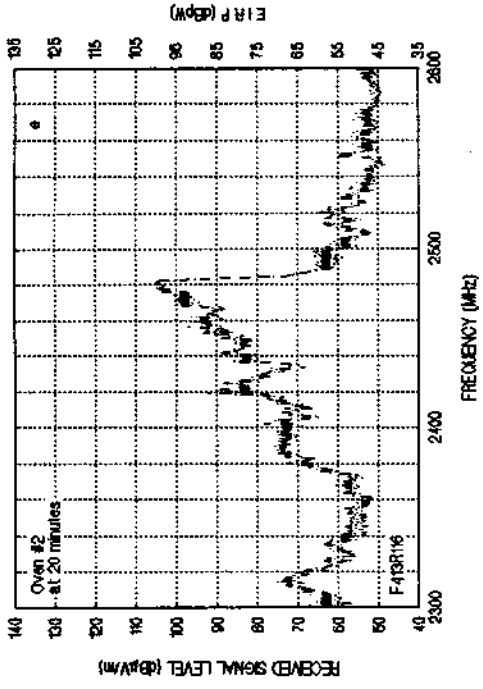


Figure 4-2. Temperature variation test of Oven #2.





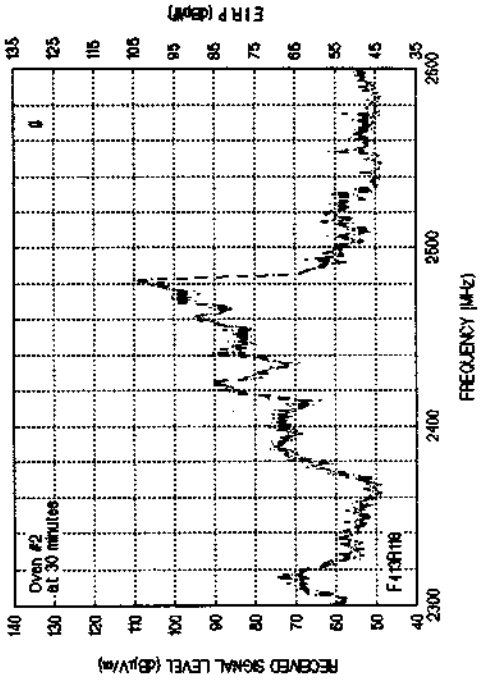
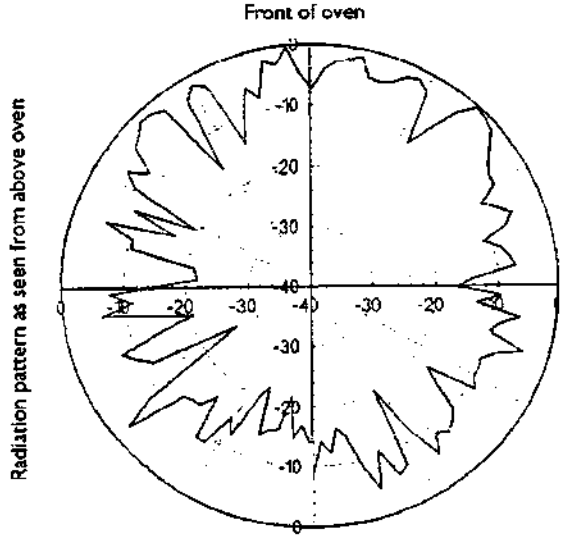


Figure 4-2 cont. Temperature variation test of Oven #2.

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.



dB relative to peak emission vs. angle

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

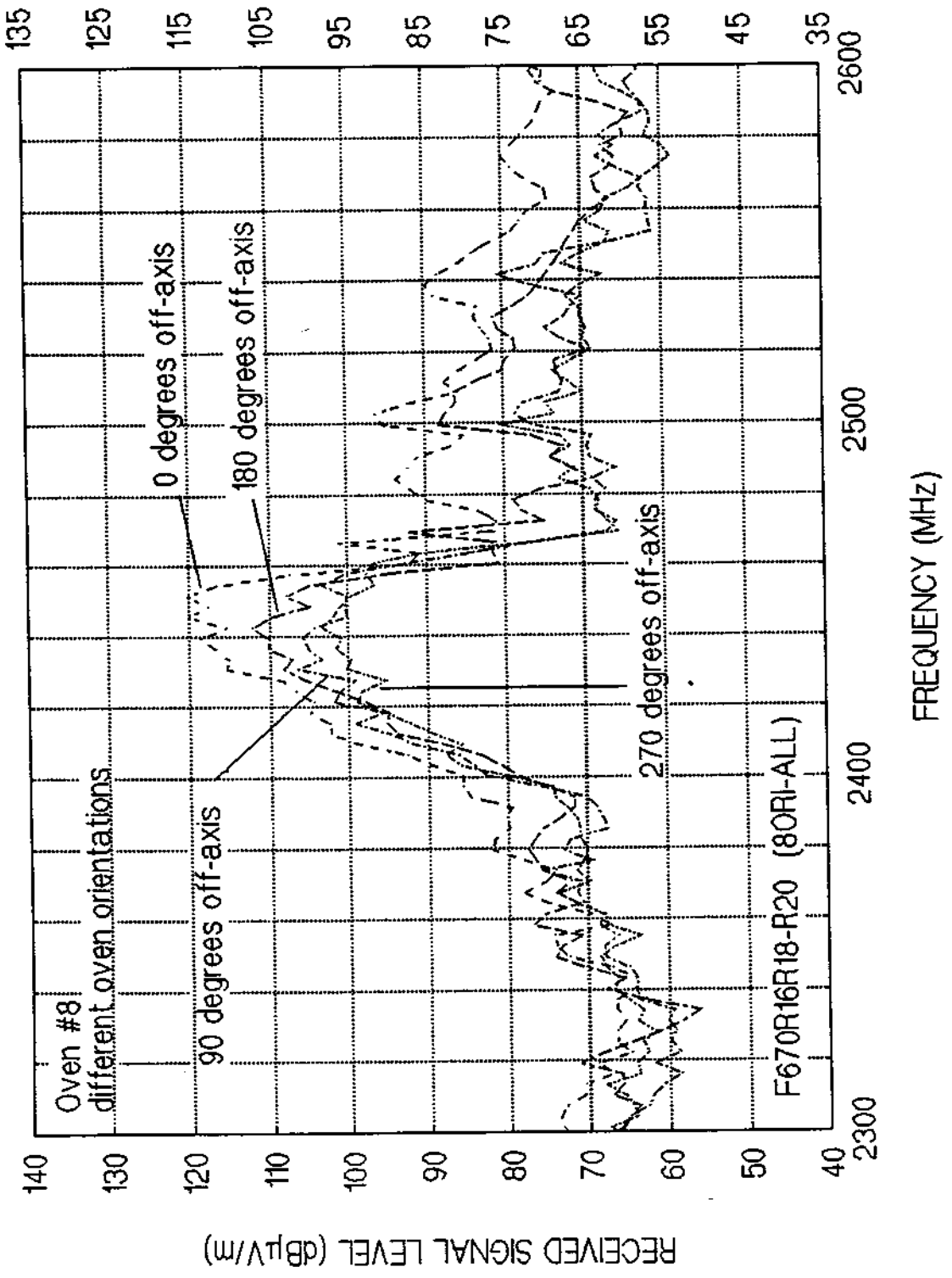


Figure 4-4. Orientation variation of Oven #8.

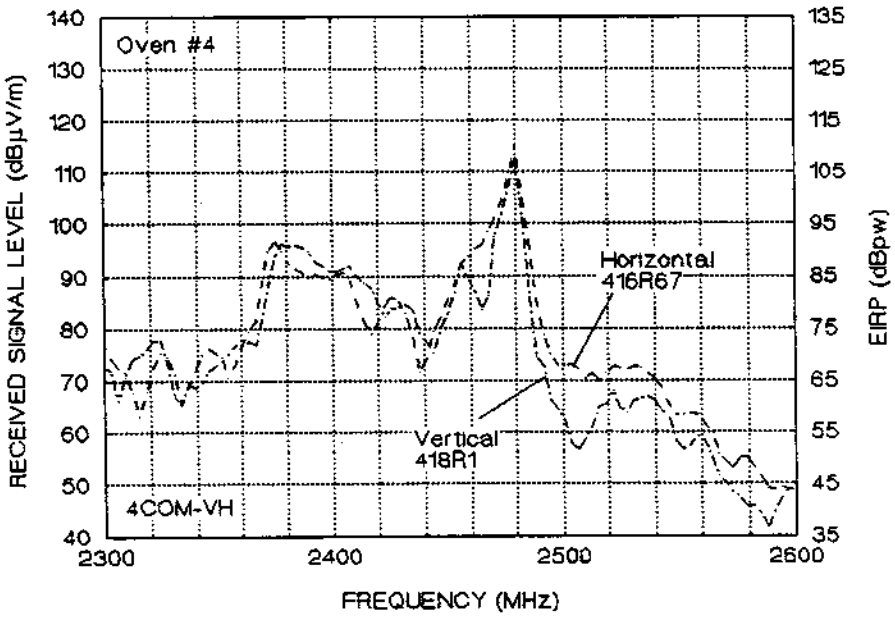


Figure 4-5. Antenna polarization variation with Oven #4.

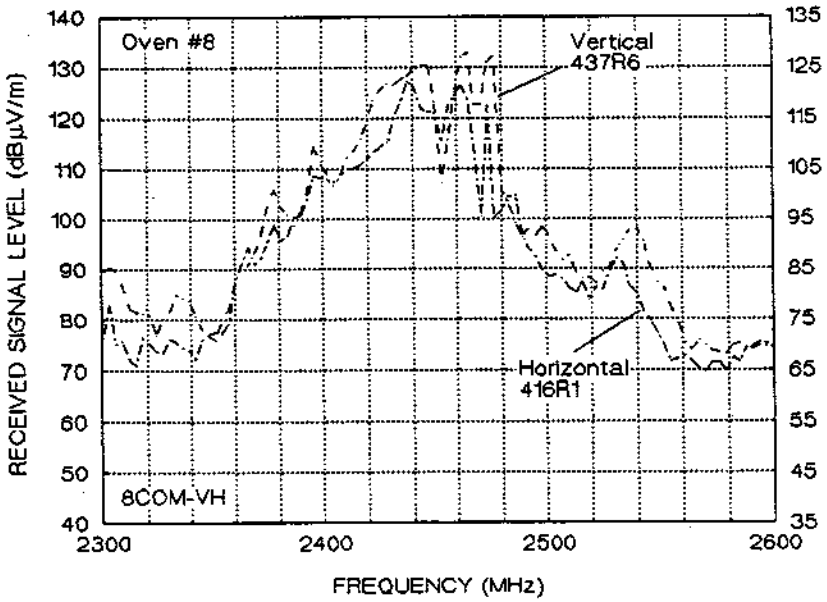


Figure 4-6. Antenna polarization variation with Oven #8.

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.

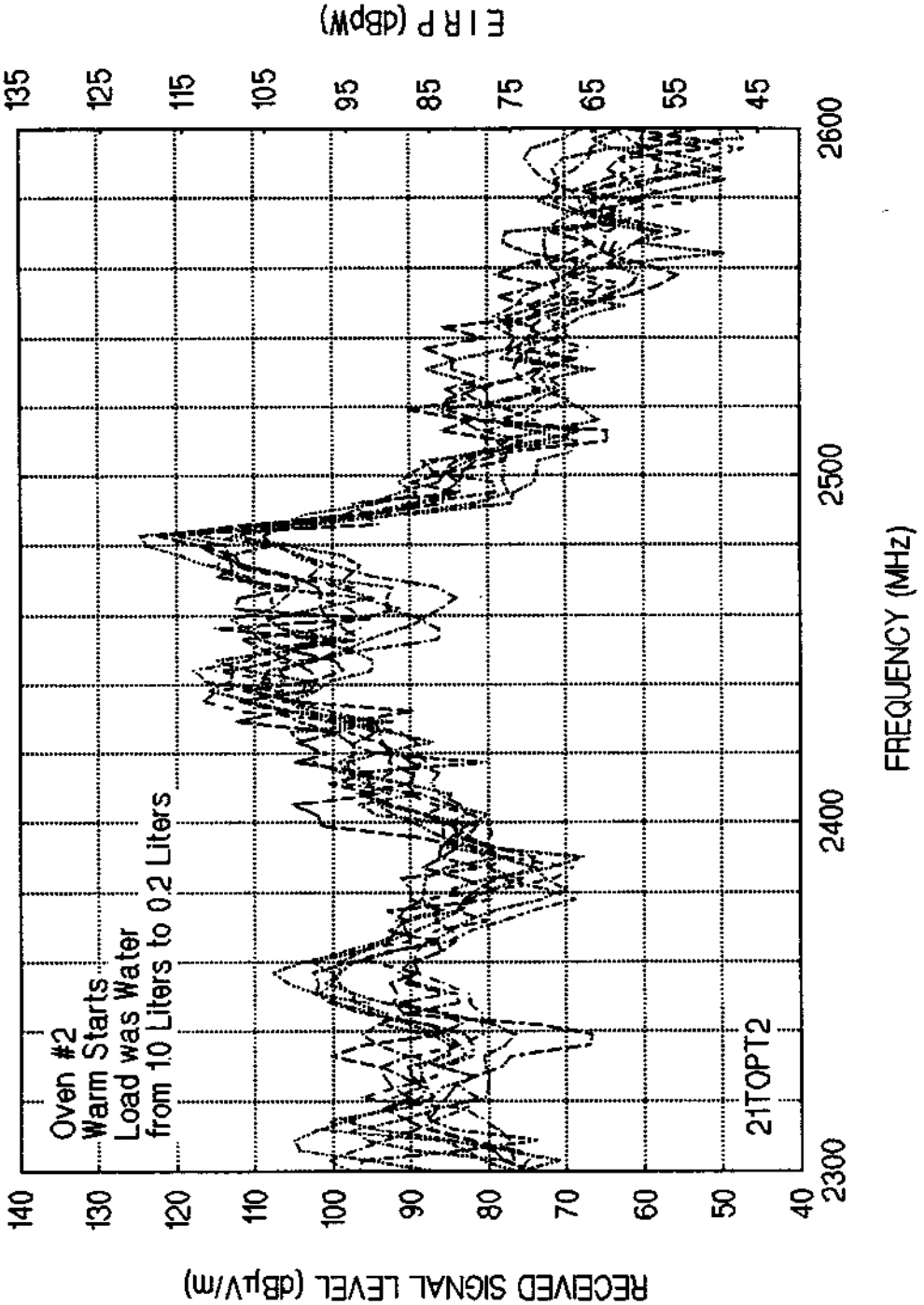


Figure 4-7. Oven #2 with varied water loads.

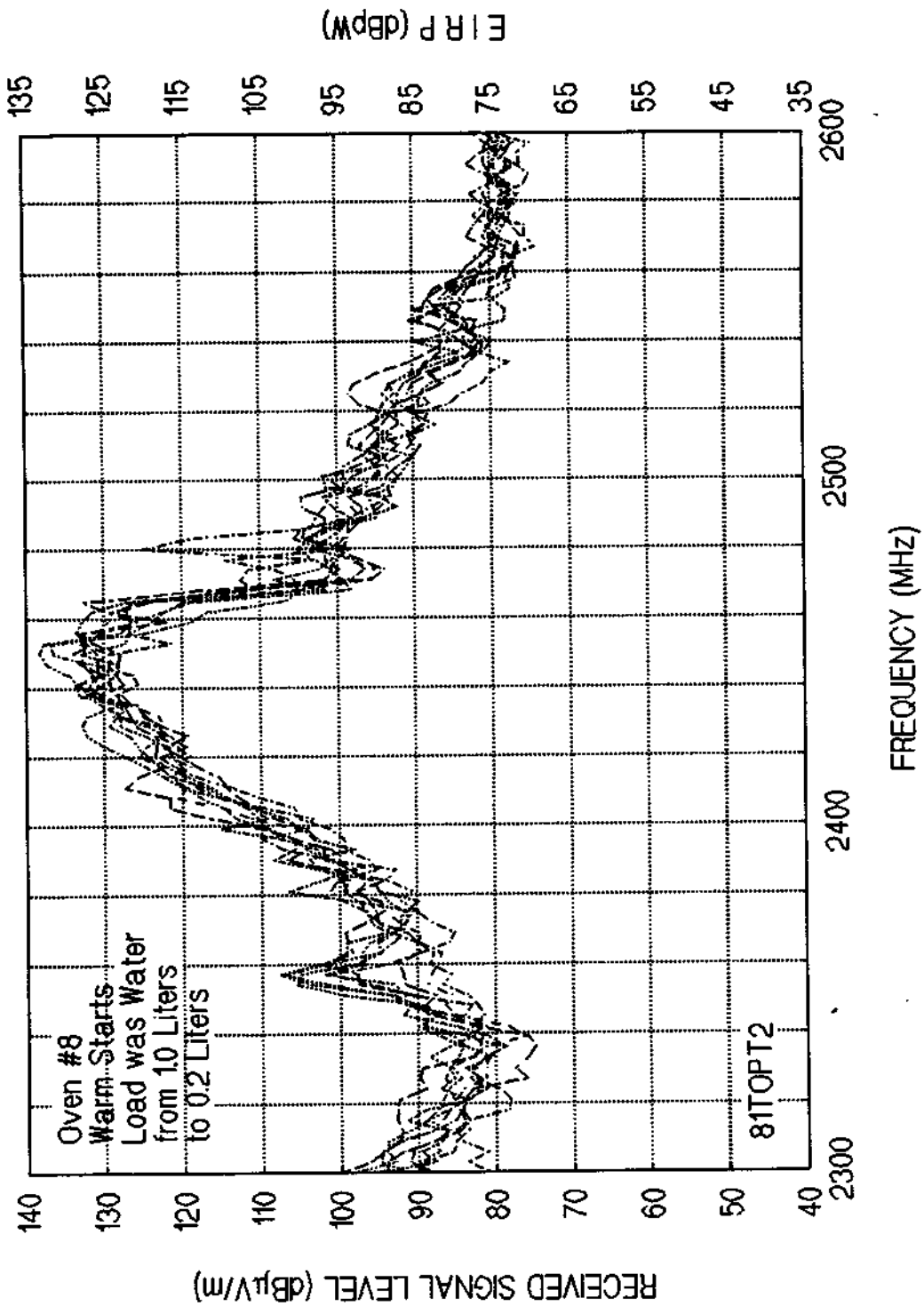


Figure 4-8. Oven #8 with varied water loads.

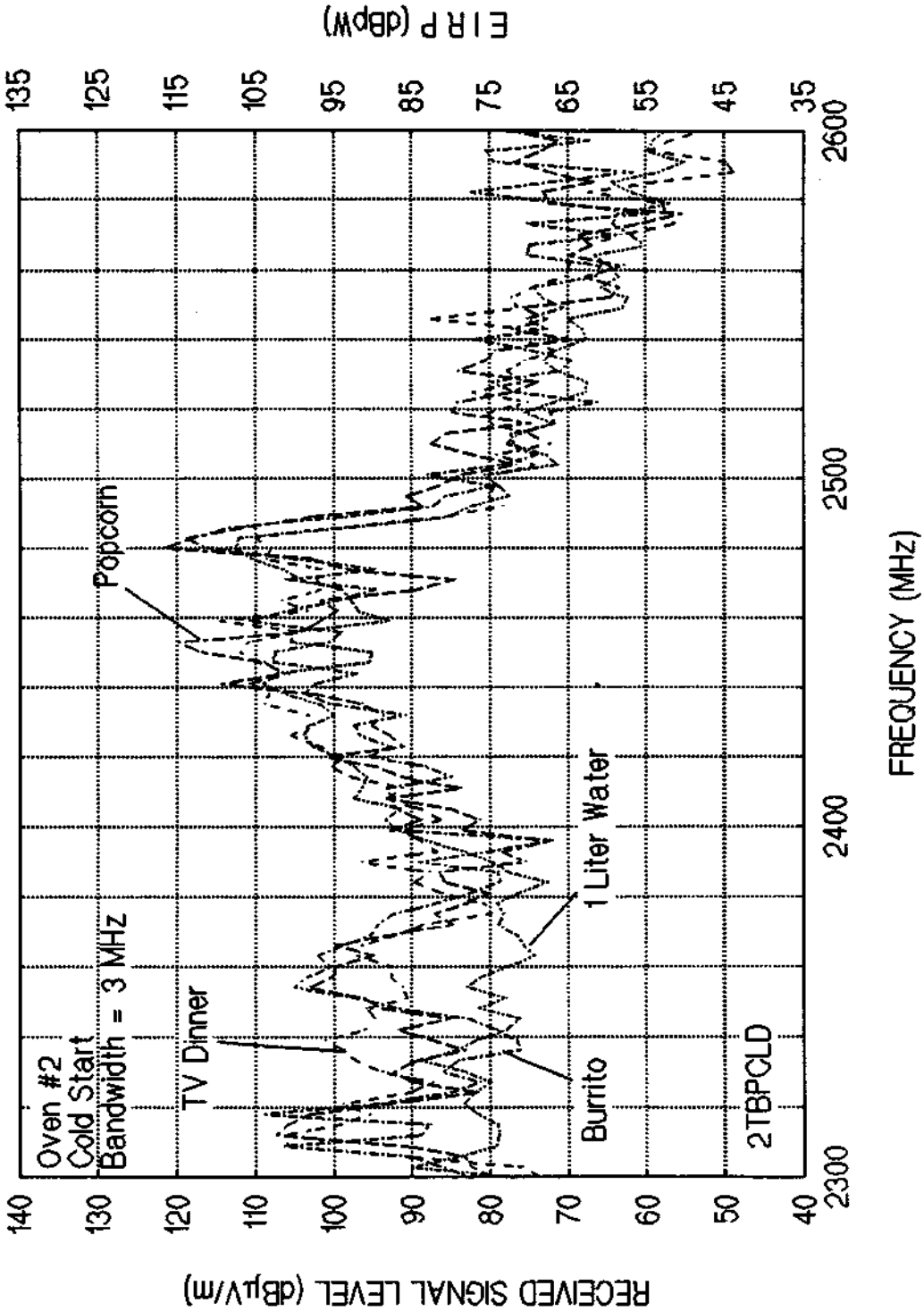


Figure 4-9. Oven #2 with varied consumer loads.

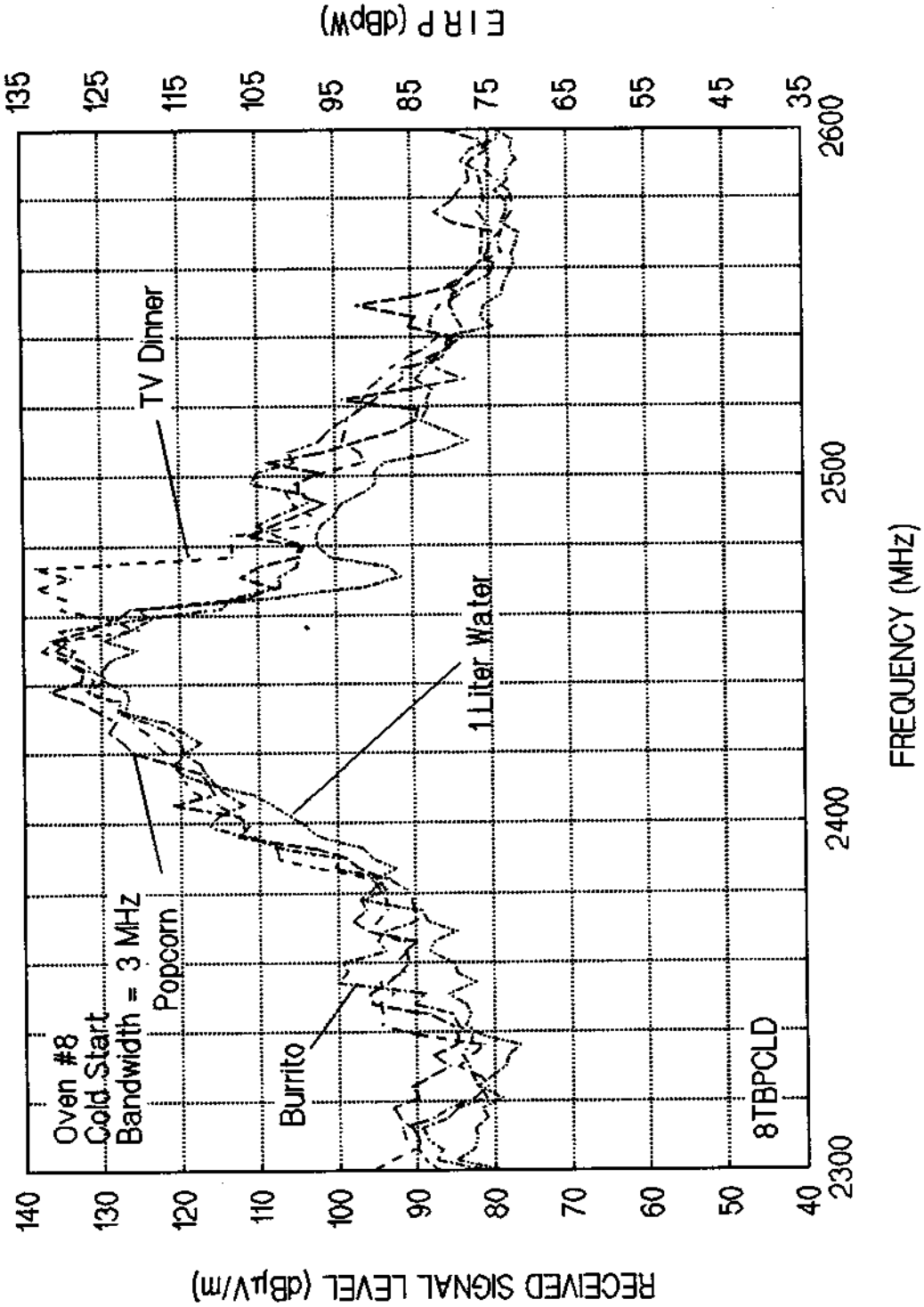


Figure 4-10. Oven #8 with varied consumer loads.

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.