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 7th. 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

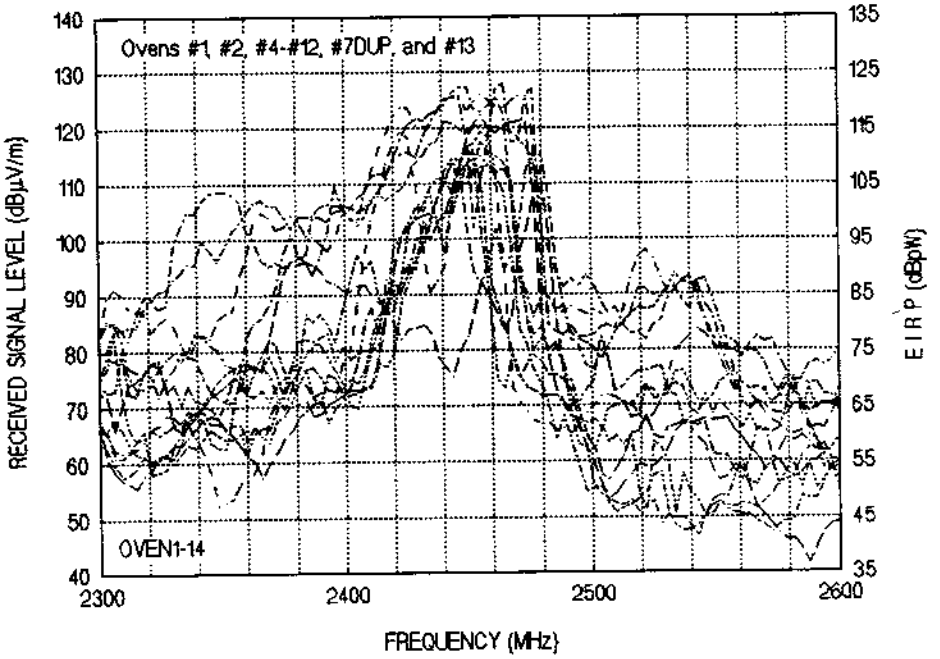

Figure 5-1a. Measurements of Ovens #1, #2, #4 through #12, #7DUP, and #13.

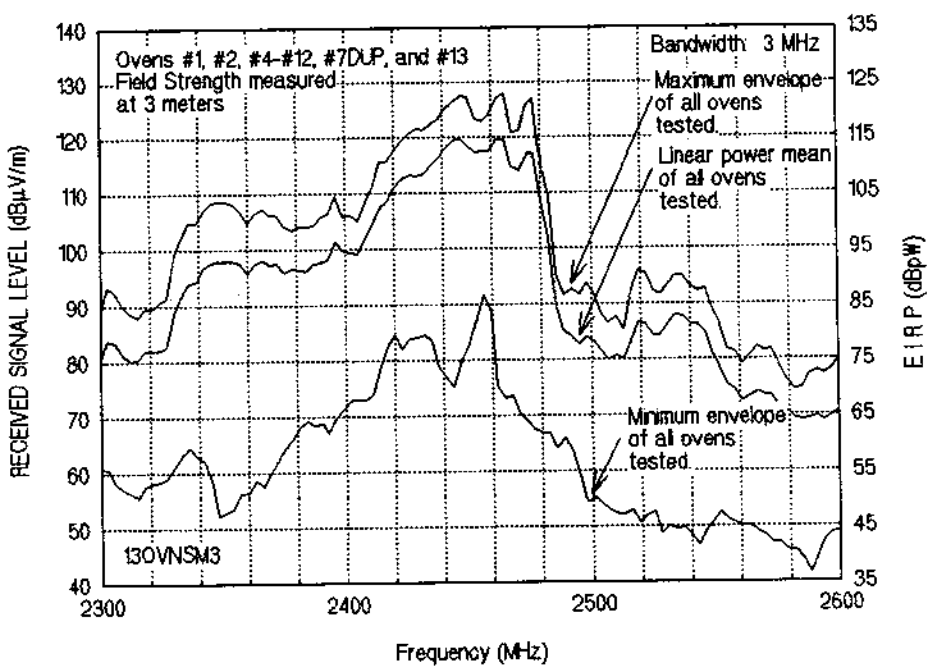

Figure 5-1b. A composite display of the results obtained for 13 ovens.

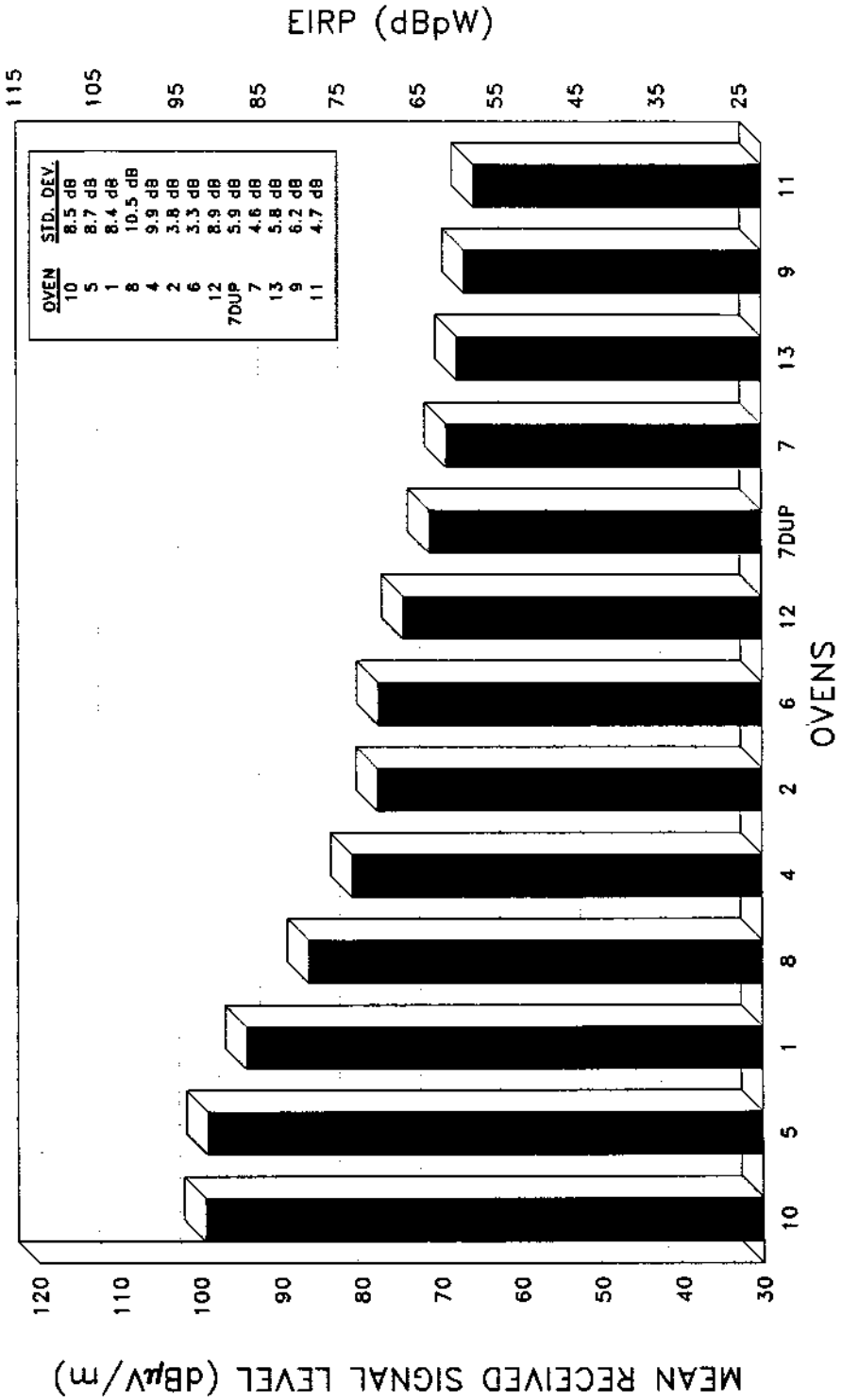

Figure 5-2. Mean signal level for each microwave oven in the lower adjacent band, 2300-2400 MHz.

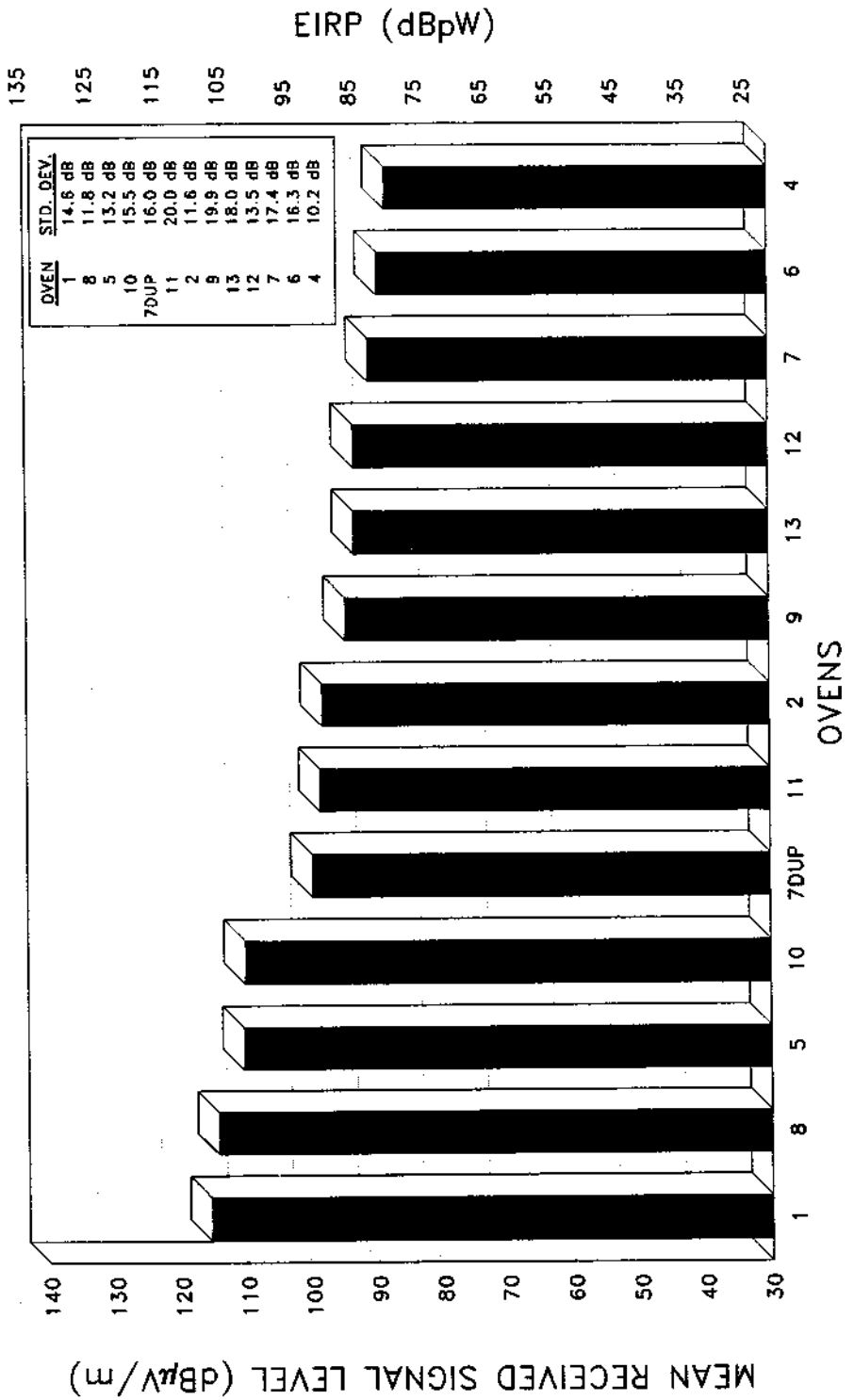

Figure 5-3. Mean signal level for each microwave oven in the assigned operating band, 2400-2500 MHz.

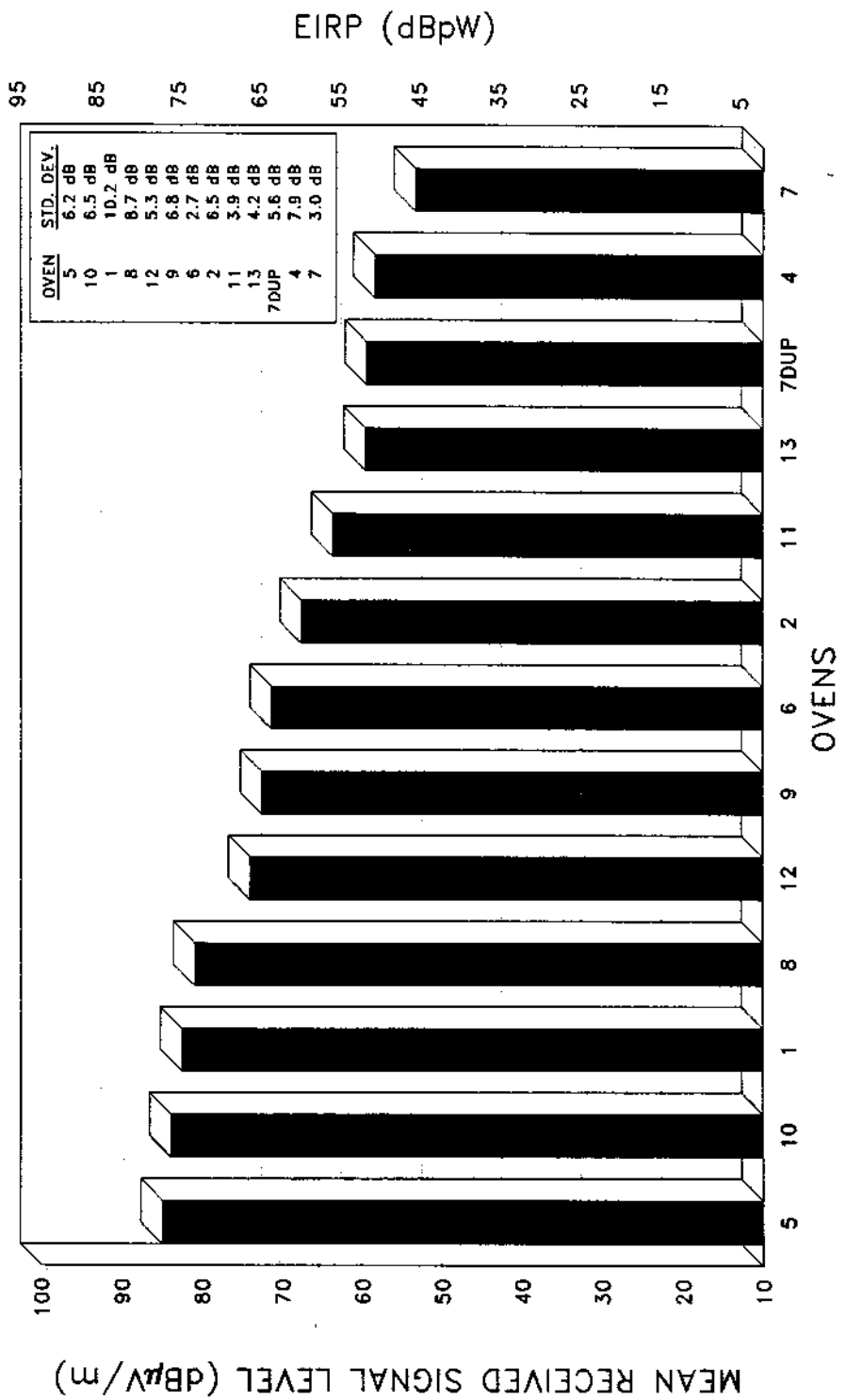

Figure 5-4. Mean signal level for each microwave oven in the upper adjacent band, 2500-2600 MHz.

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

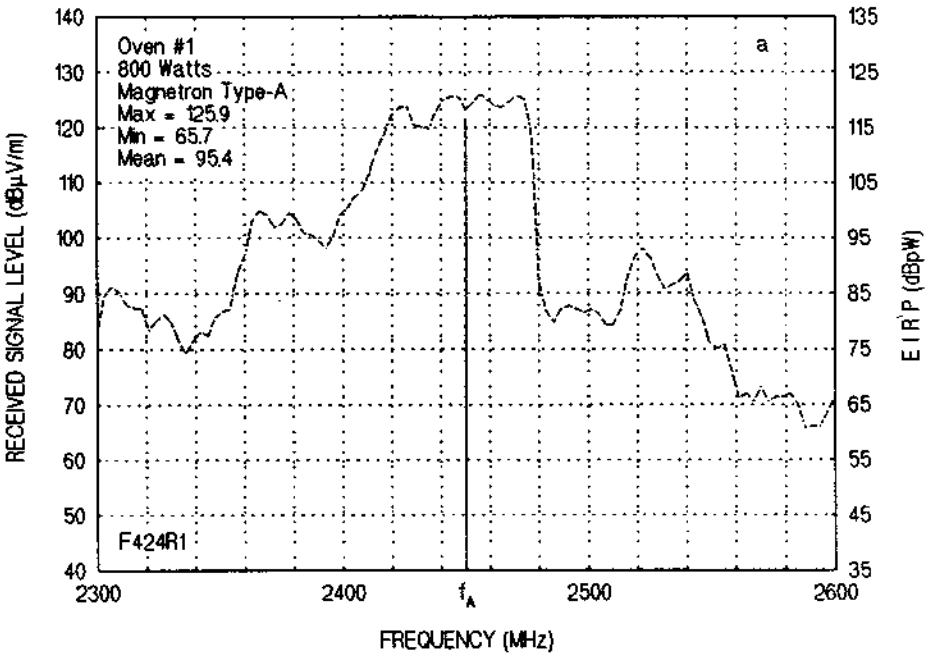

Figure 5-5a. Oven #1, Frequency vs. Amplitude.

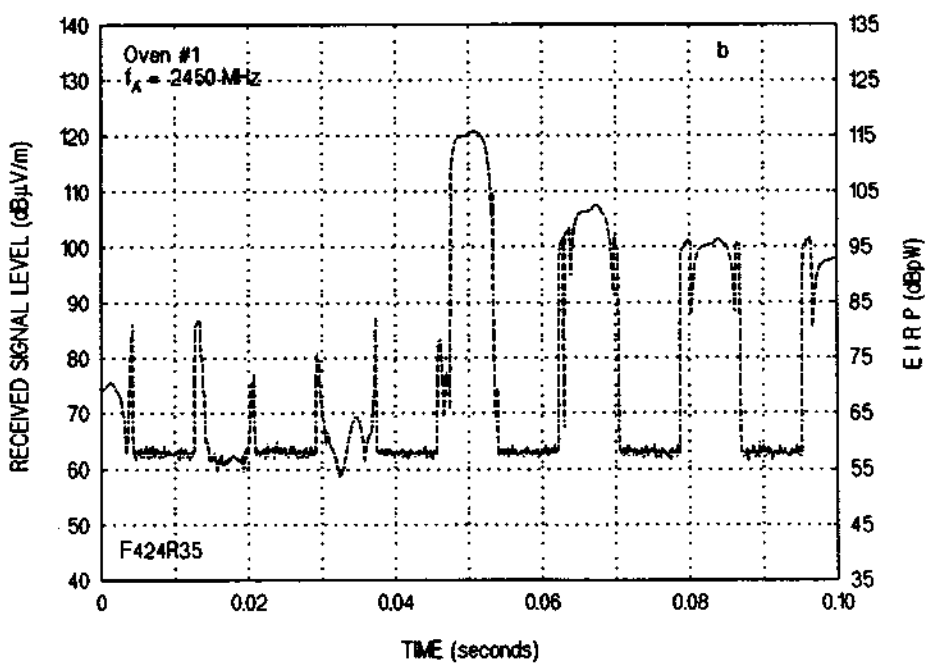

Figure 5-5b. Oven #1, Time vs. Amplitude at 2450 MHz.

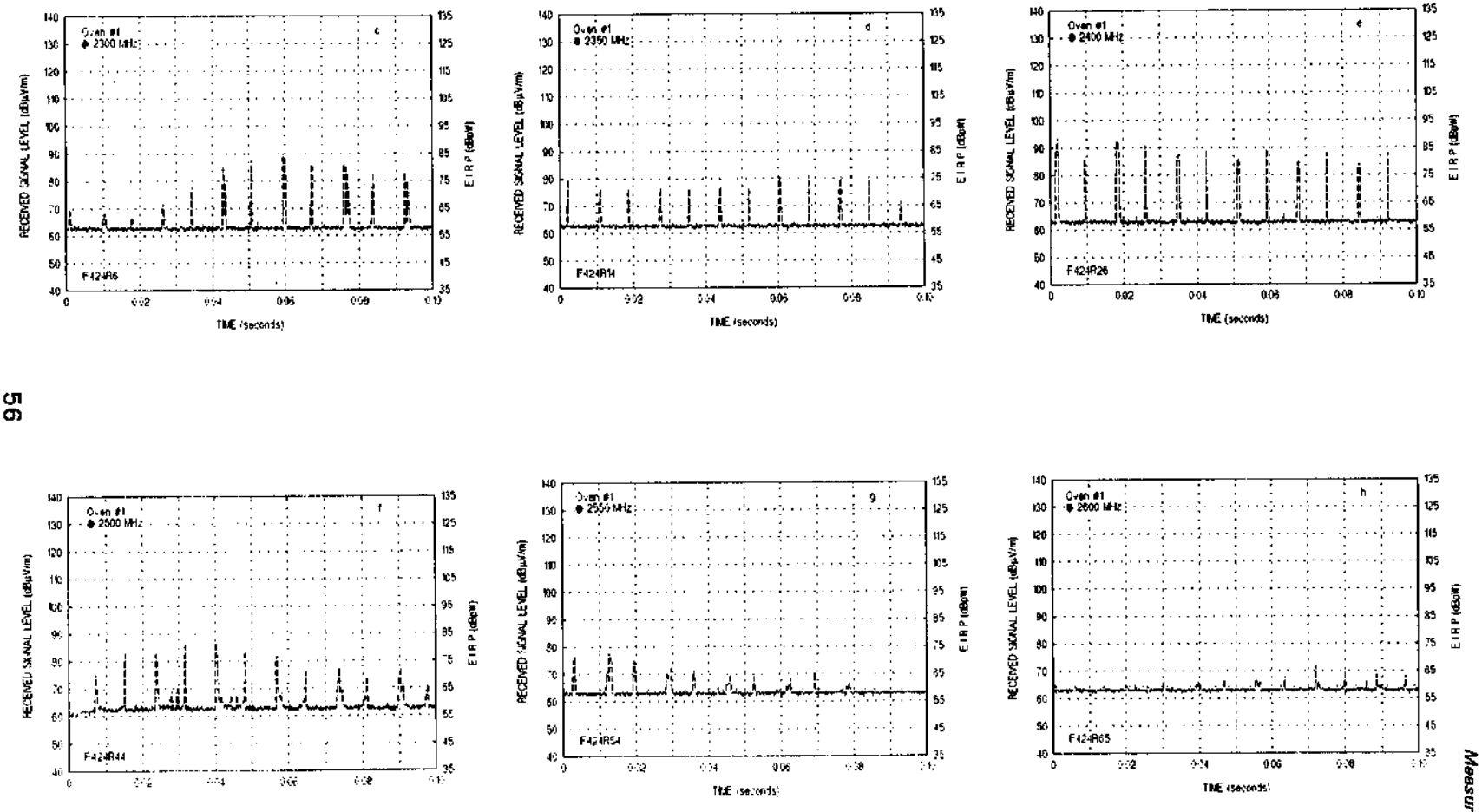

Figure 5-5c through 5-5h. Oven #1, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

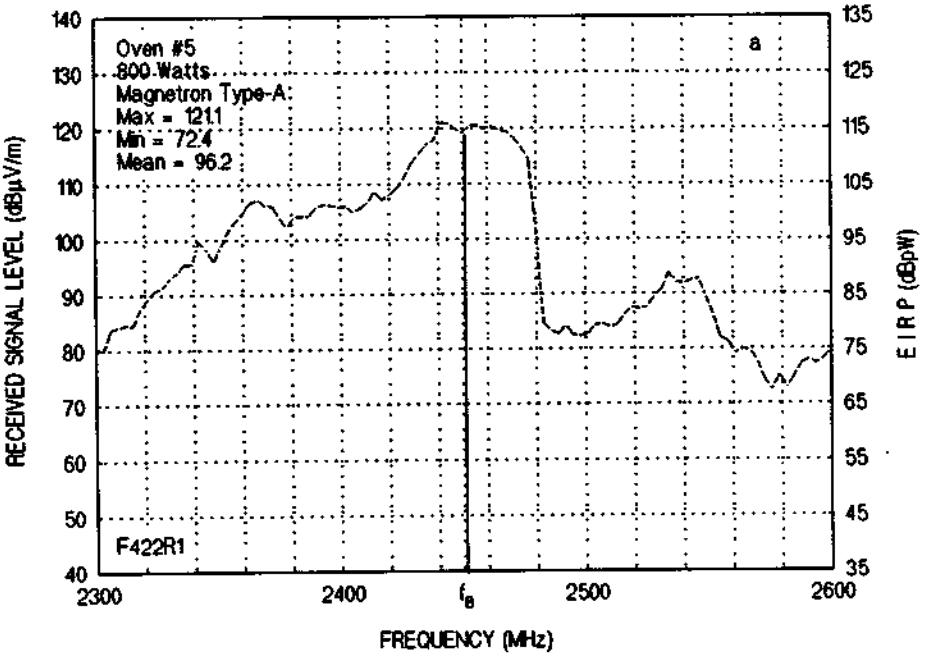

Figure 5-6a. Oven #5, Frequency vs. Amplitude.

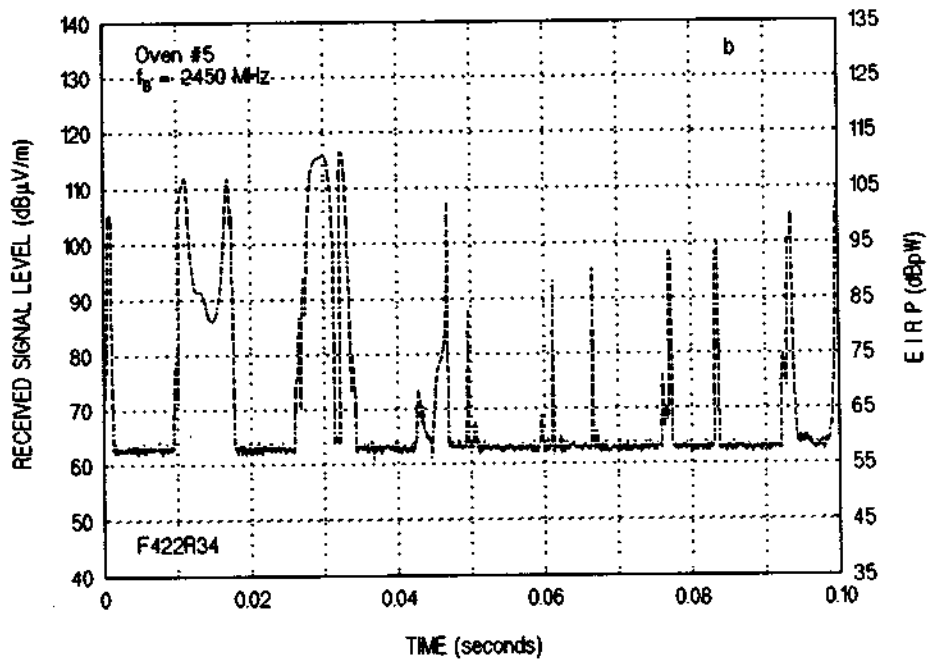

Figure 5-6b. Oven #5, Time vs. Amplitude at 2450 MHz.

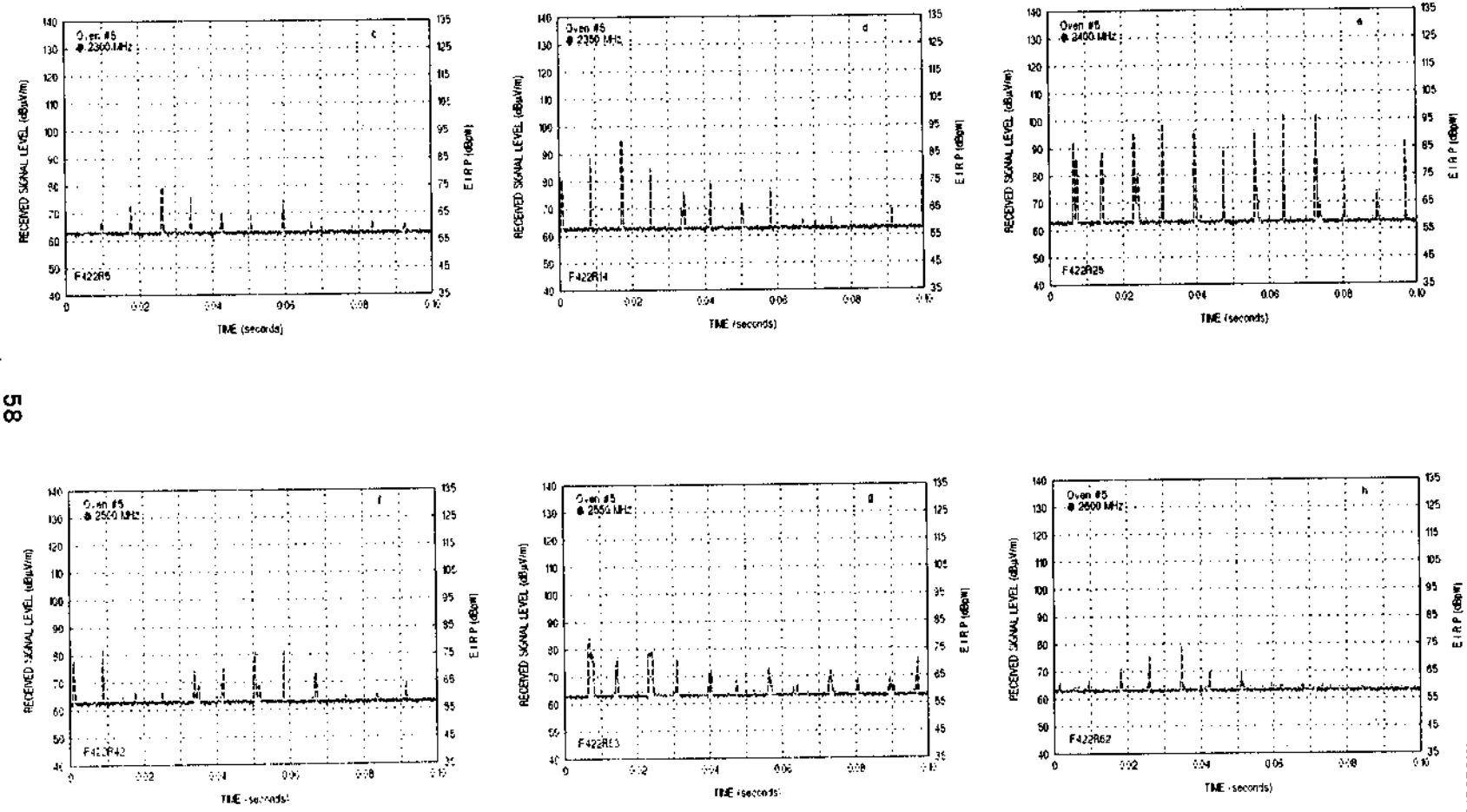

Figure 5-6c through 5-6h. Oven #5, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

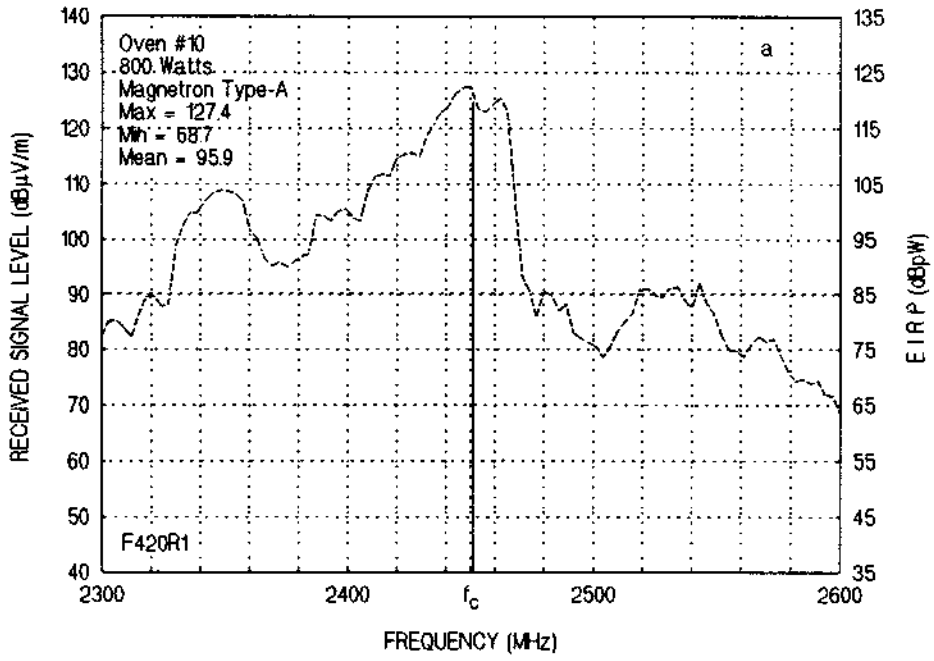

Figure 5-7a. Oven #10, Frequency vs. Amplitude.

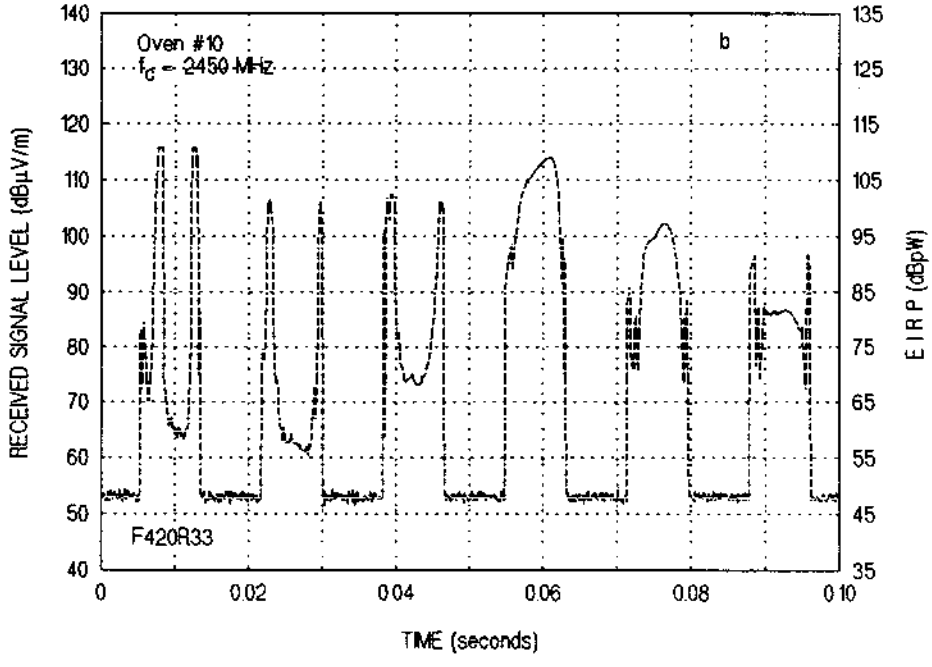

Figure 5-7b. Oven #10, Time vs. Amplitude at 2450 MHz.

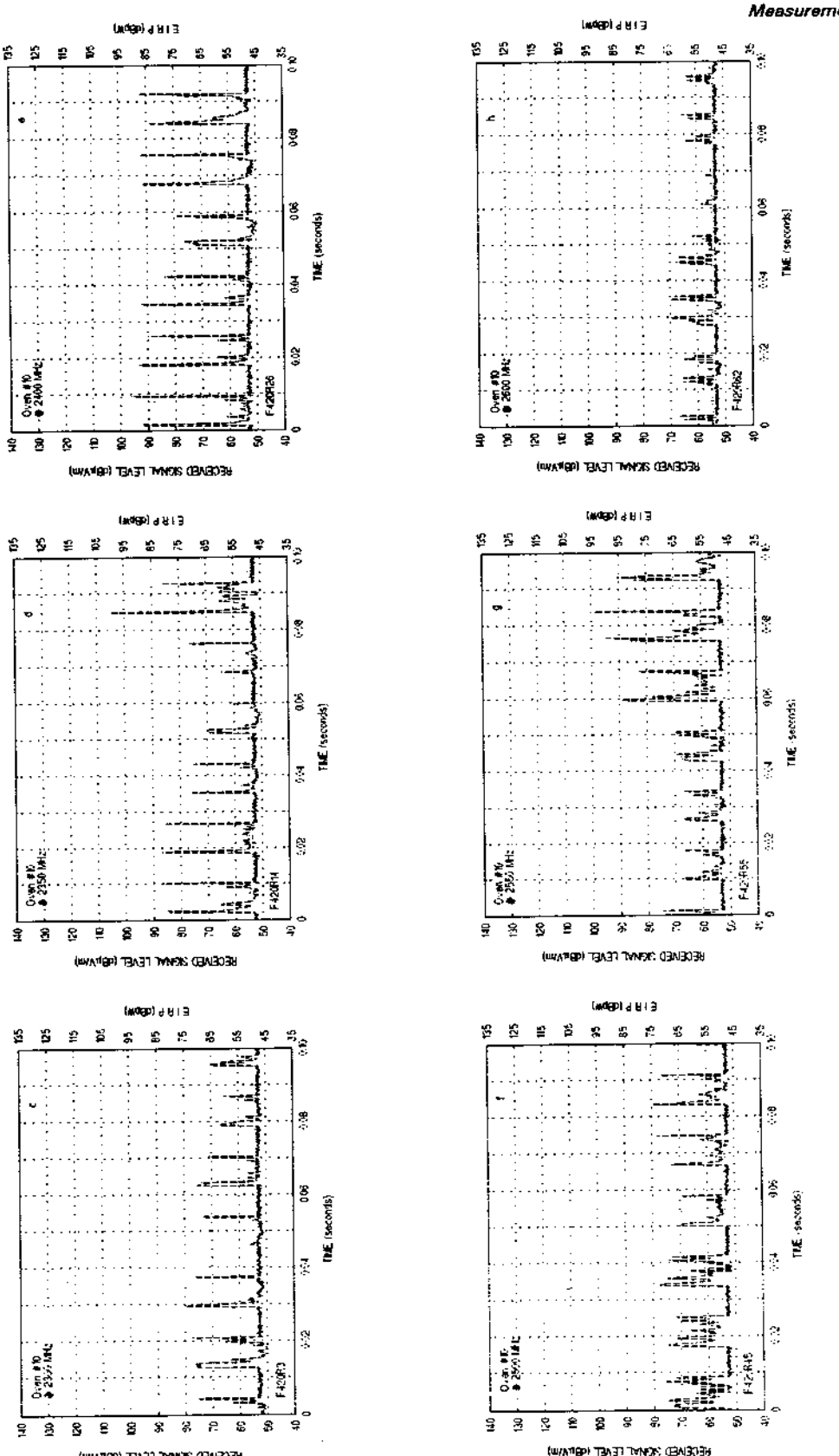

Figure 5-7c through 5-7h. Oven #10, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

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

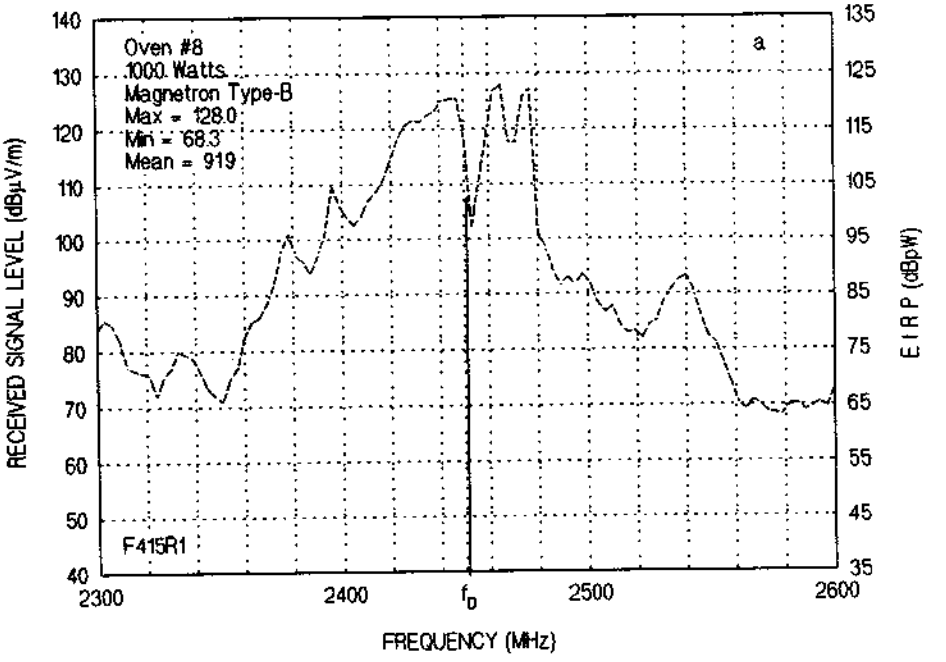

Figure 5-8a. Oven #8, Frequency vs. Amplitude.

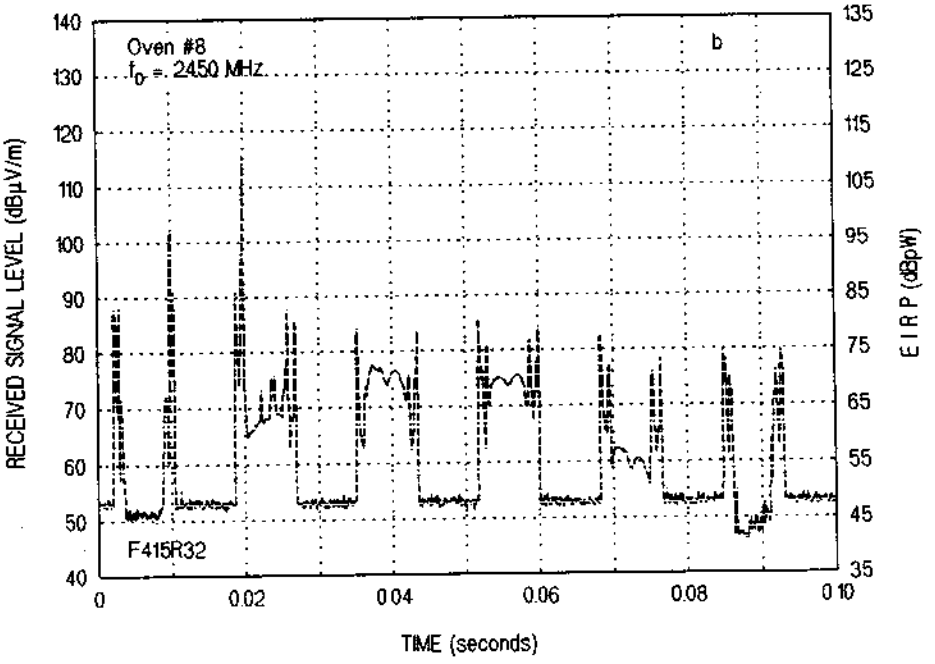

Figure 5-8b. Oven #8, Time vs. Amplitude at 2450 MHz.

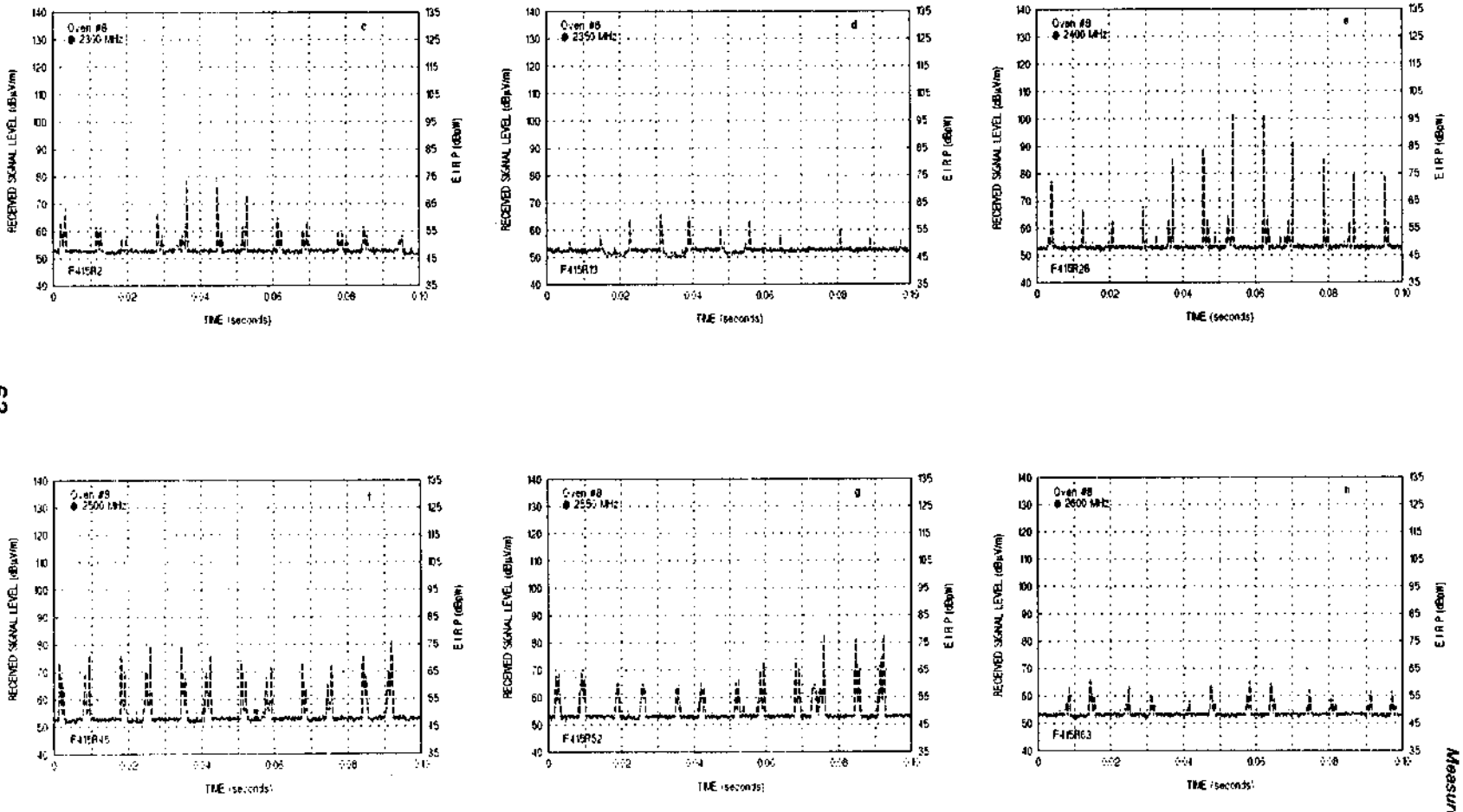

Figure 5-8c through 5-8h. Oven #8, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

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

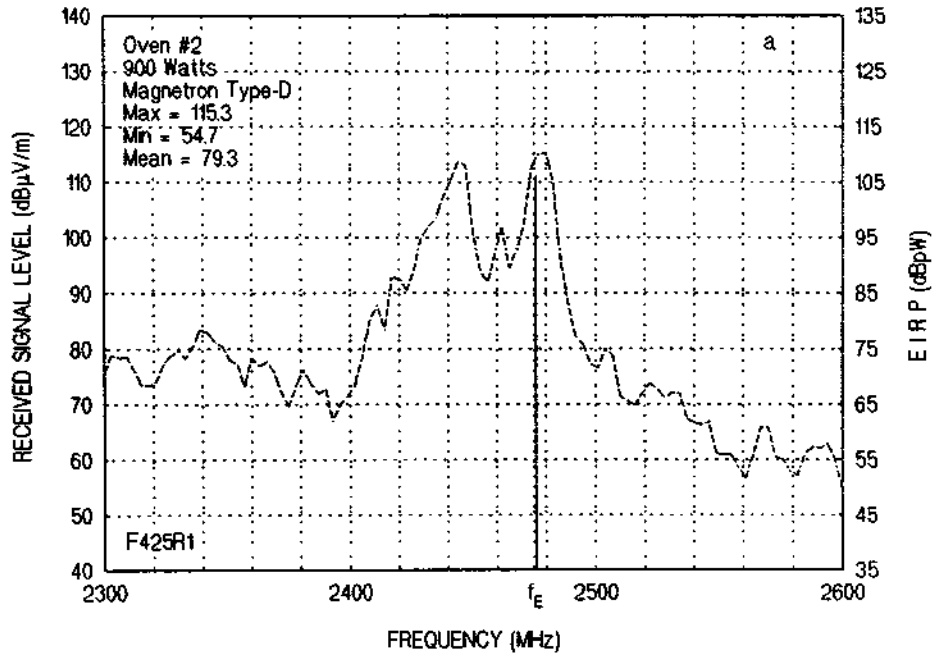

Figure 5-9a. Oven #2, Frequency vs. Amplitude.

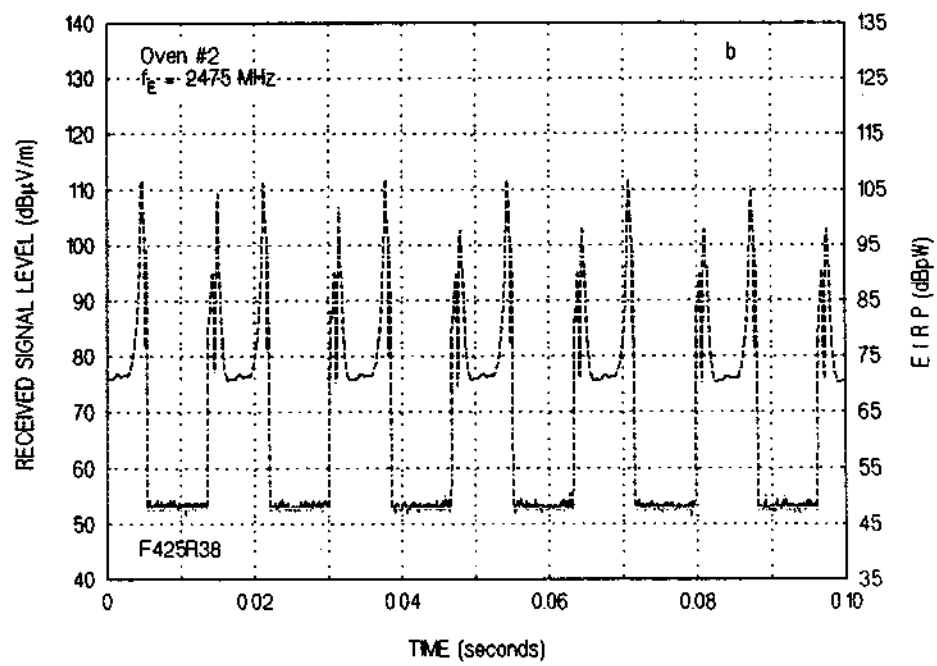

Figure 5-9b. Oven #2, Time vs. Amplitude at 2475 MHz.

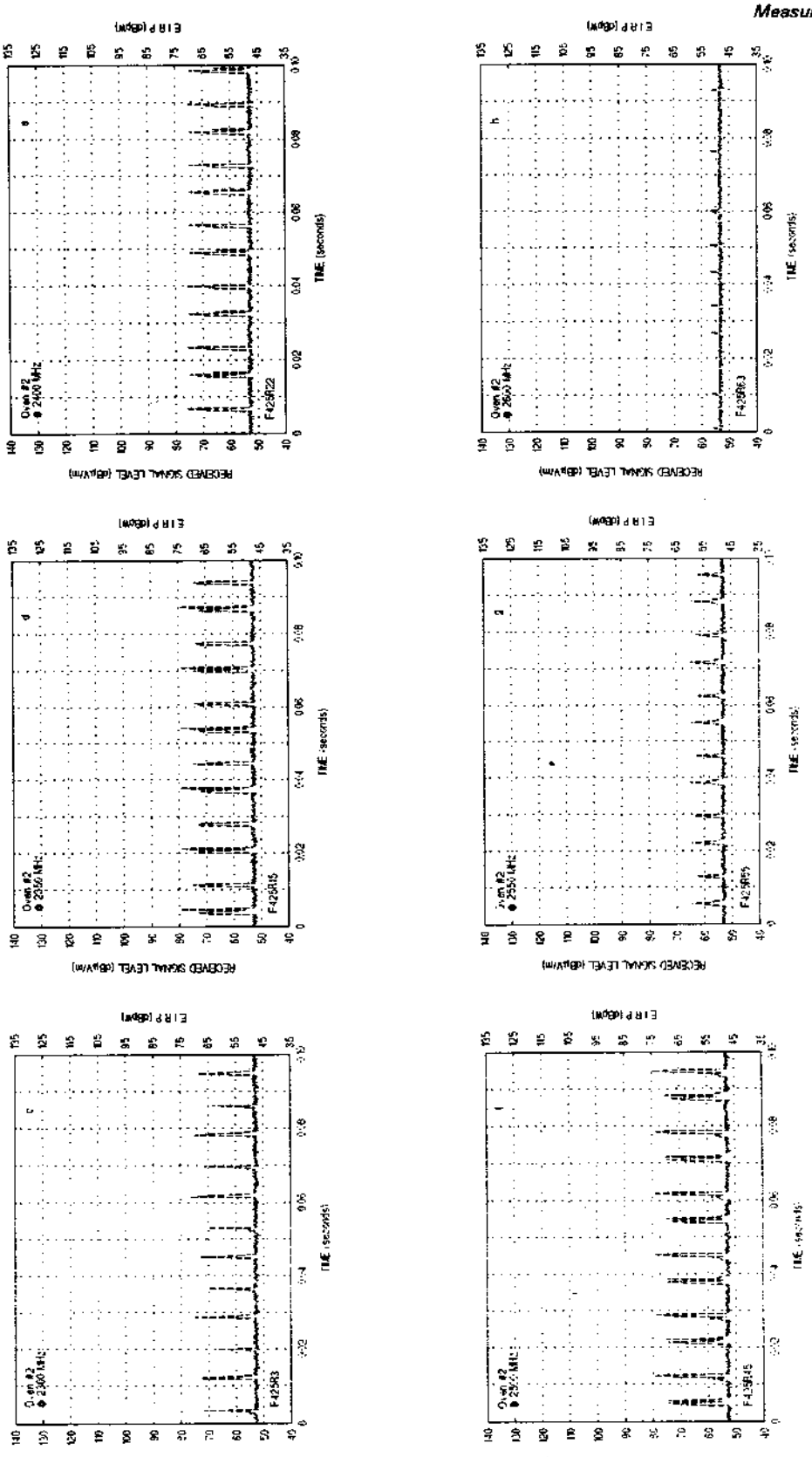

Figure 5-9c through 5-9h. Oven #2, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

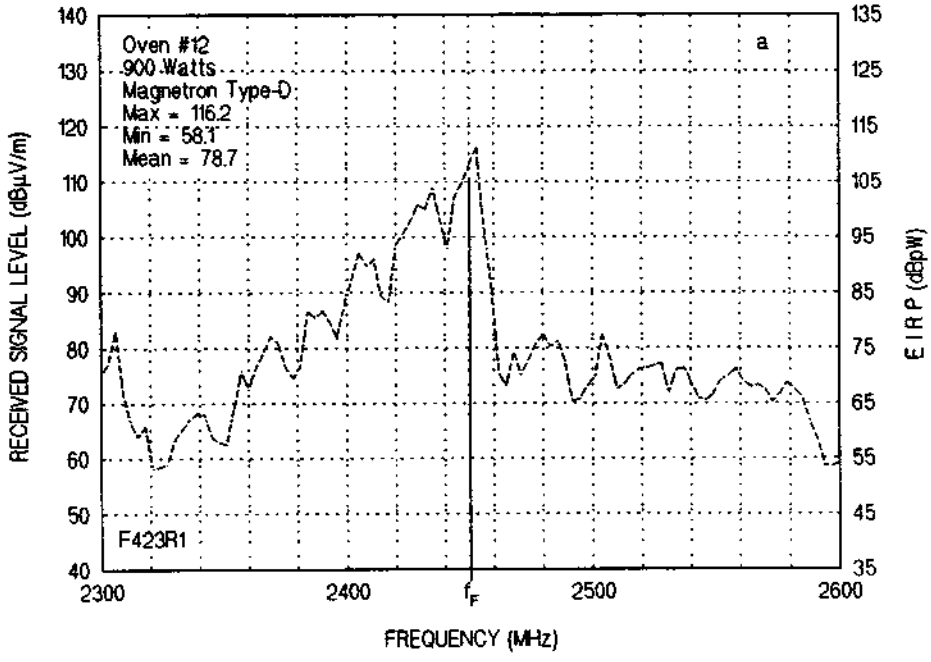

Figure 5-10a. Oven #12, Frequency vs. Amplitude.

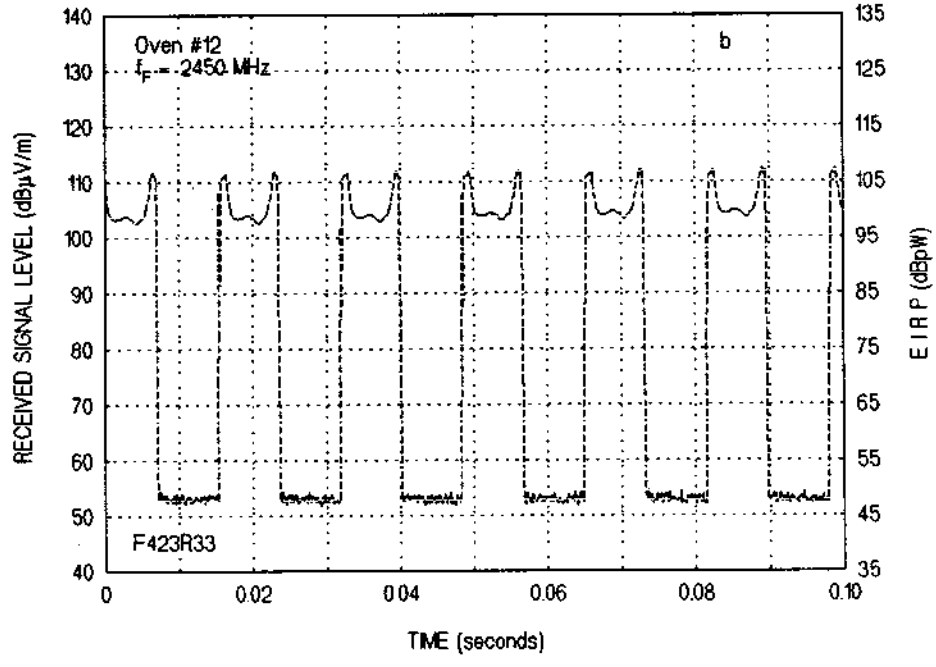

Figure 5-10b. Oven #12, Time vs. Amplitude at 2450 MHz.

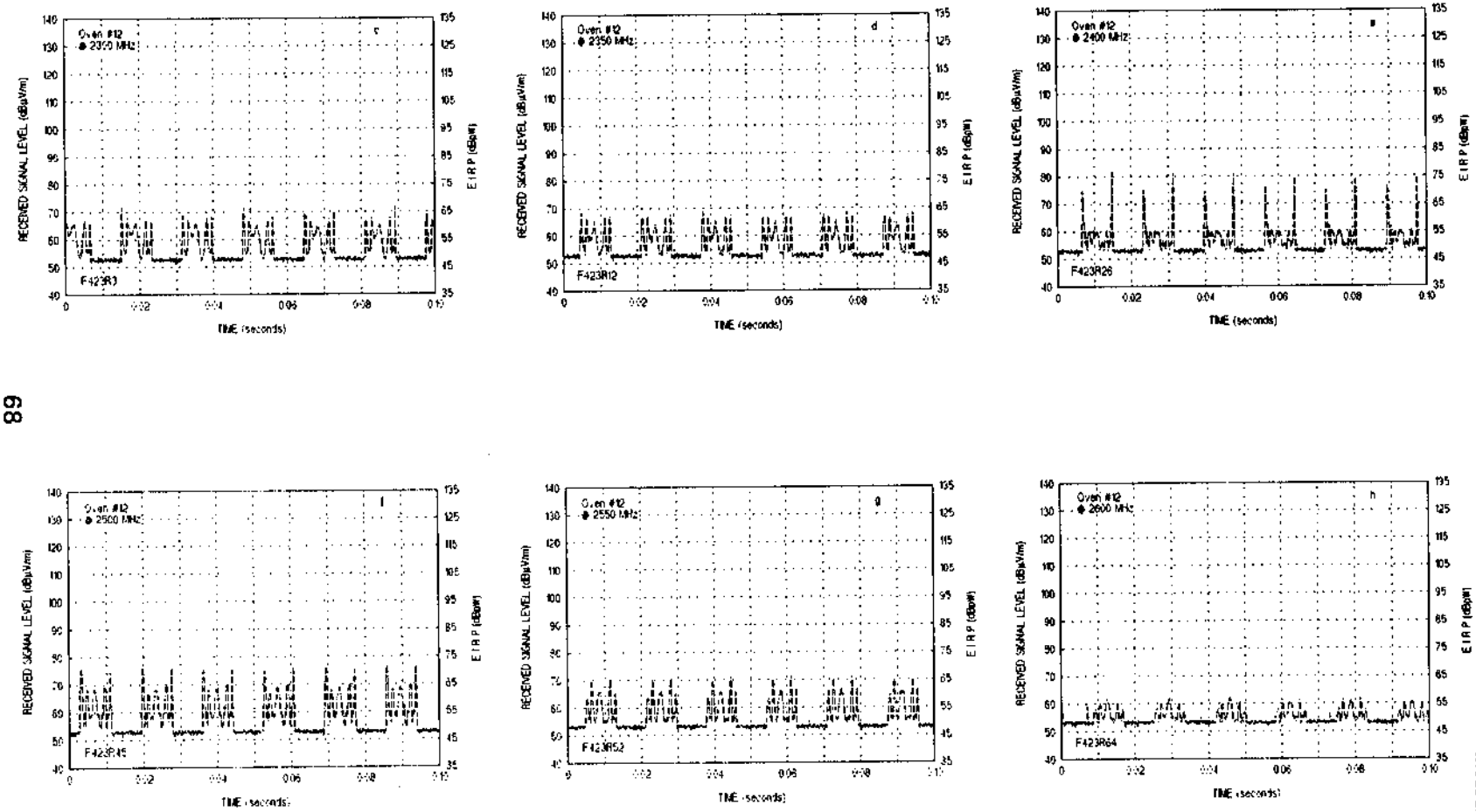

Figure 5-10c through 5-10h. Oven #12, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

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

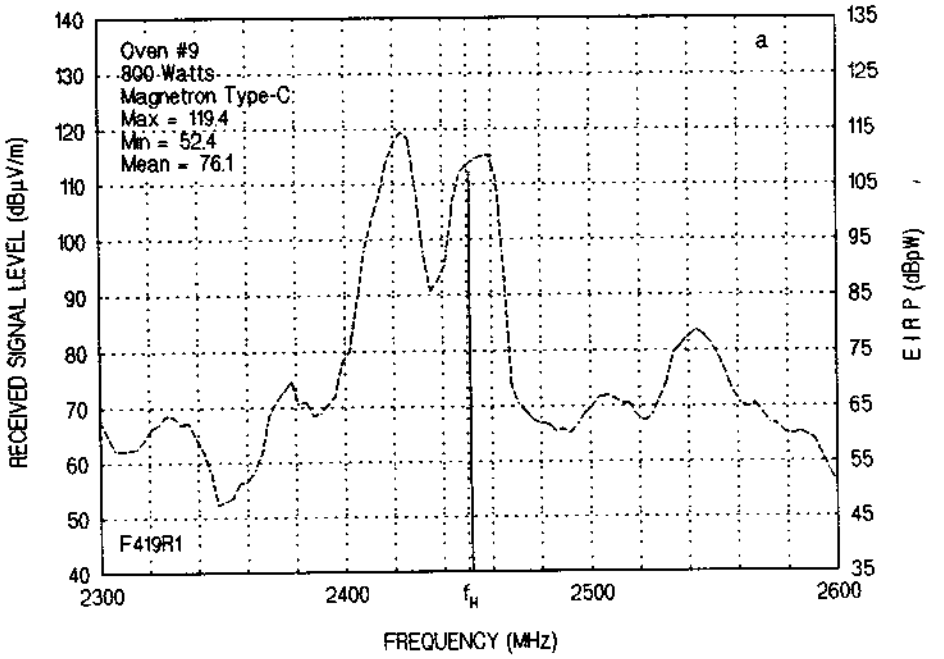

Figure 5-11a. Oven #9, Frequency vs. Amplitude.

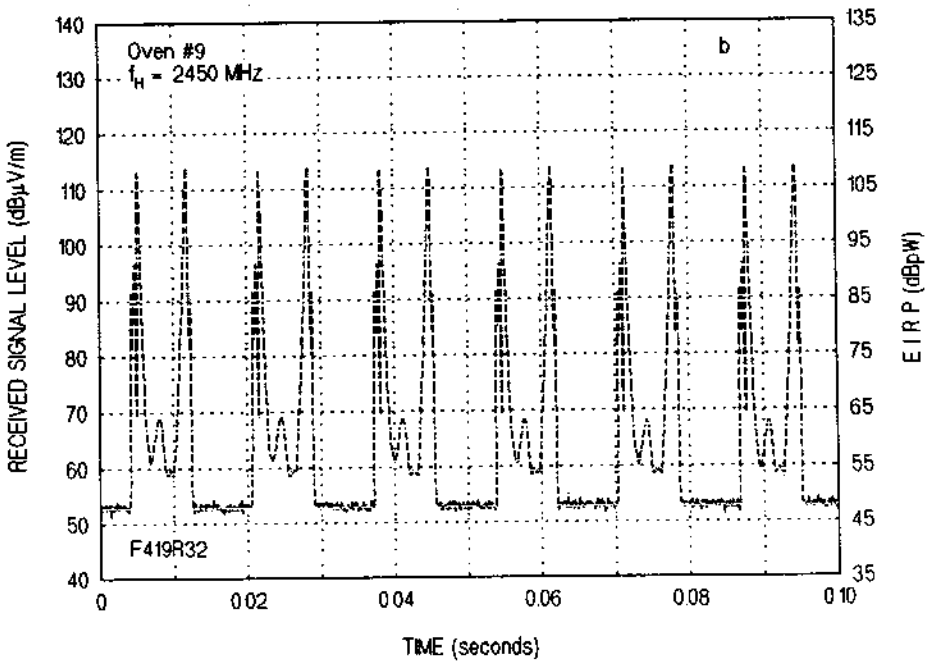

Figure 5-11b. Oven #9, Time vs. Amplitude at 2450 MHz.

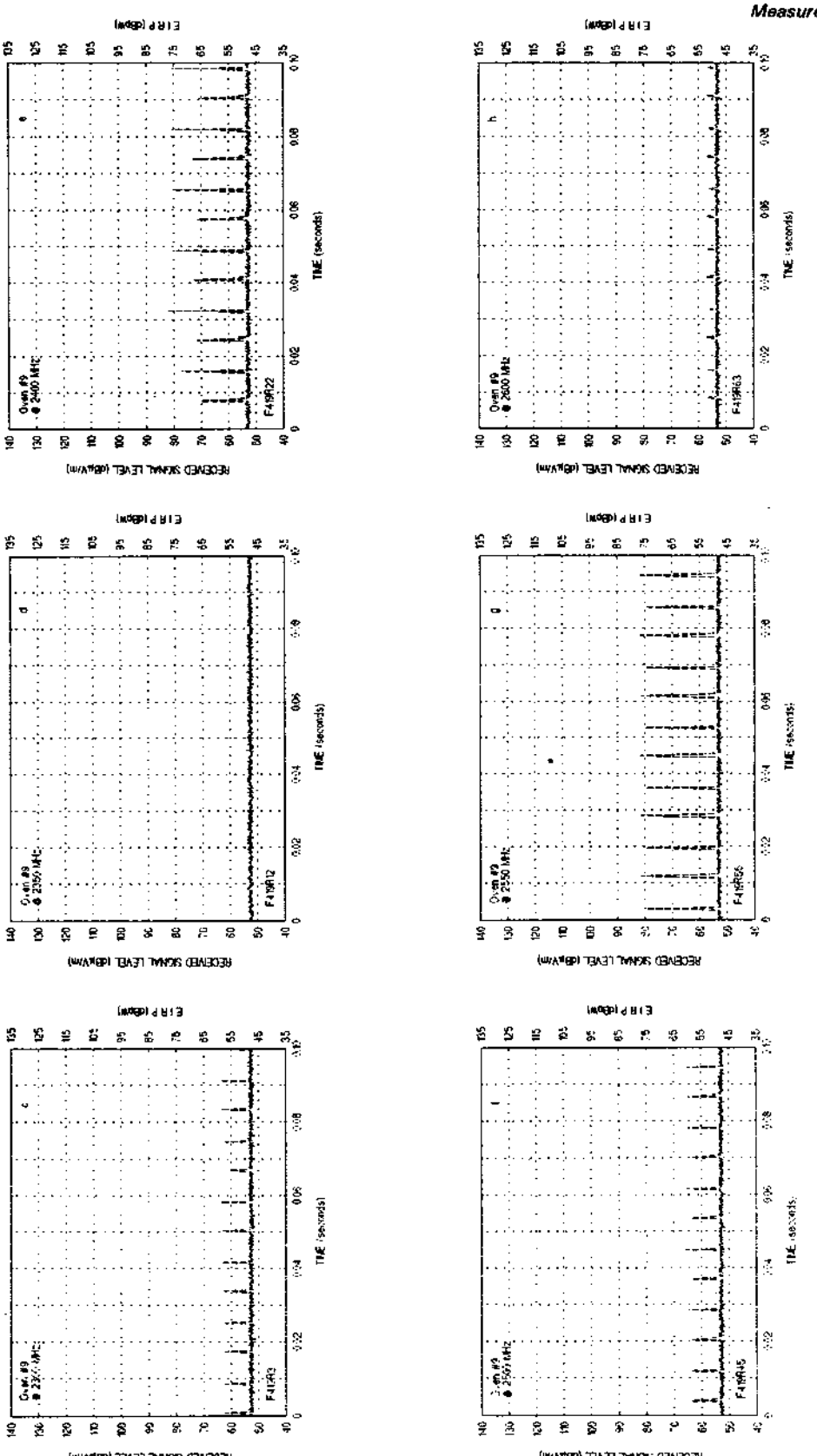

Figure 5-11c through 5-11h. Oven #9, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

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

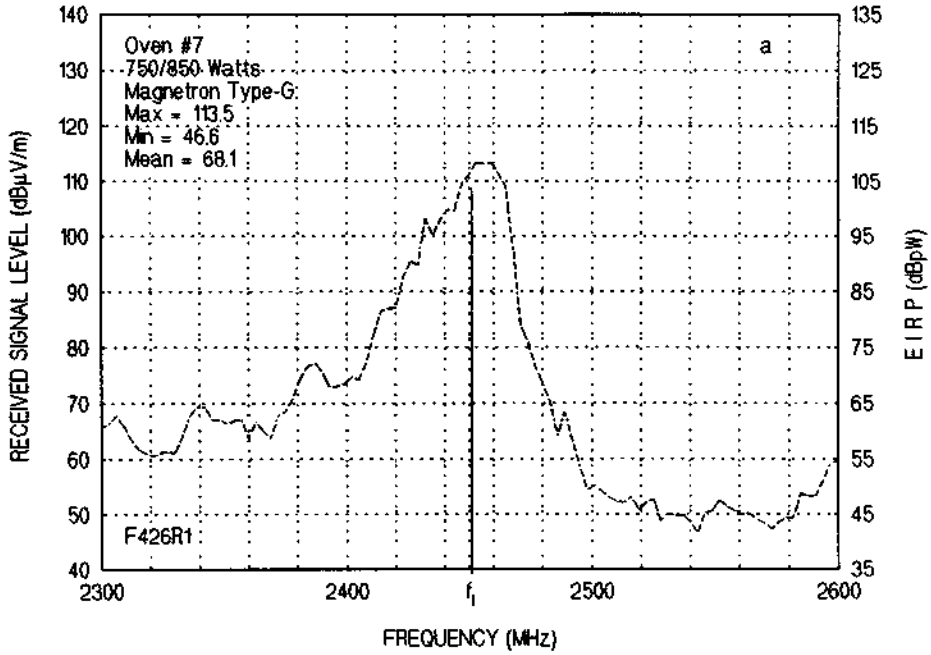

Figure 5-12a. Oven #7, Frequency vs. Amplitude.

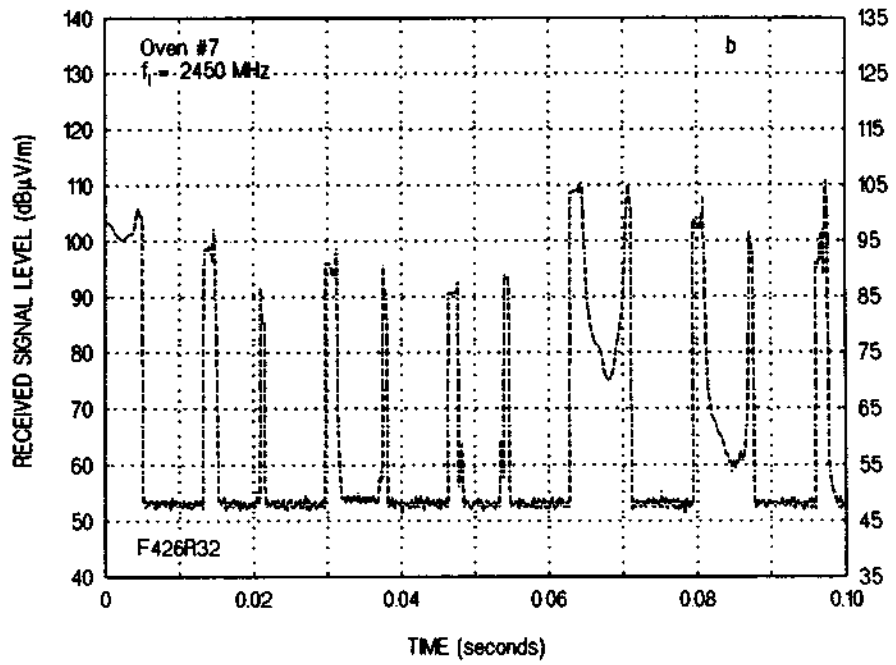

Figure 5-12b. Oven #7, Time vs. Amplitude at 2450 MHz.

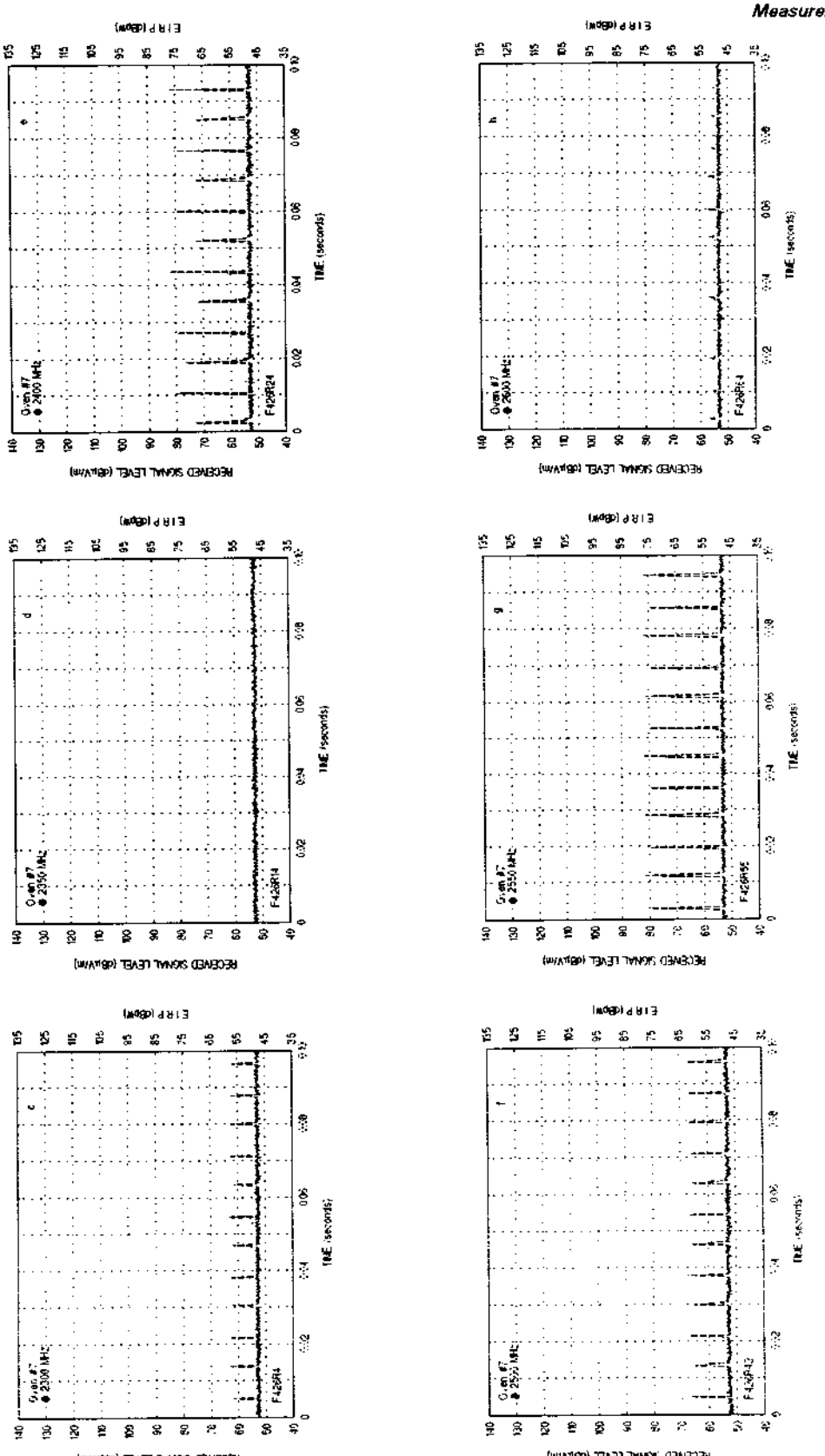

Figure 5-12c through 5-12h. Oven #7, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

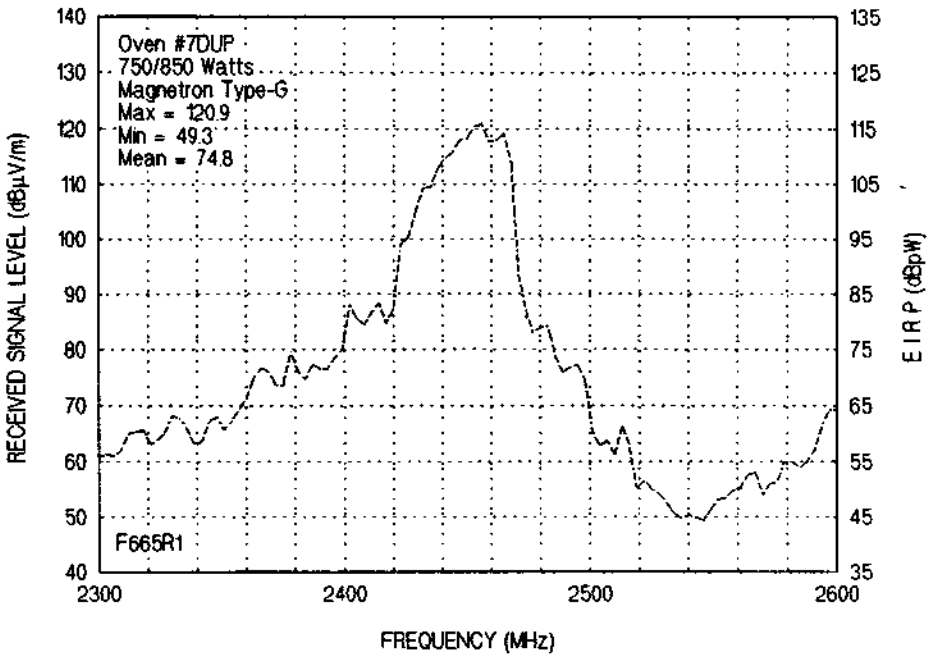

Figure 5-13. Oven #7DUP, Frequency vs. Amplitude.

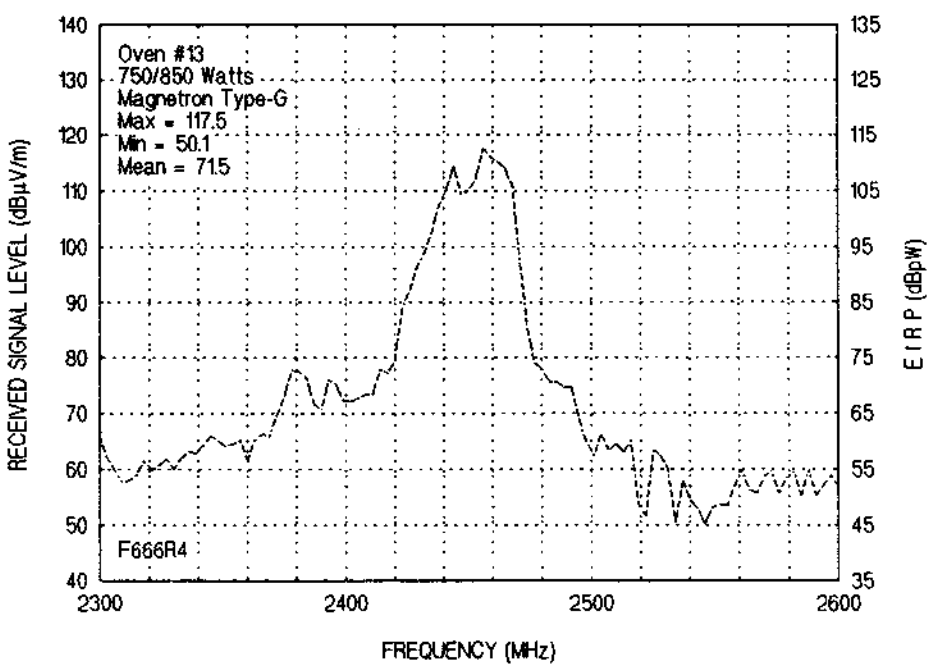

Figure 5-14. Oven #13, Frequency vs. Amplitude.

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

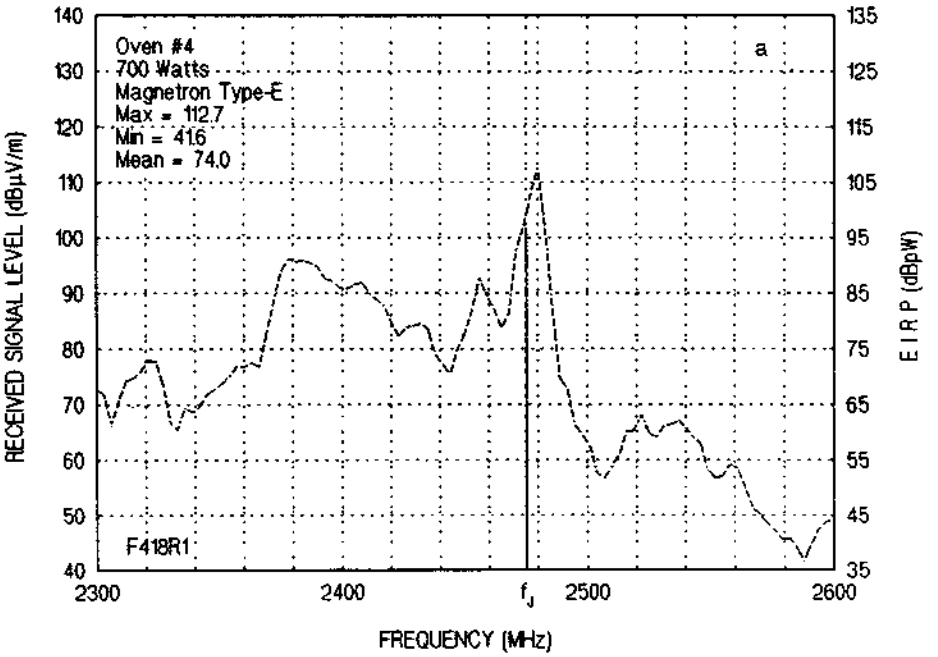

Figure 5-15a. Oven #4, Frequency vs. Amplitude.

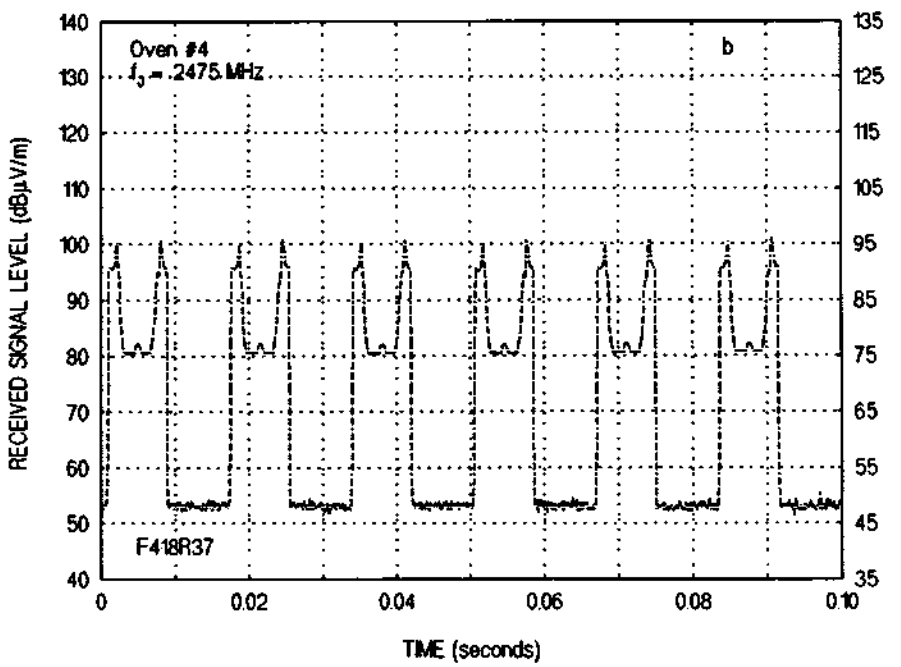

Figure 5-15b. Oven #4, Time vs. Amplitude at 2475 MHz.

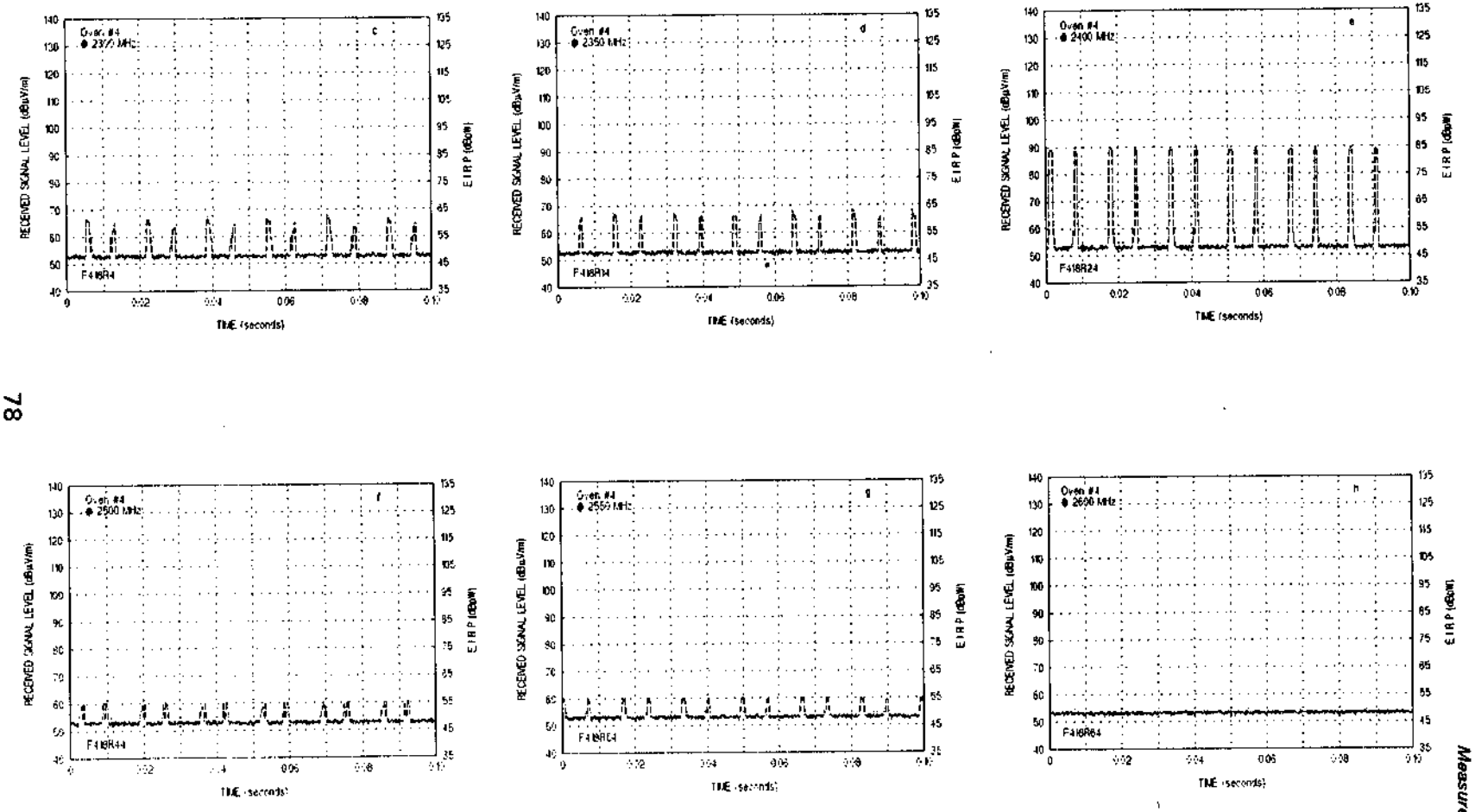

Figure 5-15c through 5-15h. Oven #4, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

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

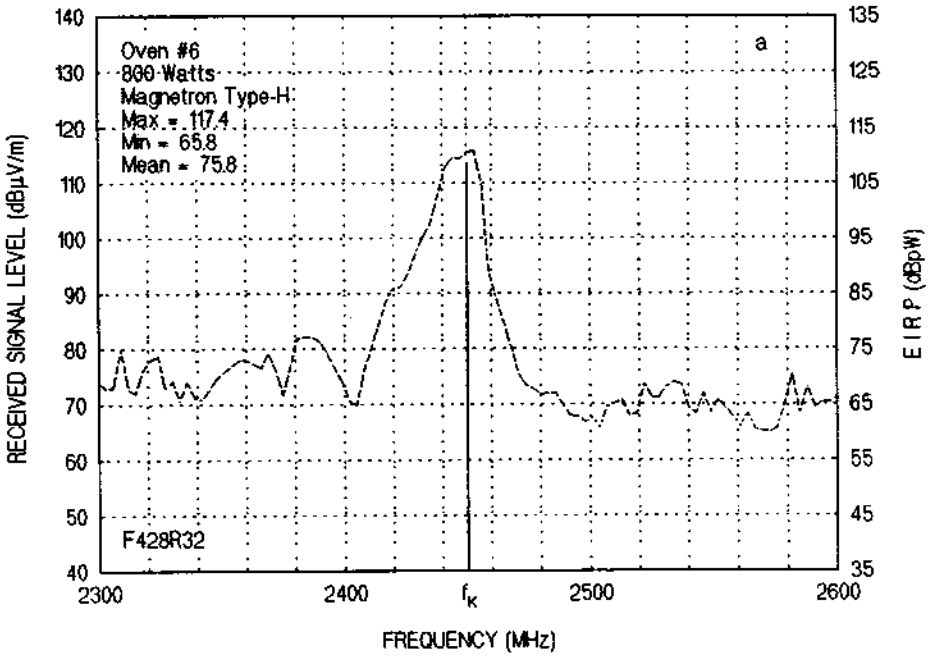

Figure 5-16a. Oven #6, Frequency vs. Amplitude.

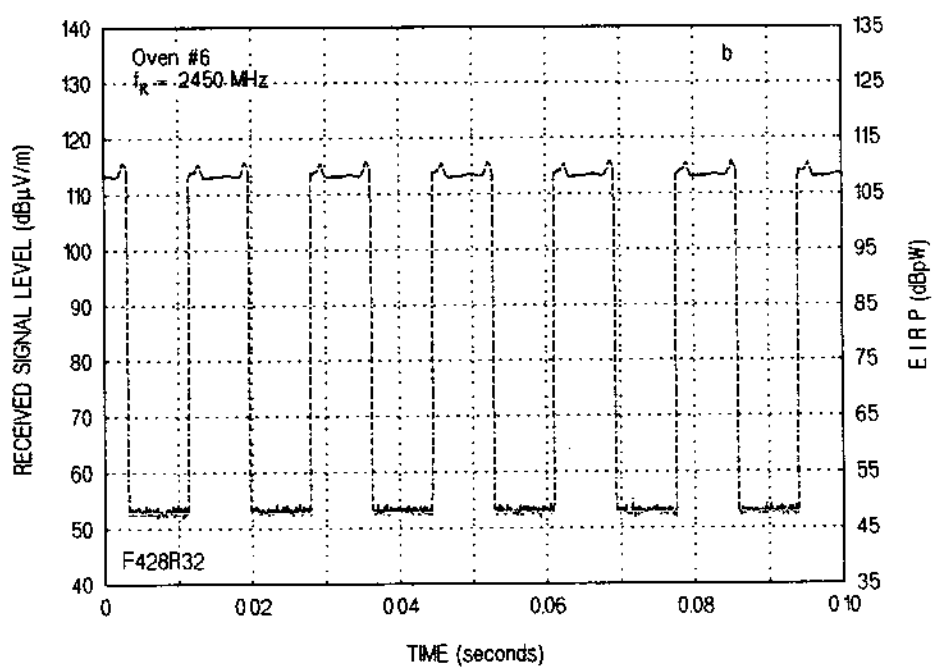

Figure 5-16b. Oven #6, Time vs. Amplitude at 2450 MHz.

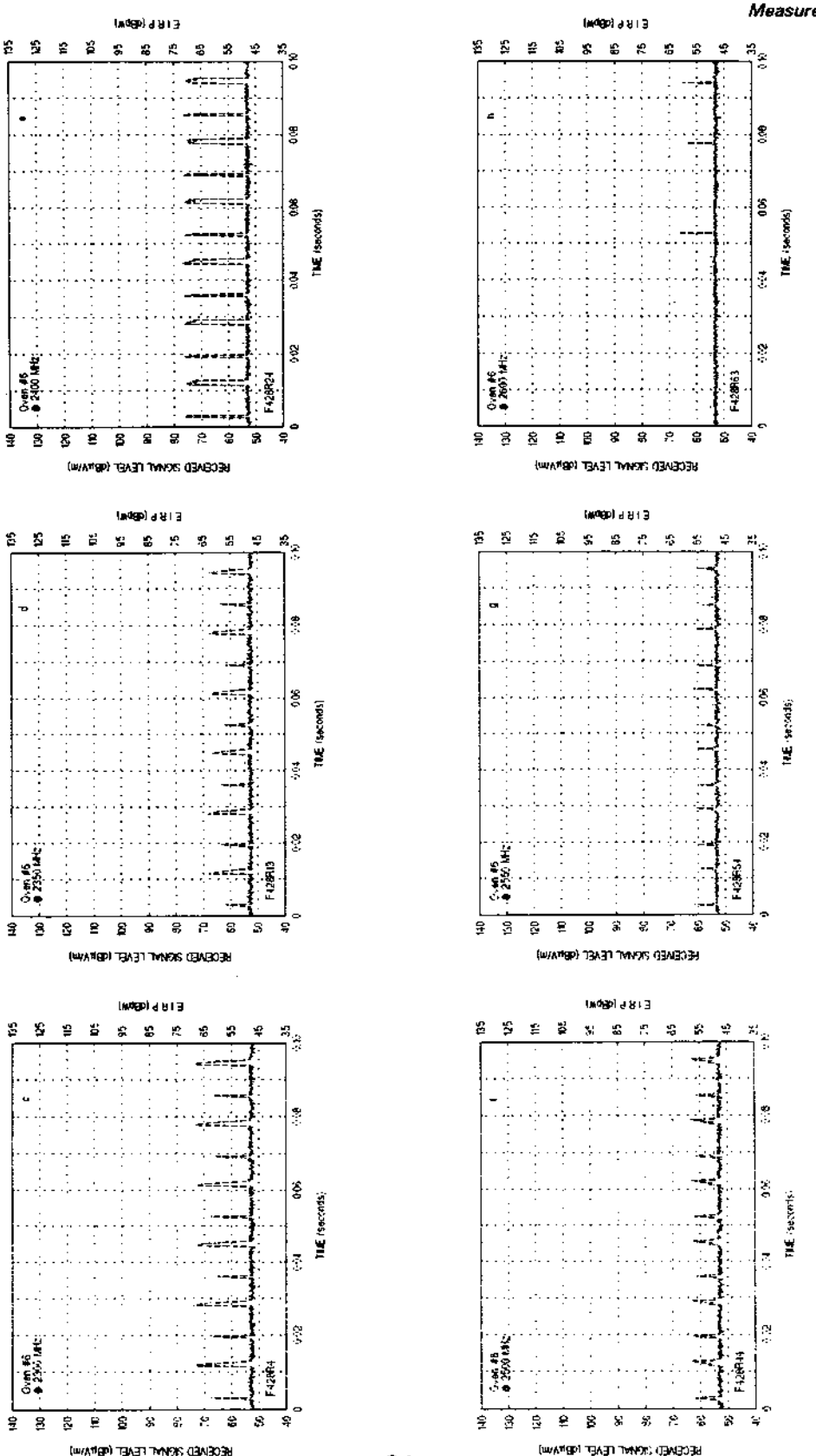

Figure 5-16c through 5-16h. Oven #6, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

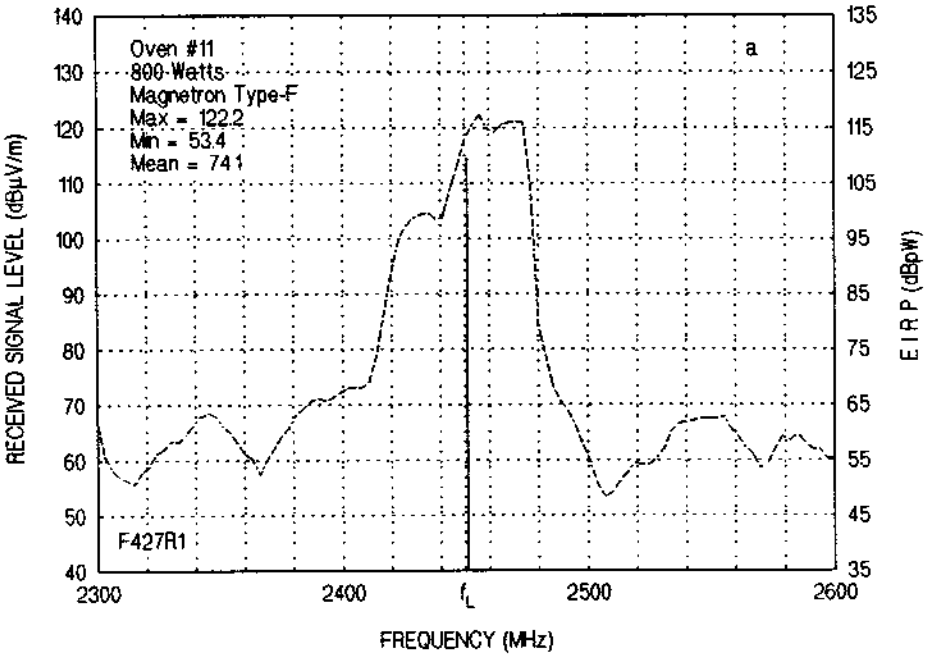

Figure 5-17a. Oven #11, Frequency vs. Amplitude.

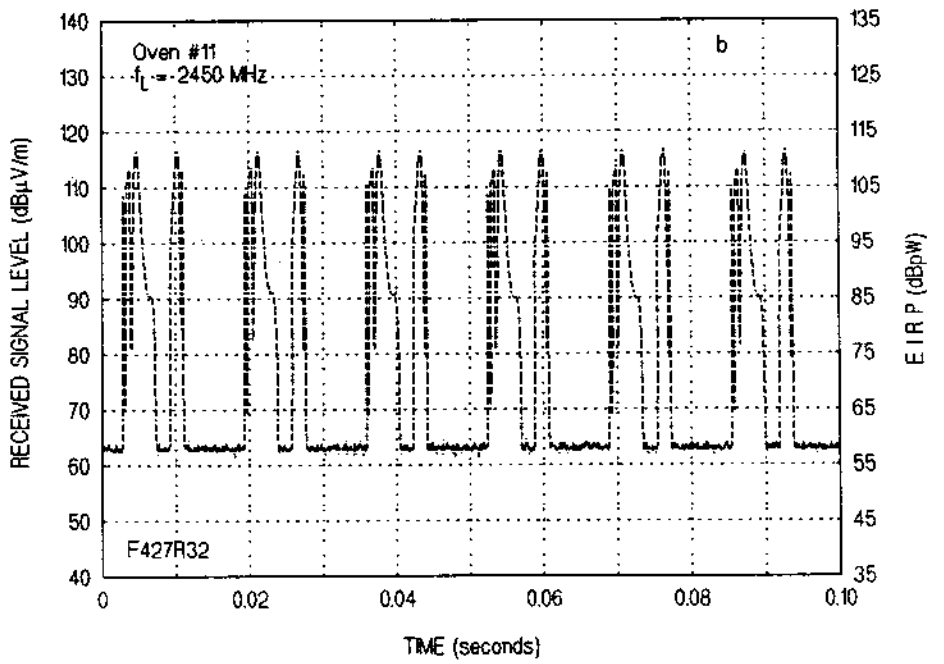

Figure 5-17b. Oven #11, Time vs. Amplitude at 2450 MHz.

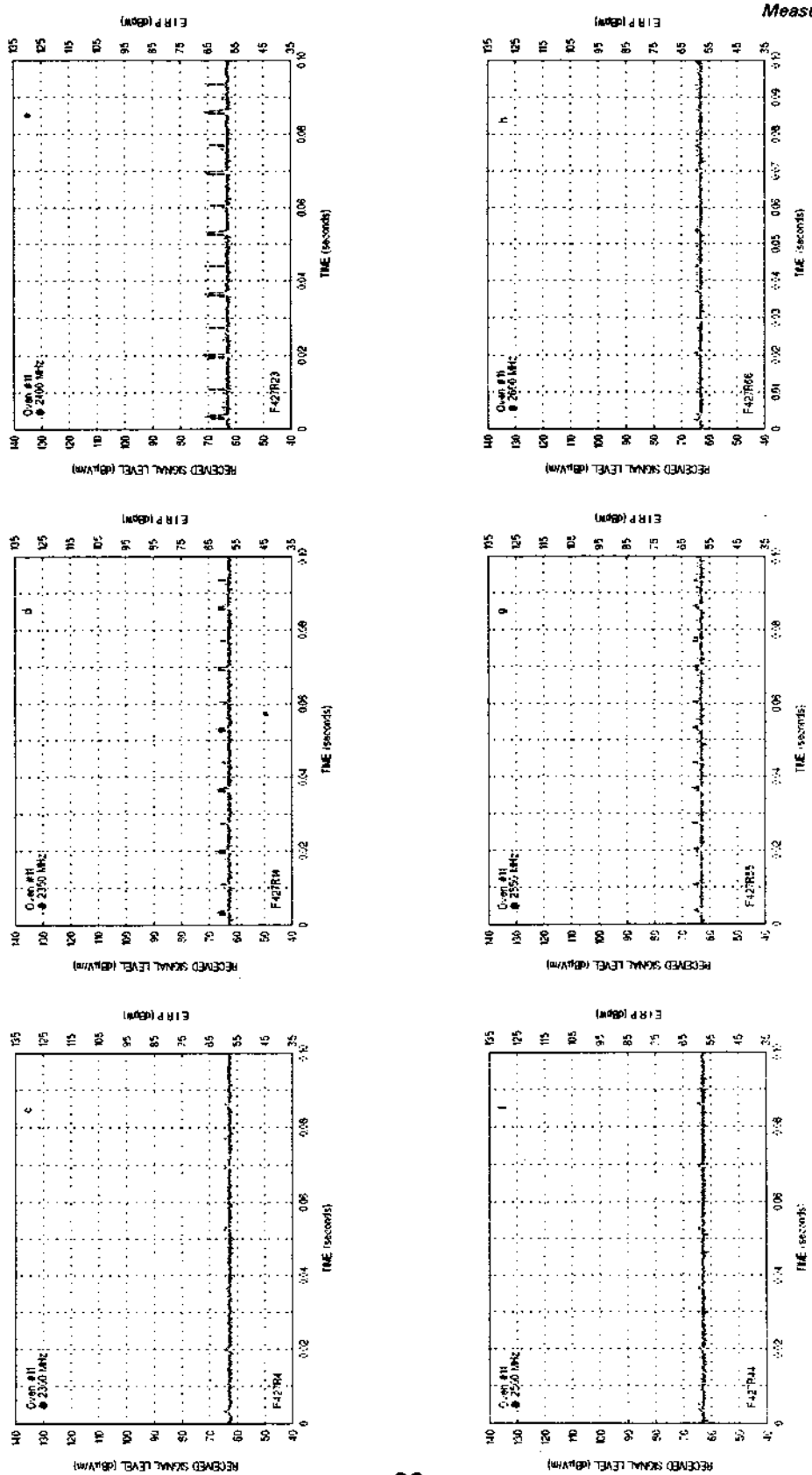

Figure 5-17c through 5-17h. Oven #11, Time vs. Amplitude at 2300, 2350, 2400, 2500, 2550, and 2600 MHz.

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.

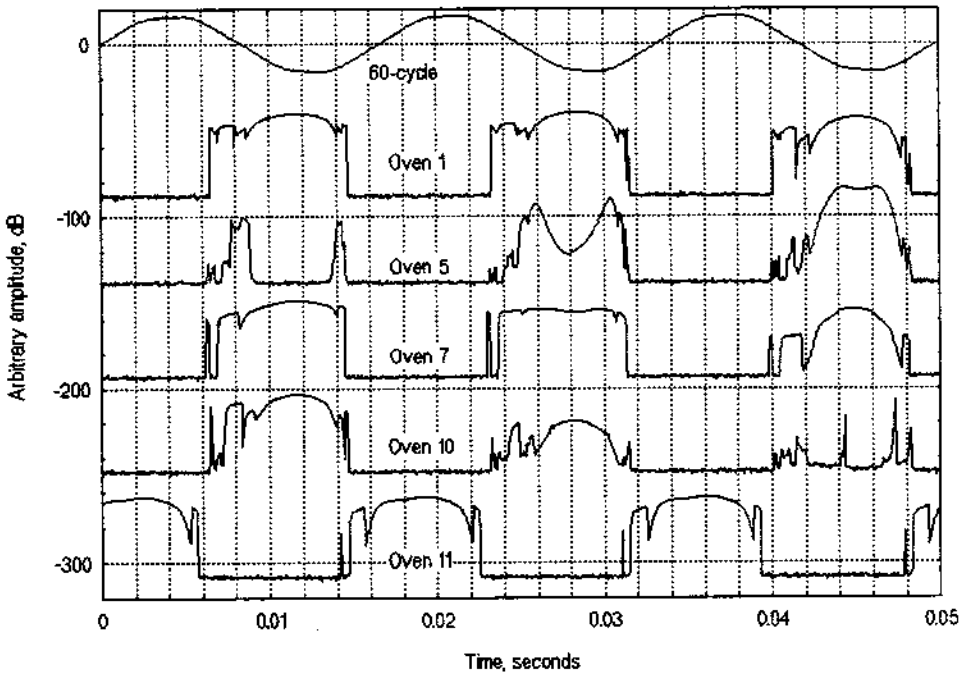

Figure 5-18. Results of trigger point examination.

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.

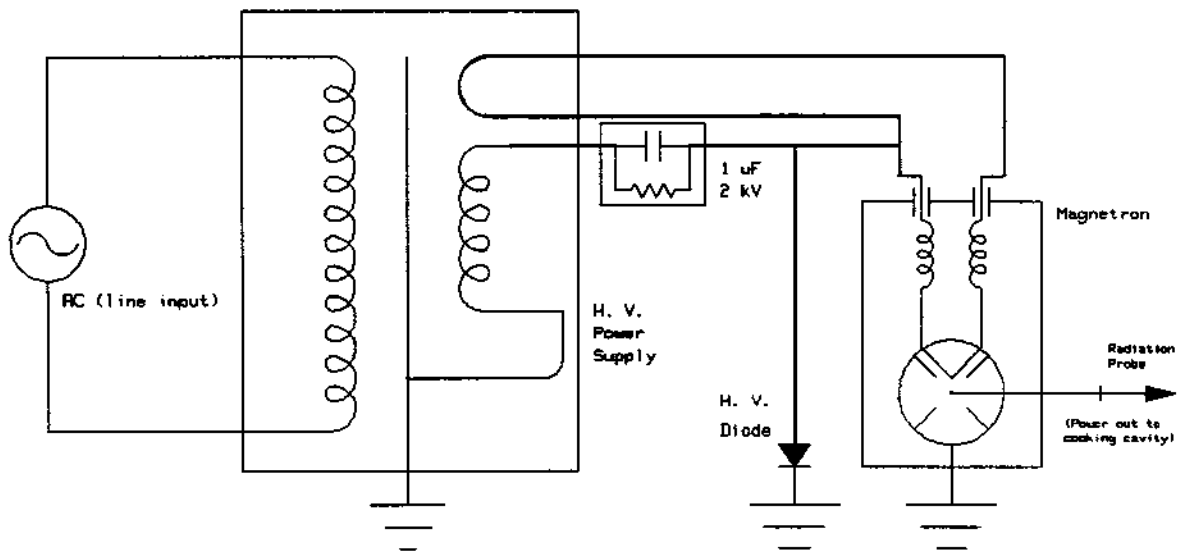

Figure 5-19. Schematic of a typical microwave oven. This diagram is representative of all ovens used in the NTIA tests described in this report.

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.

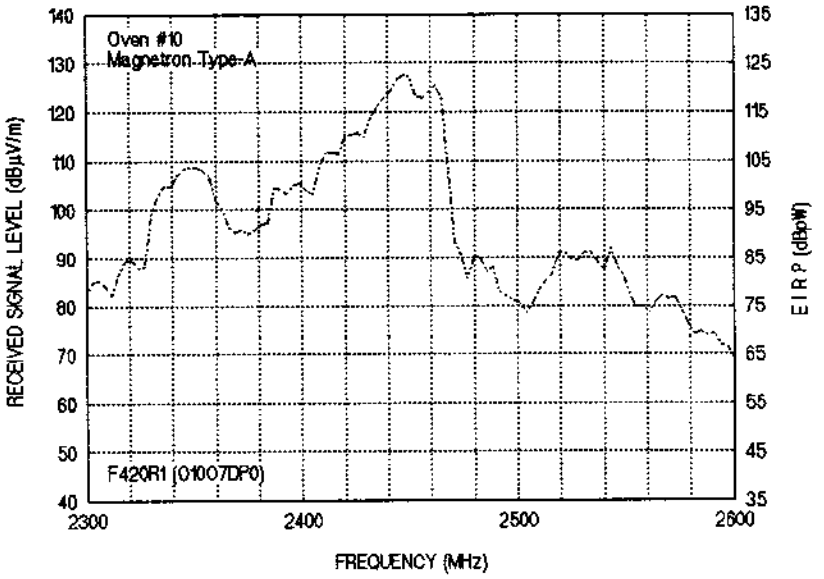

Figure 5-20. Frequency vs. Amplitude for Oven #10.

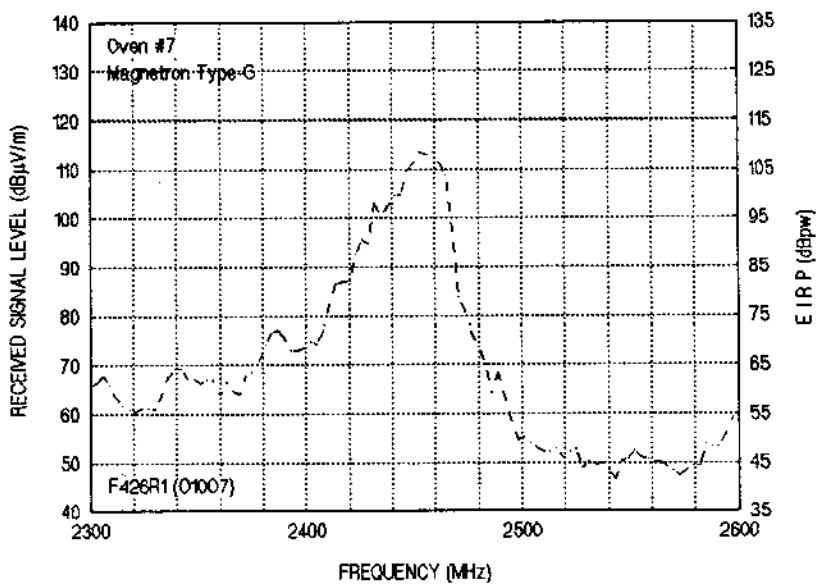

Figure 5-21. Frequency vs. Amplitude for Oven #7.

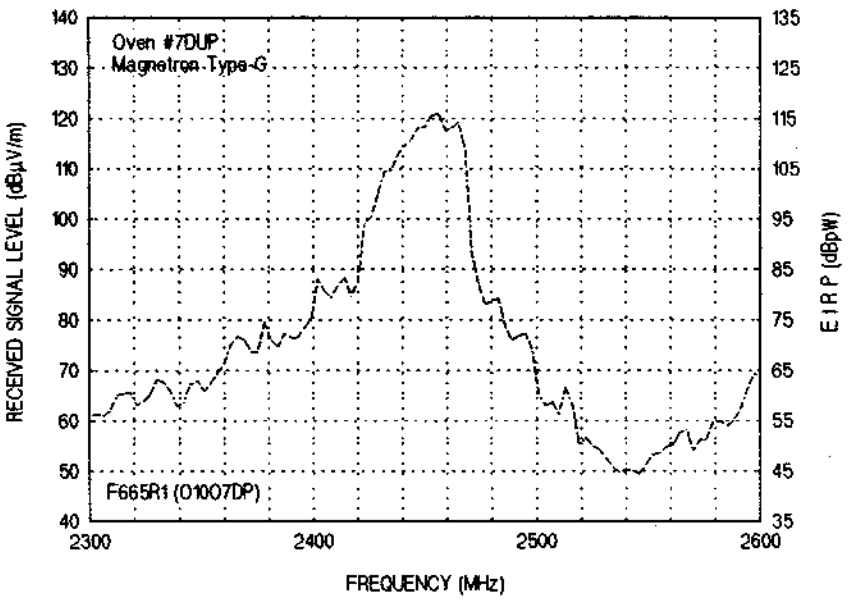

Figure 5-22. Frequency vs. Amplitude for Oven #7 DUP.

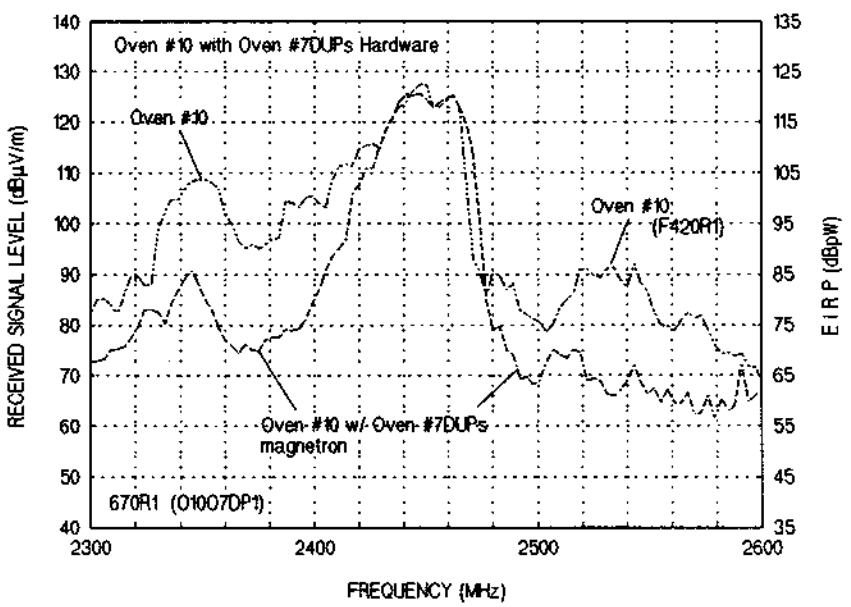

Figure 5-23. Frequency vs. Amplitude for Oven #10 and Oven #10 with Oven #7 DUP magnetron tube type installed.

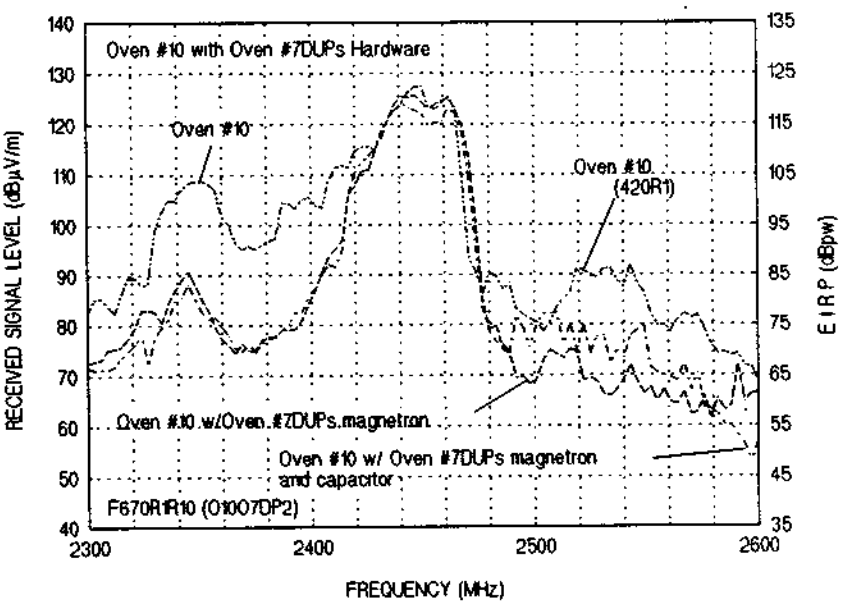

Figure 5-24. Frequency vs. Amplitude for Oven #10; for Oven #10 with Oven #7 DUPs magnetron tube type installed; and Oven #10 with Oven #7 DUPs magnetron tube type and capacitor installed.

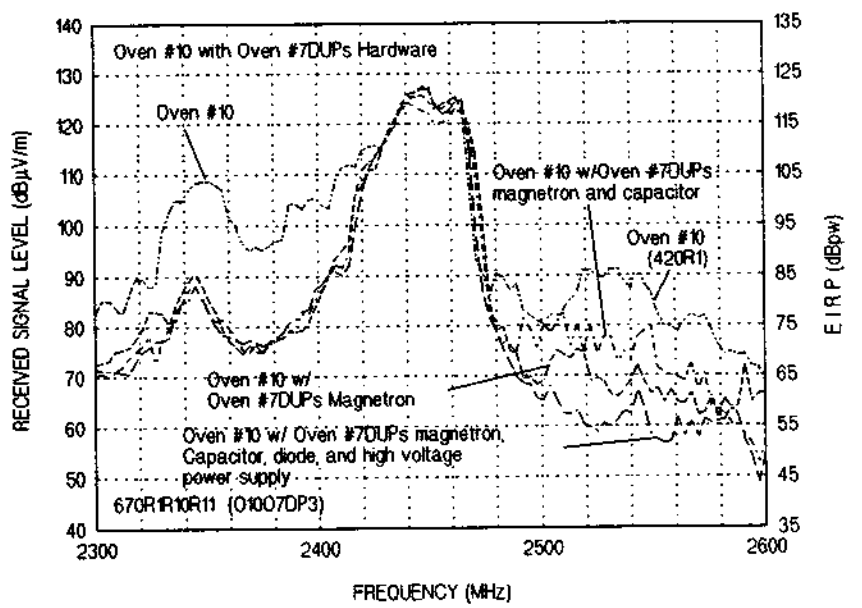

Figure 5-25. Frequency vs. Amplitude for Oven #10; for Oven #10 with Oven #7 DUPs magnetron; for Oven #10 with Oven #7 DUPs magnetron & capacitor installed; and for Oven #10 with Oven #7 DUPs magnetron, capacitor, and high voltage power supply installed.

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.

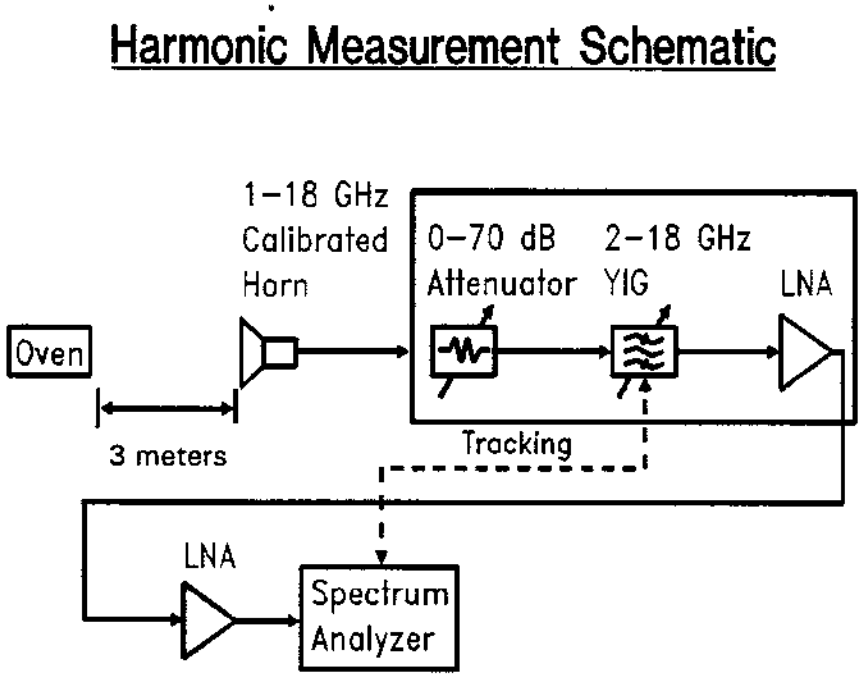

Figure 5-26. Harmonic measurement set-up for the tested microwave ovens.

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 4th harmonic.

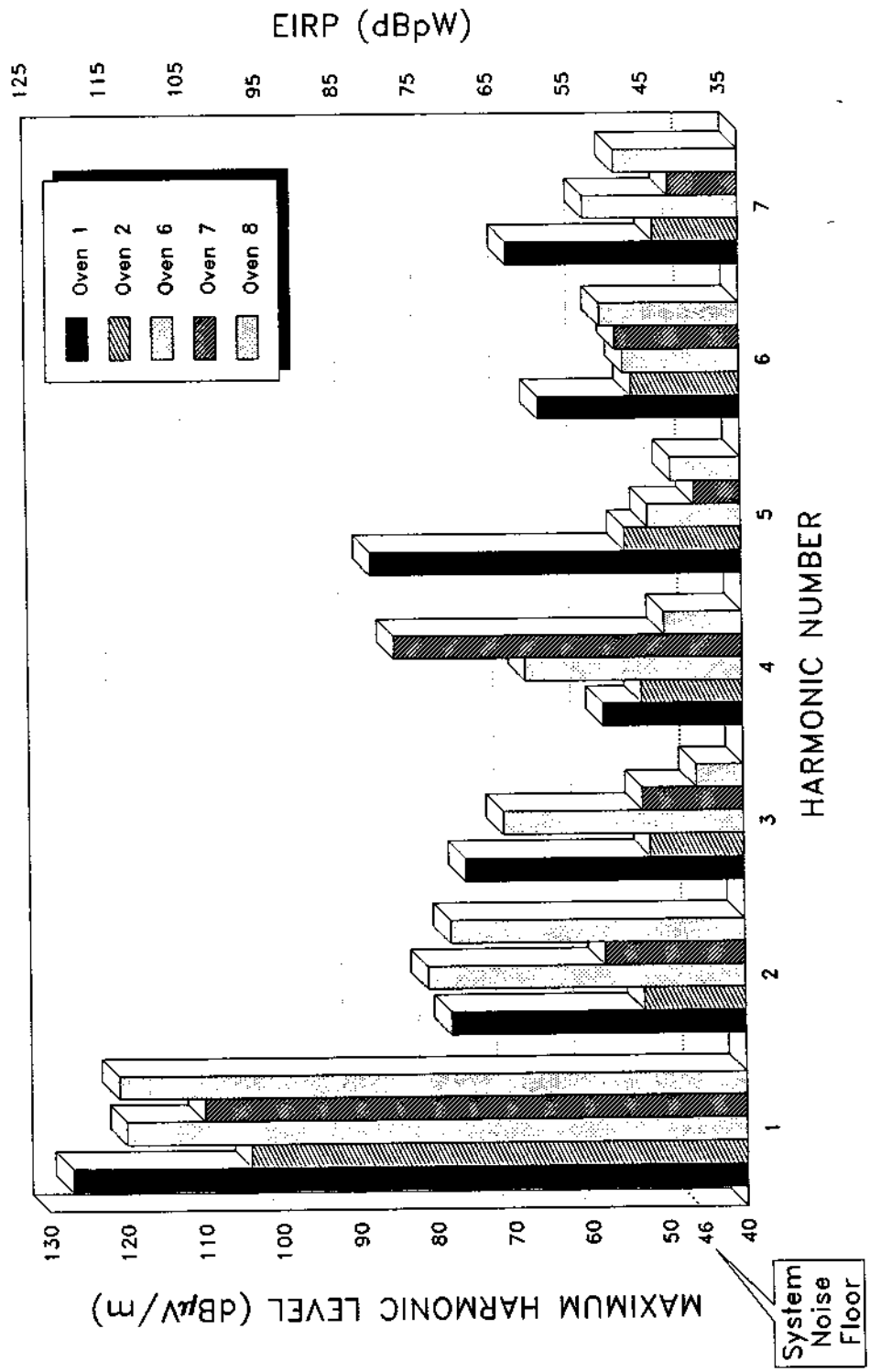

Figure 5-27. Harmonic emission levels of Ovens #1, #2, #6, #7, and #8.

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.

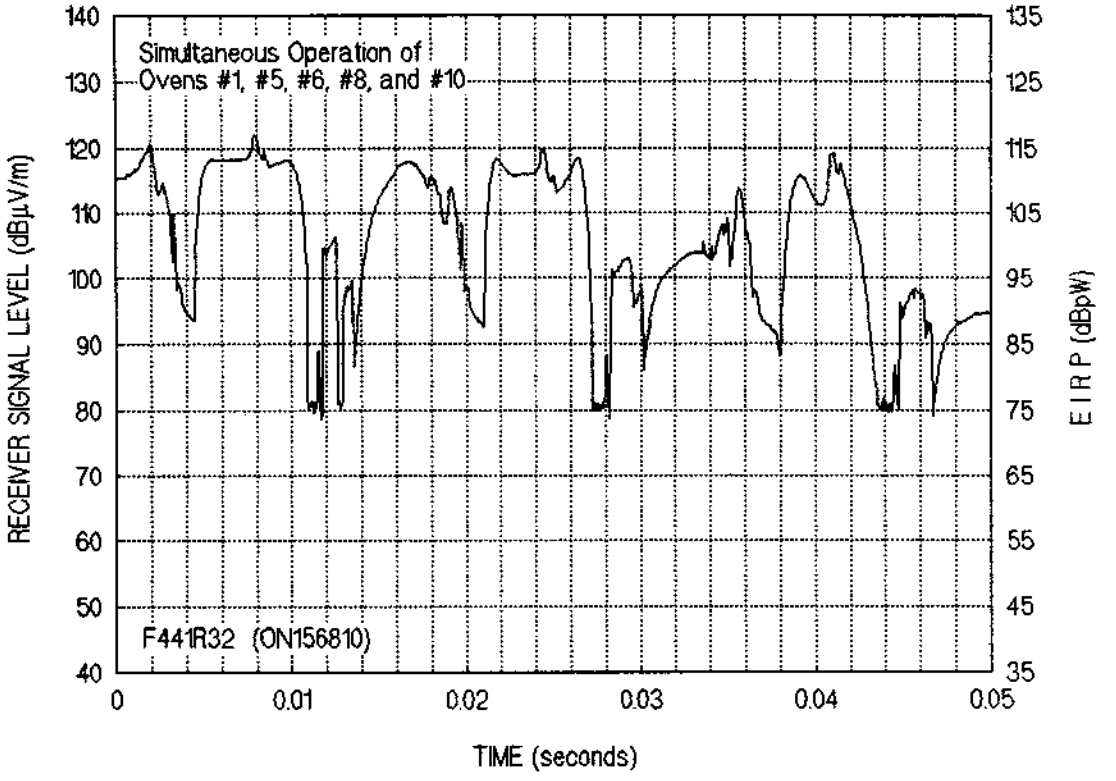

Figure 5-28. Multiple operation of ovens #1, #5, #6, #8, and #10.

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,

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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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