



ARL-TR-8268 • JAN 2018



An Automated Energy Detection Algorithm Based on Consecutive Mean Excision

by Kwok F Tom

Approved for public release; distribution is unlimited.

NOTICES

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.



An Automated Energy Detection Algorithm Based on Consecutive Mean Excision

by Kwok F Tom

Sensors and Electron Devices Directorate, ARL

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
<p>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</p>					
1. REPORT DATE (DD-MM-YYYY) January 2018		2. REPORT TYPE Technical Report		3. DATES COVERED (From - To) 1 October 2016–30 September 2017	
4. TITLE AND SUBTITLE An Automated Energy Detection Algorithm Based on Consecutive Mean Excision				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Kwok F Tom				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US Army Research Laboratory ATTN: RDRL-SER-E Aberdeen Proving Ground, MD 21005-5066				8. PERFORMING ORGANIZATION REPORT NUMBER ARL-TR-8268	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT This report contains the statistical analysis of some RF spectral data files. These data files were evaluated with the consecutive mean excision algorithm. The algorithm automatically established a detection threshold based on the data of the RF spectrum measurement. It was able to determine the detection threshold level even when there were signals present in the RF spectrum.					
15. SUBJECT TERMS RF spectrum, detection threshold algorithm, consecutive mean excision, rank order filter, statistical processing					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 44	19a. NAME OF RESPONSIBLE PERSON Kwok F Tom
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (Include area code) 301-394-2612

Contents

List of Tables	iv
Preface	v
1. Introduction	1
2. Data Collection and Statistical Summary	1
3. Statistical Processing	2
3.1 Statistical Analysis	2
3.1.1 Moments	3
3.1.2 Mean	3
3.1.3 Variance	3
3.1.4 Standard Deviation	3
3.1.5 Kurtosis	4
3.1.6 Maximum	4
3.1.7 Minimum	4
3.1.8 Median	4
3.1.9 Rank Order Filter (ROF)	4
3.1.10 Crest Factor (CF)	5
3.2 Statistical Summary	6
4. Algorithm	7
5. Conclusion	8
6. References	9
Appendix A. MATLAB Code	11
Appendix B. Graphs of RF Spectrum Files Calculated Detection Threshold	17
List of Symbols, Abbreviations, and Acronyms	34
Distribution List	35

List of Tables

Table 1	Summary of the RF spectrum collection	2
Table 2	Statistical analysis of the RF spectrum measurements	6

Preface

Energy detection in the RF spectrum is the most basic technique for signal detection. Typically, this requires establishing an energy detection threshold based on a noise-only condition (i.e., no signal present in the RF spectrum). Initially, the area of exploration for this report was to examine the potential of an automatic energy detection thresholding algorithm based on the RF measurement. It would not require the preliminary RF spectrum noise-only measurements to establish the energy detection threshold.

A series of RF spectrum measurements were collected at the US Army Research Laboratory in 2013. The data files contained different segments of the RF spectrum with various resolution bandwidths. In addition, the data files represented RF spectral conditions with and without RF signals. Some of these data files were used to examine a technique for automatic energy detection thresholding determination.

This report summarizes the examination of the consecutive mean excision algorithm. In this algorithm, the RF spectral data is sorted. An iterative elimination of the highest amplitude value is performed until this value is below the mean threshold calculated on the entire remaining data array. This is the fourth of 5 reports that detail the energy detection techniques examined with the recorded RF spectrum measurements.¹⁻⁴

¹ Tom K. An automated energy detection algorithm based on morphological filter processing with a semi-disk structure. Adelphi (MD): Army Research Laboratory (US); 2018 Jan. Report No.: ARL-TR-8271.

² Tom K. An automated energy detection algorithm based on morphological filter processing with a modified watershed transform. Adelphi (MD): Army Research Laboratory (US); 2018 Jan. Report No.: ARL-TR-8270.

³ Tom K. An automated energy detection algorithm based on morphological and statistical processing techniques. Adelphi (MD): Army Research Laboratory (US); 2018 Jan. Report No.: ARL-TR-8272.

⁴ Tom K. An automated energy detection algorithm based on kurtosis-histogram excision. Adelphi (MD): Army Research Laboratory (US); 2018 Jan. Report No.: ARL-TR-8269.

INTENTIONALLY LEFT BLANK.

1. Introduction

Energy detection is the simplest method of detecting a signal in the frequency spectrum. When doing so, a comparison is made between the frequency spectral component energy and a detection threshold level. Knowledge of the frequency spectrum is usually necessary to establish this detection threshold level. Various methods can be used to determine the detection threshold level, such as establishing the system noise statistics offline and setting the threshold for a given probability of detection versus probability of false alarm.

The goal of this evaluation was to develop an automated thresholding level algorithm for the RF spectrum. This algorithm is named consecutive mean excision. The underlying assumption is that the RF spectrum noise has a white Gaussian distribution. A threshold can be determined for the Gaussian distribution for a predetermined false alarm rate. Initially, the spectral data are applied to a rank order filter (ROF). The data set is sorted from lowest to highest amplitude value. Starting from the highest value, the amplitude value is deleted from the ROF array and the mean value is recomputed. A threshold value is obtained by multiplying this new mean value by a constant. The remaining highest amplitude value is checked to see if it exceeds the threshold value. This elimination of the highest value and threshold checking continues until the highest value is below the computed threshold.

2. Data Collection and Statistical Summary

The local RF spectrum was measured in 2013 on the rooftop of building 204 at the US Army Research Laboratory's (ARL's) Adelphi location. An Agilent N9342CN spectrum analyzer and a Discone antenna was used to collect RF spectrum data. This spectrum analyzer was operated under the control of a LabVIEW software program to acquire and store data with different resolution bandwidth (RBW) from 1 kHz to 1 MHz.

These data files represent various sizes of RF spectral coverage from 10 MHz up to 4 GHz. The number of data files for each spectral band varied. The larger RBW files were acquired over seconds of data acquisition time versus the small RBW files. Small RBW provides fine spectral resolution, but it has impact on data acquisition time for spectral coverage and data size. Depending on the RBW and spectral coverage, a data file could require a few hours of acquisition.

Table 1 summarizes the data collection measurement files. The RF spectral bands covered the spectrum from 10 MHz to 4 GHz. In general, various spectral bands were measured with 4 RBW configuration. Data file size is inversely proportional to the RBW. Data file size is proportional to the spectral band coverage. The data size varied from approximately 1 KSample to 4 MSample data points per file.

Table 1 Summary of the RF spectrum collection

Spectral band coverage	Number of RBW measurement	RBW
1.1–1.6 GHz	4	1 kHz, 10 kHz, 100 kHz, 1 MHz
2–3 GHz	4	1 kHz, 10 kHz, 100 kHz, 1 MHz
3–4 GHz	3	10 kHz, 100 kHz, 1 MHz
4–6 GHz	3	10 kHz, 100 kHz, 1 MHz
10 MHz–1 GHz	4	1 kHz, 10 kHz, 100 kHz, 1 MHz
10 MHz–2 GHz	4	1 kHz, 10 kHz, 100 kHz, 1 MHz
10 MHz–3 GHz	4	1 kHz, 10 kHz, 100 kHz, 1 MHz
10 MHz–4 GHz	4	1 kHz, 10 kHz, 100 kHz, 1 MHz
100 MHz–1 GHz	1	100 kHz

3. Statistical Processing

3.1 Statistical Analysis

Statistical analysis is the mathematical science dealing with the analysis or interpretation of data. The data analyst uses a few straightforward statistical techniques as a means of summarizing the collected data. These statistical techniques are under the area of descriptive statistics, which is a methodology to condense the data in quantitative terms.

In commercial prognostics and diagnostic vibrational monitoring applications, statistical techniques that are mainly used for alarm purposes in industrial plants are the statistical moments of order 2, 3, and 4. The probability density function (PDF) of the vibrational time series of a good bearing has a Gaussian distribution (also known as a normal distribution), whereas a damaged bearing results in a non-Gaussian distribution with dominant tails because of a relative increase in the number of high levels of acceleration. These techniques can be applied to the RF spectral data with a different interpretation of the results.¹

3.1.1 Moments

If these moments are calculated about the mean, they are called central statistical moments. The first and second moments are well known, being the mean and the variance, respectively. These are analogous to the first and second area moments of inertia with the area shape defined by the PDF. The third moment is termed skewness and the fourth moment is termed kurtosis. The general equation for the order of moment is as follows:

$$M_p = \frac{1}{N} \sum_{i=1}^N (x_i - \bar{x})^p,$$

where p is the order of the moment,

N is the number of data value,

i is the index of the data value, and

\bar{x} is the mean value of the data set.

3.1.2 Mean

Mean is the most common measure of a statistical distribution. In this case, mean is the arithmetic average for a set of measurements.

$$\bar{x} = \mu = \frac{1}{N} \sum_{i=1}^N x_i.$$

3.1.3 Variance

Variance is a measure of the dispersion of a waveform about its mean—also called the second moment of the measurements.

$$\sigma^2 = \frac{1}{N} \sum_{i=1}^N (x_i - \bar{x})^2.$$

3.1.4 Standard Deviation

Standard deviation is a measure of the variation of a set of data values. The standard deviation is defined as the square root of the variance moment.

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \bar{x})^2}.$$

3.1.5 Kurtosis

Kurtosis is the fourth statistical moment, normalized by the standard deviation to the fourth power. It is a measure of whether the data are peaked or flat relative to a normal distribution. The noise in the RF spectrum is typically considered to have a normal distribution. The normal distribution has a value of 3.

$$\kappa = \frac{M_4}{\sigma^4}.$$

$$\kappa = \frac{\frac{1}{N} \sum_{i=1}^N (x_i - \bar{x})^4}{\sigma^4}.$$

$$\kappa = \frac{1}{N\sigma^4} \sum_{i=1}^N (x_i - \bar{x})^4.$$

3.1.6 Maximum

“Max” is the largest value of a set of numbers.

$$y = \max[x(n)].$$

3.1.7 Minimum

“Min” is the smallest value of a set of numbers.

$$y = \min[x(n)].$$

3.1.8 Median

The statistical median is an order statistic that gives the “middle” value of a set of samples. Median is the middle value of a set of data values that divides the set into 2 groups. Half the groups exist below and half exist above this value.

3.1.9 Rank Order Filter (ROF)

ROF is a sorting process by which a set of numbers is ordered from the smallest to the largest value. Rank order filtering is a nonlinear filtering technique that orders the contents of a filter kernel and selects the sample indexed by rank from the magnitude ordered samples.

Rank order filtering can be summarized as follows:

$$y = \sum_{i=1}^N a_i \tilde{x}_{(i)}.$$

where $\tilde{x}_{(l)}, l = 1, \dots, N$ is the result of sorting the data in ascending order. With this definition, the max, min, and median can be obtained from a rank order filter as follows²:

Min:

$$y = \sum_{i=1}^N a_i \tilde{x}_{(i)},$$

$$a_i = 1 \text{ for } i = 1,$$

$$0 \text{ otherwise.}$$

Max:

$$y = \sum_{i=1}^N a_i \tilde{x}_{(i)},$$

$$a_i = 1 \text{ for } i = N,$$

$$0 \text{ otherwise.}$$

Median:

$$y = \sum_{i=1}^N a_i \tilde{x}_{(i)},$$

$$a_i = 1 \text{ for } i = \frac{N}{2},$$

$$0 \text{ otherwise.}$$

3.1.10 Crest Factor (CF)

Crest factor (CF) is a measure of a waveform showing the ratio of peak values to the effective value. In other words, CF indicates how extreme the peaks are in a waveform.

$$Crest\ Factor = \frac{|x|_{peak}}{x_{rms}}.$$

Noise sources are characterized by their CF, which is the peak to average ratio of the noise. In a technical bulletin, XiTRON reported CF values between 5 and 7 for random noise.³ For example, a 5:1 CF of the noise voltage is $20\log 5 = 14$ dB. This is a measure of the quality of the noise distributions and one way to measure its Gaussian nature.⁴ For the purpose of algorithm development, the CF equation was modified as follows:

$$Crest\ Factor = \frac{Max}{Median}.$$

3.2 Statistical Summary

There were 31 different groupings of the RF spectrum data measurements. The number of data files under each of the main groupings was varied. For the purpose of developing the algorithm, only a single data file was selected from each group. Each data file was processed to obtain the following characteristics: RBW, mean, standard deviation, median, max, min, kurtosis, and CF. A summary of the results is in Table 2. The following results were noted:

- The smaller the RBW, the lower the noise floor. The equation for thermal noise power is $P = kTB$, where B is bandwidth. In this case, the RBW of 1 kHz has the lowest noise value. The RBW of 1 MHz has the highest noise value.
- Each 10-fold increase in bandwidth results in a 10-dB increase in noise power. This relationship is illustrated in this data set.
- The calculated mean and median values are very close for a given RF measurement configuration.

Table 2 Statistical analysis of the RF spectrum measurements

Filename	Spectral Band	RBW	Mean	SD	Median	Max	Min	Kurtosis	CF
Air_test_1.1GHz_1.6GHzb_03_28_14_06_33_22	1.1 - 1.6 GHz	1000	-112.694	3.8444	-112.3	-101.2	-138.4	3.5571	11.1
Air_test_1.1GHz_1.6GHza_03_27_14_07_14_05	1.1 - 1.6 GHz	10000	-102.12	3.7226	-101.8	-91.69	-124.5	3.5134	10.11
Air_test_1.1GHz_1.6GHzc_03_31_14_06_47_26	1.1 - 1.6 GHz	100000	-90.9109	2.597	-90.75	-83.13	-101.2	3.0217	7.62
Air_test_1.1GHz_1.6GHzd_04_01_14_06_54_03	1.1 - 1.6 GHz	1000000	-80.5634	3.5741	-80.745	-55.36	-89.8	14.6861	25.385
Air_test_2GHz_3GHza_06_05_14_07_15_58	2 - 3 GHz	1000	-111.219	4.4991	-111.1	-77.55	-139	6.8918	33.55
Air_test_2GHz_3GHzb_05_29_14_06_28_28	2 - 3 GHz	10000	-101.006	4.1808	-100.8	-74.67	-122	6.1995	26.13
Air_test_2GHz_3GHzc_05_29_14_04_09_27	2 - 3 GHz	100000	-89.5666	3.4154	-89.68	-64.27	-100.3	13.2282	25.41
Air_test_2GHz_3GHzd_05_28_14_00_06_18	2 - 3 GHz	1000000	-79.6014	3.0753	-79.6	-58.74	-88.88	8.4466	20.86
Air_test_3GHz_4GHza_06_12_14_06_30_17	3 - 4 GHz	10000	-100.51	3.7072	-100.2	-89.68	-123.7	3.5901	10.52
Air_test_3GHz_4GHzc_06_11_14_06_44_40	3 - 4 GHz	100000	-89.1625	2.5513	-89.075	-80.68	-102.3	3.0774	8.395
Air_test_3GHz_4GHzd_06_09_14_07_09_51	3 - 4 GHz	1000000	-79.0828	2.445	-78.94	-72.76	-88.5	2.9651	6.18
Air_test_4GHz_6GHza_04_24_14_07_05_26	4 - 6 GHz	1000	-107.559	4.1793	-107.2	-94.31	-136.3	3.3696	12.89
Air_test_4GHz_6GHzb_04_28_14_06_23_12	4 - 6 GHz	10000	-97.245	4.0398	-96.95	-84.05	-119.7	3.3249	12.9
Air_test_4GHz_6GHzc_04_29_14_06_48_42	4 - 6 GHz	100000	-85.9125	3.082	-85.77	-75.84	-98.78	2.9068	9.93
Air_test_10MHz_1GHza_04_17_14_07_09_30	10 MHz - 1 GHz	1000	-110.348	8.6126	-112.1	-28.37	-140.3	6.4788	83.73
Air_test_10MHz_1GHzb_04_21_14_07_17_44	10 MHz - 1 GHz	10000	-100.168	8.4775	-102	-27.95	-126.7	6.7602	74.05
Air_test_10MHz_1GHzc_04_22_14_06_39_58	10 MHz - 1 GHz	100000	-87.948	8.8113	-90.74	-27.28	-103.6	6.513	63.46
Air_test_10MHz_1GHzd_04_23_14_06_36_16	10 MHz - 1 GHz	1000000	-78.1054	8.3327	-80.59	-27.82	-89.88	7.5282	52.77
Air_test_10MHz_2GHzd_03_06_14_08_52_04	10 MHz - 2 GHz	1000	-111.275	6.9798	-112.1	-27.34	-138.3	9.5085	84.76
Air_test_10MHz_2GHzc_02_27_14_06_43_55	10 MHz - 2 GHz	10000	-100.894	7.0157	-101.8	-26.58	-125.9	10.4224	75.22
Air_test_10MHz_2GHzb_02_25_14_06_35_53	10 MHz - 2 GHz	100000	-89.242	6.7487	-90.59	-26.09	-102.4	12.7961	64.5
Air_test_10MHz_2GHz_02_20_14_06_55_36	10 MHz - 2 GHz	1000000	-78.8448	7.3203	-80.6	-26.54	-92.41	11.3819	54.06
Air_test_10MHz_3GHz_03_11_14_06_32_51	10 MHz - 3 GHz	1000	-111.373	6.1356	-111.8	-29.42	-140.5	11.0474	82.38
Air_test_10MHz_3GHzb_03_13_14_06_32_45	10 MHz - 3 GHz	10000	-100.787	6.3591	-101.4	-25.36	-125.9	11.7254	76.04
Air_test_10MHz_3GHzc_03_18_14_06_32_08	10 MHz - 3 GHz	100000	-89.1614	6.0257	-90.14	-24.16	-102.4	15.3376	64.98
Air_test_10MHz_3GHzd_03_20_14_08_09_07	10 MHz - 3 GHz	1000000	-78.6492	6.7418	-80.8	-25.81	-90.38	13.0673	54.99
Air_test_10MHz_4GHza_04_10_14_07_01_22	10 MHz - 4 GHz	1000	-111.158	5.6813	-111.4	-28.22	-143.1	10.9573	83.18
Air_test_10MHz_4GHzb_04_11_14_06_10_18	10 MHz - 4 GHz	10000	-100.838	5.5851	-101.1	-26.85	-128	12.2576	74.25
Air_test_10MHz_4GHzc_04_15_14_07_01_09	10 MHz - 4 GHz	100000	-89.4431	5.1076	-90.03	-25.05	-103.5	18.317	64.98
Air_test_10MHz_4GHzd_04_16_14_06_42_27	10 MHz - 4 GHz	1000000	-79.0396	5.5441	-79.89	-26.72	-91.64	16.9073	53.17
Air_test_100MHz_1GHz_02_19_14_07_20_46	100 MHz - 1 GHz	100000	-88.0772	9.0701	-90.82	-23.91	-102.2	6.994	66.91

4. Algorithm

The development process was executed in MATLAB. Appendix A is the code used to process and generate the enclosed RF spectrum signature with the corresponding results of the detection threshold level. Basically, the algorithm sorts the RF spectrum amplitude or applies an ROF to the data. This sorting process creates an array that is similar to the cumulative density function of the RF spectrum. The max value is deleted from the array and the mean of the array recalculated. A threshold detection level is then formed from this mean by multiplying it by 6.9078.⁵ This process of deletion and mean calculation is repetitive until the max value of the array is below the calculated threshold. This value is then declared to be the detection threshold level once the criteria has been reached. The following is a description of the detection thresholding level generation based on this technique:

- 1) Apply ROF to the spectrum data file by sorting the spectral amplitude from low to high.
- 2) Calculate the mean value of the data file. Since the data file represents the spectrum in units of decibel-milliwatts, the mean value is in log space.
- 3) Convert the mean value into linear space.
- 4) The initial threshold level is calculated to be the linear mean $\times 6.9078$.
- 5) Convert the threshold back into log space.
- 6) Check to see if the max value in the array is less than threshold; if so, the threshold has been determined.
- 7) Remove the 100 highest values from the sorted spectral data. The size of the removal was selected as a large value to reduce the computation time for the algorithm.
- 8) Calculate the mean value of the reduced spectral data.
- 9) Convert the mean value into linear space.
- 10) Set the threshold level as the linear mean value $\times 6.9078$.
- 11) Convert the mean value back into log space.
- 12) Check to see if any spectral data are greater than the calculated threshold; if so, stop and use that threshold value. If not, repeat from step 7.

5. Conclusion

The consecutive mean excision algorithm generates a single value threshold based on the spectral data. It is a straightforward process to implement. The implementation of the algorithm was conducted with a slight variation where the 100 highest data values were eliminated on each pass through the algorithm loop. Appendix A is the MATLAB code developed in the evaluation for this algorithm. Further assessment is necessary to determine the number of data points to delete on each pass through the loop versus performance and speed.

Appendix B displays the results of the threshold overlaid on top of the RF spectrum signature. The graphs are intended to provide the reader with a qualitative sense of the effectiveness of the automatic detection threshold generation algorithm. The following observations were noted from examining the graphs:

- Performance of the algorithm is not great when the spectrum band coverage is large.
- RF spectrum is not necessarily flat over the spectral bands.
- False alarm detections were higher for the smaller RBW data sets and noise-only conditions.
- Algorithm performance seems to be better when there are signals in the RF spectrum data.

6. References

1. Tom KF. A primer on vibrational ball bearing feature generation for prognostics and diagnostics algorithms. Adelphi (MD): Army Research Laboratory (US); 2015 Mar. Report No.: ARL-TR-7230.
2. Mitra AK, Lewis TL, Paul AS, Shaw AK. Ultra-wideband radar data models and target detection with adaptive rank-order filters. Proc SPIE 4727; 2002.
3. Crest factors and power analyzers. San Diego (CA): XiTRON Technologies; nd. Technical Brief TB 103 [accessed 2017 Nov 8]. <http://www.xitrontech.com/assets/002/5788.pdf>.
4. Noise: frequently asked questions. East Hanover (NJ): Noisewave; nd [accessed 2017 Nov 8]. <http://www.noisewave.com/faq.pdf>.
5. Vartiainen J, Lehtomaki J, Saarnisaarl H, Juntti M. Analysis of the consecutive mean excision algorithms. Journal of Electrical and Computer Engineering. 2010;2010. Article ID: 459623. doi: 10.1155/2010/459623.

INTENTIONALLY LEFT BLANK.

Appendix A. MATLAB Code

```

function CME2report()

% Make selection for data file to process
% SELECT = 1 to 31

SELECT = 1;

dir{1} = 'K:\CognitiveRadar\spectrum monitoring\data\building204-4c085\Air_test_1.1GHz_1.6GHza\';
filename{1} = 'Air_test_1.1GHz_1.6GHza_03_27_14_07_14_05';

dir{2} = 'K:\CognitiveRadar\spectrum monitoring\data\building204-4c085\Air_test_1.1GHz_1.6GHzb\';
filename{2} = 'Air_test_1.1GHz_1.6GHzb_03_28_14_06_33_22';

dir{3} = 'K:\CognitiveRadar\spectrum monitoring\data\building204-4c085\Air_test_1.1GHz_1.6GHzc\';
filename{3} = 'Air_test_1.1GHz_1.6GHzc_03_31_14_06_47_26';

dir{4} = 'K:\CognitiveRadar\spectrum monitoring\data\building204-4c085\Air_test_1.1GHz_1.6GHzd\';
filename{4} = 'Air_test_1.1GHz_1.6GHzd_04_01_14_06_54_03';

dir{5} = 'K:\CognitiveRadar\spectrum monitoring\data\building204-4c085\Air_test_2GHz_3GHza\';
filename{5} = 'Air_test_2GHz_3GHza_06_05_14_07_15_58';

dir{6} = 'K:\CognitiveRadar\spectrum monitoring\data\building204-4c085\Air_test_2GHz_3GHzb\';
filename{6} = 'Air_test_2GHz_3GHzb_05_29_14_06_28_28';

dir{7} = 'K:\CognitiveRadar\spectrum monitoring\data\building204-4c085\Air_test_2GHz_3GHzc\';
filename{7} = 'Air_test_2GHz_3GHzc_05_29_14_04_09_27';

dir{8} = 'K:\CognitiveRadar\spectrum monitoring\data\building204-4c085\Air_test_2GHz_3GHzd\';
filename{8} = 'Air_test_2GHz_3GHzd_05_28_14_00_06_18';

dir{9} = 'K:\CognitiveRadar\spectrum monitoring\data\building204-4c085\Air_test_3GHz_4GHzb\';
filename{9} = 'Air_test_3GHz_4GHzb_06_12_14_06_30_17';

dir{10} = 'K:\CognitiveRadar\spectrum monitoring\data\building204-4c085\Air_test_3GHz_4GHzC\';
filename{10} = 'Air_test_3GHz_4GHzC_06_11_14_06_44_40';

dir{11} = 'K:\CognitiveRadar\spectrum monitoring\data\building204-4c085\Air_test_3GHz_4GHzd\';
filename{11} = 'Air_test_3GHz_4GHzd_06_09_14_07_09_51';

```

```

dir{12} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_4GHz_6GHza\';
filename{12} = 'Air_test_4GHz_6GHza_04_24_14_07_05_26';

dir{13} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_4GHz_6GHzb\';
filename{13} = 'Air_test_4GHz_6GHzb_04_28_14_06_23_12';

dir{14} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_4GHz_6GHzc\';
filename{14} = 'Air_test_4GHz_6GHzc_04_29_14_06_48_42';

dir{15} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_1GHza\';
filename{15} = 'Air_test_10MHz_1GHza_04_17_14_07_09_30';

dir{16} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_1GHzb\';
filename{16} = 'Air_test_10MHz_1GHzb_04_21_14_07_17_44';

dir{17} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_1GHzc\';
filename{17} = 'Air_test_10MHz_1GHzc_04_22_14_06_39_58';

dir{18} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_1GHzd\';
filename{18} = 'Air_test_10MHz_1GHzd_04_23_14_06_36_16';

dir{19} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_2GHz\';
filename{19} = 'Air_test_10MHz_2GHz_02_20_14_06_55_36';

dir{20} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_2GHzB\';
filename{20} = 'Air_test_10MHz_2GHzB_02_25_14_06_35_53';

dir{21} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_2GHzC\';
filename{21} = 'Air_test_10MHz_2GHzC_02_27_14_06_43_55';

dir{22} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_2GHzd\';
filename{22} = 'Air_test_10MHz_2GHzd_03_06_14_08_52_04';

dir{23} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_3GHz\';
filename{23} = 'Air_test_10MHz_3GHz_03_11_14_06_32_51';

dir{24} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_3GHzB\';
filename{24} = 'Air_test_10MHz_3GHzB_03_13_14_06_32_45';

dir{25} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_3GHzC\';

```

```

filename{25} = 'Air_test_10MHz_3GHzC_03_18_14_06_32_08';

dir{26} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_3GHzd\';
filename{26} = 'Air_test_10MHz_3GHzd_03_20_14_08_09_07';

dir{27} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_4GHza\';
filename{27} = 'Air_test_10MHz_4GHza_04_10_14_07_01_22';

dir{28} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_4GHzb\';
filename{28} = 'Air_test_10MHz_4GHzb_04_11_14_06_10_18';

dir{29} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_4GHzc\';
filename{29} = 'Air_test_10MHz_4GHzc_04_15_14_07_01_09';

dir{30} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_4GHzd\';
filename{30} = 'Air_test_10MHz_4GHzd_04_16_14_06_42_27';

dir{31} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_100MHz_1GHz\';
filename{31} = 'Air_test_100MHz_1GHz_02_19_14_07_20_46';

str_meta =
sprintf('%s%s.mspectrawdata',dir{SELECT},filename{SELECT});
str_data =
sprintf('%s%s.specrawdata',dir{SELECT},filename{SELECT});

% Get metadata on selected data file

fid_meta = fopen(str_meta);
META = textscan(fid_meta,'%s');
ave = META{1}{1};
ref = META{1}{2};
attn = META{1}{3};
rbw = META{1}{4};

% Read in data file

fid_data = fopen(str_data);
g=0;
f=0;
a=0;
while(g==0)
    ft=fgetl(fid_data);
    f=[f,str2num(ft)];
    at=fgetl(fid_data);
    a=[a,str2num(at)];
    g=feof(fid_data);
end

```

```

f=f(2:end);
a=a(2:end);

% Plot data file

figure(1);
plot(f/1e6,a);
axis tight;
grid;
xlabel('Frequency (MHz)');
ylabel('Power (dBm)');
title(strcat(rbw,'--',ave,'--',ref,'--',attn),'Interpreter','none');

% Determine some statistics values for data

M = mean(a);

Med = median(a);

S = std(a);

Max = max(a);

Min = min(a);

Kurt = kurtosis(a);

Range = abs(Min - Max);

Number = floor(Range);

Bins = Number * 2;

disp([M S Med Max Min Kurt]);

% Sort and plot data

figure(8);
Ampsort = sort(a);
plot(Ampsort);

% Convert back into linear domain and establish initial threshold

index = length(Ampsort);
AmpsortMean = mean(Ampsort);
UnBel = 10. ^ (AmpsortMean/10);
AmpsortThreshold = 10. * log10(UnBel * 6.9078);

% Eliminate the highest values. In this case, by group of 100.
A finer

```

```

% resolution by one value at a time can be used, but would result
in more
% computation time. Compare the highest remaining value to see
if above
% the recalculate mean. If true, then continue to eliminate
until it below
% the threshold.
index = index - 100;

while Ampsort(index) > AmpsortThreshold

    index = index - 100;

    for m = 1:index
        Ampsortred(m) = Ampsort(m);
    end

    AmpsortMean = mean(Ampsortred);
    UnBel = 10. ^ (AmpsortMean/10);
    AmpsortThreshold = 10. * log10(UnBel * 6.9078);
    display(index);
end

% Plot RF spectrum and the threshold

figure(3);

plot(f/1e6,a);
axis tight;
grid;
xlabel('Frequency (MHz)');
ylabel('Power (dBm)');

title(strcat(filename(SELECT),' -- ',rbw,'
Hz'),'Interpreter','none');
hold;
xa = [f(1)/1e6 f(end)/1e6];
yb = [AmpsortThreshold AmpsortThreshold];
plot(xa,yb,'r-o');

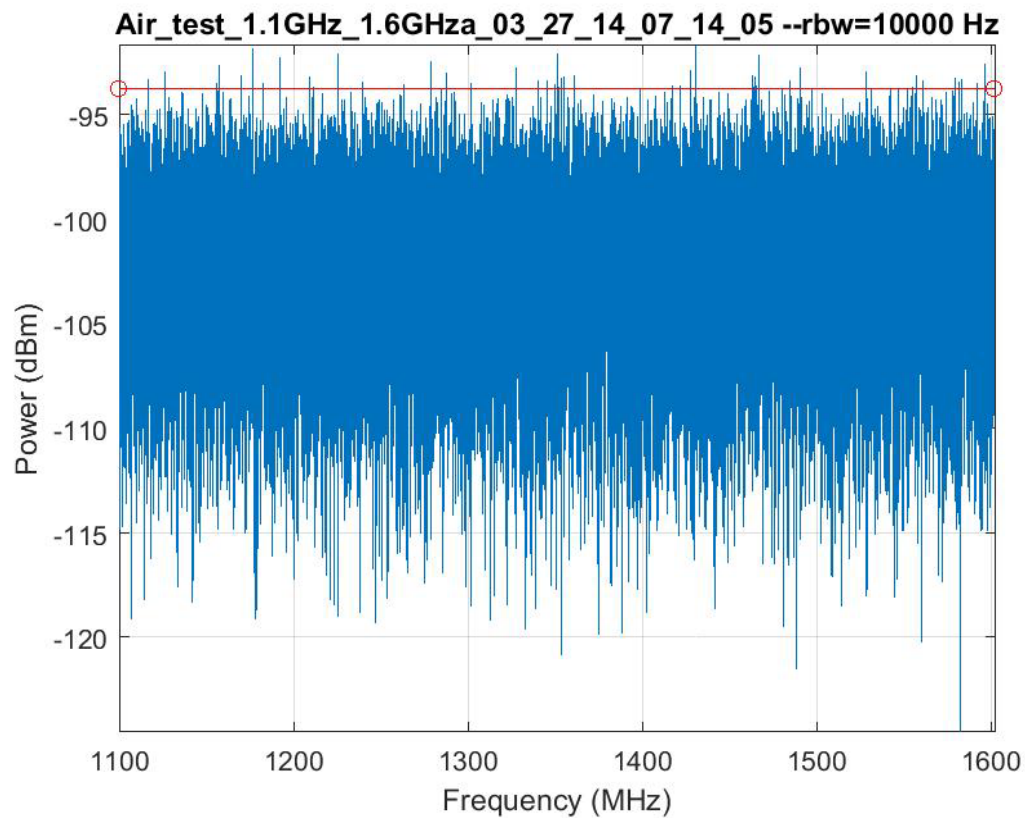
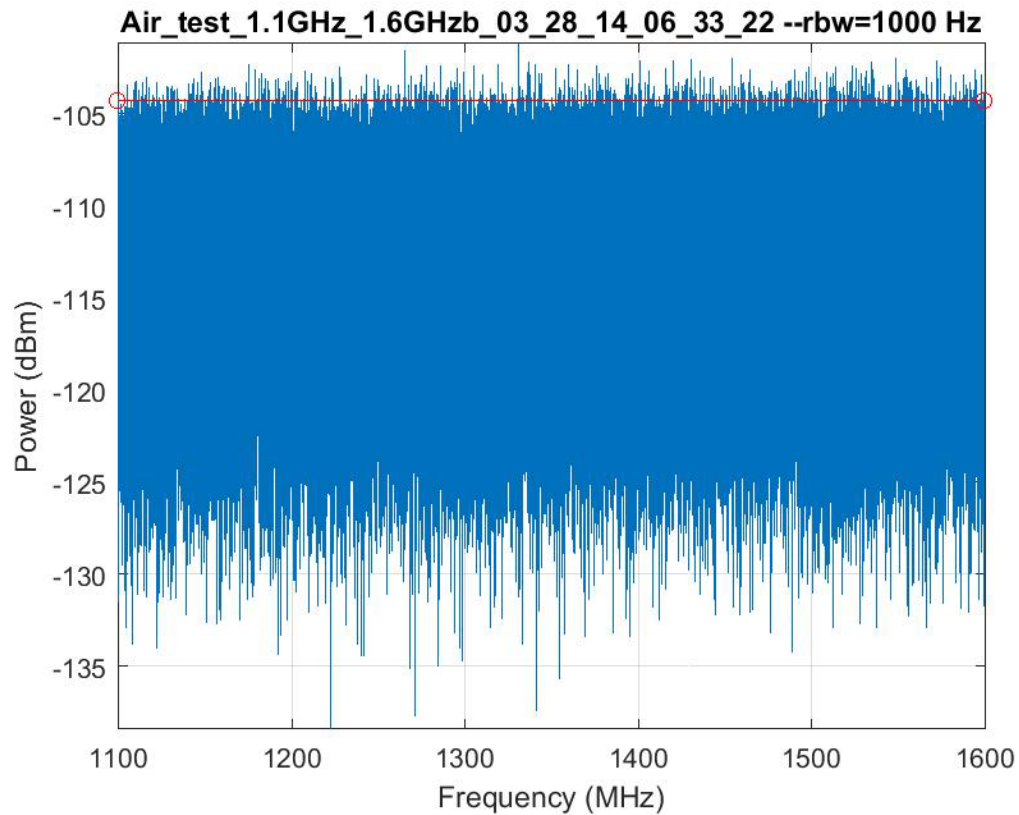
% Save results to data file

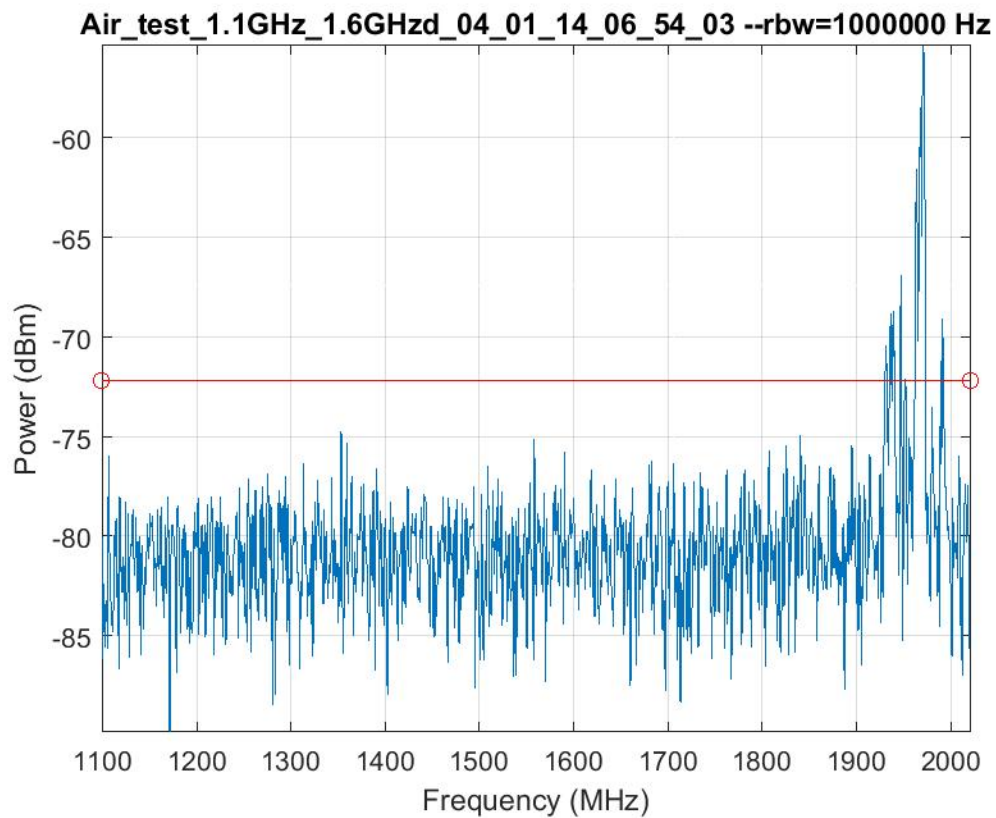
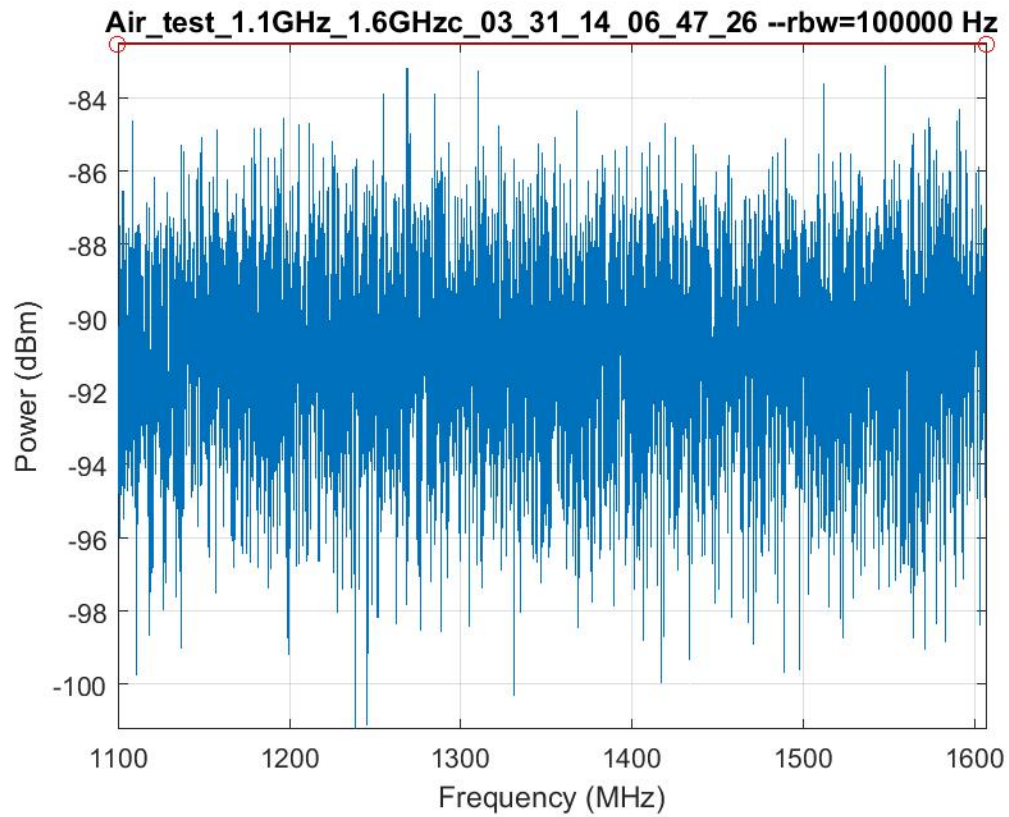
hold off;
lab = num2str(SELECT);
label = strcat('CME-Figure',lab, '.jpg');
saveas(gcf,label);

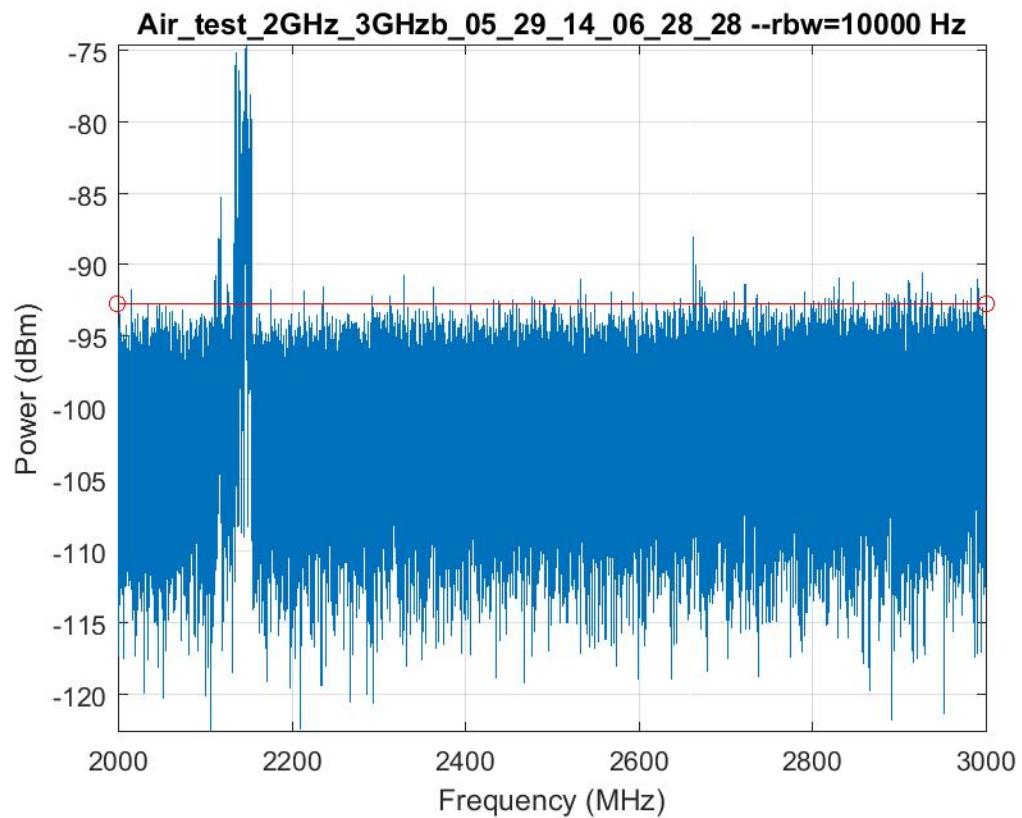
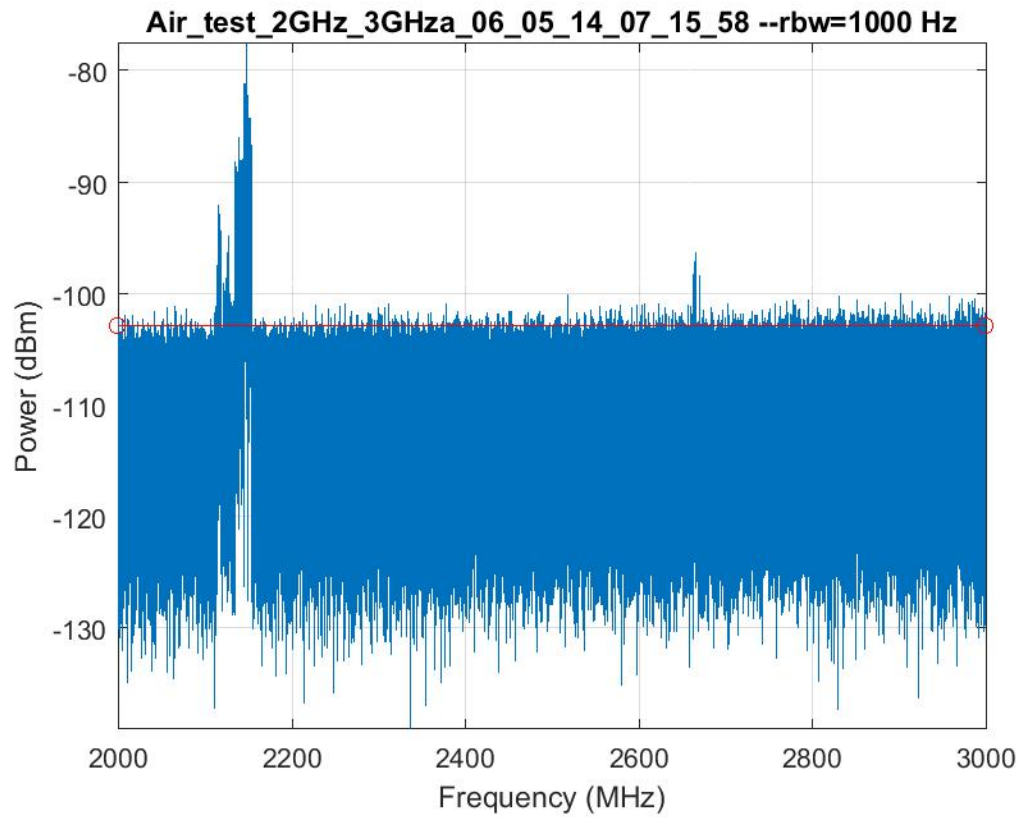
end

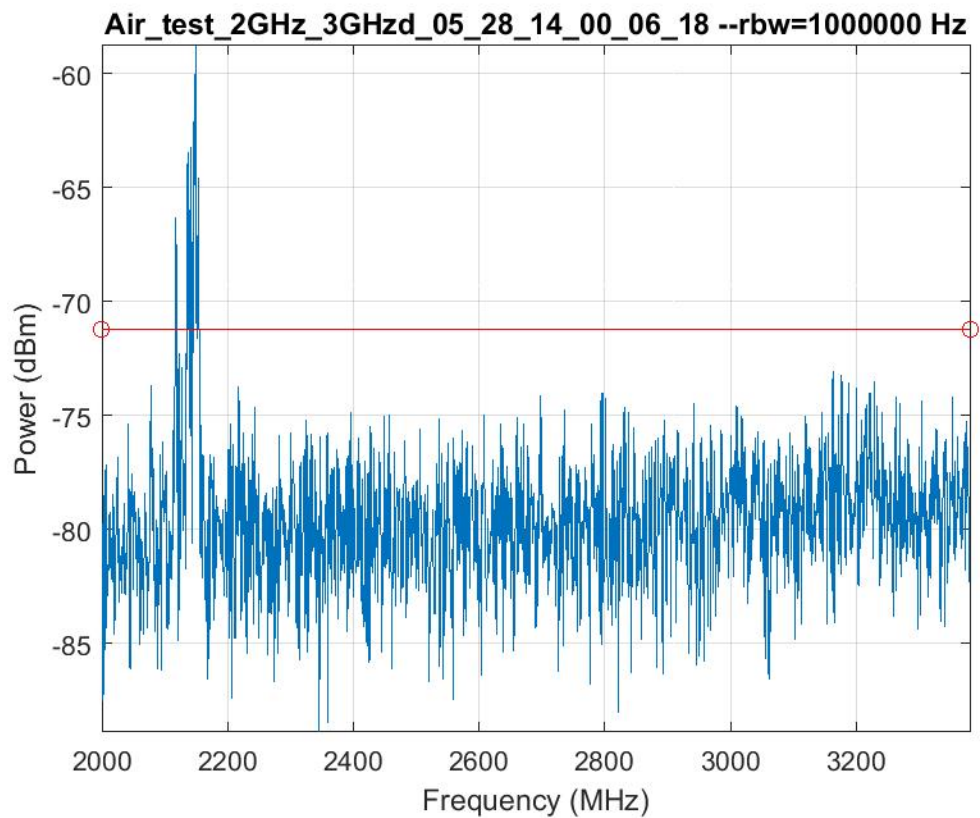
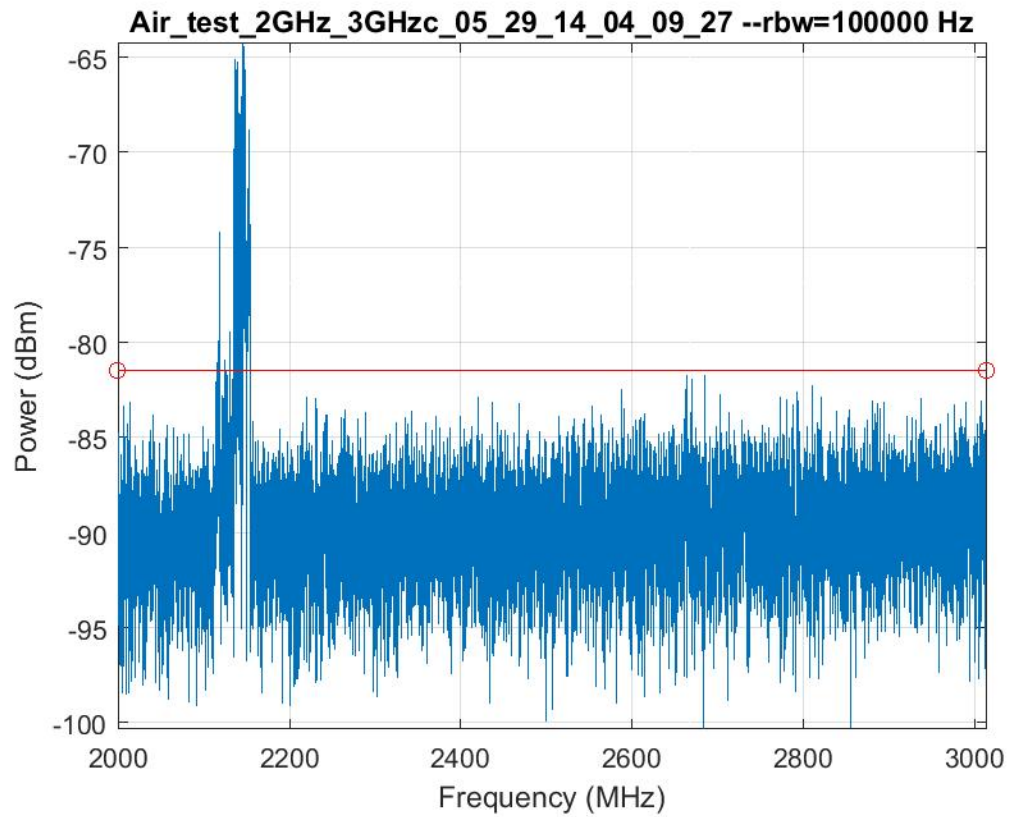
```

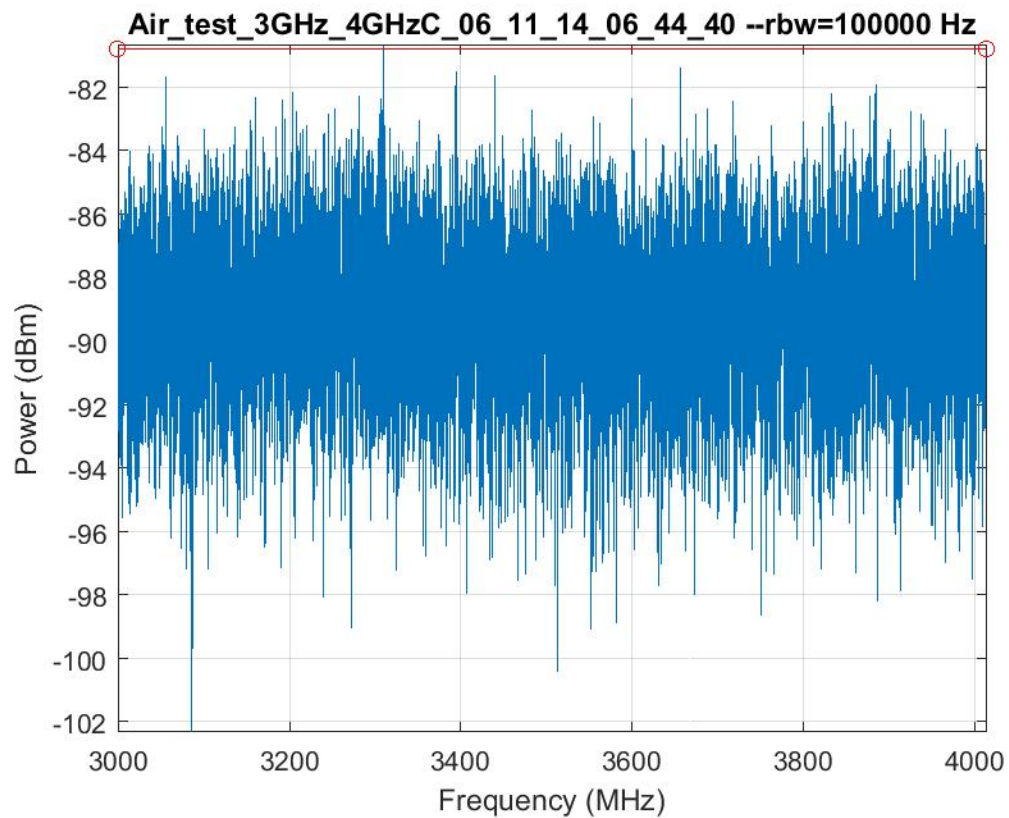
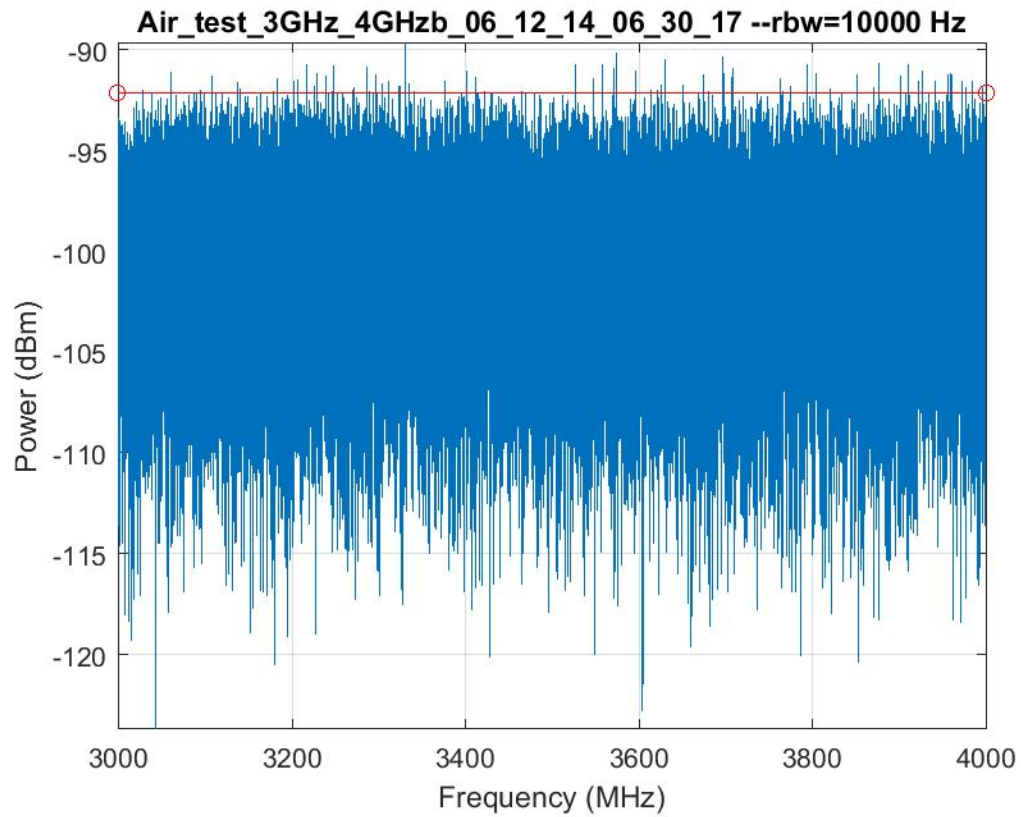

Appendix B. Graphs of RF Spectrum Files Calculated Detection Threshold

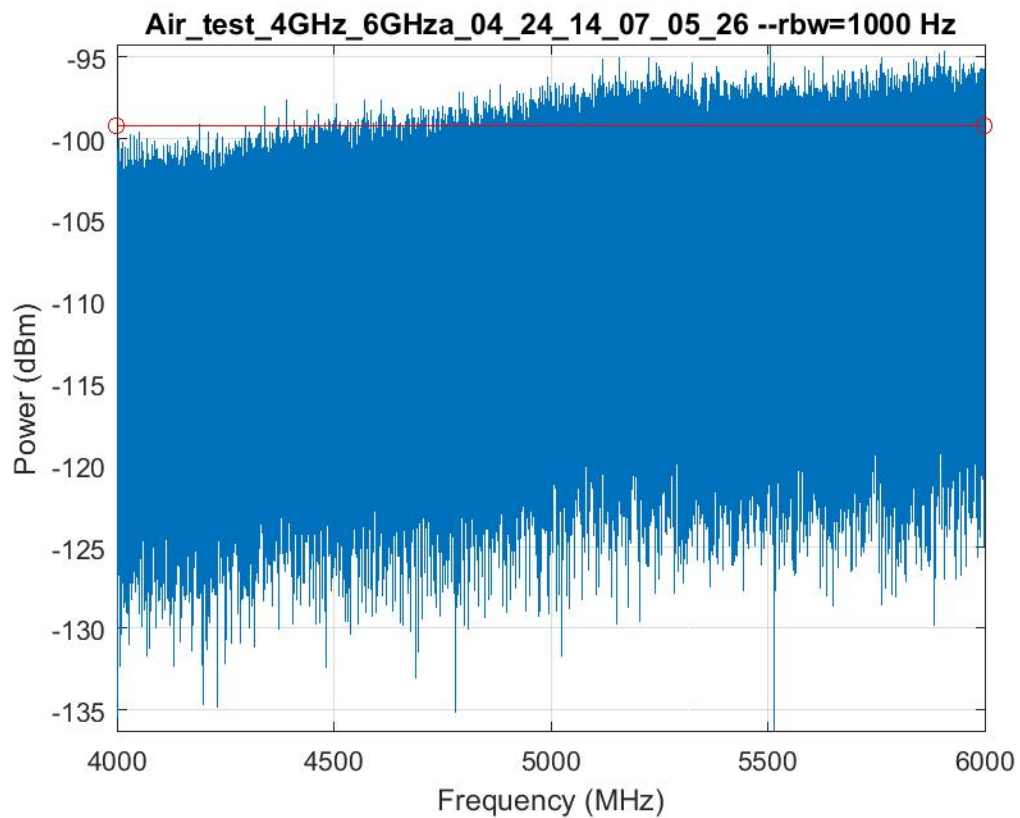
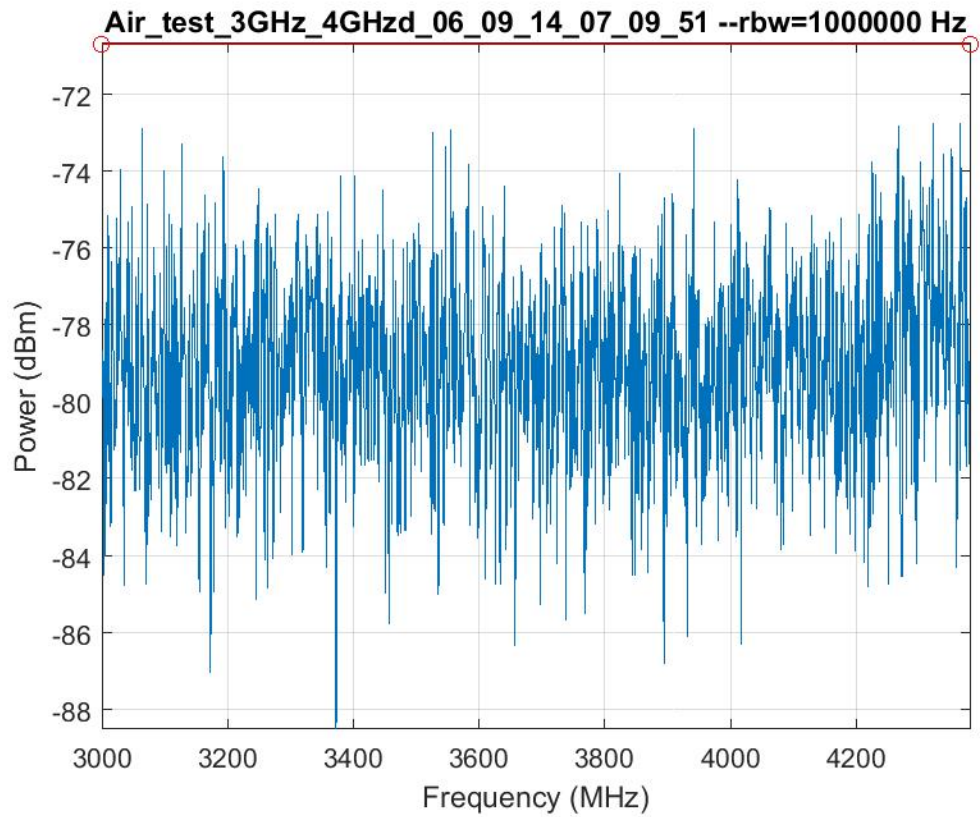


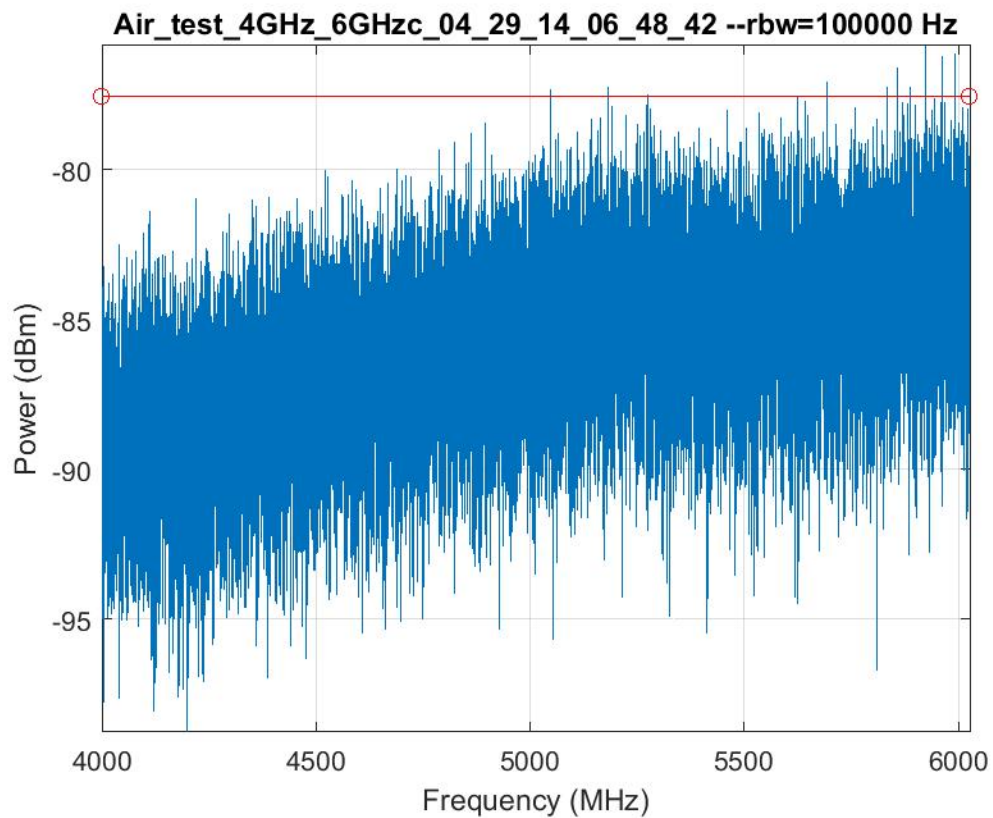
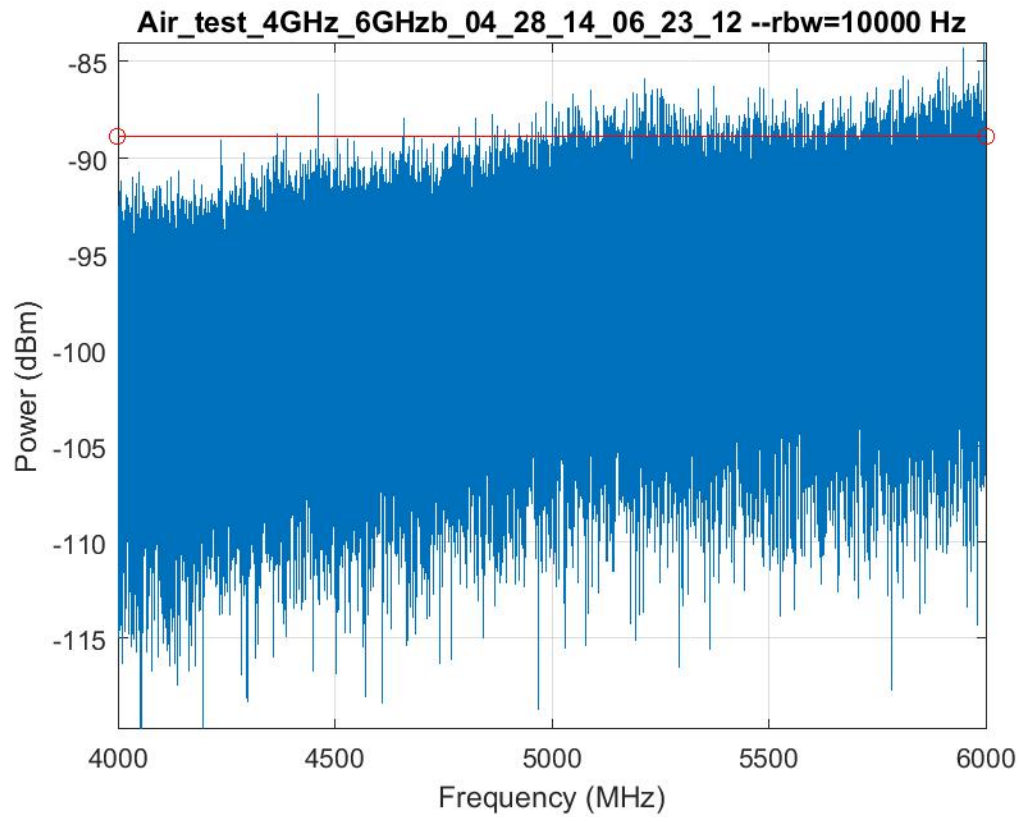


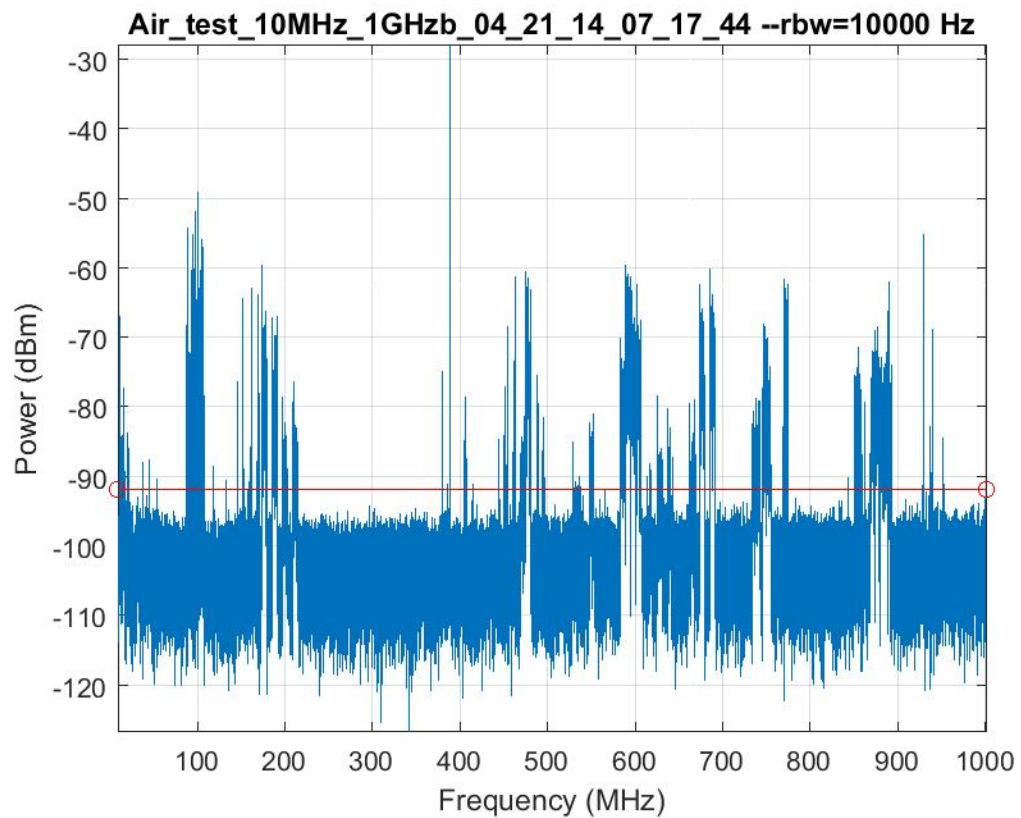
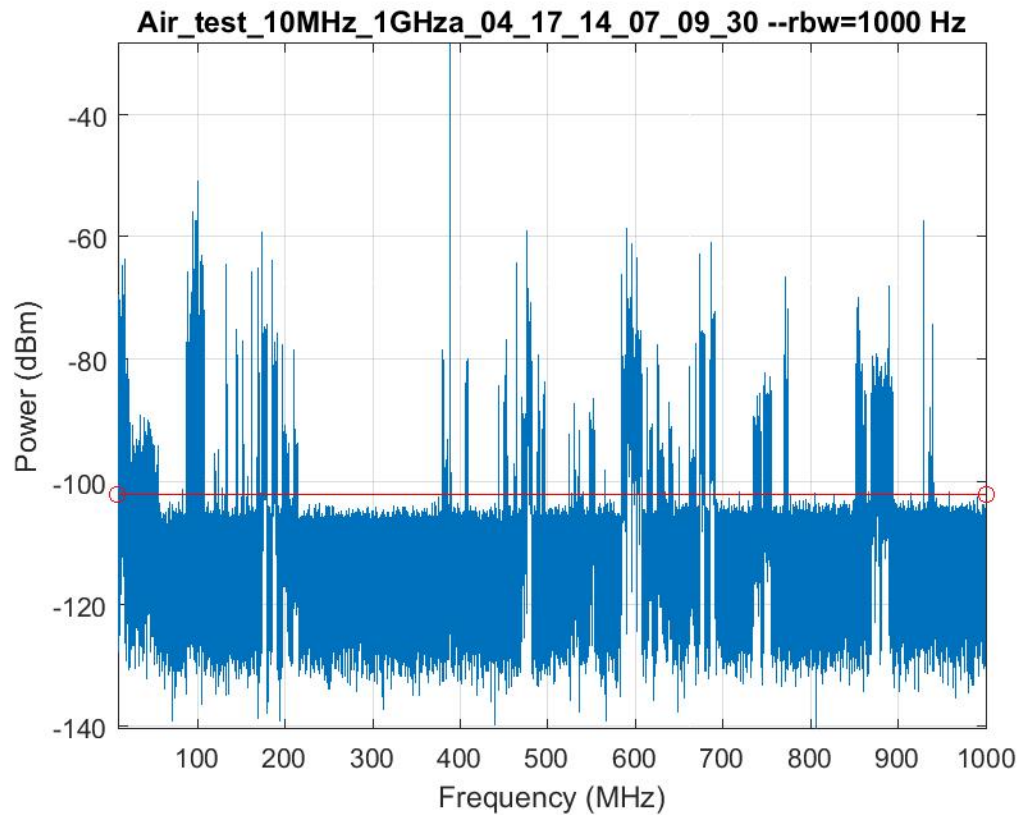


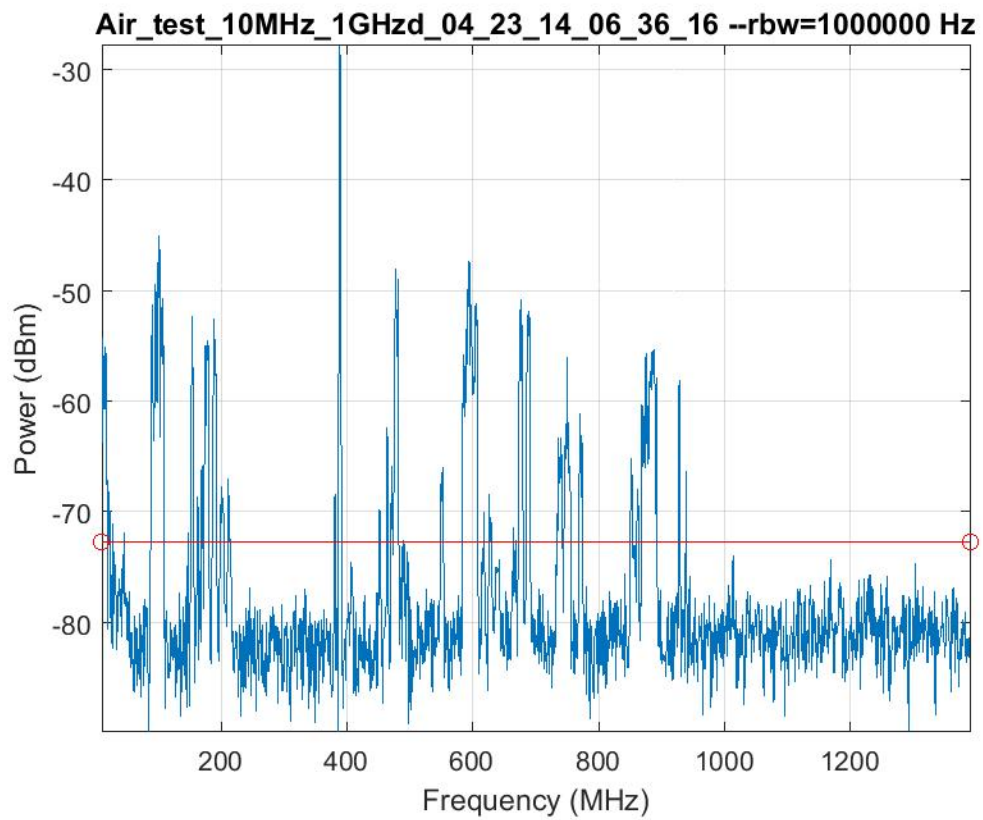
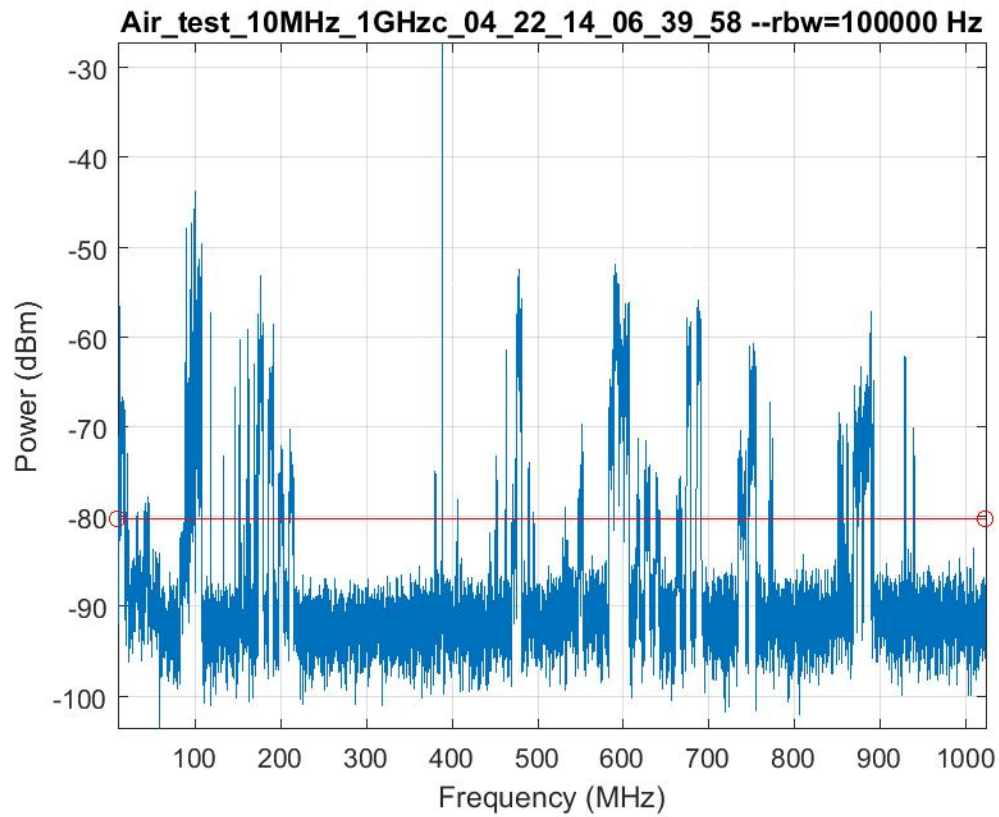


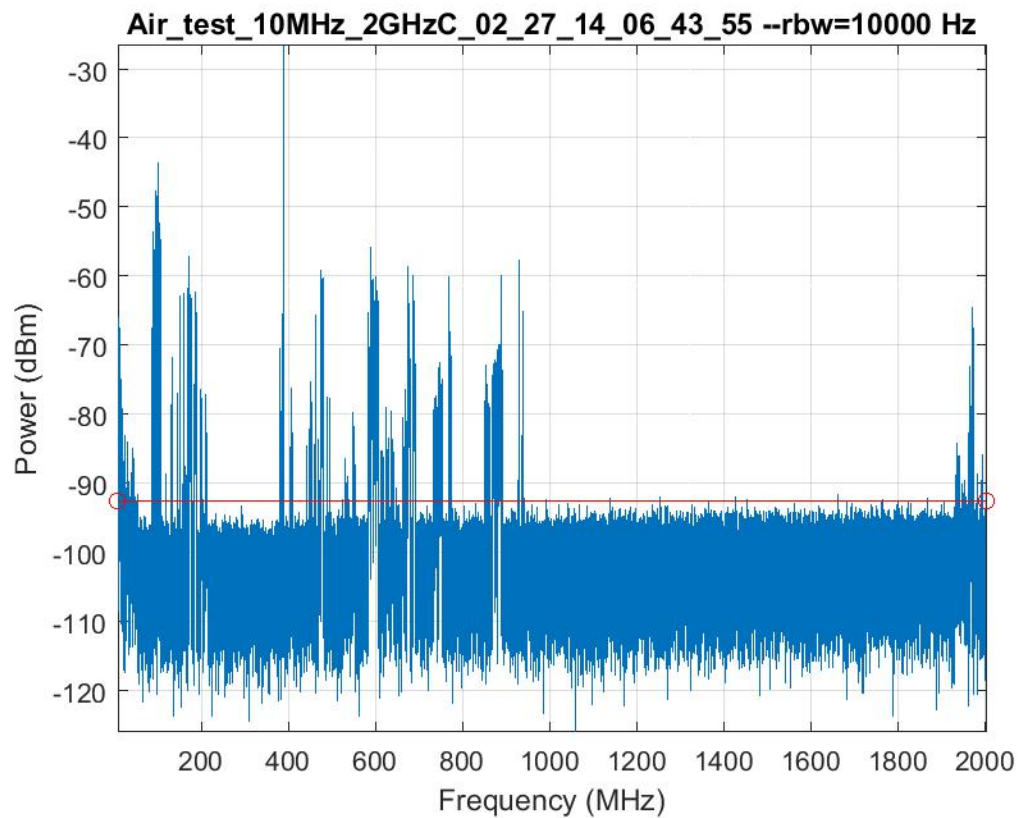
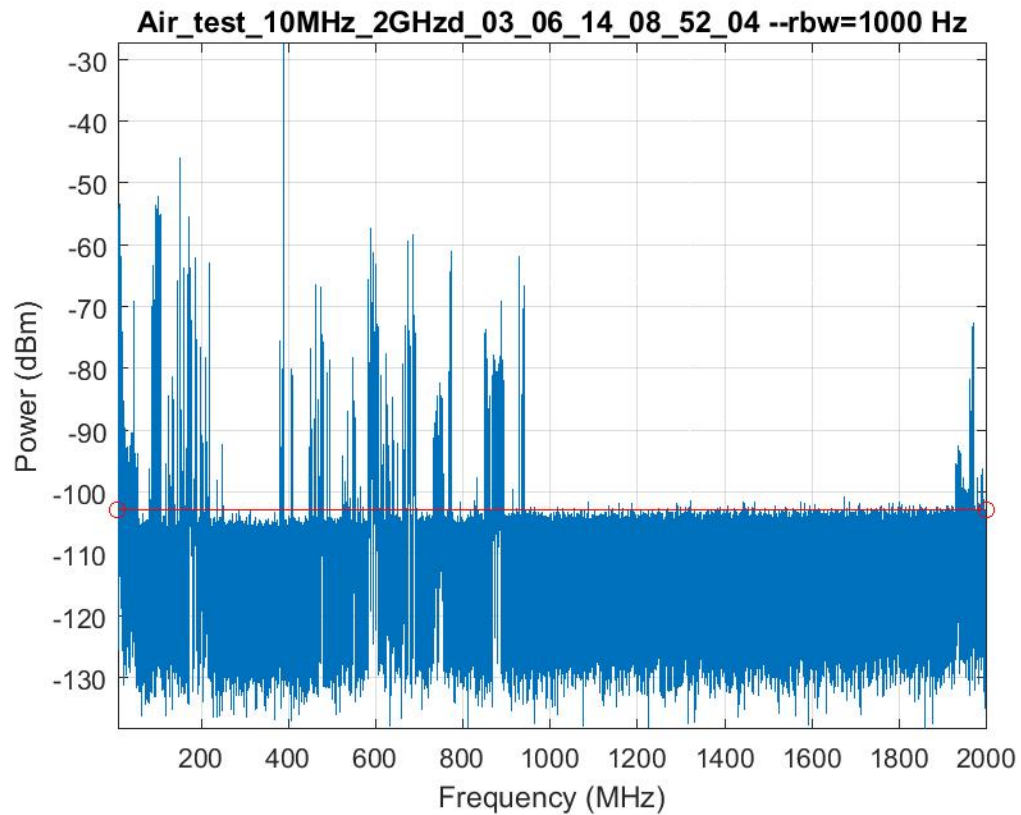


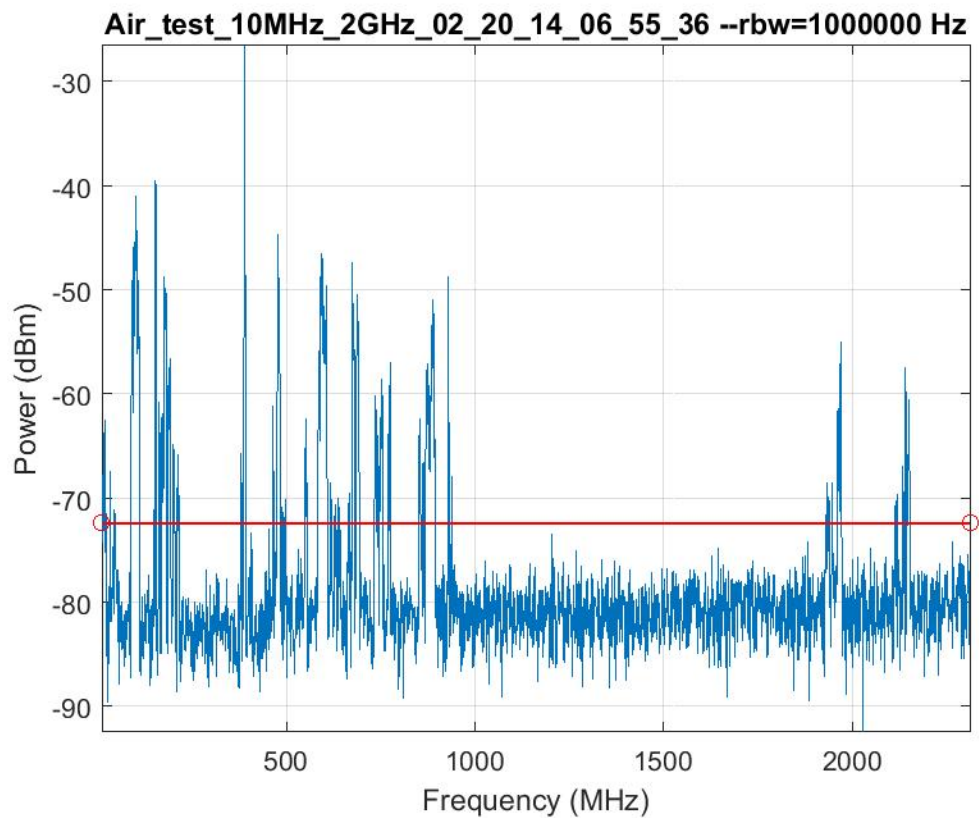
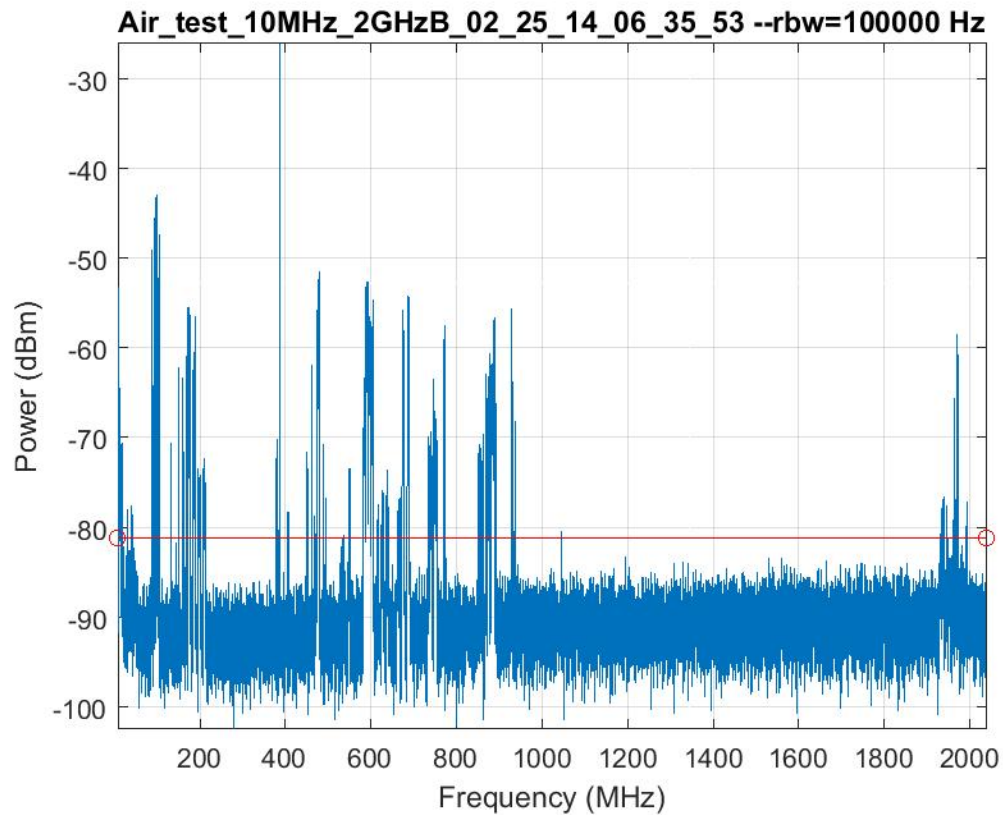


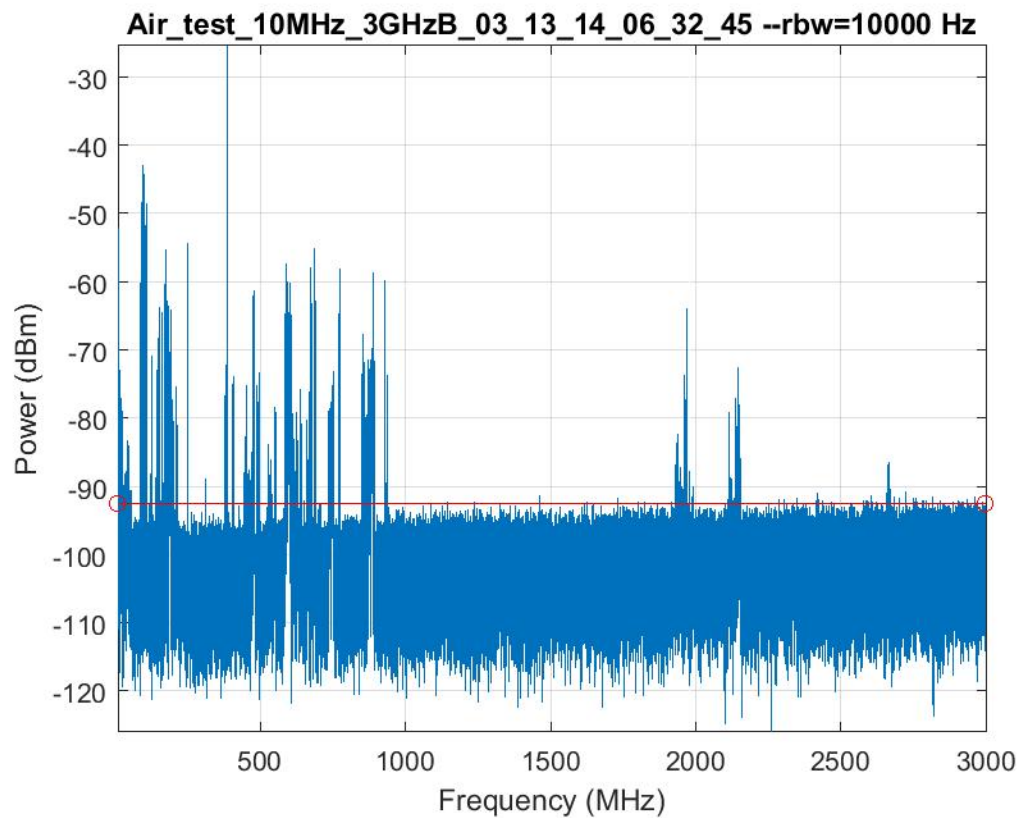
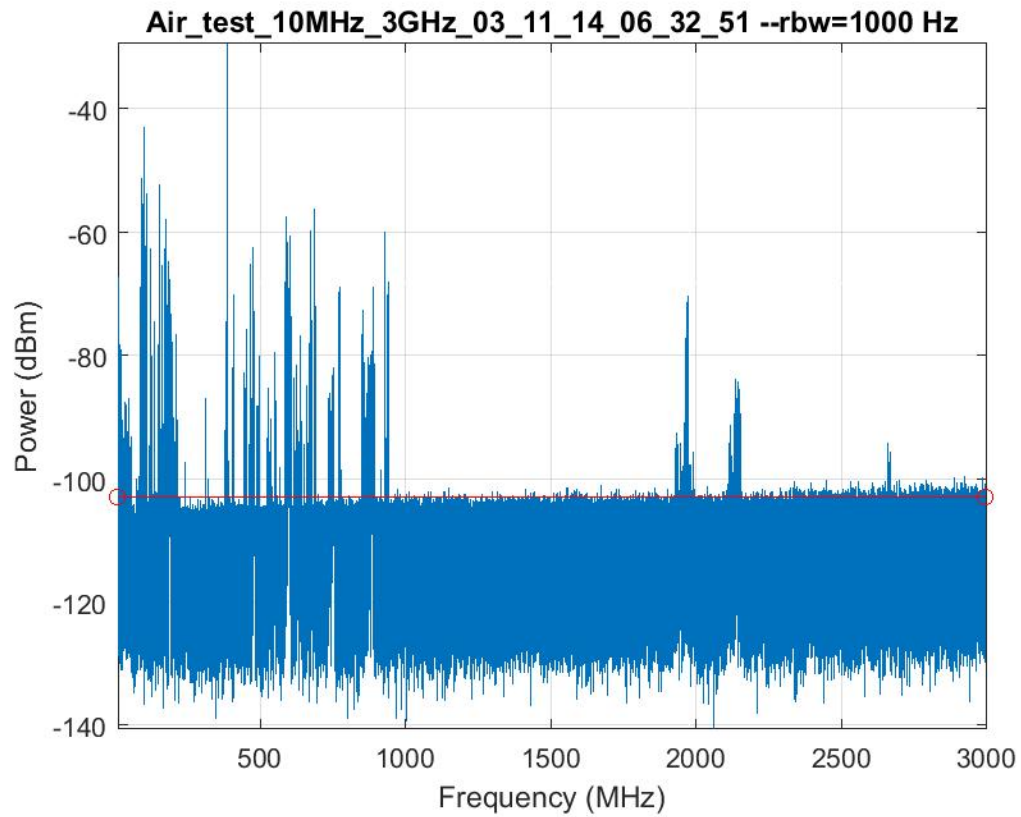


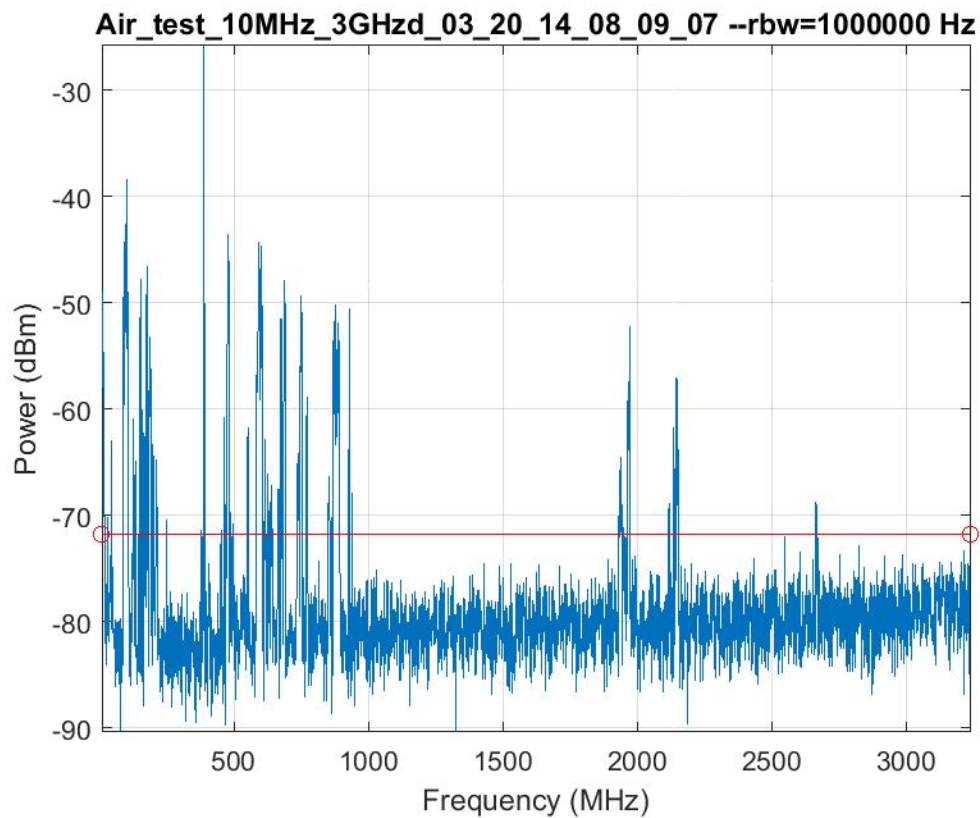
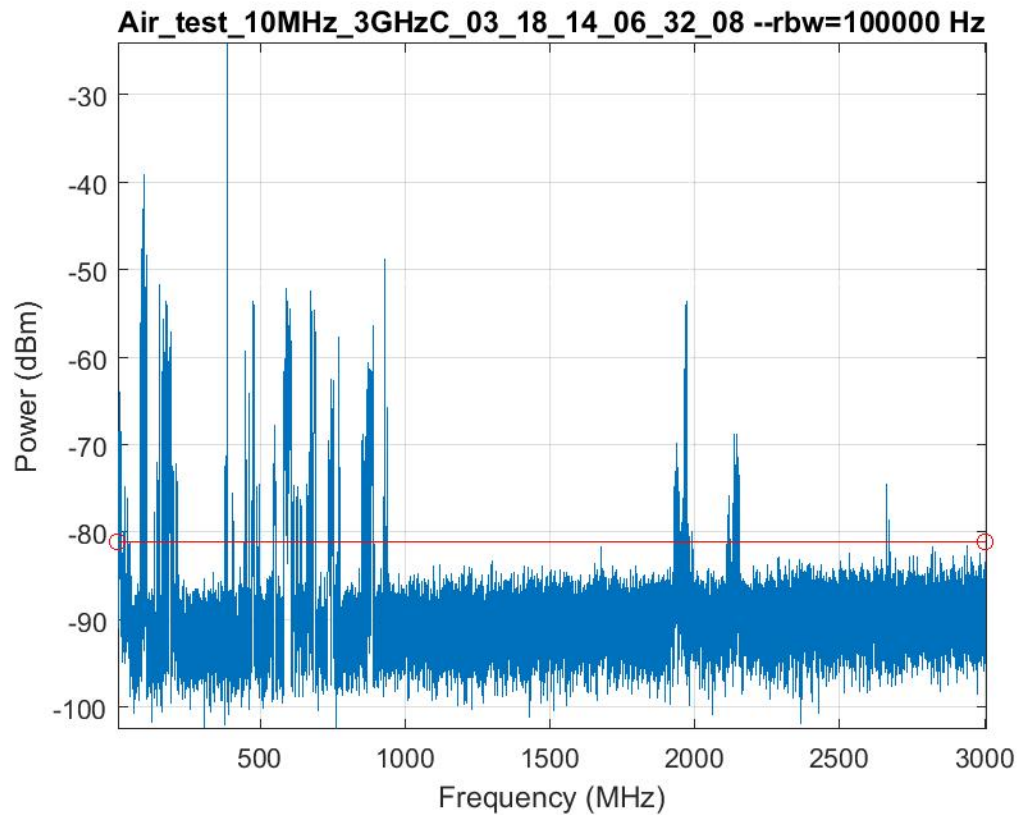


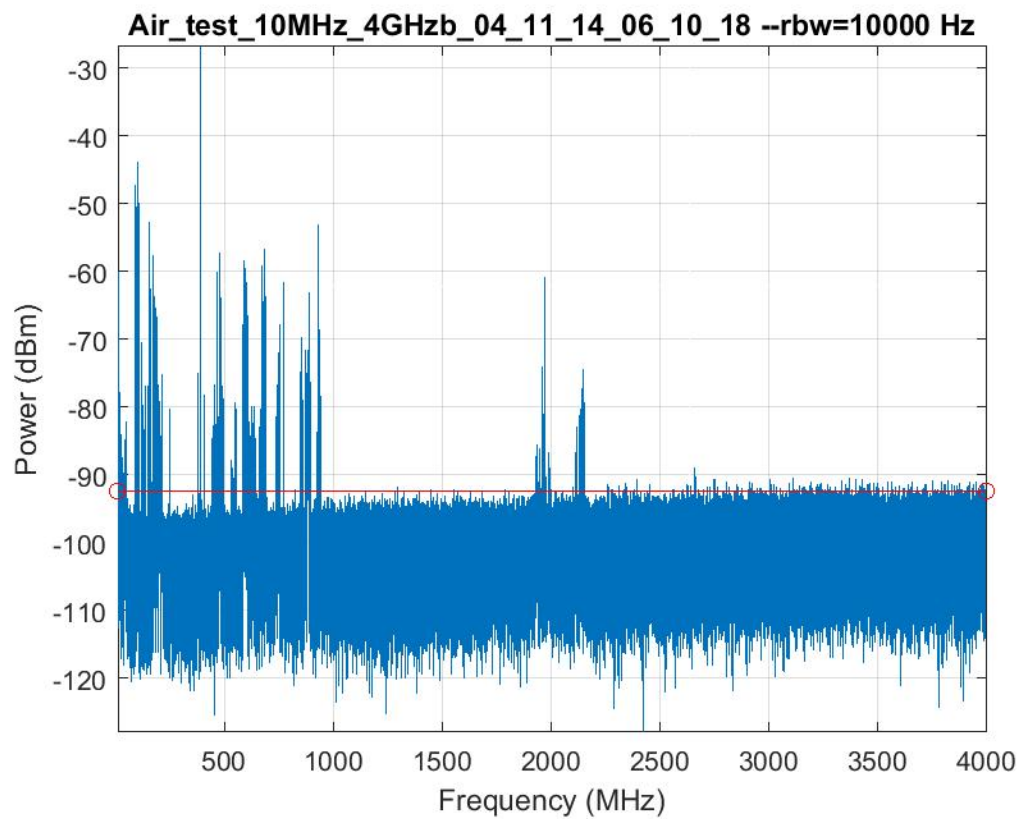
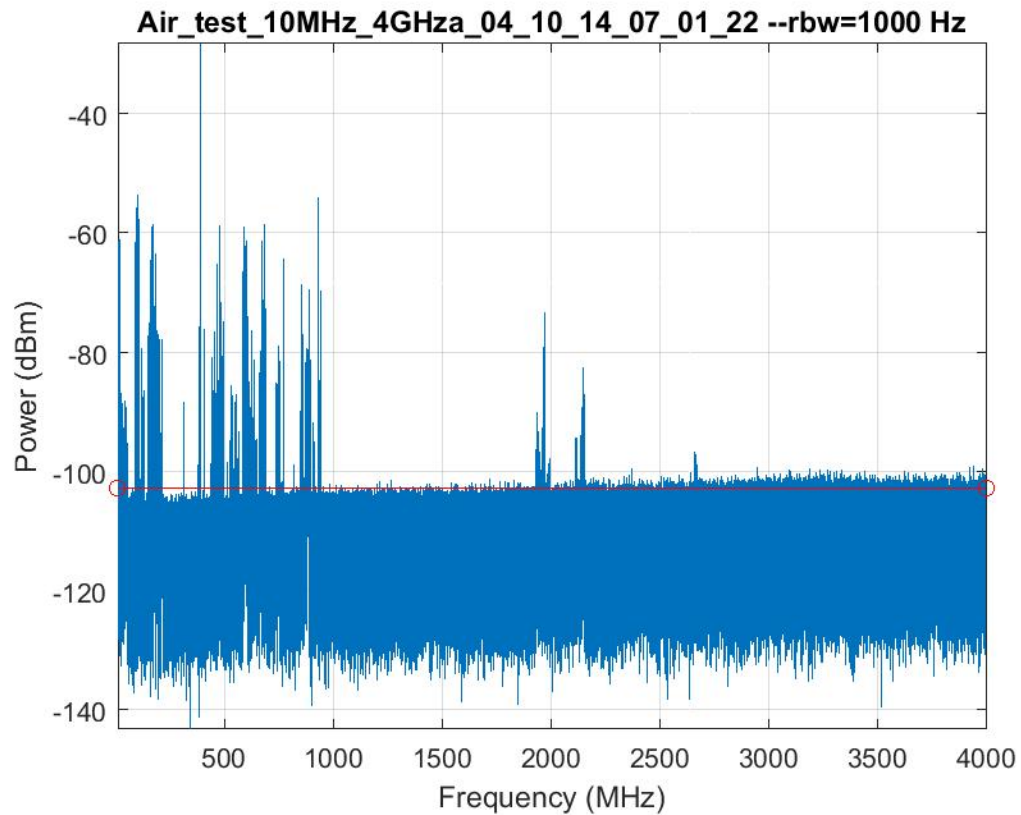


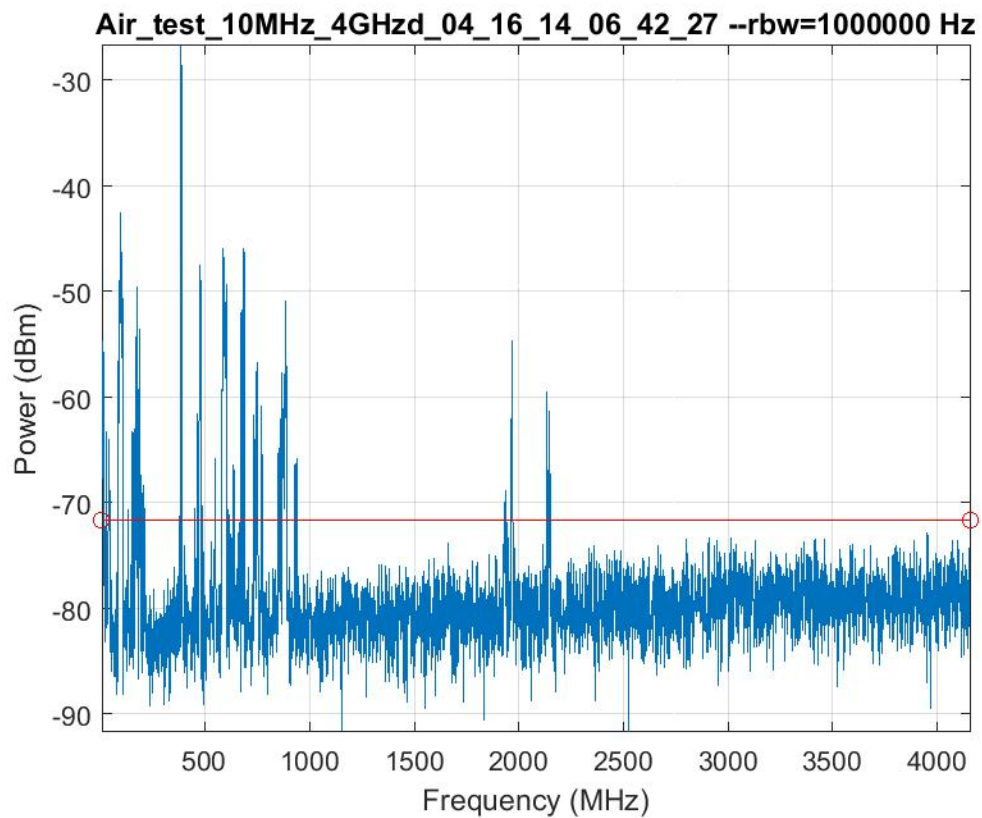
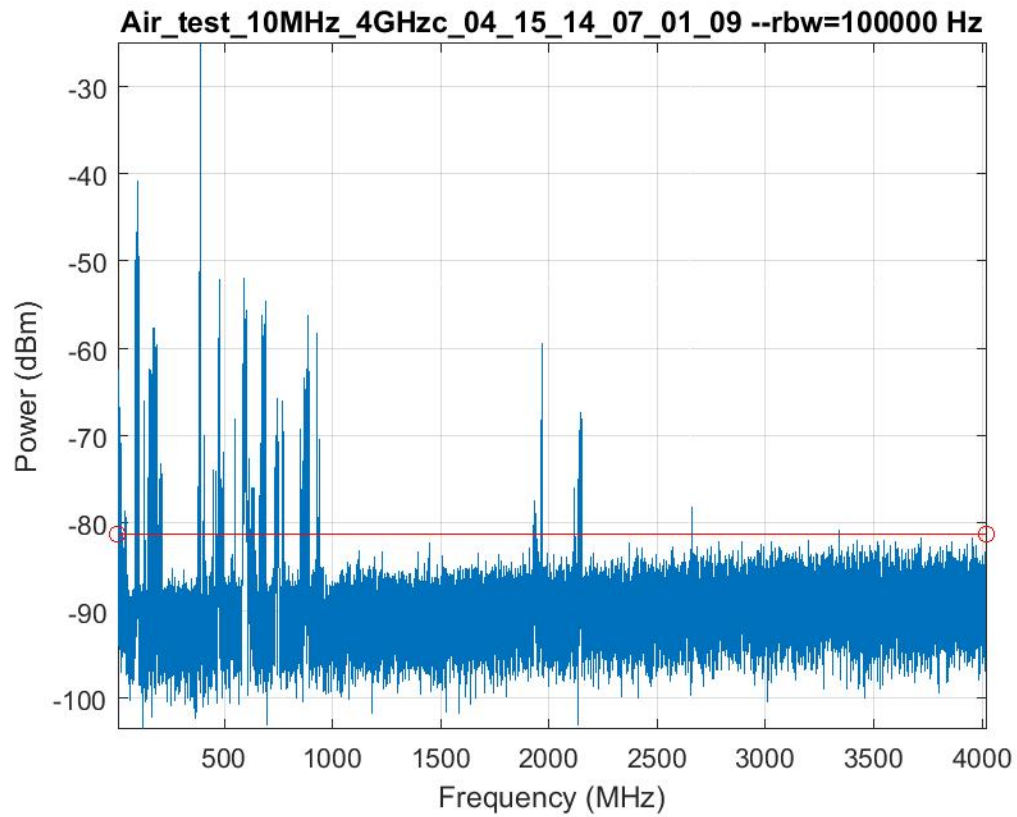


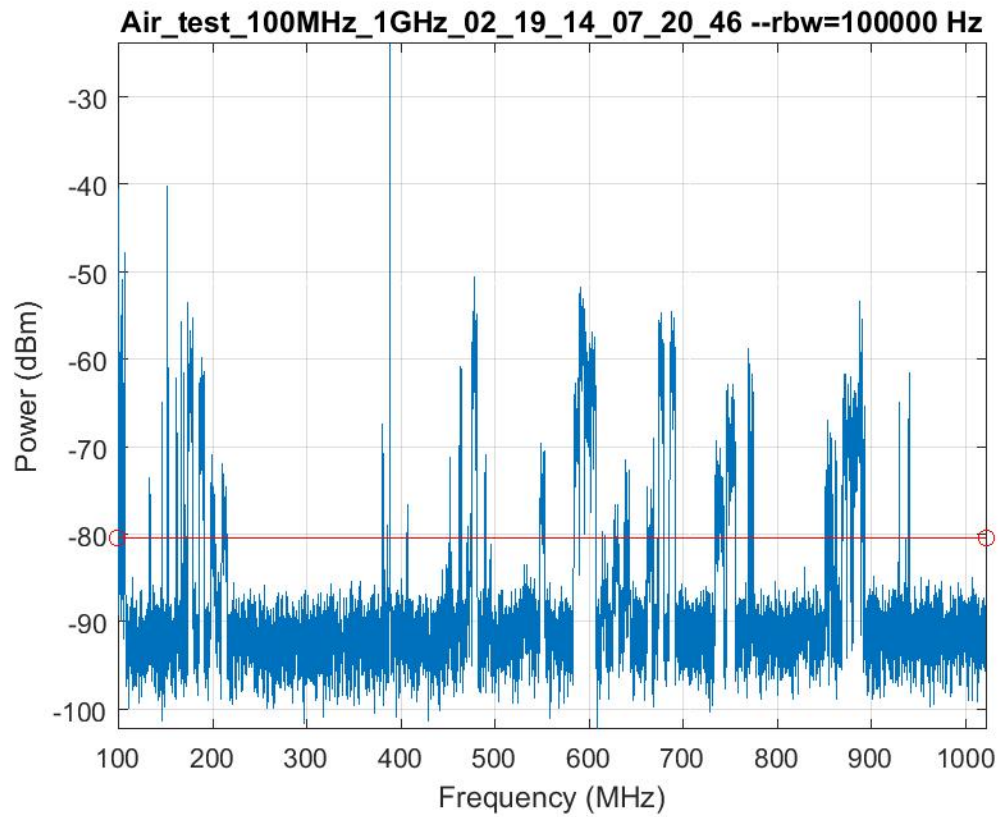












List of Symbols, Abbreviations, and Acronyms

ARL	US Army Research Laboratory
CF	crest factor
dBm	power ratio referenced to 1 milliwatt
GHz	gigahertz
kHz	kilohertz
MHz	megahertz
PDF	probability density function
RBW	resolution bandwidth
RF	radio frequency
ROF	rank order filter

1 DEFENSE TECHNICAL
(PDF) INFORMATION CTR
DTIC OCA

2 DIR ARL
(PDF) IMAL HRA
RECORDS MGMT
RDRL DCL
TECH LIB

1 GOVT PRINTG OFC
(PDF) A MALHOTRA

7 ARL
(PDF) RDRL SER E
M CONN
R DEL ROSARIO
K F TOM
D WASHINGTON
RDRL SER M
J SILVIOUS
RDRL SER U
A MARTONE
RDRL SER W
K RANNEY

INTENTIONALLY LEFT BLANK.