Initial Evaluation of the Performance of Prototype TV- Band White Space Devices

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Table of Contents

Executive Summary .... **vi**

1 Introduction **1**

1.1 TV Band Incumbent Uses *2*

1.2 Interference Concerns, and Test Objectives *3*

1.3 Test Scope and Approach *4*

1.3.1 Assessing Sensing Ability and Interference Potential with respect to Television Services 5

1.3.2 Assessing Sensing Ability and Interference Potential with respect to Wireless Microphones 6

2 White Space Prototype Devices **7**

2.1 Prototype A (Versions 1 and 2) *7*

2.2 Prototype B *10*

3 DTV Scanning/Spectrum Sensing Capability Tests **11**

3.1 Test Approach *11*

3.2 Bench Tests to Determine Minimum DTV Signal Detection Threshold *12*

3.2.1 Baseline Detection Threshold Tests (Single DTV Input Signal) 12

3.2.2 Multiple-Signal Detection Threshold Tests (Two DTV Input Signal). 15

3.3 Field Tests with Over-the-Air Signals *18*

3.3.1 Field Test Site 1 20

3.3.2 Field Test Site 2 25

3.3.3 Field Test Site 3 29

3.3.4 Field Test Site 4 33

3.4 Field Test Summary *37*

4 Transmitter Emissions Characterization Measurements **39**

4.1 Transmitter Description *39*

4.2 Measurement Approach *39*

4.3 Measurement Equipment Configuration *40*

4.4 Channel Consistency Test *42*

4.5 Fundamental Channel Emissions Measurements *44*

4.6 Out-of-Channel Emissions Measurements *46*

4.7 Emissions Characterization Data Summary *47*

5 Over-The-Air Interference Test **49**

5.1 Test Approach *49*

5.2 Test System *51*

5.3 Test Procedure *54*

5.4 Test Results *54*

6 Data Observations Relevant to TV Services **56**

6.1 Scanning/Spectrum Sensing Capability Tests *56*
6.1.1 Prototype A Results 56
6.1.2 Prototype B Results 57

6.2 Transmitter Emissions Characterization Measurements *58*

6.3 OTA Interference Test *58*

7 Wireless Microphones Measurements **59**

7.1 Introduction *59*

7.2 Sensing of Wireless Microphones by White Space Devices *61*
7.2.1 Prototype A Device 63
7.2.2 Prototype B Device 64

7.3 Interference to Wireless Microphones *66*

Appendix A – Measurement Systems **72**

Appendix B – Service Contours of TV Stations at Field Test Sites **74**

Figures

Figure 2-1. WSD Prototype A Sensing and Transmitting Device........ 9
Figure 2-2. Prototype B WSD........ 10
Figure 3-1. Baseline Detection Threshold Test Equipment Configuration. 13
Figure 3-2. Single-Signal Laboratory-Generated DTV Input. 13
Figure 3-3. Baseline Detection Threshold Results for Prototype A........ 14
Figure 3-4. Baseline Detection Threshold Results for Prototype B........ 14
Figure 3-5. Multiple (Two)-Signal Detection Threshold Test Equipment Configuration........ 16
Figure 3-6. Lab-Grade DTV Signals Used in Two-Signal Detection Threshold Tests (N-1)........ 16
Figure 3-7. Lab-Grade DTV Signals Used in Two-Signal Detection Threshold Tests (N+2)........ 17
Figure 3-8. Two-Channel Detection Threshold Test Results for WSD Prototype A. 18
Figure 3-9. Two-Channel Detection Threshold Test Results for WSD Prototype B........ 18
Figure 4-1. Fundamental Channel Measurement System (without BPF)........ 40
Figure 4-2. Fundamental Channel Measurement System (with BPF) 41
Figure 4-3. Adjacent Channel Measurement on WSD without filter........ 41
Figure 4-4. Adjacent Channel Measurement on WSD with Filter........ 42
Figure 4-5. Prototype A Transmitter Spectral Envelope Centered in Channel 21........ 43
Figure 4-6. Prototype A Transmitter Spectral Envelope Centered in Channel 36........ 43
Figure 4-7. Prototype A Transmitter Spectral Envelope Centered in Channel 51........ 44
Figure 4-8. Prototype A Fundamental Channel Emissions in Channel 30........ 45
Figure 4-9. Prototype A Emissions on Channel 30 and N±5 Adjacent Channels........ 46
Figure 4-10. Prototype A Spectral Envelope with and without Notch Filter. 47
Figure 5-1. Service Contour for WMPB-DT on Channel 29. 50
Figure 5-2. Measured DTV Signal in TV Channel 29 at DTV Test Receive Antenna Location........ 51
Figure 5-3. Test System Block Diagram. 52
Figure 5-4. Test Receive System........ 52
Figure 5-5. Prototype WSD Transmitter on Wheeled Cart........ 53
Figure 5-6. WSD Prototype Transmitter Downrange from Test Antenna........ 53
Figure 7-1. WM1 Wireless Microphone Spectrum Characteristics........ 60
Figure 7-2. WM2 Wireless Microphone Spectrum Characteristics........ 60
Figure 7-3. Simulated DTV Signal........ 61
Figure 7-4. Sensing Test Setup 62
Figure 7-5. Prototype A Device Transmit Spectrum........ 68
Figure 7-6. Interference Test Set Up........ 71

Tables

Table 2-1. Prototype A Manufacturer-Reported Scanner/Sensor Technical Specifications................ 8
Table 3-1. Broadcast TV Stations within Prototype Tuning Range (21-51) with Service Contours that Include Test Site 1.. 22
Table 3-2. Test Site 1 Field Survey Data.. 23
Table 3-3. Summary of Field Data Collected at Test Site 1 24
Table 3-4. Broadcast TV Stations within Prototype Tuning Range (21-51) with Service Contours that Include Test Site 2.. 26
Table 3-5. Test Site 2 Field Survey Data.. 27
Table 3-6. Summary of Field Data Collected at Test Site 2 28
Table 3-7. Broadcast TV Stations within Prototype Tuning Range (21-51) with Service Contours that Include Test Site 3.. 30
Table 3-8. Test Site 3 Field Survey Data.. 31
Table 3-9. Summary of Field Data Collected at Test Site 3 32
Table 3-10. Broadcast TV Stations within Prototype Tuning Range (21-51) with Service Contours that Include Test Site 4... 34
Table 3-11. Test Site 4 Field Survey Data.. 35
Table 3-12. Summary of Field Data Collected at Test Site 4 36
Table 3-13. Summary of Field Test Data with Prototype A Version 2.................................. 37
Table 4-1. Summary of Prototype Transmitter Channel Consistency Test Data. 44
Table 4-2. Summary of Emissions Characterization Data.. 48
Table 4-3. Summary of Emissions Characterization Data.. 48
Table 5-1. Available DTV Test Channels. 50
Table 5-2. Summary of OTA Interference Test Results.. 55
Table 7-1. Prototype A Sensing 63
Table 7-2. Prototype B Sensing with WM1 Microphone at Center of Channel 44........................... 64
Table 7-3. Prototype B Sensing with WM1 Microphone 50 kHz from Low End of Channel 44...... 65
Table 7-4. Prototype B Sensing with WM2 Microphone 200 kHz from High End of Channel 45... 65
Table 7-5. Prototype B Sensing - Channels Sensed As Occupied.. 66
Table 7-6. Co-channel Undesired Interference Power Level (dBm) 68
Table 7-7. Adjacent Channel Undesired Interference Power Level (dBm) for Simulated WSD Signals.. 69
Table 7-8. 1st and 2nd Adjacent Channel Prototype A Device Interference Power Level (dBm) 69

Executive Summary

Introduction. The Federal Communications Commission's (FCC) Laboratory has conducted a measurement study of the spectrum sensing and transmitting functions of prototype unlicensed low power radio transmitting devices that would operate on frequencies in the broadcast television bands that are unused in each local area. These locally unused frequencies are known as "white spaces." This research is part of the FCC's ongoing proceeding to consider rules for permitting such devices to operate on TV white spaces. As established previously by the Commission, fixed "white space devices" (WSDs) will be allowed into the TV spectrum simultaneous with the completion of the transition from analog to digital television broadcasts on February 17, 2009. The Commission is also considering whether to allow unlicensed "personal/portable" WSDs to operate in the TV spectrum.

One approach under consideration for determining the unused frequencies in local areas is for a WSD to employ a "detect and avoid" or "listen before talk" strategy. This approach would use "spectrum sensing" techniques that listen for the signals of TV stations, wireless microphones and perhaps other incumbent services. The Commission has requested comment on whether to require that the sensing capability of devices using this approach be able to detect signals as low at -116 dBm. A second issue is the potential for WSDs to interfere with TV reception and wireless microphone operations. To address these issues, the Commission announced that it would conduct testing of WSD spectrum sensing and transmitting capabilities.

This report presents an initial evaluation of WSDs based on tests performed on prototype devices submitted by industry for evaluation by the FCC Laboratory. We recognize, however, that the devices we have tested represent an initial effort, and do not necessarily represent the full capabilities that might be developed with sufficient time and resources. Accordingly, we are open to the possibility that future prototype devices may exhibit improved performance.

WSD Prototype Devices Submitted for Evaluation. The Office of Engineering and Technology in December 2006 issued a Public Notice inviting interested parties to submit WSD prototype devices for testing at the FCC Laboratory in Columbia, Maryland.[1] Two parties provided prototype personal/portable WSDs to the Laboratory for testing. The devices submitted by these parties are designated "Prototype A" and "Prototype B" herein; both have a sensing capability but only the Prototype A device has a transmitter. The test project was provided three units of Prototype A and one unit of Prototype B. These devices are not intended as actual consumer products but rather are development tools for evaluating the viability of spectrum sensing and potential interference. They do not communicate with other devices.

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[1] FCC Public Notice DA 06-2571, Office of Engineering and Technology Invites Submittal of Prototype TV Band Devices for Testing, ET Docket No. 04-186, December 21, 2006.

Spectrum Sensing of TV broadcasting signals. This portion of the study examined the ability of the prototype devices to detect whether channels are occupied by TV signals. Measurements were limited to TV signals on UHF channels 21-51, the operating range of the prototype devices. Both bench and field tests were performed for the Prototype A devices. Only bench tests were performed for the Prototype B device because the supplier formally declared that the device was not suitable for field testing and requested that it not be included in those tests.

The bench testing of the sensing function of the Prototype A device found that this device is generally not able to detect DTV signals on any of the tested channels at the -116 dBm/6 MHz level detection threshold for DTV signals on which the Commission requested comment or at the -114 dBm level detection threshold suggested by the device's manufacturer. Prototype A is able to detect DTV signals reliably, that is, in a very high percentage of instances, at levels of -95 dBm or higher. The testing found that the Prototype A device takes approximately 27 seconds to scan each channel, or approximately 14 minutes to scan the full range of all 31 channels that it covers.

Field testing was performed with one unit of the Prototype A device (the last unit submitted) in order to assess the scanning/sensing capability under "real-world" conditions. The selected unit of the Prototype A device was tested at a number of sites representative of typical residences where over-the-air television broadcasts, including DTV, are currently being received. The sample sites were limited to residences already set up for and receiving over-the-air (OTA) DTV broadcasts in order to provide a means for verifying the OTA stations (and associated RF channels) that could actually be successfully received at the site using a typical DTV receiving system. Several independent test locations were identified within each test site (*e.g.*, the tests were performed within several rooms of each house). In these tests the prototype's scanning feature was activated and the scanning results were recorded for each location.

The sensing field tests investigated the Prototype A device's performance with respect to two aspects: 1) correct identification of channels as occupied and 2) correct identification of channel as available, *i.e.*, unoccupied. The field tests also investigated performance in certain subcategories for identification of occupied channels: 1) detection of analog TV signals, 2) detection of DTV signals where the signal could not be received on the site's TV receiver (in these cases it was assumed that the signal strength at the site was too low for the TV receiver to receive the signal), and 3) detection of DTV signals where the signal could be received on site's TV receiver.

In general, the Prototype A scanner did not provide consistently accurate determinations on an overall basis or with respect to any of the subcategories in the field tests. First, these tests found that the Prototype A scanner often reports a channel to be available, or vacant, when the broadcast signal is expected to be present. The summary results for the four subcategories in this area of performance are (note that in all cases the test site was within the predicted service contour of TV signals considered):

1. In the cases where the NTSC signal is being broadcast, the scanner reports the channel to be free or available between 11.1% and 27.8% of the time, with the average of 19.4% of the time.
2. Where a DTV signal was being broadcast but was not received on the site's TV set, the scanner reported its channel to be free or available 81.3% to 91.7% of the time, with an average of 85.4% of the time.
3. Where a DTV signal was strong enough to be received on the TV, the scanner reported its channel to be free or available 40% to 75% of the time with an average of 58.2% of the time. These percentages are particularly high for Sites 3 and 4.
4. When no signal was expected to be present, the scanner reported the channel to be free or available from 78.1% to 91.7 % of the time, with an average of 85.2 % of the time.

With respect the Prototype B, the bench tests results indicate that, under Laboratory conditions, this device is generally able to reliably detect DTV signals at -115 dBm in the single channel tests and at -114 dBm in the two-channel tests. Prototype B's sensing performance declines very rapidly as the signal levels are reduced. The testing found that the Prototype B device takes approximately 8 seconds to scan each channel or slightly more than 4 minutes to scan the full channel range.

Spectrum Sensing of Wireless Microphones. The wireless microphone portion of the testing looked at the ability of the Prototype A and Prototype B sensors to scan for and detect Part 74 wireless microphones. It also looked at the susceptibility of wireless microphones to the signals emitted by the Prototype A transmitter and simulated broadband signals modulated using several alternative methods. Wireless microphone testing was conducted in the laboratory only; no field tests were performed for these devices. Bench tests of the Prototype A and Prototype B devices ability to sense wireless microphones were performed using signals generated by wireless microphones. These signals were coupled directly to the input terminals of the prototype devices. Wireless Microphone interference testing was performed using both simulated signals and signals from the Prototype A transmitter. Three different Part 74 wireless microphone systems were used in these tests.

The results of these tests indicated that the Prototype A was generally unable to sense wireless microphones. This device was tested with wireless microphone signals at various power levels and locations within a TV channel, and with and without the presence of a DTV signal on a different channel at different power levels. In many cases, the device incorrectly sensed the wireless microphone signal as a DTV signal. In view of the performance of the Prototype A device in the initial tests under moderate conditions, there appeared to be no additional insight to be gained at this time from testing this device under other conditions and so further measurements were not performed.

The performance of Prototype B device was mixed when tested in a variety of situations and conditions. This device was found to be able to sense wireless microphone signals located in the center of a TV channel in all scans at a signal levels as low as

-120 dBm. However, on some scans it also incorrectly indicated the presence of a microphone on channel 24. In addition, when the wireless microphone signal was at the -36.6 dBm level, Prototype B also incorrectly sensed wireless microphone signals on six additional channels. The testing further found that the device's ability to sense wireless microphones decreases somewhat as the location of the microphone signal is moved closer to the edge of the TV channel on which it operates. The test results show that Prototype A tends to make more false detections of microphone signals on adjacent channels as the power level of the operating microphone is increased. When tested in the presence of both DTV and wireless microphone signals the device also tends to make more false detections of DTV signals, analog TV signals, and wireless microphone signals as the level of the DTV signal increases.

Tests were conducted to characterize the susceptibility of Part 74 wireless microphone systems to possible interference from unlicensed WSDs. Before the Prototype A became available, this test project examined the potential for interference to wireless microphones using the three Part 74 wireless microphone systems and WSD signals that were simulated using an audio modulated FM signal, a wideband noise signal and a wideband OFDM signal. When the Prototype A WSD became available, it was tested for interference to a wireless microphone system. In these tests, interference was defined to occur at the point where the signal-to-noise plus distortion (SINAD) ratio reading at the audio output of the microphone receiver was 30 dB. The results show that in most cases the wireless microphones are generally at least 15 dB less susceptible to interference from the simulated WSD signals on first adjacent channels than on the same channel.

Transmitter Characterization and Interference Testing. Tests were performed to characterize the transmitter signal, which is an important element for assessing the interference potential of these devices. Field tests were performed to evaluate potential interference, however, for reasons explained below these tests were quite limited.

The Commission has proposed to establish an average limit on power at the fundamental frequency of a device in terms of an equivalent isotropic radiated power (EIRP) as integrated over the 6-MHz TV channel bandwidth. Measurements of the fundamental power were performed on a conducted basis (via a coaxial connection between the transmit antenna output port and the input to the measurement instrument). These measurements showed that the adjusted output power of the prototype as integrated over the 6-MHz TV channel is approximately 22 dBm, which is slightly higher than the FCC proposed power level of 100 mW (20 dBm) EIRP, assuming an omni-directional antenna. However, when operated with an external filter required to achieve compliance with FCC's current out-of-band emissions limits, the power level was seen to be approximately 14 dB lower, or 8 dBm.

The prototype devices that were submitted do not lend themselves to extensive field tests for evaluating interference potential. Moreover, only the Prototype A device included a transmitter and it operated independently of the sensing function. While the transmitter's power level can be adjusted manually, its maximum level was below the

FCC proposed power level of 100 mW EIRP when used with the required filter. Certain techniques that are claimed to reduce interference potential, such as adaptive power control and reducing the transmitter power based on measurements of DTV signal levels in adjacent channels, were not implemented in the prototype device. The time to perform scans of the TV channels, which took up to 14 minutes, also impacted the pace of testing.

The record in the Commission's rule making proceeding includes differing views as to the appropriate analytical models and criteria that should be used to evaluate the interference potential of WSDs. This includes discussion of the signal levels that should be protected, physical relationship and separation distances between the devices, assumed path losses, etc. A large number of field tests would be required to be statistically valid relative to the scenarios and assumptions in the record. We anticipate the technical arguments will be fully explored in the Commission's rule making and that the data from this report will be one factor, together with a complete analysis of the record that is taken into account in arriving at a decision on final rules.

However, this project conducted limited, or anecdotal, tests in the field of the prototype WSD transmitter to provide information on its potential to interfere with TV reception. These tests were performed in a large outdoor area to evaluate the performance with an unobstructed line-of-sight (LOS) propagation path between the WSD transmit antenna and the DTV test receiver antenna. A test DTV receiver was placed in the area and connected to an indoor antenna with the antenna oriented towards a DTV transmitter on channel 29. The WSD transmitter was then placed in the "mainbeam" of the receive antenna, tuned to the same channel, and activated at incremental distances from the DTV receive antenna while observing for interference effects to the picture quality. Tests were also performed with the WSD tuned to a first (N+1) and second (N+2) adjacent channel. These adjacent channel tests were performed both with and without the use of the external transmit filter. Co-channel interference with the WSD transmitting without the transmit filter was observed out to a distance of 87 meters. First adjacent-channel interference with the WSD transmitting without the external filter was observed out to a distance of 47-50 meters, and second adjacent-channel interference was observed at a distance of 11-14 meters. First adjacent-channel interference with the external transmit filter applied was observed at a maximum distance of 2 meters, but as indicated above, the transmit power with the filter attached is attenuated by an additional 14 dB. In practice, the distance at which adjacent channel interference occurs would be expected to be greater if the device were operating at the proposed output power level of 100 mW EIRP.

Conclusions. This report determined that the sample prototype White Space Devices submitted to the Commission for initial evaluation do not consistently sense or detect TV broadcast or wireless microphone signals. Our tests also found that the transmitter in the prototype device is capable of causing interference to TV broadcasting and wireless microphones. However, several features that are contemplated as possible options to minimize the interference potential of WSDs, such as dynamic power control and adjustment of power levels based on signal levels in adjacent bands, are not

WM1 microphone signal on channel 49 at 680.125 MHz, which is 125 kHz from the low end of channel 49. In these tests, the device was again used to scan all channels from 21 to 51 searching for DTV, analog TV, and wireless microphone signals. The results of these tests with the microphone signal at -114 dBm and a variable DTV signal level are shown in Table 7-5.

Table 7-5. Prototype B Sensing - Channels Sensed As Occupied

DTV Power dBm	DTV Channels (48)	Analog TV Channels (none)	Microphone Channels (49)
-28	48,49,50	47,48,49,50	33,34,44,45,46,51
-53	48,49	48,49	47,50
-68	48	48	27,47,49,50
-84	48	48	44,46,49

On this table, the number in parentheses at the head of the column is the correct response. The device correctly identified the presence of DTV signal on channel 48 but also incorrectly indicated the presence of DTV signals on channels 49 and 50 when the DTV signal on channel 48 was at -53 dBm and higher. It incorrectly indicated the presence of an analog TV signal on the channel occupied by the DTV signal at all levels of the DTV signal actually present and also incorrectly indicated the presence of analog TV signals on other channels, especially as the level of the DTV signal present was raised. The prototype correctly sensed the wireless microphone only at the two lowest DTV power levels and incorrectly sensed its presence on several other channels at all power levels. In a separate trial in which the device was instructed to scan only channel 49 and to search only for microphones and with the microphone on channel 49 at -114 dBm and a DTV signal on channel 48, it correctly sensed the microphone signal on channel 49 over the DTV signal power range -28 to -84 dBm.

7.3 Interference to Wireless Microphones

Tests were conducted to gauge the susceptibility of Part 74 wireless microphone systems to possible interference from unlicensed WSDs. Before the Prototype A device became available, this test project first examined the potential for interference to wireless microphones using the three Part 74 wireless microphone systems described above and WSD signals that were simulated using an audio modulated FM signal, a wideband noise signal and a wideband OFDM signal. When the Prototype A WSD became available, it was tested for interference to a wireless microphone system. In these tests, interference was defined to occur at the point where the signal-to-noise plus distortion (SINAD) ratio reading at the audio output of the microphone receiver was 30 dB. The desired wireless microphone signals were modulated at 1000 Hz with 24 kHz deviation level and were input to the receiver at -80 dBm. The microphone transmitter spectrum characteristics for the System 1, 2, and 3 signals are shown in Figures 7-1 and 7-2. The undesired signals were: 1) an FM signal audio modulated with a 400 Hz tone at 24 kHz deviation, 2) a white Gaussian noise signal with a 3 dB bandwidth of 5.4 MHz, and 3) an OFDM signal with a 3 dB bandwidth of approximately 4.75 MHz. The signal from the Prototype A device was an OFDM signal with a 3 dB bandwidth of 4.125 MHz as shown in Figure 7-5. No additional filtering was used because no filters were available for the channels on which the wireless microphones operated.

Testing was performed using the test setup of Figure 7-6. Preliminary tests revealed that the Prototype A device was very susceptible to direct pickup of the RF signal from the microphone. It was therefore necessary to isolate the microphone from the Prototype A device and the test equipment. The test procedure consisted of modulating the microphone as specified and adjusting the band power to -80 dBm input to the microphone receiver. The undesired signal input to the receiver was then increased until the SINAD decreased to 30 dB as indicated on the audio analyzer. The band power of the undesired signal at the input to the receiver was then recorded. Tests were made for co-channel and first and second adjacent channel interference. For co-channel tests the desired signal was located near the center of the TV channel. For adjacent channel tests the desired signal was located near the center or the upper or lower edge of a TV channel and the undesired signal was located in the first or second adjacent channel nearest to the desired signal. The test results are shown on Tables 7-6, 7-7 and 7-8.

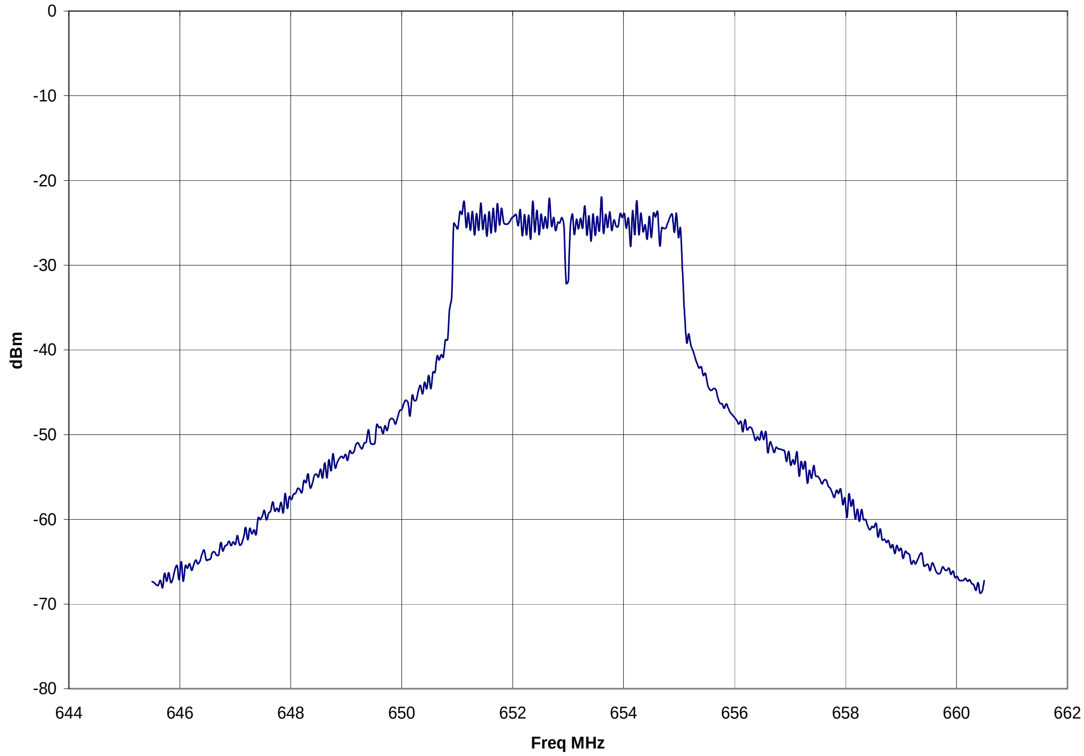

Figure 7-5. Prototype A Device Transmit Spectrum

Table 7-6 below shows the undesired signal power level for each type of signal above which the SINAD was less than 30 dB for co-channel interference for each microphone transmitter and receiver combination. Note that the power level for the undesired signals, except the FM signal, is for a wideband signal as compared to the relatively narrowband desired signal. The power of the broadband signals (noise, ODFM and Prototype A) is spread over a wider bandwidth compared to the FM signal. The difference in the power level below is because of the difference in the occupied bandwidth.

Table 7-6. Co-channel Undesired Interference Power Level (dBm)

Microphone	WM1	WM1-2	WM2	WM3	WM3-2
System	1		2	3	
FM	-87.0	-87.0	-88.0	-87.5	-87.0
Noise	-75.4	-75.3	-88.0	-74.3	-74.3
OFDM	-76.1	-76.0	-88.9	-74.2	-74.2
Prototype A	-76.5		-89.0	-76.7	

Table 7-7 shows the undesired signal power level above which the SINAD was less than 30 dB for first adjacent channel interference from the simulated WSD signals. In some cases the desired signal was lost before the SINAD indication decreased to 30 dB as the undesired signal level was increased. The undesired FM signal was located 50 kHz from the edge of the desired signal channel nearest to the desired signal. These measurements show wide variability in the microphone systems' susceptibility to both FM and wideband signals. These results show that in most cases the wireless microphones are 15 dB or more less susceptible to interference from the simulated WSD signals on first adjacent channels than on the same channel. As might be expected, the results for System 1 also show that this system tends to be more susceptible to an undesired signal on an adjacent frequency closer to the frequency used by the system. However, the System 1 measurements at the closer 50 kHz spacing show less susceptibility to interference than the wideband measurements for Systems 2 at greater frequency spacings.

Table 7-7. Adjacent Channel Undesired Interference Power Level (dBm) for Simulated WSD Signals

Microphone	WM1		WM2	WM3
System	1		2	3
Distance of desired signal from edge of channel	50 kHz	200 kHz	200 kHz	200 kHz
FM	-89.9	-22.8	-46.9	-45.0
Noise	-60.3	-55.4	-70.1	-51.5
OFDM	-26.0	-24.3	-35.9	-16.3

Table 7-8 shows the results from measurements with the Prototype A device operating in the first and second adjacent channels. These measurements show that wireless microphones susceptibility to interference from Prototype A's signals decrease significantly as the frequency difference between the desired and undesired channels increases.

Table 7-8. 1st and 2nd Adjacent Channel Prototype A Device Interference Power Level (dBm)

Microphone	WM1			WM2		WM3	
System	1			2		3	
Distance of desired signal from edge of channel	50 kHz	200 kHz	Center	200 kHz	Center	200 kHz	Center
1st Adj Channel	-51.8-	-52.6	-38.7	-63.3	-48.5	-51.5	-37.3
2nd Adj Channel	-32.0	-30.4	-28.4	-48.7	-35.4	-31.5	-27.4

Beside the white space device power level, the two main factors that determine the susceptibility of wireless microphone systems to interference from those devices are the RF spectrum occupied by the undesired signal and the selectivity of the microphone receiver. The spectrum characteristics of the Prototype A device as delivered to the FCC Laboratory for testing is as shown in Figures 7-5 above. The interference susceptibility data in Table 7-8 demonstrates the effect of these two factors. In all cases, interference occurs at lower device power levels when the microphone operating frequency is 200 kHz from the channel edge closest to the undesired signal than when it is at the center of the TV channel in which it is operating. This is caused by the out-of-channel skirts of the device spectrum. However, System 2 suffers interference at lower device power levels because of the wider selectivity of its receiver.