

WiFi Measurements & GMS Analysis

**Conducted at the
Various Off Season Events**

**October 17, 2015
thru
November 14, 2015**

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Overview:

There **have** been discussions, and concerns raised over the last year plus regarding the potential interference of WiFi devices to the FIRST Field Management System—specifically the use of the GMS¹.

Both systems operate using standard WiFi frequencies in compliance with the current IEEE 802.11 (n) Specifications and Protocols in the 5 GHz band.

The data reported herein quantifies the results of numerous conversations with interested parties, and actual field measurements made at the following off seasons events:

Duel on the Delaware	Salem Community College (Carneys Point, NJ)	October 17, 2015
Brunswick Eruption	North Brunswick High School)	November 7, 2015
Ramp Riot	Wissahickon High School, Ambler, PA	November 14, 2015

The anecdotal information obtained from numerous personnel associated with the competitions was a key consideration in selecting the test equipment complement and testing criteria used for all tests.

It was anticipated that one or more of the following conditions might be causing the problems during the game play:

- 1) The GMS operation was directly interfering with the FMS during game play
- 2) The overall WiFi spectrum was being saturated by the attending public
- 3) Teams or others associated with the event were using WiFi APs² that caused on-channel interference
- 4) The various venue's WiFi systems were saturating or channel hopping onto or near the GMS operation.

Confident that any interference could be observed and quantified, the next steps were to develop the test criteria and conduct measurements are various venues to test for differing field conditions.

The following Observations and Recommendations are based upon the collected data and analysis of same. The supporting data follows these sections.

Overall Analysis:

An analysis of the collected data from all three competitions at different venues clearly demonstrates that the GMS system, operating at the channel spacing and normal and heavy data rates shown herein, does not interfere with the FMS operating at the measured channels in normal operation.

Even in the instances when the GMS system artificially flooded the venue with large data file transfers the spectrum measurements show adequate isolation between the two systems.

The FTA did not notice any data transmissions issues between the FMS and the robots. The latency displayed for all stations was consistently under 2 ms (typically 0 ms) even though the GMS AP was on a 5 GHz channel throughout the event.

I must stress that the GMS data flooding test were an **artificial condition** that will never happen during normal operation. It was an effort to determine whether such a high data rate would infringe on the lower channels.

Also, problems encountered with the FMS operations not related to the testing or the GMS forced the cancellation of the anticipated interference testing of the GMS and FMS with the flooded data due to time constraints at the Duel on the Delaware.

The following observations apply to the tests detailed herein:

- 1) The resident WiFi background activity at a venue is low enough not to cause a problem to either FMS or GMS.
- 2) If the resident system has significant energy in the FMS band then either the venue has to rechannel their system or the FMS has to rechannel its operation. Because of the significant amount of WiFi concentration in the FMS bandwidth during competitions almost any additional WiFi traffic will most likely contribute to the degradation of the FMS operation. This has nothing to do with GMS operation but with general WiFi usage by the attending public.

1. Game Management System
2. Access Points

Overall Analysis: (cont'd)

- 3) No entity, including FIRST can block or inhibit WiFi operations in any manner. The FCC has issued some very strict rulings on this issue that any blockage violates 47 U.S.C. § 333 of the Communications Act, as amended. In one case, Marriott was fined in excess \$600K. Granted these were against public corporations and as some of the venues are schools, one cannot comment on the liability.
- 4) The low data rates involved with the GMS system has nothing to do with any data issues with the FMS operation.
- 5) The technical facts as detailed in the WiFi report stand on their own merit, as the tests can be repeated at any venue with similar results ("Similar" because the background WiFi system has an impact on the overall measurements).
- 6) The GMS equipment and operations DOES NOT interfere with the FMS operation in any way.

Recommendation on Technology:

MAR should consider purchasing equipment used in these tests to serve as a reference point for competition venues. This allows MAR to investigate the WiFi spectrum to ascertain the residual energy and any potential interference to the FMS operation.

The IT and/or MAR personnel at the appropriate school or venue can witness in real time, demonstrations of congestion or significant data usage for possible resolution. The FMS and GMS channels can possibly be shifted to a section of the spectrum not exhibiting congestion.

This would eliminate ambiguity during event setup, and game play reducing scheduling delays as a result of the FMS being off-line.

The capital outlay for the test configuration is:

Ubiquiti Bullet	\$75.00
MobileMark Antenna	\$185.00
Tripod	<u>\$75.00</u>
Total:	\$335.00

Any laptop running Firefox or a similar web browser with Java enabled can be used to connect to the Bullet.

The setup and operation of the proposed system takes approximately 15 minutes. The system allows data retention for archival purposes.

Test Criterion:

Various methodologies were discussed in group with following protocol being able to measure the real world conditions on the playing field:

- “Interfering” Transmitters: Multiple pad-type devices will be used as WiFi transmitters and at a distance from the FMS transmitter. These are the same pad computers used for the GMS so that any potential interference is generated by the actual devices.
- WiFi Monitor: A Ubiquiti Bullet WiFi AP will monitor the entire FMS area. It will not transmit but will measure and display signal strengths and data transmissions in the 5 GHz WiFi band.

Periodic display snapshots will serve as records of the measured data. FMS statistics; e.g., latency, lost packets, etc. for the corresponding periods will be obtained from the field and logged.
- GMS AP Unit: One GMS access point will be installed to operate with the tablets for queuing. The AP will be located in the gaming area not close to the field but within range to serve as a realistic potential interfering source.
- GMS System: The GMS was used for queuing only. The test configuration consisted of multiple tablets for queuing and 2 tablets for load testing.
- Measurements: The protocol is multifaceted - to procure the most data without interfering with the games being the main objective.

The FMS will be using a few channels in the low range. The proposed tests should not adversely affect the FMS; however, test will immediately stop if requested by the FTA.

The measurement criteria is:

- A pseudo-base line measurement of the environment without, or with minimal, people using personal computing devices. It is impossible to obtain a true “no PCD³” measurement environment as the site was populated by a large number of students and guests nearly all operating PCDs.
- The Wide Band Test: Make band measurements from 5.180 to 5.825 GHz to identify any existing WiFi energy that could interfere with the FMS operations.
- The Narrow Band Test: Make band measurements to show the the operating channels for both the FMS and GMS operations. The smaller band segment allows for more specific data collection.

These measurements will serve to exonerate any residual WiFi energy from PCDs and the school’s resident WiFi system.

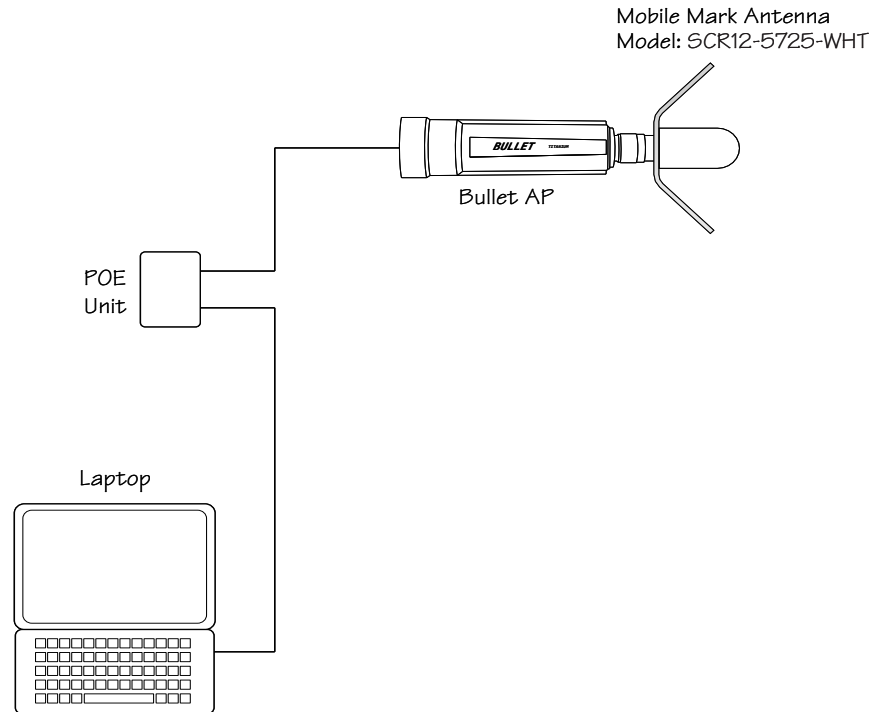
- The recording of several measurements of the FMS system operating in competition mode with the GMS system running over an hour period.
- A test which floods the GMS channels. This is accomplished using a wired laptop and 4 tablets operating centered on a specific channel and exchanging about 50 Mbits/sec, on demand. While this may not saturate the channel, it is significantly more data than the typical GMS usage and will serve to show if any energy is encroaching upon the FMS channels.

In all instances, the measurements made during the match had the advance approval of the FMA at each venue.

3. Personal Computing Device; e.g., iPad, Android device, etc.

Test Configuration:

The test configuration consisted of:



The above arrangement allows a simple technique to test repeatability and measurements using standard WiFi equipment. As can be seen there are no data routers, switches, etc. in the measurement system to possibly corrupt or alter the measured data and energy.

The WiFi AP⁴ is the Bullet series as manufactured by Ubiquiti Networks and was specifically selected for:

- The ability to add antennas with different patterns and gain.
- It is the preferred AP for the GMS upon deployment.
- The Ubiquiti Networks AirView application which transforms the Bullet AP into a spectrum viewer in the 5 GHz frequency band. This application measures and displays:
 - Aggregate energy collected.
 - Real-time Energy is shown in real-time as a function of frequency and depicts the volume of data transmitted during the measurement period.

The Bullet AP connects directly, thru the system POE⁵ unit, to the laptop's Ethernet port for data capture and display. The AP unit connects directly to the rear of the antenna *via* an N-type RF coax connector.

The antenna bracket in-turn supports both the AP and the antenna on the 8' high tripod assembly.

The selected antenna is manufactured by Mobile Mark and exhibits the following specifications:

Model:	SCR12-5725-WHT
Gain:	12 dBi @ 5.72 to 5.93 GHz
Front-to-Back Ratio:	30 dB or better
Beamwidth:	35° Elevation
	25° Azimuth

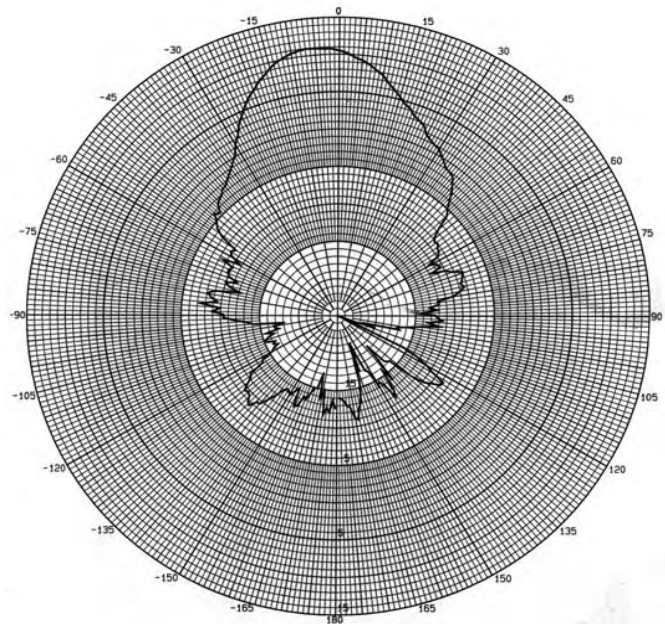
4. Access Point

5. Power Over Ethernet device which powers the Access Point separately from the computer's Ethernet port.

Test Configuration:

The corner reflector antenna insures that the energy under measurement is from the field as the antenna high front-to-back ratio significantly attenuates energy from the sides and rear as shown in this horizontal radiation pattern:

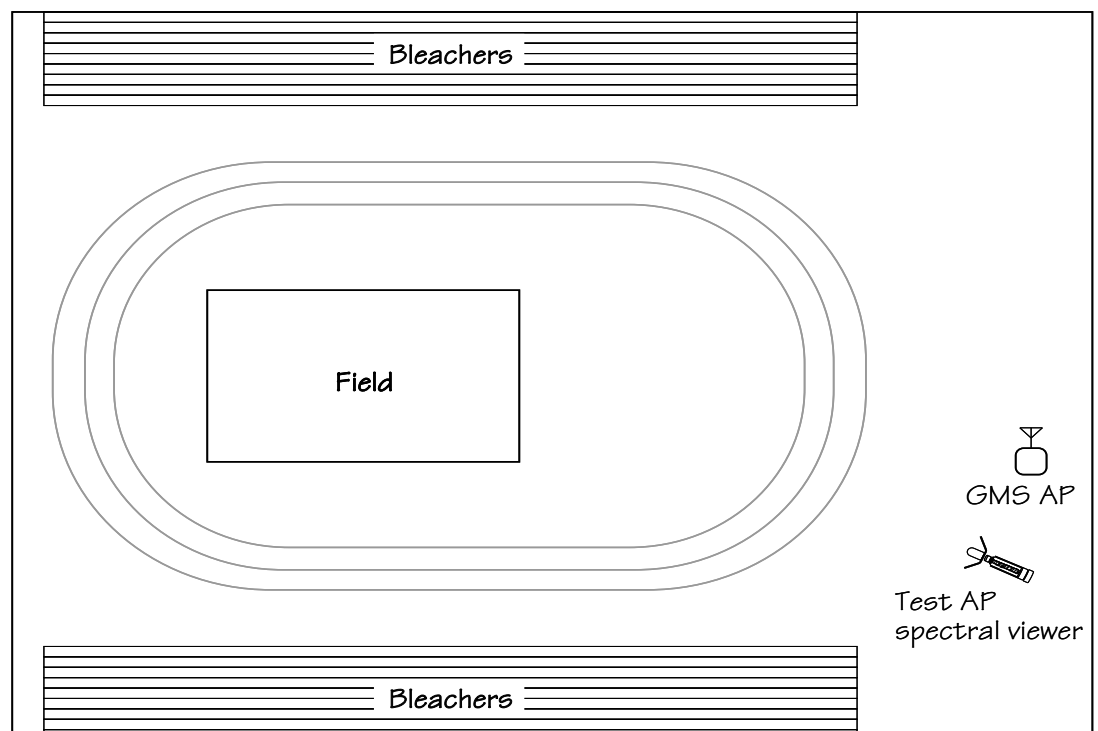
Antenna Azimuth Pattern:



Horizontal Pattern

Floor Plans:

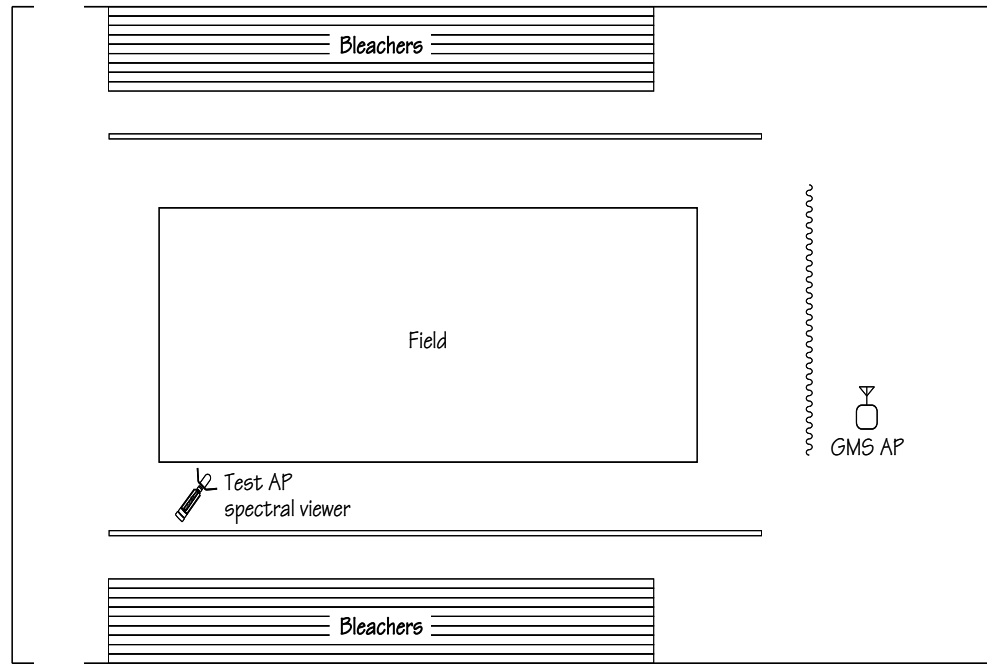
The play field is identical for all three venues and the antenna was located in the corner of each arena and oriented to cover the majority of the playing and observation areas as seen here:



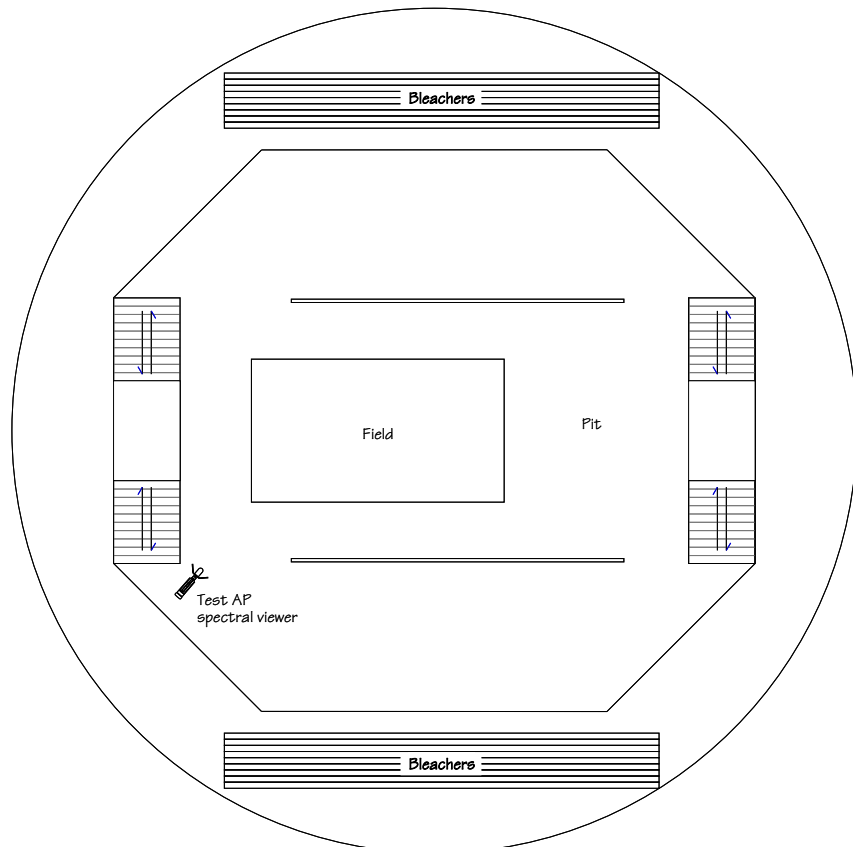
Playing Field Representation - Duel on the Delaware

(Not to scale)

Test Configuration:



Playing Field Representation - Brunswick Eruption
(Not to scale)



Playing Field Representation - Ramp Riot
(Not to scale)

Test Results:

The test results are grouped by venue and follow a similar format with specific measurements made to reflect the frequency congestion and usage noted at a specific venue.

All measurement screens incorporate three trace areas:

- Upper: Percentage of channel usage by frequency
- Middle: Activity by frequency
- Lower: Power density by channel

Duel on the Delaware:

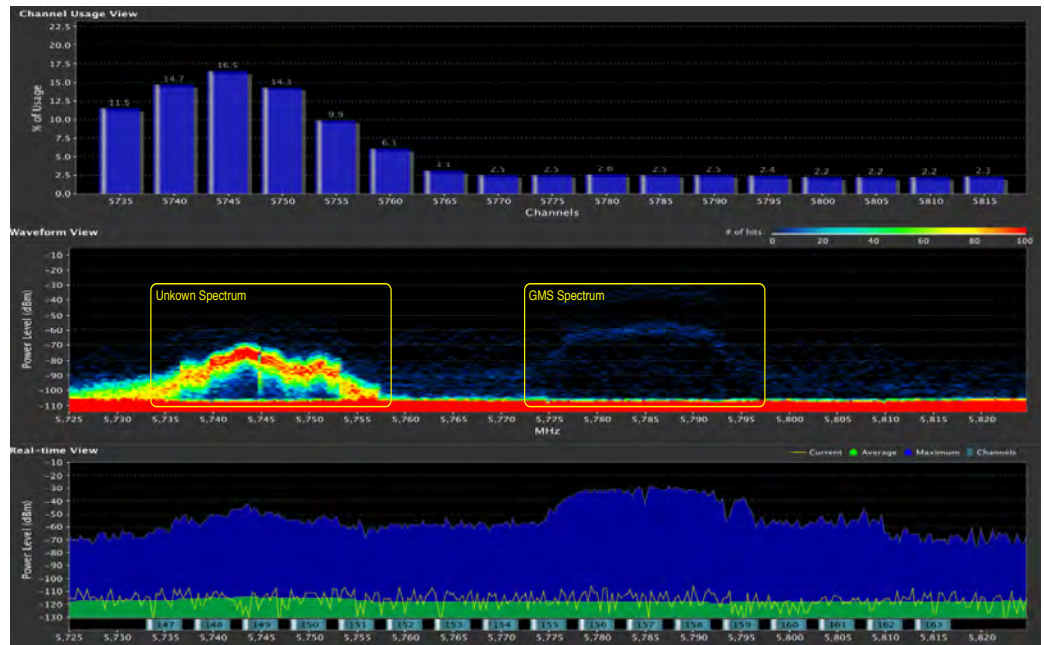
Measurements were made over approximately a 2 hour period and in compliance with the stated measurement protocols; however, several site specific and operational considerations shifted the sequence of the measurements.

All measurements used the test AP unit located in the fixed position as shown on the playing field representation. No changes to the test setup were made once the testing commenced at 10:40am.

The following five (5) screens detail each measured criterion along with the specific information for each.

Photo #2:

- Time: 10:40 to 10:55am
- Frequency Band: 5.725 to 5.820 GHz
- Explanation: Narrow band observations of the FMS and GMS operations with public PCDs present.
- Comments:
 - 1) Field system is operating nominally
 - 2) GMS system on and operational but not flooding the channel with test traffic. GMS data usage was about 300 Kbits/sec for Queuing operations.



Observations:

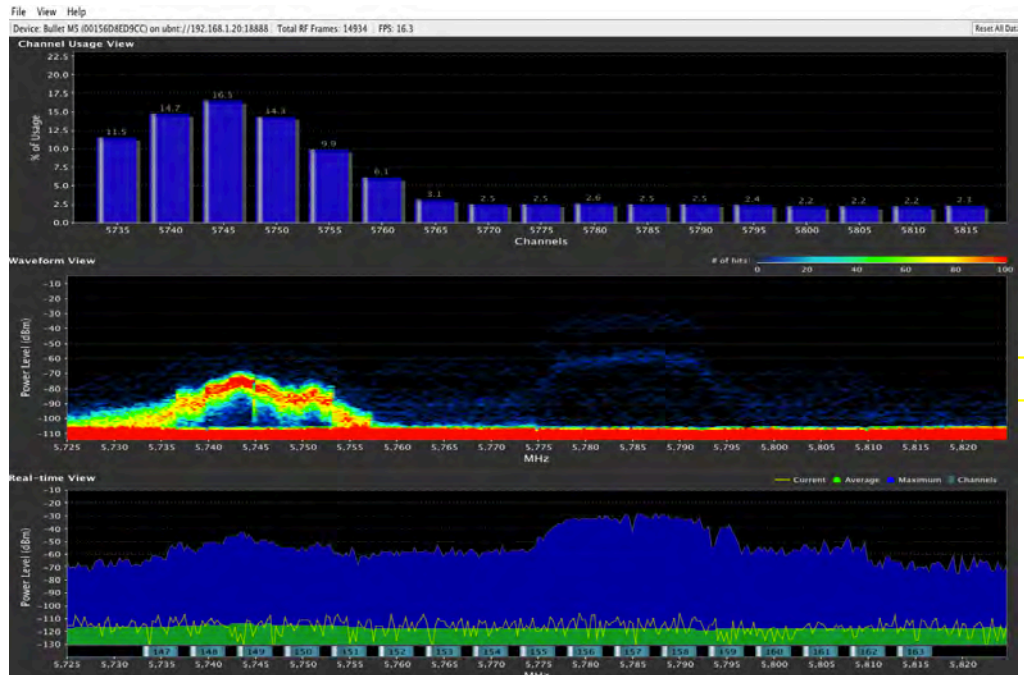
- 1) The above shows the unknown and GMS spectrums on the center trace.

Test Results:

Duel on the Delaware:

Photo #3:

Time: 11:50am to 12:05pm
Frequency Band: 5.725 to 5.820 GHz
Explanation: Narrow band observations of the GMS operation with public PCDs present.
Comments: 1) Field system is operating nominally
2) GMS system on and operational but not flooding the channel with test traffic. GMS data usage was about 300 Kbits/sec for Queuing operations
3) Apparent heavy field hits



Observations:

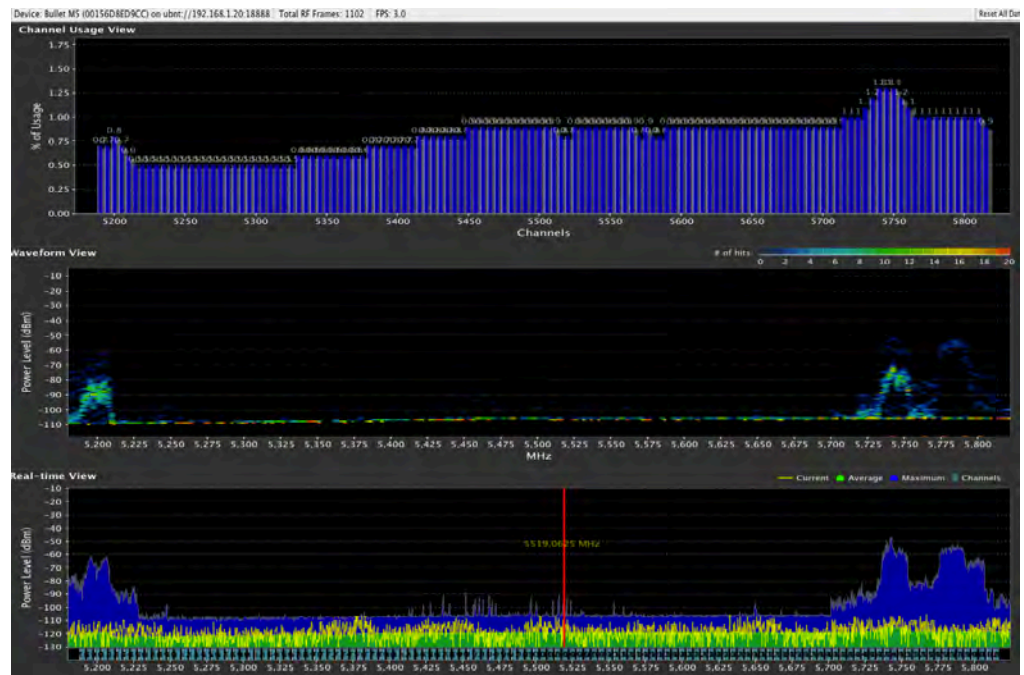
- 1) The GMS spectrum, while showing higher power levels due to it being closer to the measurement antenna, has minimal data activity by contrast.

Test Results:

Duel on the Delaware:

Photo #1:

Time: 12:07 to 12:13pm
Frequency Band: 5.180 to 5.825 GHz
Explanation: Wide band observations of the FMS and GMS operations with public PCDs present.
Comments: 1) Field system is operating nominally
2) GMS system on and operational
3) Noted the heavy usage from 5.0 to 5.25 GHz
4) Noticed heavy usage at the lower end of the band (5.700 GHz to 5.8 GHz plus)
5) Base line measurement for comparison.



Observations:

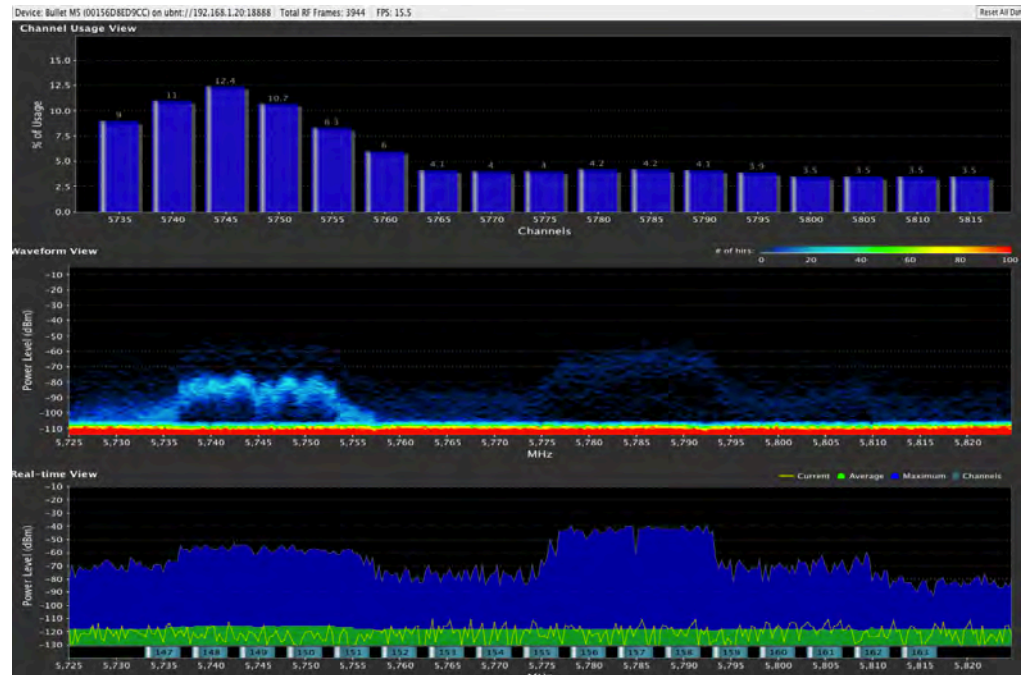
- 1) This is a wide band measurement to determine the overall frequency usage of the band from 5.180 to 5.825 GHz.
- 2) *Identify the FMS*

Test Results:

Duel on the Delaware:

Photo #4:

Time: 12:40 to 12:48pm
Frequency Band: 5.725 to 5.820 GHz
Explanation: Wide band observations of the GMS operations with public PCDs present.
Comments: 1) Field system is operating nominally
2) Reduced field attendees
3) Minimal data usage
4) GMS system on and operational
5) Measurement made during lunch break; no competition



Observations:

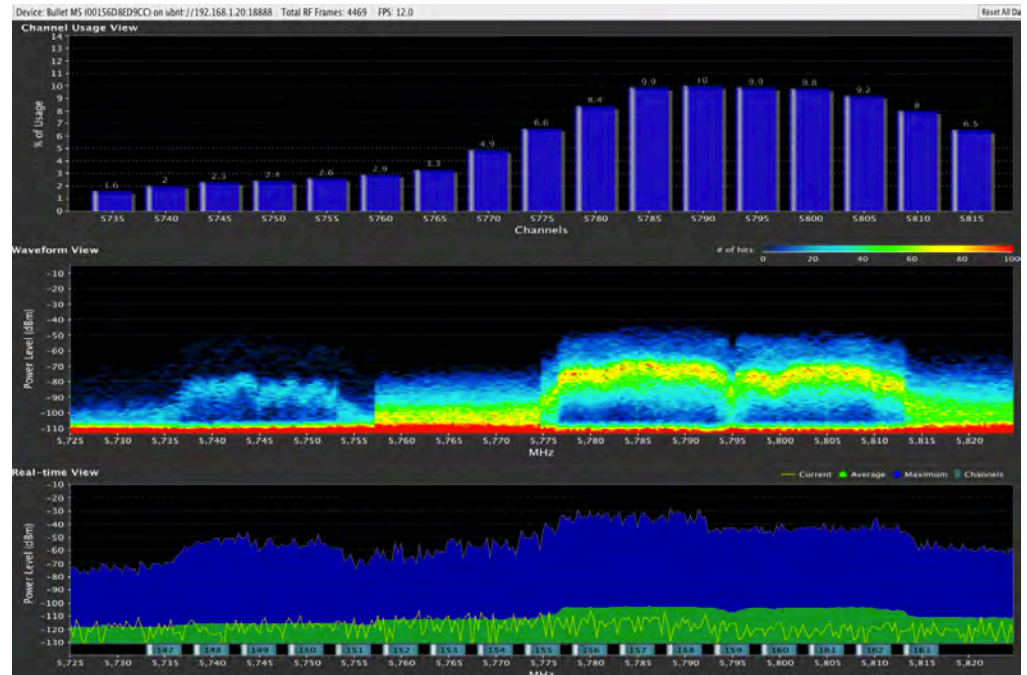
1)

Test Results:

Duel on the Delaware:

Photo #5:

Time: 12:50 to 12:54pm
Frequency Band: 5.725 to 5.820 GHz
Explanation: Same as test #4 but with two GMS tablets sending large packet transfers.
Comments: 1) Field system is operating nominally
2) Reduced field attendees
3) GMS system on and operational
4) Measurement made during lunch break; no competition.



Observations:

- 1) This is a narrow band display showing the GMS system artificially flooding the GMS channels with 50 MBs of data files.

Test Results:

Brunswick Eruption:

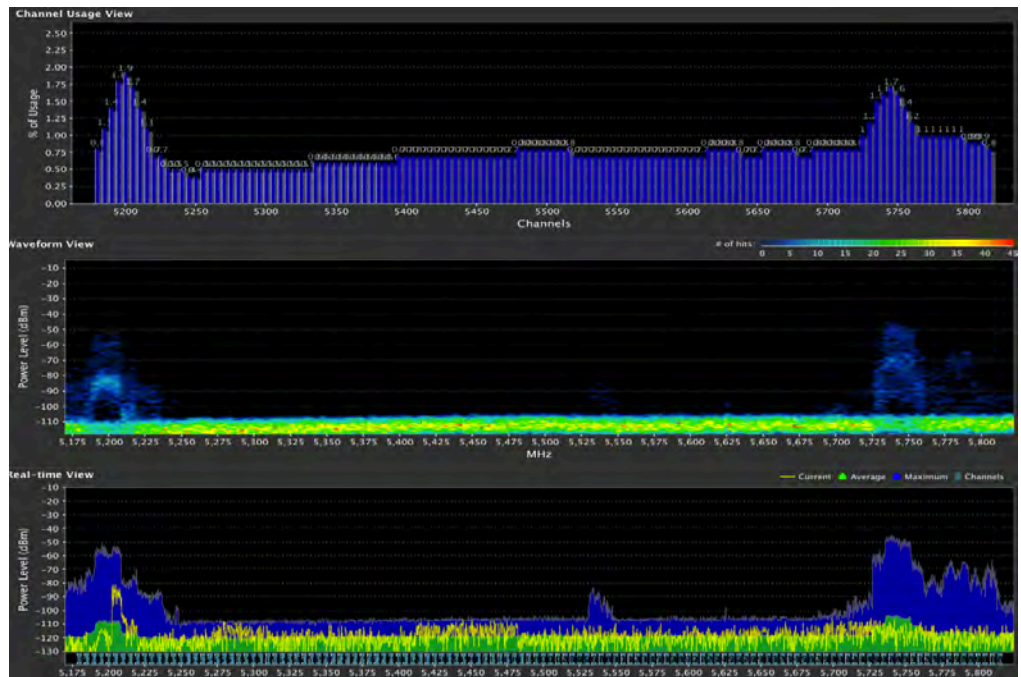
Measurements lasted approximately a 15 minute period and in compliance with the stated measurement protocols. The abbreviated time schedule was due to test personnel availability.

All measurements used the test AP unit located in the fixed position as shown on the playing field representation. No changes to the test setup were made once the testing commenced at 1:30am.

The following four (4) screen shots detail the measured criterion along with the specific information relating to each data capture. In all photos, the three measurement areas are:

Photo #1:

Time: 1:30 to 1:32 pm
Frequency Band: 5.170 to 5.825 GHz
Explanation: Wide band observations of the FMS and GMS operations with public PCDs present.
Comments: 1) Field system is operating nominally
2) GMS system on and flooding the GMS channels
3) Measurements made during the match with the approval of the FMA.



Observations:

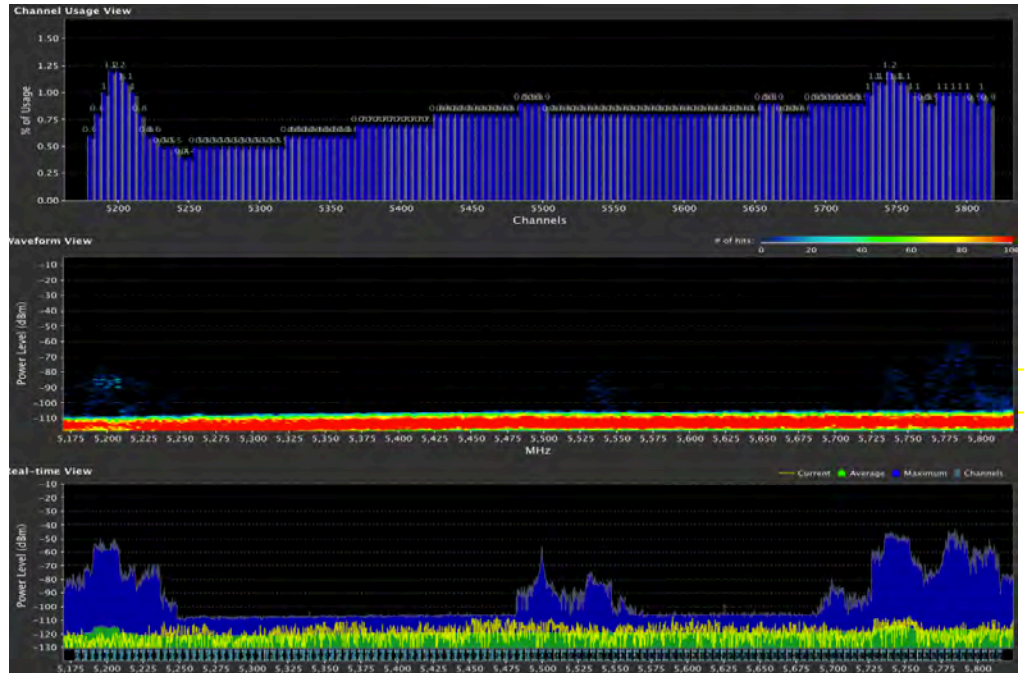
- 1) The above data capture clearly shows the significant frequency separation between the FMS operating on channel 40 and GMS system on channel 149.
- 2) The small energy burst centered on the lower trace is an unknown transmitter.
- 3) The center trace shows the significant traffic on the FMS channel versus the GMS channel although the GMS channel was flooded with data at 40 Mbits/sec, at a sustained data rate.

Test Results:

Brunswick Eruption:

Photo #2:

- Time: 1:30 to 1:36pm
 Frequency Band: 5.170 to 5.825 GHz
 Explanation: Wide band observations of the FMS and GMS operations with public PCDs present.
 Comments: 1) Field system is operating nominally
 2) GMS system on and operational but not flooding the channel with test traffic. The operational GMS data usage was about 300 Kbits/sec.
 3) Measurements made during the match with the approval of the FMA.



Observations:

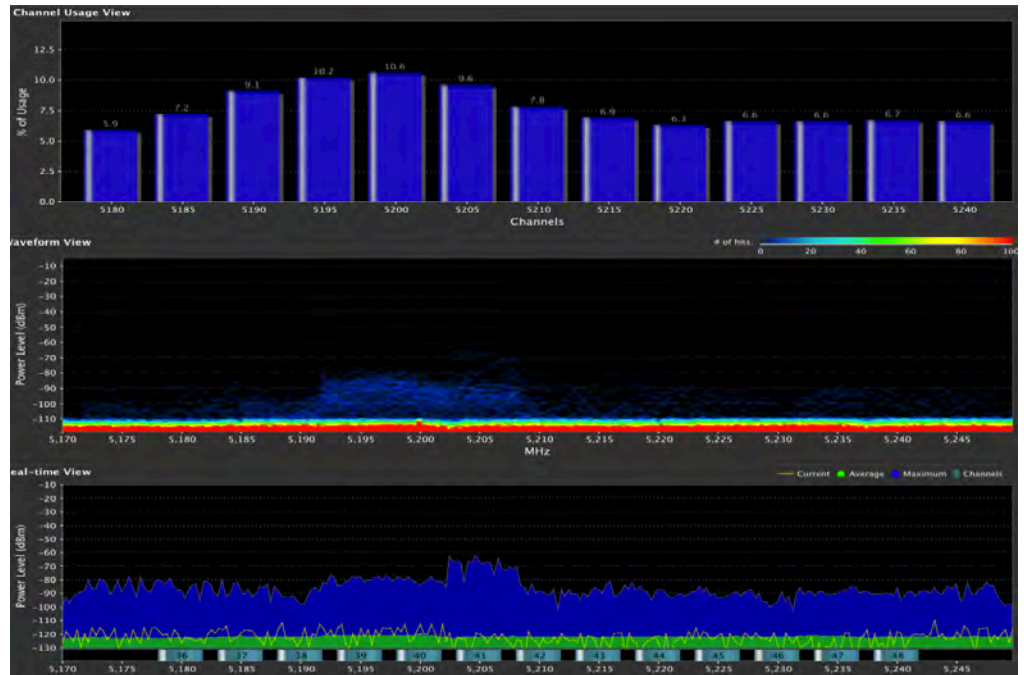
- 1) The mobile device and GMS AP were on opposite ends of the field, i.e., the test traffic was going directly through the field. We could terminate the transmission if the FTA reported any problems.
- 2) The lack of any interference between the operations precluded the need for extensive time measurements.

Test Results:

Brunswick Eruption:

Photo #3:

Time: 1:38 to 1:41pm
Frequency Band: 5.170 to 5.825 GHz (Channels 36 to 48)
Explanation: Narrow band observations of the FMS operation with public PCDs present.
Comments: 1) Field system is operating nominally
2) GMS system on and operational in nominal conditions with operational GMS data usage of about 300 Kbits/sec.



Observations:

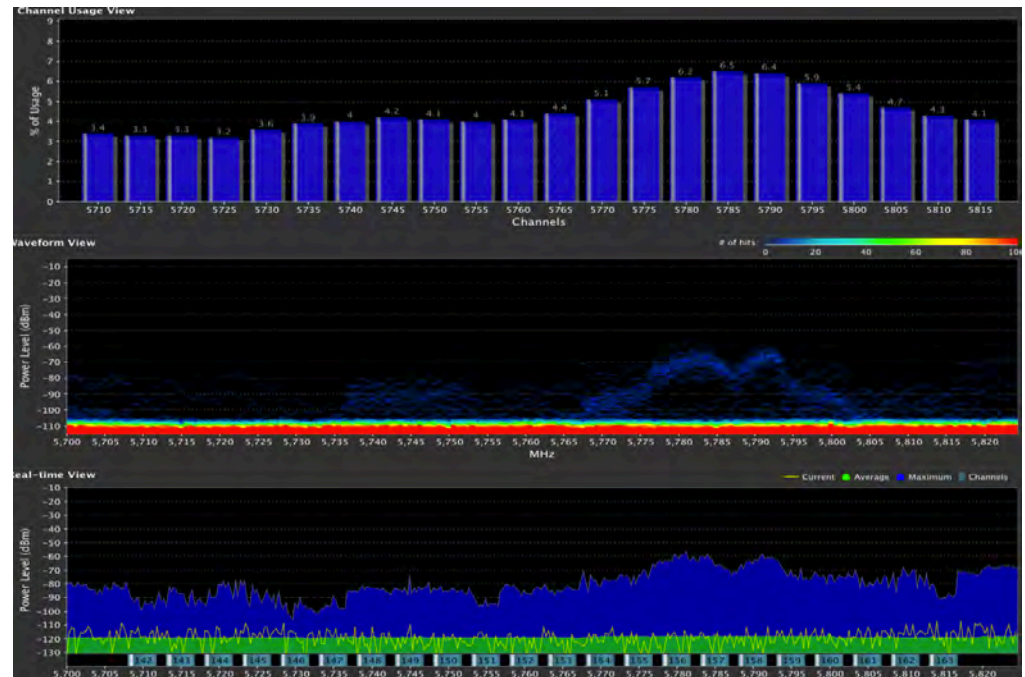
- 1) None.

Test Results:

Brunswick Eruption:

Photo #4:

Time: 1:42 to 1:45pm
Frequency Band: 5.700 to 5.825 GHz (Channels 142 to 163)
Explanation: Narrow band observations of the GMS operations with significant public PCDs present.
Comments: 1) Field system is operating nominally.
2) System on and operational.



Observations:

1) None.

Test Results:

Ramp Riot:

The measurements at this event were severely curtailed by the absence of Rajaram Pejaver due to illness.

A preliminary wideband spectrum investigation noted that this venue shows significant RF spectral use; however, the cumulative hits are minimal as evidenced by the center trace of photo #1 shown below.

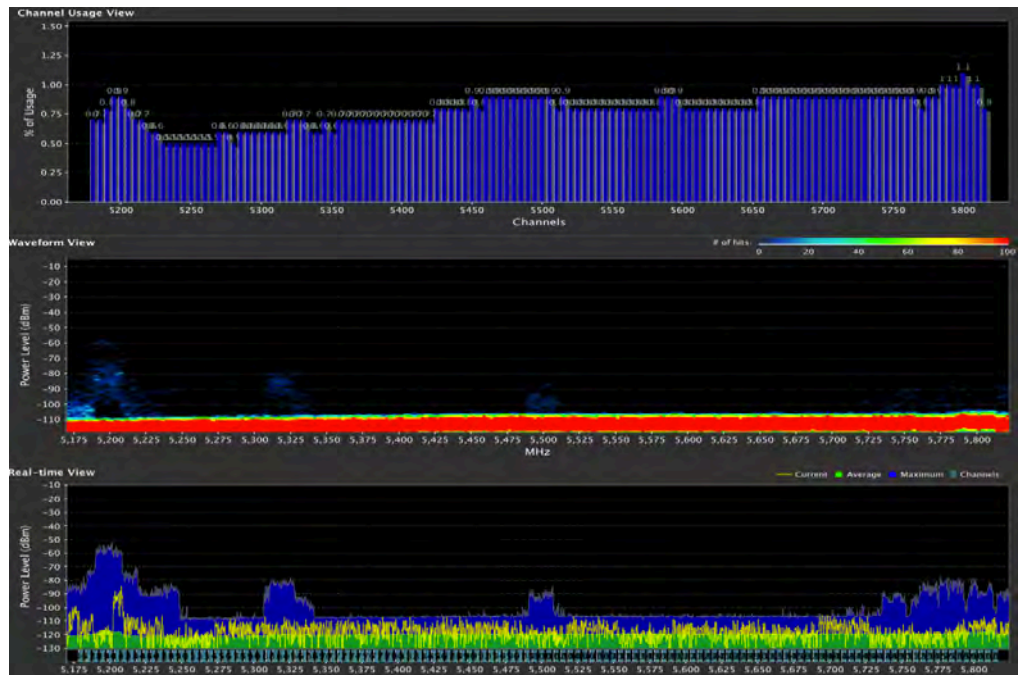
Photo #1:

Time: 2:51 to 3:06pm

Frequency Band: 5.170 to 5.825 GHz

Explanation: Wide band observations of the WiFi spectrum with public PCDs present.

Comments: 1) Field system is operating nominally
2) Measurements made during the match with the approval of the FMA.
3) GMS not in use.



Observations:

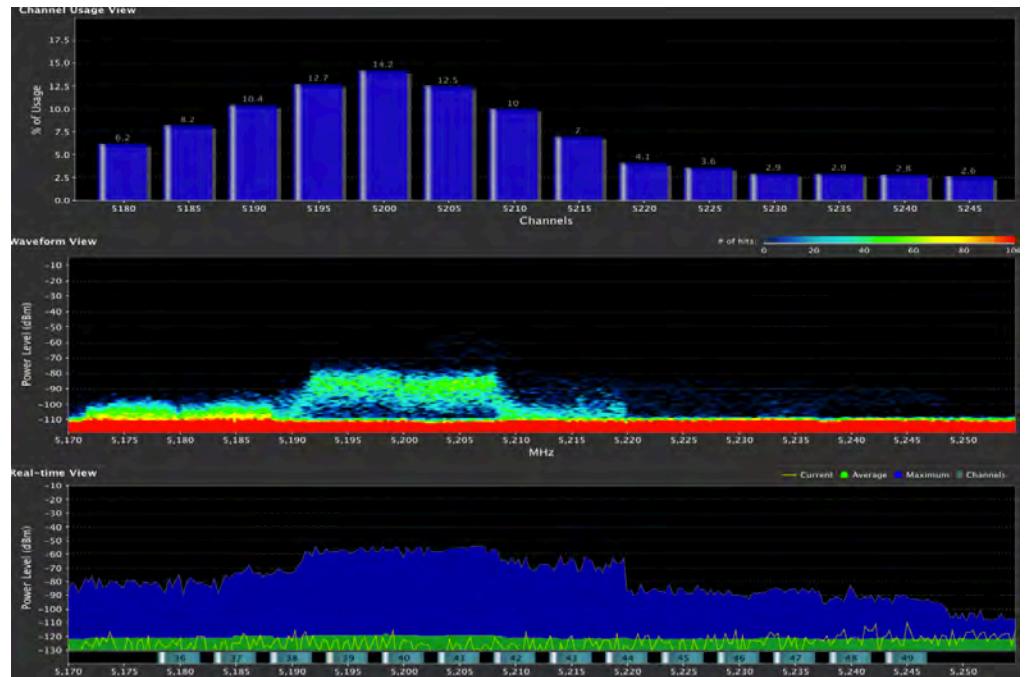
1) None.

Test Results:

Ramp Riot:

Photo #2:

Time: 3:07 to 3:17pm
Frequency Band: 5.17 to 5.255 GHz
Explanation: Observations of the FMS and GMS operations with public PCDs present.
Comments: 1) Field system is operating nominally
2) Measurements made during the match with the approval of the FMA.



Observations:

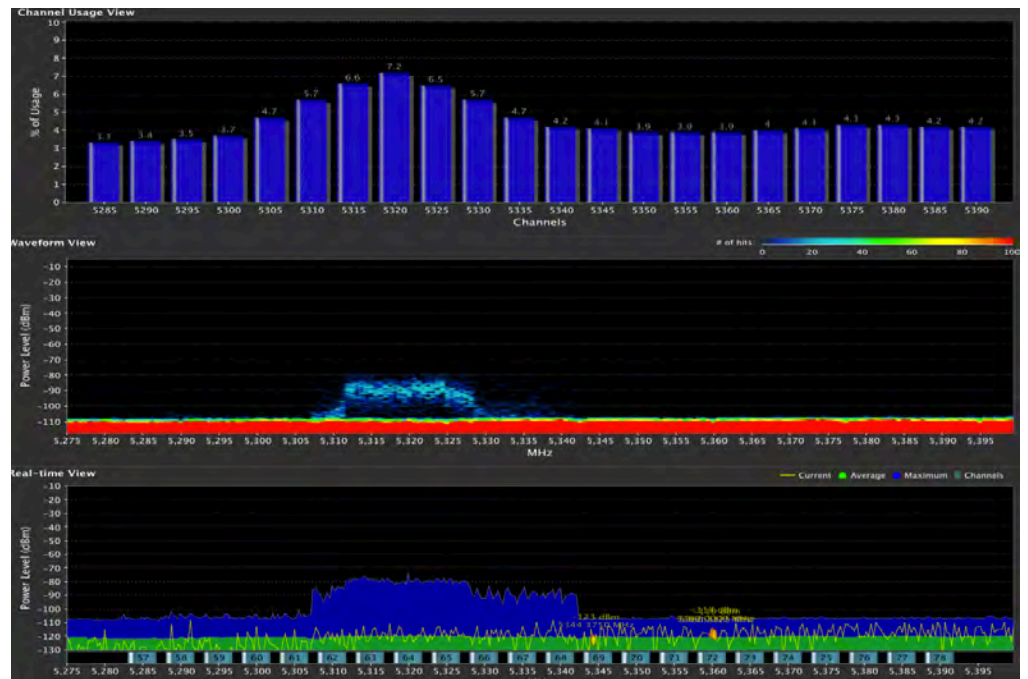
1)

Test Results:

Ramp Riot:

Photo #3:

Time: 3:19 to 3:28pm
Frequency Band: 5.275 to 5.400 GHz
Explanation: Narrow band observations of the FMS operation with public PCDs present.
Comments: 1) Field system is operating nominally
2) Measurements made during the match with the approval of the FMA.



Observations:

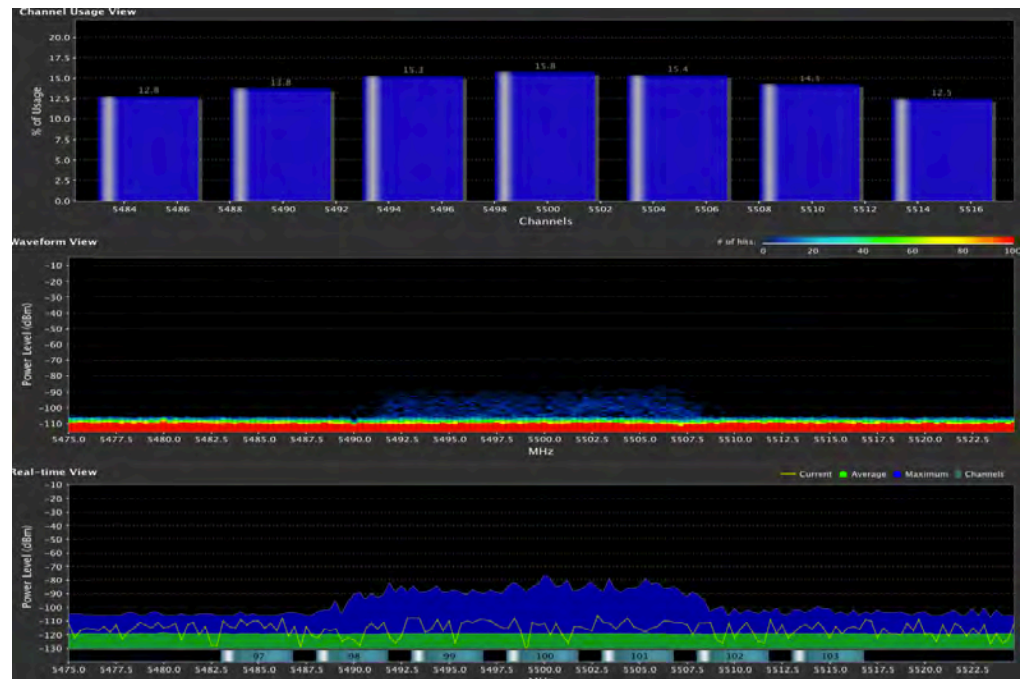
- 1) None.

Test Results:

Ramp Riot:

Photo #4:

Time: 3:29 to 3:33pm
Frequency Band: 5.475 to 5.520 GHz
Explanation: Narrow band observations of the FMS operation with public PCDs present.
Comments: 1) Field system is operating nominally
2) Measurements made during the match with the approval of the FMA.



Observations:

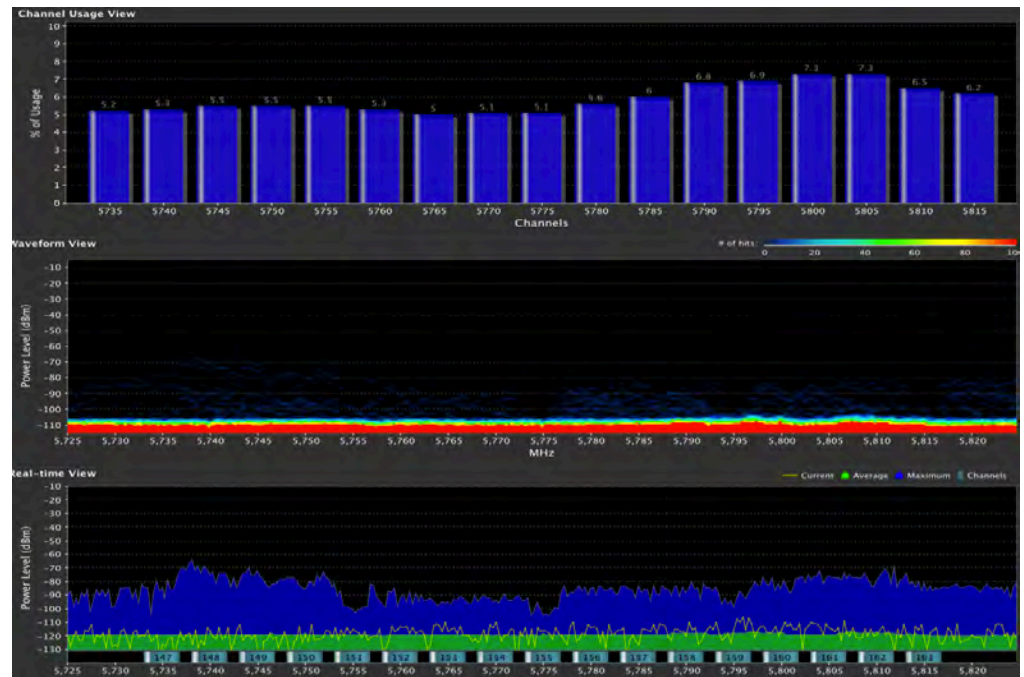
- 1) None.

Test Results:

Ramp Riot:

Photo #5:

Time: 3:35 to 3:45pm
Frequency Band: 5.475 to 5.800 GHz
Explanation: Wide band observations of the FMS operation with public PCDs present.
Comments: 1) Field system is operating nominally
2) Measurements made during the match with the approval of the FMA.



Observations:

- 1) None.