Survey Site: Yale Payne Whitney Gym (PWG)
70 Tower Parkway
New Haven, CT

Introduction

360°RF was retained to perform an RF survey from 100 MHz through 1 GHz above the roof level of the Payne Whitney Gym of Yale University (listed above and pictured at right).

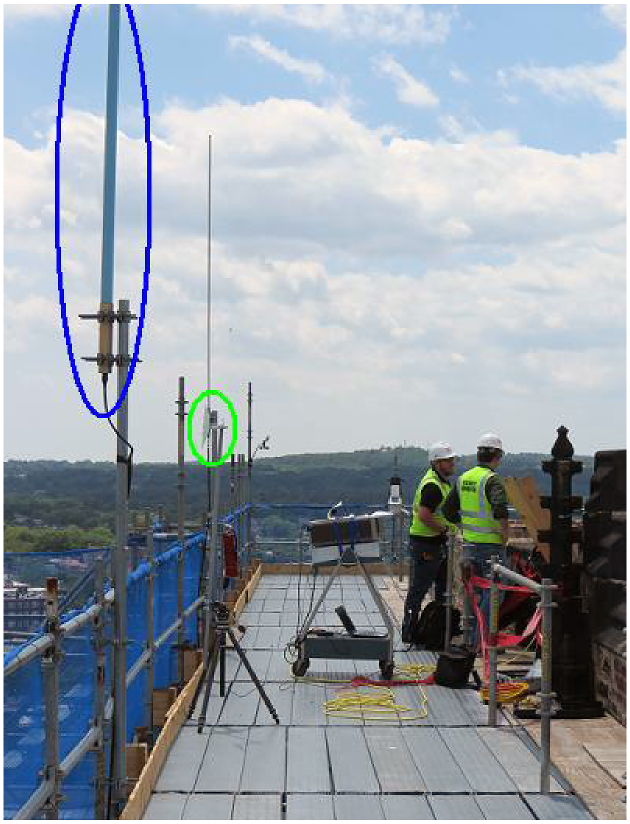
The survey took place June 9th, 2013 between approximately 10:00 am and approximately 4:00 pm, above, one level below, and at roof level scaffolding.

Setup

360°RF utilized a calibrated Hewlett Packard model 8569A spectrum analyzer (frequency range from 10 MHz to 22 GHz), and a calibrated log periodic test antenna covering 400 to 1000 MHz. The log periodic (LP) has a relatively flat response across the 400 to 1000 MHz range with a gain of approximately 3.5 to 6 dBi over that band. Tuned, telescoping dipoles were also available for use at lower frequencies had the need arose (which it did not). The length of the telescoping dipoles can be adjusted to set their resonant frequency; their gain is approximately 2.0 dBi when resonant.

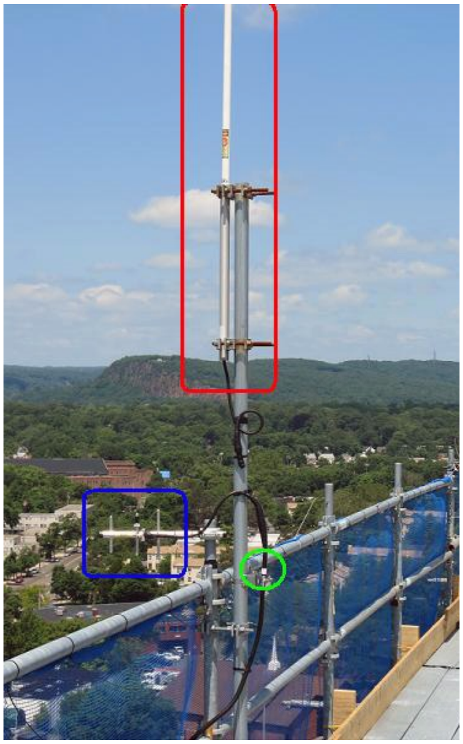
The survey was executed by mounting the appropriate antenna on an insulating fiberglass pole which was supported by a tripod, then placed in the desired location (usually either 3 or 4 meters from an Antenna-of-Interest). The antenna was connected to the spectrum analyzer using precision low-loss coaxial cable (Times Microwave LMR240), then the analyzer set for a desired frequency span (nominally 10 – 1000 MHz).

Plots were created for each antenna under surveillance. A GPIB-USB adapter from Prologix provided the hardware connection between the spectrum analyzer and a Sony VAIO laptop computer. The plotting software included “Prologix GPIB Configurator”, which established the data link between the spectrum analyzer and the laptop computer. Actual plot files, with



customizable text blocks, were created on the laptop using “7470A Plotter Emulator” then later transferred to other computers for actual data analysis and/or printing using flash memory sticks.

The image to the left shows a typical antenna-measurement setup; the 400 – 1000 MHz LP is highlighted within the green oval while the antenna being measured is highlighted within the blue oval. The 8569B spectrum analyzer is on the cart in the center of the walkway while the laptop is on a lower shelf of the cart. Power for the measurement equipment was provided by the client. This view is looking due west on the southernmost scaffolding walkway.



Seven vertical antennas were able to be energized upon command; the radiated RF field from each was then measured. In addition, a single 3-element yagi antenna was also in use, apparently transmitting data and pointed generally directly away from the roof of the gym.

This transmitter (identified as White 1) appeared to be transmitting almost continuously and although its antenna is a directional yagi pointed away from the building, there initially appeared to be significant back-radiation which level was of concern due to the apparent high duty cycle transmissions. The yagi antenna with its support and another vertical antenna (not in use) are shown in the image at right.

The small green circle in the photo highlights the means of identifying all of the antennas: by the number of strips of colored tape on the coax feedlines. The yagi is ID’d as White 1 (surrounded by a dark blue box) while the unused vertical, surrounded by the red box, is White 2.

The following presents the results of our measurements, and initial calculations of the RF power density.

Results

The table on the following page shows, in the first 8 rows, the RF power level measured from the 7 vertical collinear antennas in use plus the single 3-element yagi antenna (White 1). Although there were other antennas on the rooftop, those were either not in use (their coax cable feedlines disconnected) or for receive only.

The table shows the power level in milliwatts of the transmitted signal from each antenna, the approximate frequency (+/- 2 MHz), the coax cable gain in dB used between the 8569B spectrum analyzer and log periodic antenna, the calculated antenna factor of the log periodic (presented as antenna ratio) and its measured gain in dBi, the corrected spectrum analyzer power level in milliwatts, and finally the calculated power density in mW/cm^2.

The last two rows also present measurements of the power detected when multiple transmitters were turned on; for example, Green 1/Red 1/Blue 1/Orange 1/Orange 2/Orange3/White 4; or in the case of the last row, Green 1/Red 1/Orange 1/Orange 2/Orange 3.

Antenna	Level 1, mW	Freq, MHz	Cable Gain @ Freq, dB (negative means a loss)	Antenna Factor, dB/m	Antenna Gain, dBi	Corrected Spectrum Analyzer Power, mW	**mW/cm^2**
Green 1	1.995	460	-4.3	17.8	5.5	1.634	0.001
Orange 1	0.398	460	-4.3	17.8	5.5	0.000	0.000
Orange 2	5.012	460	-4.3	17.8	5.5	3.802	0.003
Red 1	3.981	460	-4.3	17.8	5.5	3.020	0.003
Orange 3	1.000	460	-4.3	17.8	5.5	0.759	0.001
Blue 1	10.000	460	-4.3	17.8	5.5	7.586	0.006
White 4	5.012	460	-4.3	17.8	5.5	3.802	0.003
White 1	0.141	460	-4.3	17.8	5.5	0.107	0.000
G1R1Blu1O1O2O3W4	6.310	460	-4.3	17.8	5.5	4.786	0.004
G1R1O1O2O3	6.310	460	-4.3	17.8	5.5	4.786	0.004

For measurement of Green 1, the LP antenna was placed 9.75 meters from the base of the vertical collinear due to technical limitations. For Orange 1 and White 1, the LP was placed 4 meters from the base of the vertical. For all the other individual verticals, the LP was located 3 meters from the base of the measured vertical. Since the base of all of these verticals was at a height of approximately 6 feet, the LP was aimed upward slightly to just above the vertical base.

In the cases where multiple antennas were measured, the LP was located some distance away where its beamwidth was adjudged to encompass all of the measured vertical antennas. In the case of G1R1Blu1O1O2O3W4, this location was across the roof just to the west of the center of the parapet, up on the parapet itself. This location placed the LP between 22 and 35 meters from the 7 vertical antennas, within a beamwidth of approximately 30 degrees, well within the beamwidth of the LP. In the case of G1R1O1O2O3, the LP was placed as closely as possible in line with the five verticals, looking directly North, at the southeastern corner of the roof.

The above measurements represent the highest levels measured; however, several other measurements were undertaken from the next-lower level. In addition, a measurement was taken from the actual roof level (which is approximately 10 feet lower than the upper scaffolding walkway and parapet level), and essentially shielded from the main radiation patterns from the bases of the vertical antennas. In these cases, levels were generally found to be at least 6 dB lower than at roof level.

Preliminary Conclusion

The highest RF levels found radiated from any of the antennas appear considerably lower than FCC or OSHA exposure limits, when measured 3 or 4 meters from the bases of the vertical collinear antennas. This is partially because the bases are all at head height or higher when standing on the walkway, and partially because the main radiation lobe of the antennas is likely slightly above the horizon (think of half of a bagel, the cream cheese side down; the bagel itself represents the main radiation pattern of these omnidirectional vertical collinear antennas).

However, 360° RF is still processing data to further evaluate the measured patterns and levels. An updated report will be issued once available that will also include plots of the spectrum from 10 to 1000 MHz showing the individual antenna power levels.

UPDATE: June 10, 2013

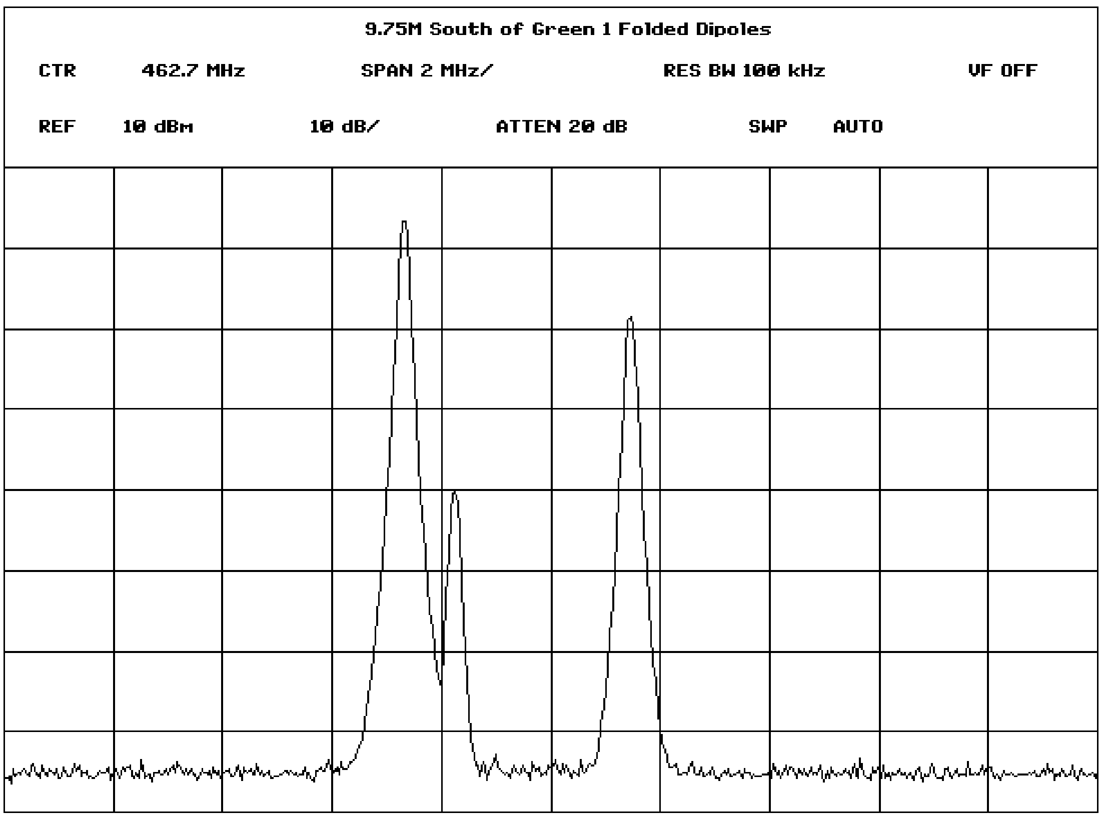
The Maximum Permissible Exposure limits are found in Part 1 of the the Federal Communications Commission rules, 47 CFR 1.1310 in terms of frequency, field strength, power density and averaging time. These limits are stated for two cases: Table 1A gives the Limits for Occupational/Controlled Exposure, while Table 1B gives the Limits for General Population/Uncontrolled Exposure. The limit in the former table, for 300 to 1500 MHz, is defined by the formula f/300 and in the latter table, for the same frequency range, as f/1500. At the frequency of interest in this case, 460 MHz, these limits are calculated as 1.53 mW/cm^2 and 0.307 mW/cm^2, respectively. The time period over which the exposure is to be averaged is 6 minutes and 30 minutes, respectively. OSHA does not seem to have published enforceable RF exposure limits but employers are encouraged to follow the “prevailing consensus”.

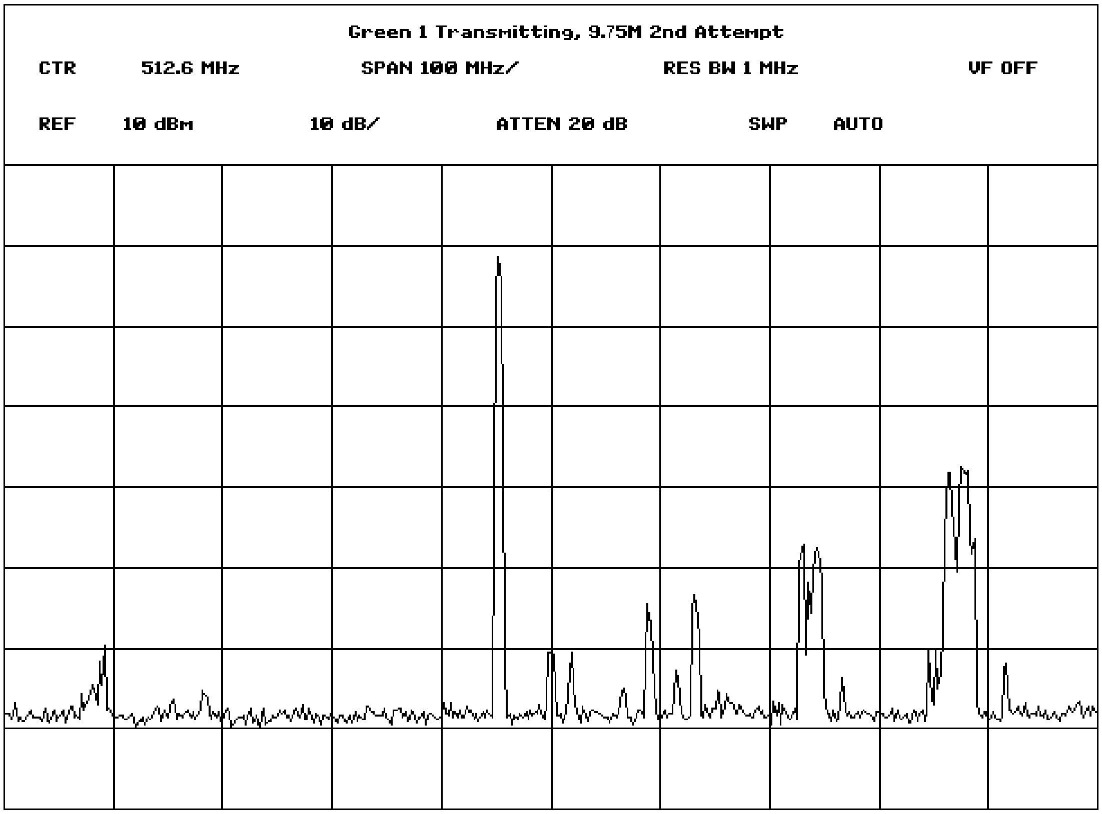
From the previous table showing the calculated power density, it is clear that even in the worst cases of Blue 1 and multiple-transmitter measurements of G1R1Blu1O1O2O3W4 and G1R1O1O2O3, the exposures are equivalent to no higher than 2% of the worst-case FCC MPE limit of 0.307 mW/cm^2. If the limit from table 1A is used, the exposure is about 0.4% of the permissible limit.

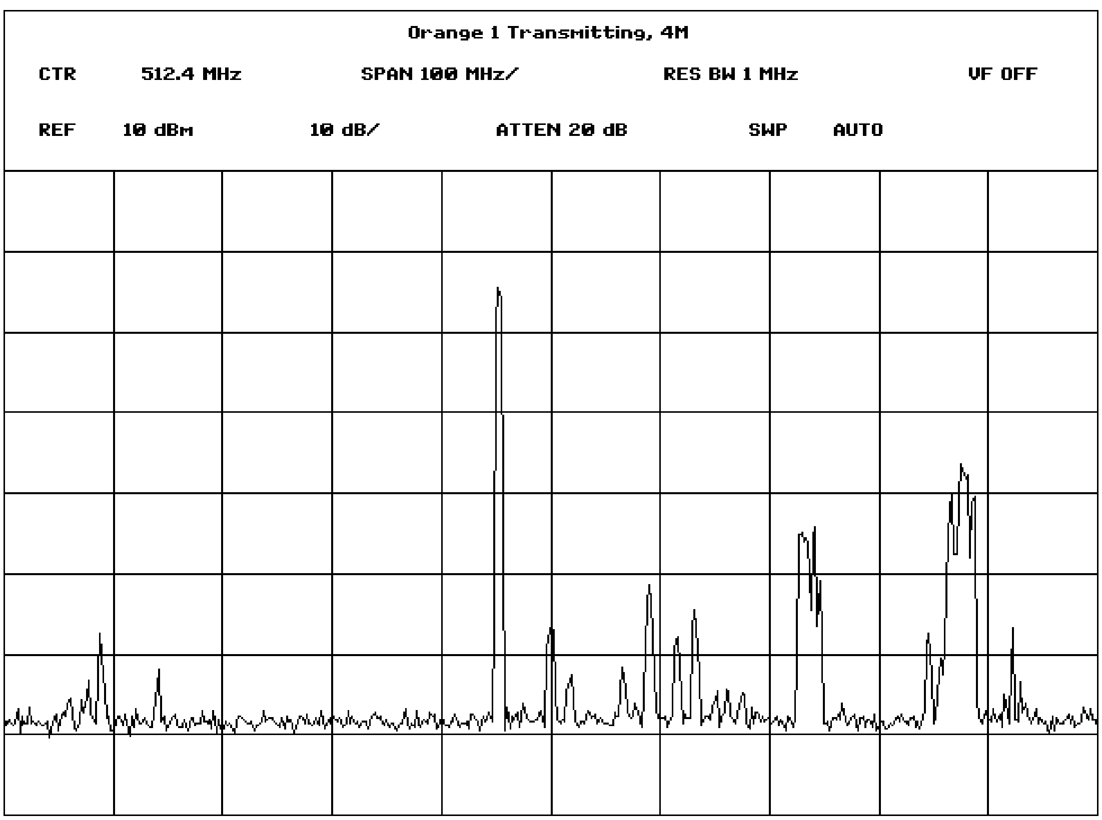
The following plots were created and recorded using the Hewlett Packard 8569B spectrum analyzer with software program HP7470A Plotter Emulator. Each of the antennas used for transmitting was put into transmitting mode for 15 to 30 seconds while the spectrum analyzer displayed the peak signal strength. In each case, a 400 – 1000 MHz log periodic was used for the spectrum analyzer, supported on a fiberglass insulating pole at least 3 feet above a metal tripod, and the feedline decoupled using three ferrite clamp-on beads. The LP was placed 9.75 meters from the base of Green 1 antenna, 4 meters from the bases of Orange 1 and White 1 antennas, and 3 meters from the bases of the other five Antennas-of-Interest (AoI). Where necessary, the LP’s attitude was adjusted slightly upward so as to “look” at a point slightly higher than the coax connector of the AoI where the highest radiated field strength would be expected.

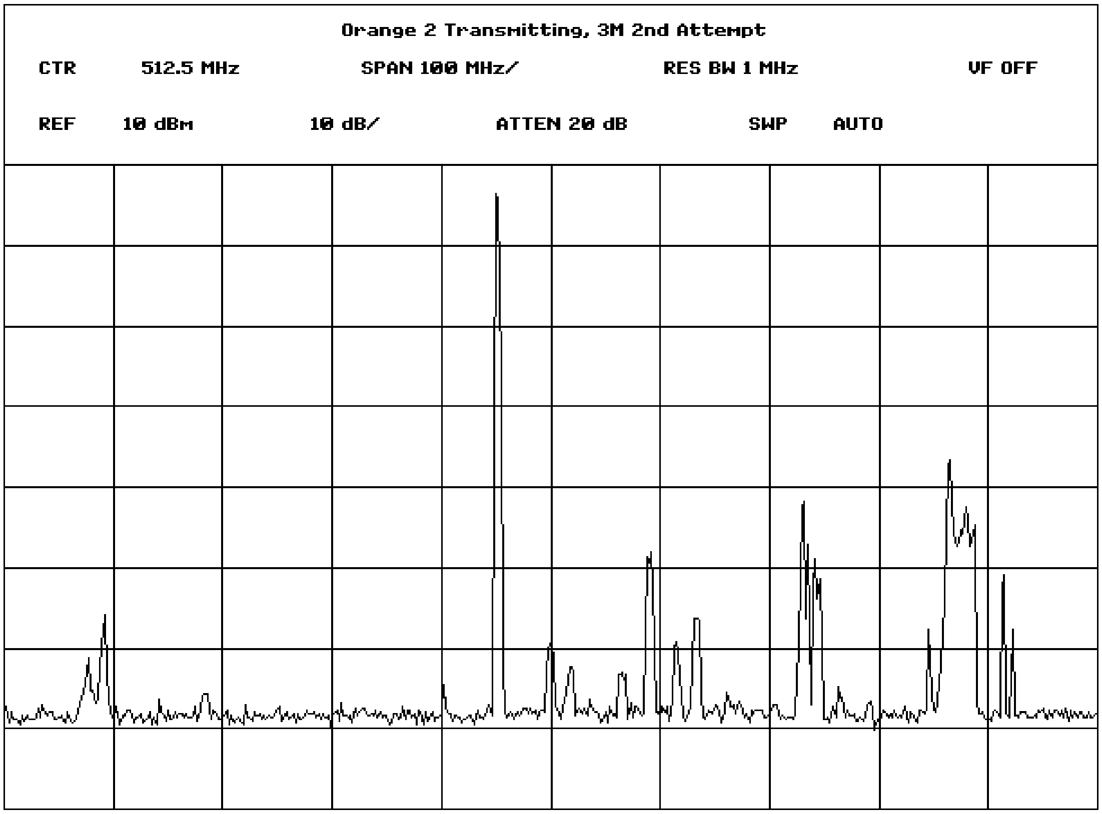
In several cases, a second plot was created due to unexpected technical difficulties; those are indicated as “Second Attempt”. In the case of Green 1, several measurements were taken at different locations and are shown as separate plots; the first plot shows the radiated power with the spectrum analyzer antenna located 9.75 meters south, while the second plot shows a lower radiation level found with the spectrum analyzer antenna located about 9.75 meters to the north of Green 1. The higher level was used in the table. The level difference is thought to result from a shift in the antenna's pattern. Green 1 is a pair of folded dipoles mounted side-by-side on the same support pipe.

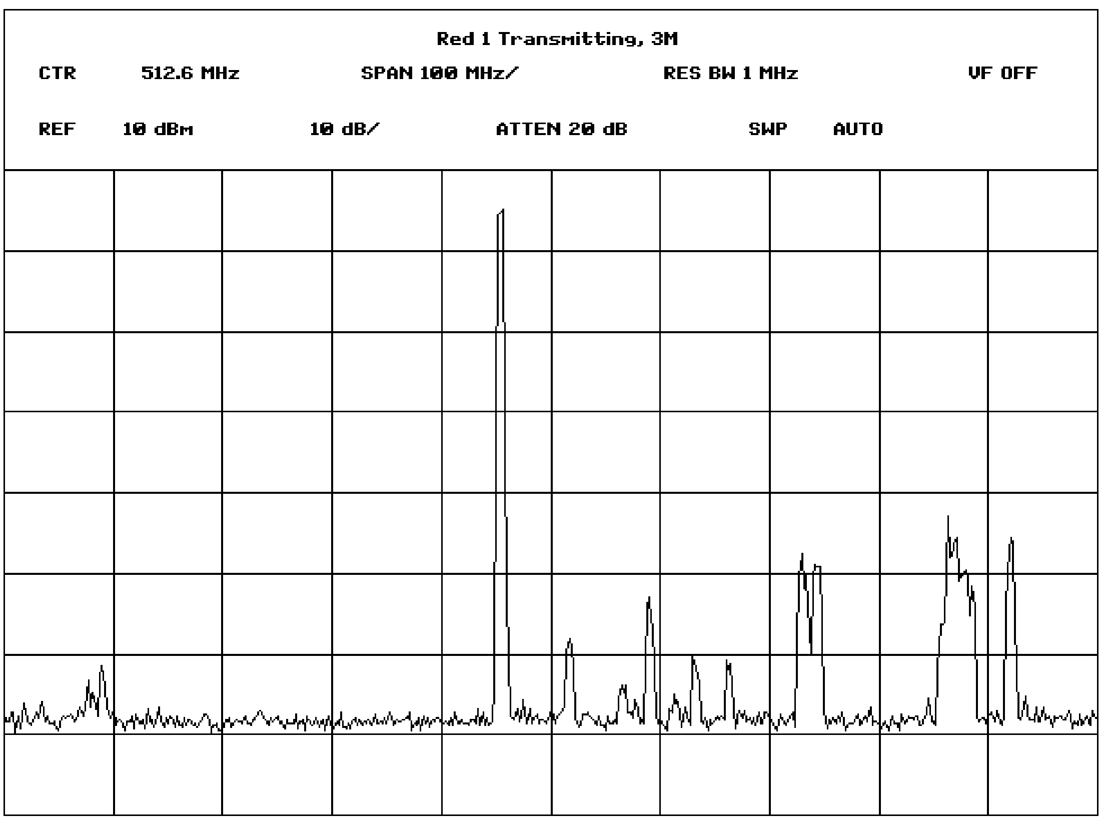
The plots are presented in the order listed in the above table. In addition, plots are shown of other measurements performed in other locations which produced signal strengths significantly lower than the aforegoing direct-radiation measurements on the scaffolding, such as at the actual roof level, and on the next-lower floor level of the scaffolding. The last plot was created with seven antennas radiating while the log periodic for the spectrum analyzer was located in the extreme northwest corner on the roof itself, which is about 15 feet lower than the base of the vertical antennas.

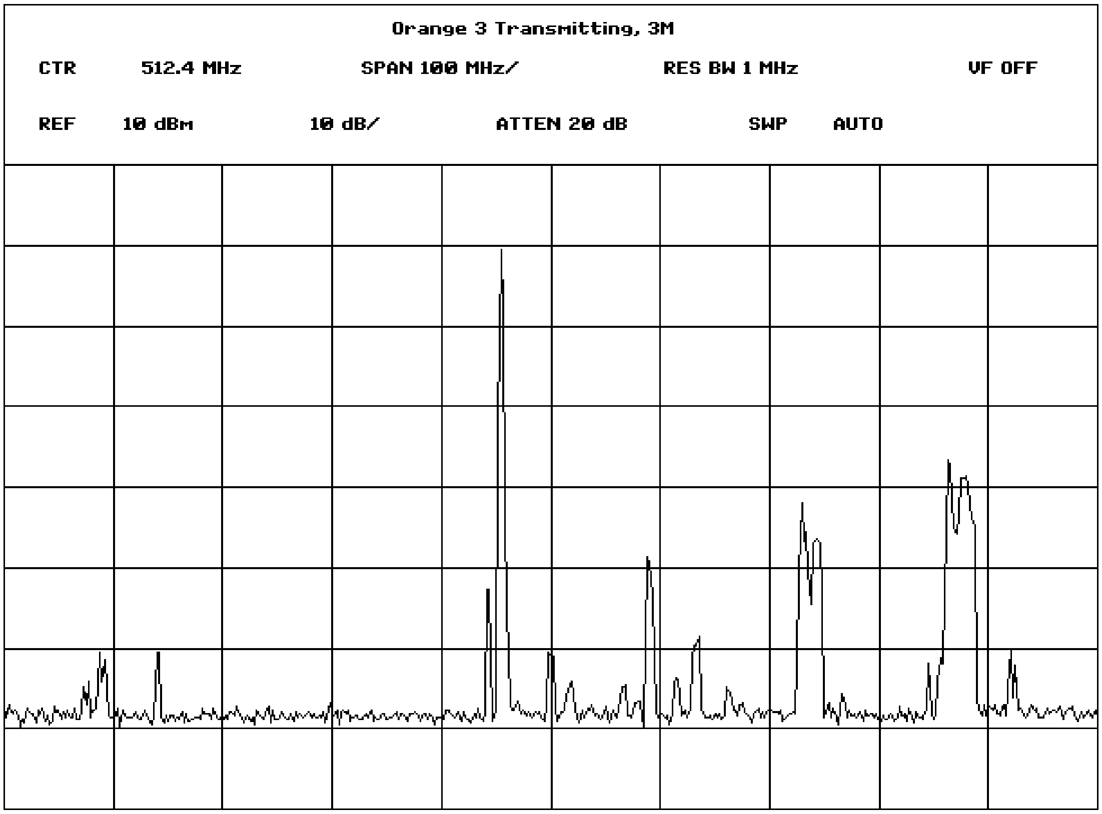


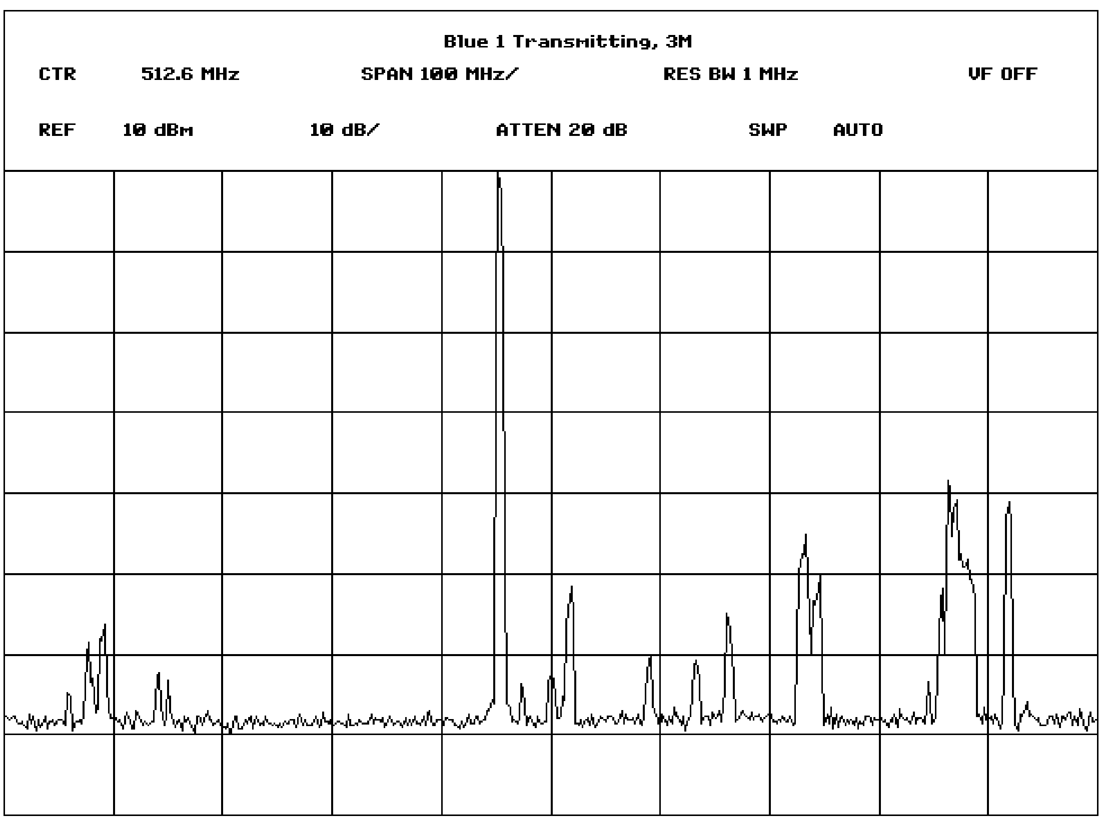

Green 1 Transmitting, 9.75M 2nd Attempt
CTR 512.6 MHz
SPAN 100 MHz/
RES BW 1 MHz
VF OFF
REF 10 dBm
10 dB/
ATTEN 20 dB
SWP AUTO

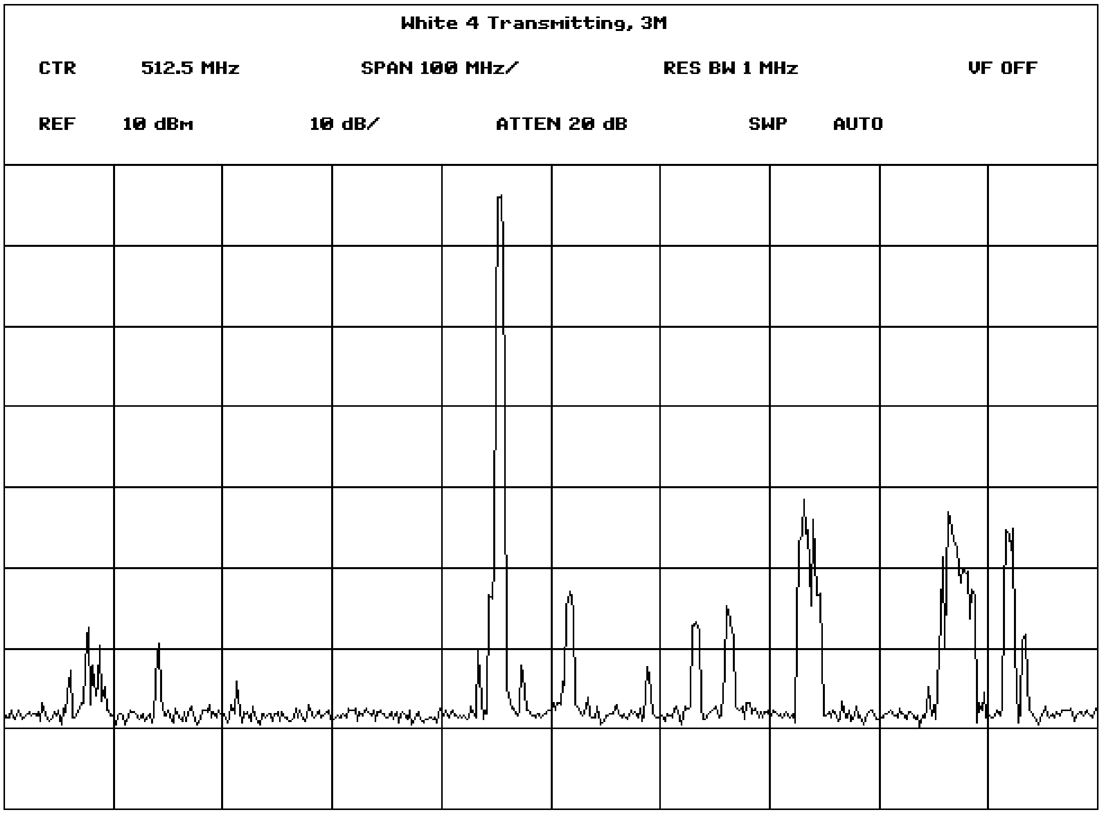

Orange 1 Transmitting, 4M
CTR 512.4 MHz
SPAN 100 MHz/
RES BW 1 MHz
VF OFF
REF 10 dBm
10 dB/
ATTEN 20 dB
SWP AUTO

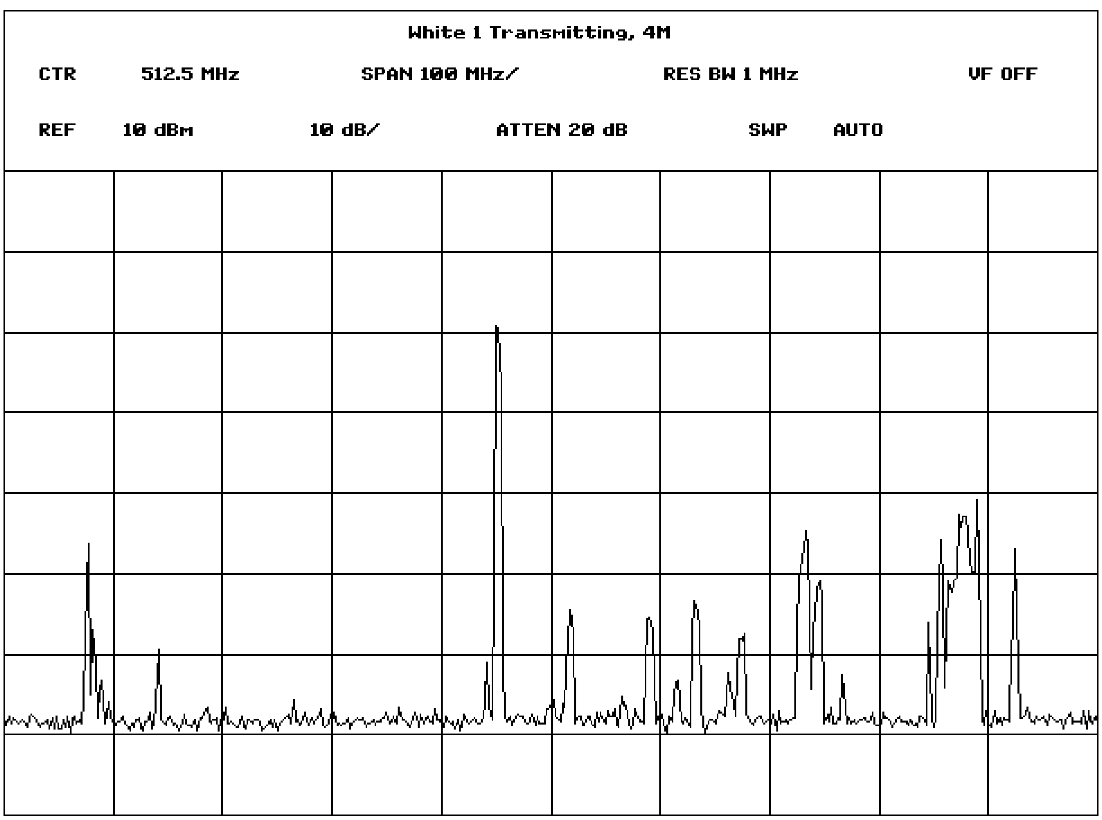

Orange 2 Transmitting, 3M 2nd Attempt
CTR 512.5 MHz
SPAN 100 MHz/
RES BW 1 MHz
VF OFF
REF 10 dBm
10 dB/
ATTEN 20 dB
SWP AUTO

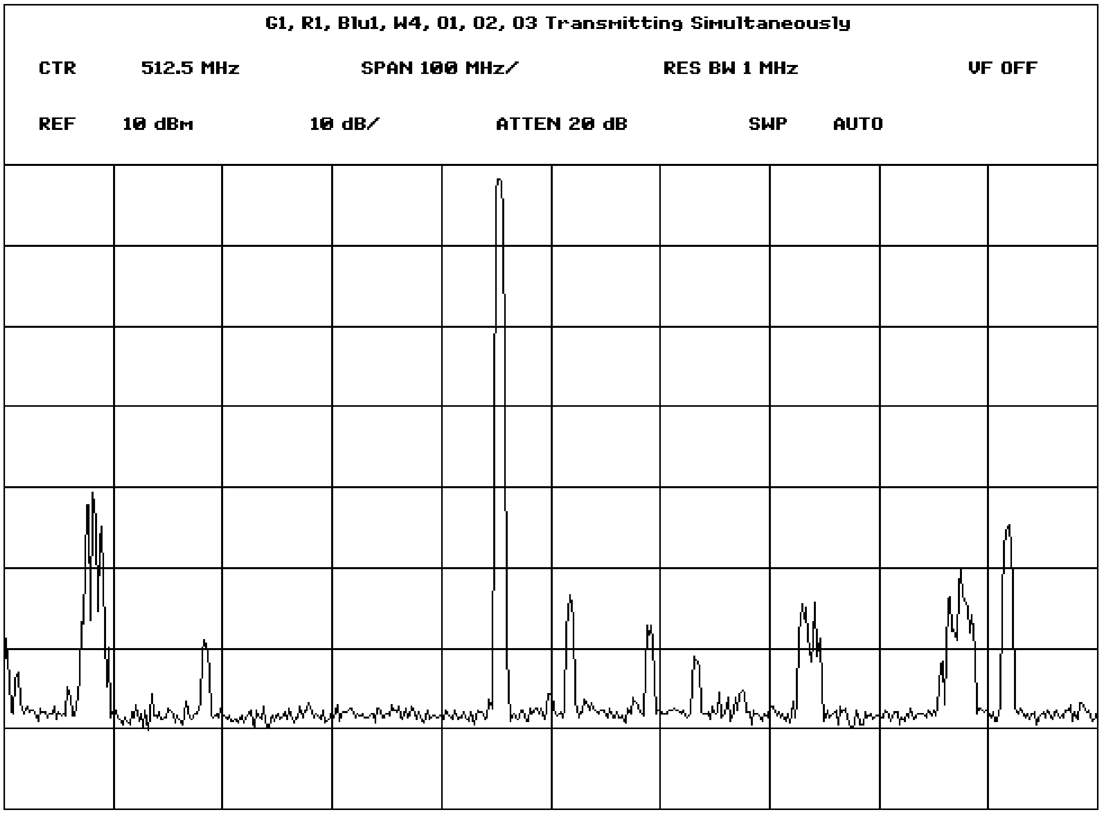

Red 1 Transmitting, 3M
CTR 512.6 MHz
SPAN 100 MHz/
RES BW 1 MHz
VF OFF
REF 10 dBm
10 dB/
ATTEN 20 dB
SWP AUTO

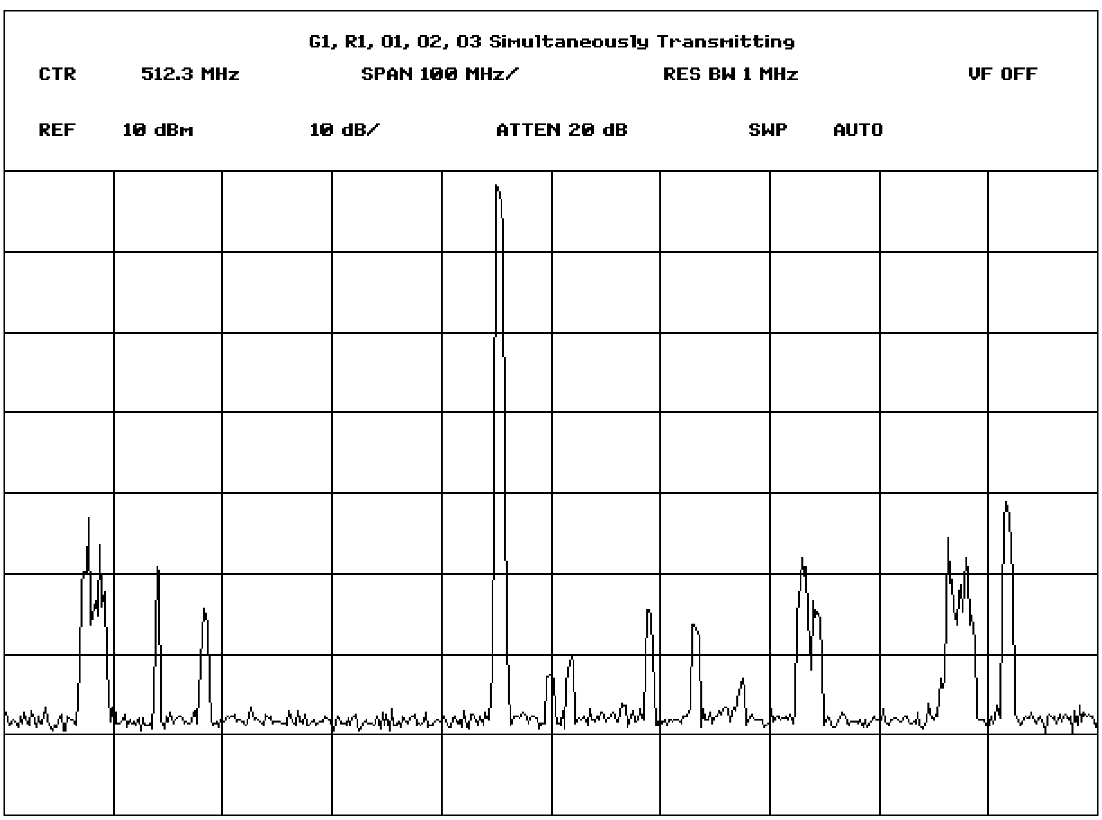

Orange 3 Transmitting, 3M
CTR 512.4 MHz
SPAN 100 MHz/
RES BW 1 MHz
VF OFF
REF 10 dBm
10 dB/
ATTEN 20 dB
SWP AUTO

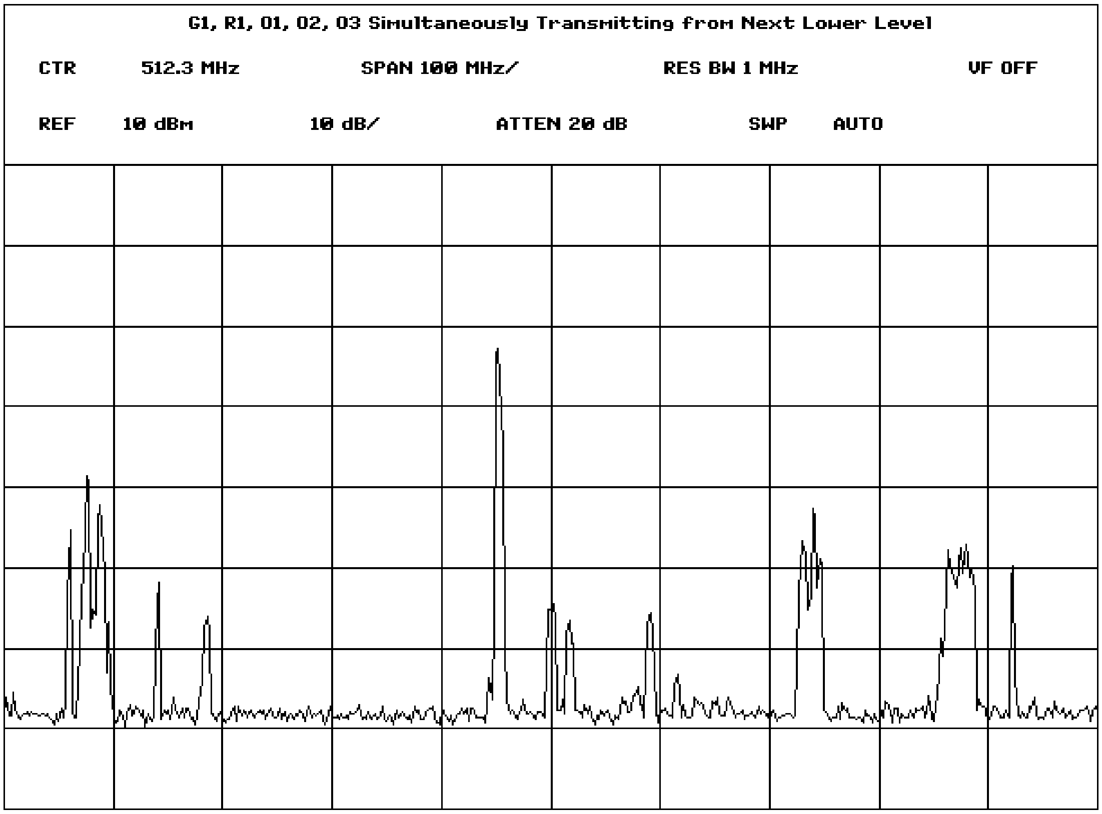

Blue 1 Transmitting, 3M
CTR 512.6 MHz
SPAN 100 MHz/
RES BW 1 MHz
VF OFF
REF 10 dBm
10 dB/
ATTEN 20 dB
SWP AUTO

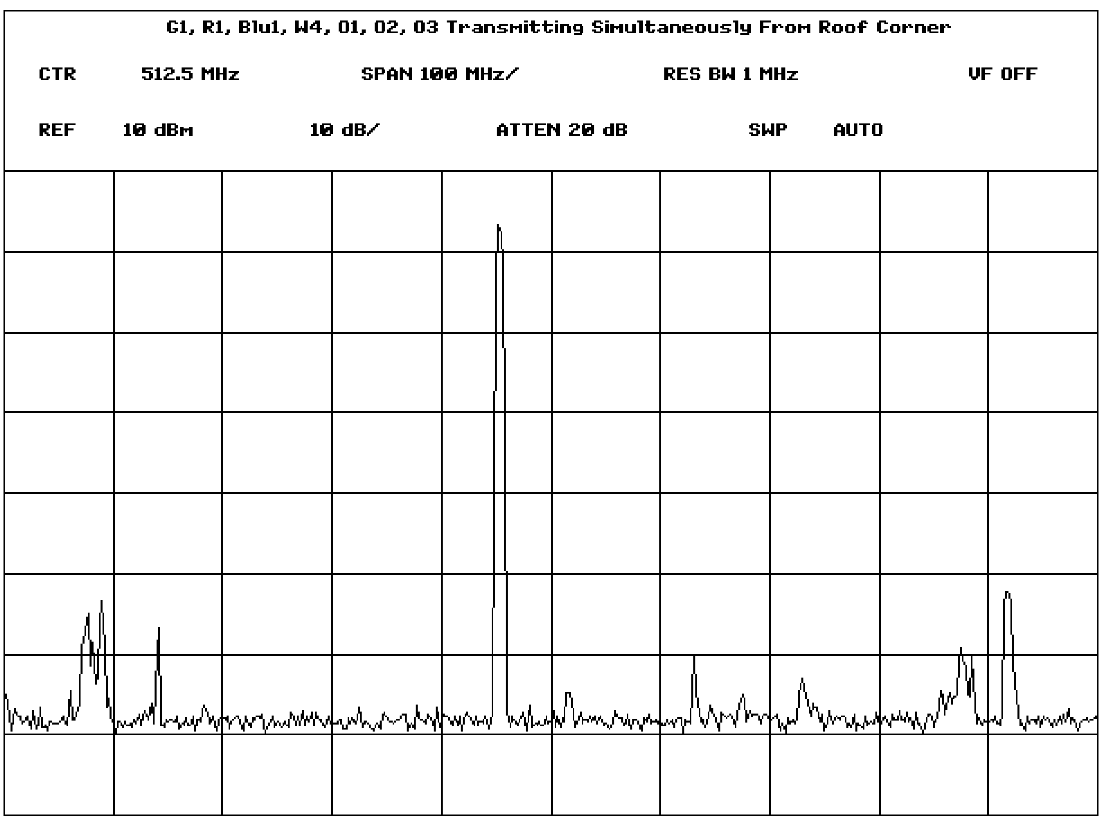

White 4 Transmitting, 3M
CTR 512.5 MHz
SPAN 100 MHz/
RES BW 1 MHz
VF OFF
REF 10 dBm
10 dB/
ATTEN 20 dB
SWP AUTO

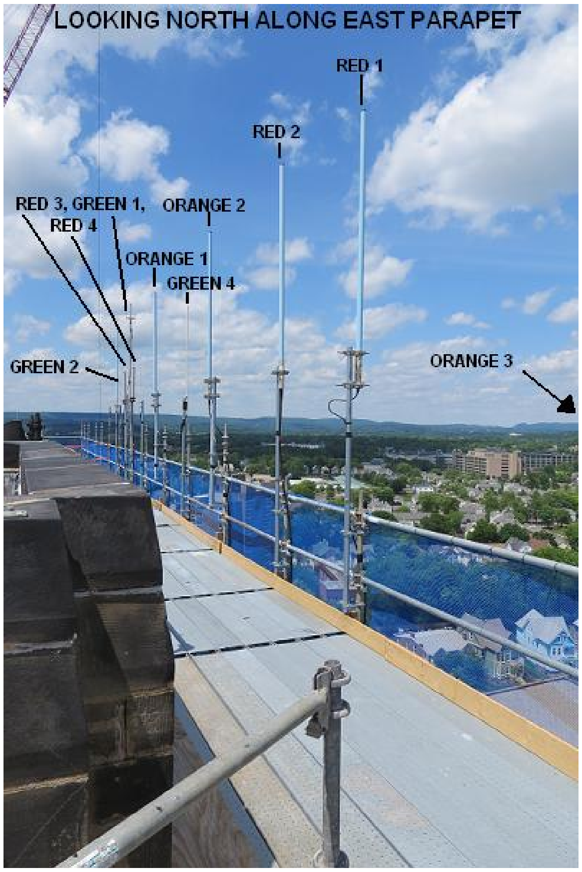

White 1 Transmitting, 4M
CTR 512.5 MHz
SPAN 100 MHz/
RES BW 1 MHz
VF OFF
REF 10 dBm
10 dB/
ATTEN 20 dB
SWP AUTO


G1, R1, Blu1, W4, O1, O2, O3 Transmitting Simultaneously
CTR 512.5 MHz
SPAN 100 MHz/
RES BW 1 MHz
VF OFF
REF 10 dBm
10 dB/
ATTEN 20 dB
SWP AUTO


G1, R1, O1, O2, O3 Simultaneously Transmitting
CTR 512.3 MHz
SPAN 100 MHz/
RES BW 1 MHz
VF OFF
REF 10 dBm
10 dB/
ATTEN 20 dB
SWP AUTO


G1, R1, O1, O2, O3 Simultaneously Transmitting from Next Lower Level
CTR 512.3 MHz
SPAN 100 MHz/
RES BW 1 MHz
VF OFF
REF 10 dBm
10 dB/
ATTEN 20 dB
SWP AUTO


G1, R1, Blu1, W4, O1, O2, O3 Transmitting Simultaneously From Roof Corner
CTR 512.5 MHz
SPAN 100 MHz/
RES BW 1 MHz
VF OFF
REF 10 dBm
10 dB/
ATTEN 20 dB
SWP AUTO



The images above illustrate the location of most of the measured antennas. Blue 1 and White 4, not shown above, are located to the rear of the photographer in the leftmost image, while White 1 is to the extreme left in the right image showing the roof-mounted center tower.

Conclusion

Measured RF radiation levels at the scaffolding level on the Yale PWG roof appeared to be sufficiently low as to not present an exposure hazard. This was true even when seven transmitters were energized simultaneously with the detection antenna pointed at the approximate geographic center of the radiating antennas.

06.17.13 UPDATE: Long-Term Exposure Measurement

On June 17th, 2013, a long-term exposure measurement was conducted by 360°RF utilizing an Aaronia HF-6085V4 spectrum analyzer, and the aforementioned 400 – 1000 MHz log periodic and coax cable as previously used on June 9, 2013. A Sony VAIO laptop was used with Aaronia's logging software program MCS to log data during the time period. The log periodic was first placed about 6.7 meters from antenna Green-1, then later moved further away to about 7.5 meters from Green 1.

The measurement period was originally intended to be over a full 8-hour workday but due to access limitations and time constraints, was limited to a total of 3 hours 35 minutes, broken into two time periods due to the need to stop the logging, move the logging antenna to provide access for workmen disassembling the parapet, then restart the logging, between 11:23 AM and 3:27 PM. The summed results of those two measurement periods are shown in the following plots.

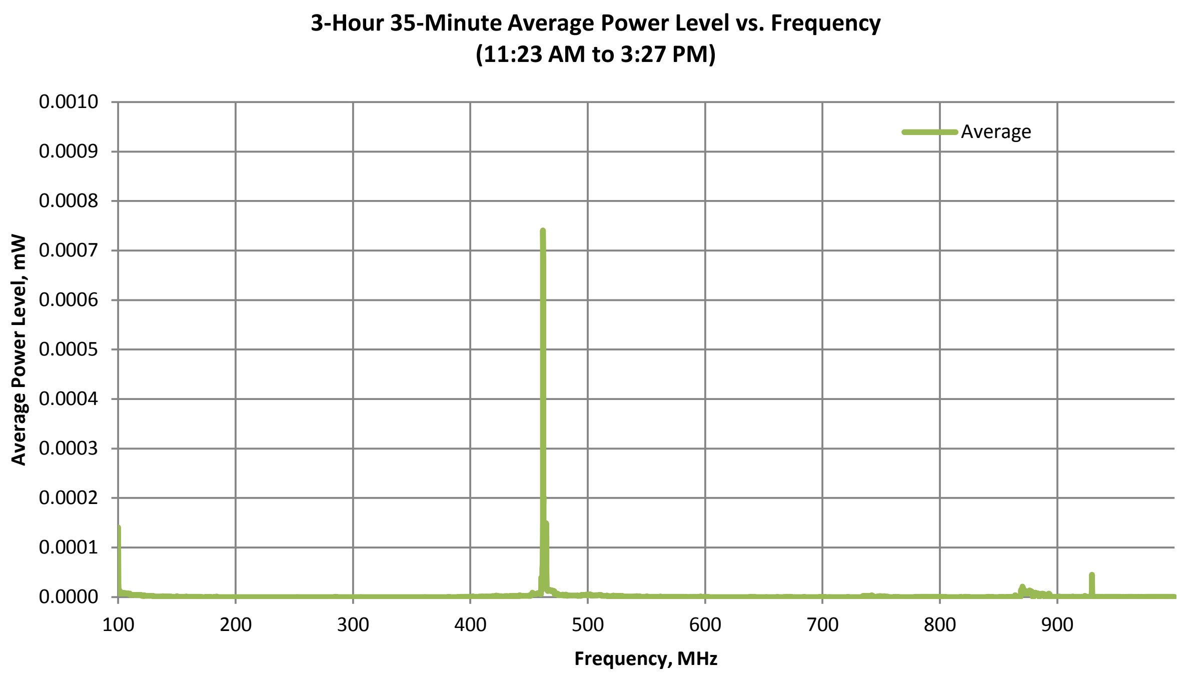
The first plot shows the average signal level in milliwatts as measured at the spectrum analyzer during those two time periods. The second plot shows the calculated average power density in microwatts per square centimeter ($\mu W/cm^2$), which takes the antenna gain response and cable loss into account.

To estimate the total exposure received over 8 hours, the following calculations were performed.

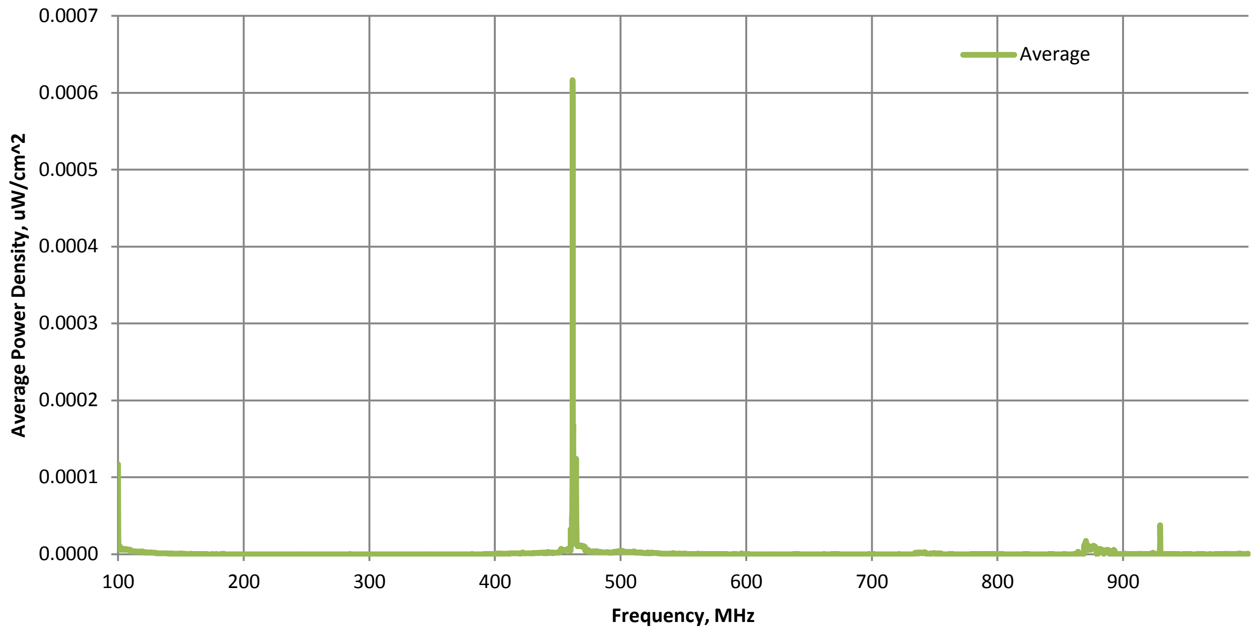
- From 100 to 1000 MHz, the spectrum analyzer sampled every 0.15 MHz, giving 6001 samples over the whole frequency range.

- A total of 821 samples per frequency were taken over the measurement time period of 3 hours 35 minutes and 26 seconds, yielding a total time per frequency sample of 2.154 seconds.

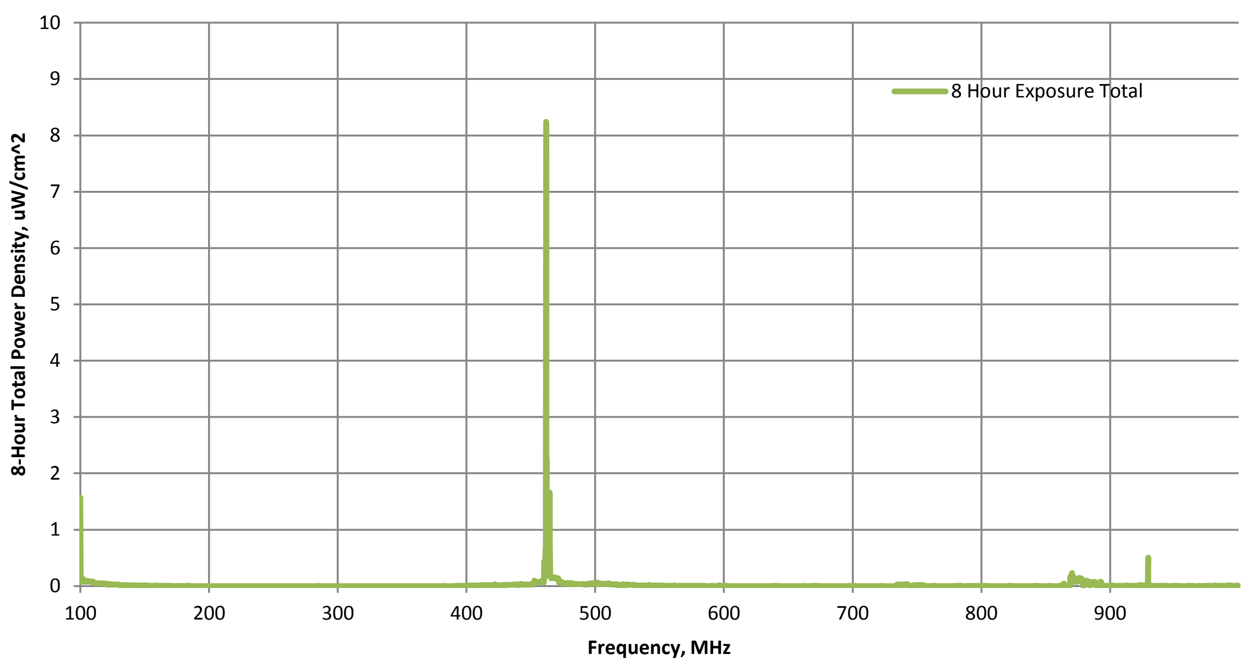
- Correcting 2.154 seconds to 8 hours requires multiplying the average power density for each sampled frequency by 13370.47; the results of this calculation are shown in the third plot below. That plot shows that averaged over 8 hours, the power density is a maximum of about 8.3 microwatts per square centimeter.



3-Hour 35-Minute Average Power Density vs. Frequency, uW/cm^2
(11:23 AM to 3:27 PM)



Estimated 8-Hour Total Power Density vs. Frequency, uW/cm^2



Conclusion

Measurements were taken over a total time period of 3 hours, 35 minutes from 100 to 1000 MHz in order to estimate the total exposure to RF over a typical 8-hour workday. The results indicate that the total exposure is considerably below the OSHA limit of 10 mW/cm^2 averaged over 6 minutes, and significantly lower than the FCC's Maximum Permissible Exposure limit of 0.2 mW/cm^2 as averaged over 6 minutes.