Maximum Permissible Exposure Study
Colorado Public Radio

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For Colorado Public Radio
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1.0 Background and Approach

Colorado Public Radio (CPR) is the licensee for two FM stations in the Denver metropolitan area: KVOD (88.1-FM) and KCFR (90.1-FM). KCFR currently operates from a tower on the west side of Lookout Mountain in Jefferson County, CO. KVOD operates from a different tower on Mt. Morrison, also in Jefferson County. CPR seeks to move both stations to a single combined antenna on the Tribune Tower (KWGN Channel 2 television) on Lookout Mountain with a center of radiation of 56.4 meters (185’) AGL. The purpose of this study is to verify that the proposed antenna complies with FCC guidance for human exposure to radio frequency energy found in CFR 47, Parts 1.1307-1.1310.

KVOD and KCFR currently operate at ERPs of 1.2 kW and 44 kW, respectively, but CPR wishes to increase the ERP of each station to 6.4 kW and 68.3 kW (pending FCC approval) and these worst-case values are used in this study.

The aperture available on the Tribune Tower is limited and it is desirable that the antenna pattern have reduced downward radiation. For these reasons, we recommend an 8-bay ERI “rototiller” antenna (EPA Type 3 element) with half wavelength element spacing. Such an antenna has a null at nadir (straight down) which reduces power densities in the vicinity of the tower base.

Lookout Mountain is a busy broadcast tower site, so we cannot neglect power densities from existing antennas. These ambient power densities are best characterized by measurements versus analysis. Our approach combines analysis and measurements. Predicted ground level power densities from the prospective antenna at each measurement point are added (as percent of standard) to the measured power density. These combined values are compared to the FCC public exposure limit to verify compliance.

2.0 RF Exposure Standards

To protect the public from harmful exposure, the FCC requires its licensees to comply with its published radio frequency exposure standards, found in Parts 1.1307 through 1.1310 of Title 47 of the Code of Federal Regulations [5]. FCC exposure limits are based on voluntary standards published by the American National Standards Institute (ANSI) and the National Council on Radiation Protection and Measurement (NCRP). Jefferson County’s exposure standards and the FCC’s are essentially the same.

The term radio frequency *radiation* is often used to describe the fields emitted by radio antennas, but we must distinguish between the non-ionizing radiation from radio waves and the ionizing radiation from much higher frequency sources such as X-rays. It is physically impossible for radio frequency sources to cause ionization in the human body. Consequently, there is no similarity between the biological effects of ionizing radiation (X-rays) and non-ionizing radiation (radio waves).

We must also distinguish radio frequency fields from extremely low frequency (ELF) fields such as those associated with 60 Hz power lines. ELF fields do not readily radiate from their source and are an entirely different phenomenon.

FCC rules apply different standards for occupational, or *controlled* environments and general population, or *uncontrolled* environments. The definitions of controlled and uncontrolled environments are as found in the FCC rules [5]:

> **Controlled Environment** - "Occupational/controlled limits apply in situations in which persons are exposed as a consequence of their employment provided those persons are fully aware of the potential for exposure and can exercise control over their exposure. Limits for occupational/controlled exposure also apply in situations when an individual is transient through a location where occupational/controlled limits apply provided he or she is made aware of the potential for exposure."
>
> **Uncontrolled Environment** - "General population/uncontrolled exposures apply in situations in which the general public may be exposed, or in which persons that are exposed as a consequence of their employment may not be fully aware of the potential for exposure or can not exercise control over their exposure."

Other than the fenced areas around the Tribune Tower and other towers, Lookout Mountain is an uncontrolled environment and the general population or *public* limit applies. For uncontrolled environments, the FCC sets a standard of 0.2 milliwatt/cm^2 in the VHF band (30-300 MHz) which includes the FM broadcast band. In this band, the general population limit is exactly a factor of five below the occupational limit. The FCC exposure standards are plotted as functions of frequency in Figure 1.

The human body does not react to high power densities instantaneously and short-term exposure to levels exceeding FCC power density limits does not necessarily exceed the FCC exposure limits. The FCC limits are for whole-body exposure averaged over a period of 6 minutes for controlled environments and 30 minutes for uncontrolled environments [1], [2], [5]. For example, if a radio technician is exposed to a power density of 0.5 milliwatts/cm^2 for a period of 4 minutes and then enters a field of 1.5 milliwatts/cm^2 for a period of 2 minutes, the average exposure in the six minute period is 0.83 milliwatts/cm^2 which is below the FCC limit for controlled environments.

Although other Federal agencies publish RF exposure standards (e.g., OSHA), the governing standard for communications sites is the FCC standard. The FCC prepared an easy-to-read publication explaining its RF exposure policy [6]. This publication is available from the FCC web site at www.fcc.gov.

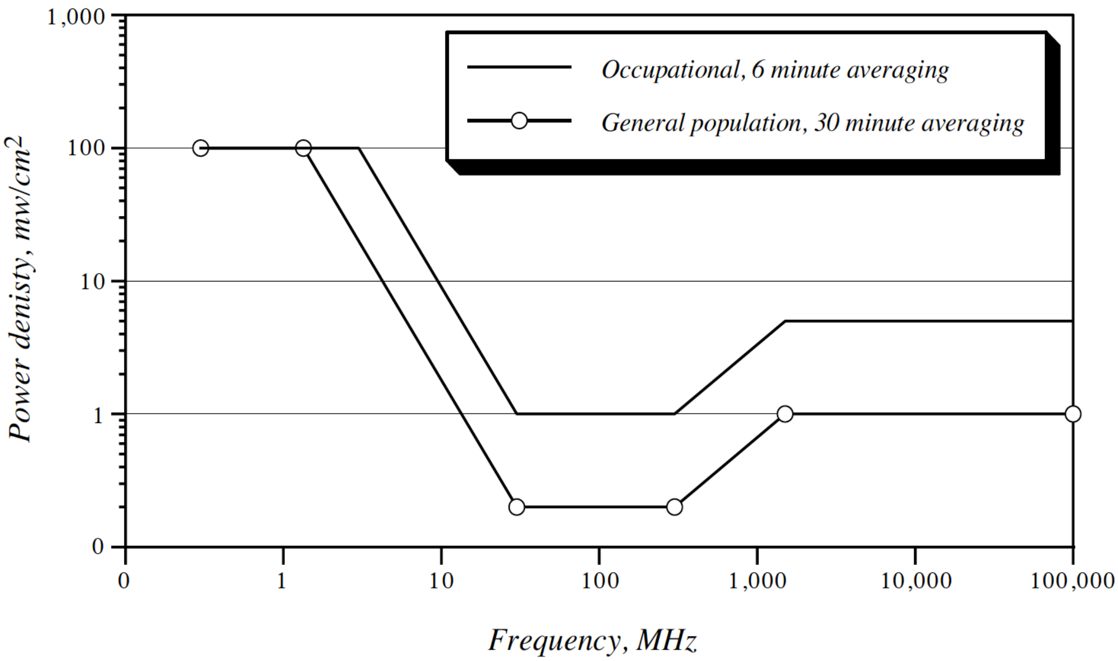

Figure 1 - FCC Exposure Standards
(Plane wave equivalent E-field power density values)

3.0 Ensuring Compliance

If the radio site has a single transmitter, one can ensure compliance by comparing the predicted power density to the FCC standard for the transmitter frequency. When the site has multiple transmitters operating over a wide range of frequencies, it becomes more difficult to ensure compliance. For example, if a tower has a paging antenna at 929 MHz and an FM broadcast antenna at 99.9 MHz, which standard do we apply for occupational exposure, 3.1 mW/cm^2 or 1.0 mW/cm^2?

In these situations, the FCC directs that a fraction of the standard be computed for each source. If the sum of the fractions is less than 1.0, the site is in compliance. Mathematically, this requirement is stated as

$$Q = \sum_{i=1}^{M} \frac{S_i}{S_{FCC}(f_i)} \leq 1.0 \qquad (1)$$

where M = the number of radiating antennas at the site, S_i = the average power density from antenna i, f_i = the operating frequency of antenna i, and $S_{FCC}(f_i)$ = the FCC power density limit for frequency f_i.

On congested sites, a non-compliance condition may be caused by numerous transmitters belonging to many different licensees. The FCC recognizes that it may be impractical to assign responsibility to every transmitter contributing to the measured power density, so the Commission employs a 5% rule in these situations. In other words, only those stations that contribute 5% or more of the applicable exposure standard are responsible for correcting the problem. This rule is reproduced below from 47 CFR 1.1307(b)(3) (Oct. 1, 2016):

> "(3) In general, when the guidelines specified in Sec. 1.1310 are exceeded in an accessible area due to the emissions from multiple fixed transmitters, actions necessary to bring the area into compliance are the shared responsibility of all licensees whose transmitters produce, at the area in question, power density levels that exceed 5% of the power density exposure limit applicable to their particular transmitter or field strength levels that, when squared, exceed 5% of the square of the electric or magnetic field strength."

4.0 Analysis

The proposed antenna is an ERI SHPX-series 8-bay antenna with half-wavelength element spacing. It has an omnidirectional antenna azimuth pattern. The elevation pattern is the product of the element pattern and the array pattern and the array pattern has a null in the nadir direction. The antenna elevation pattern is shown in Figure 2.

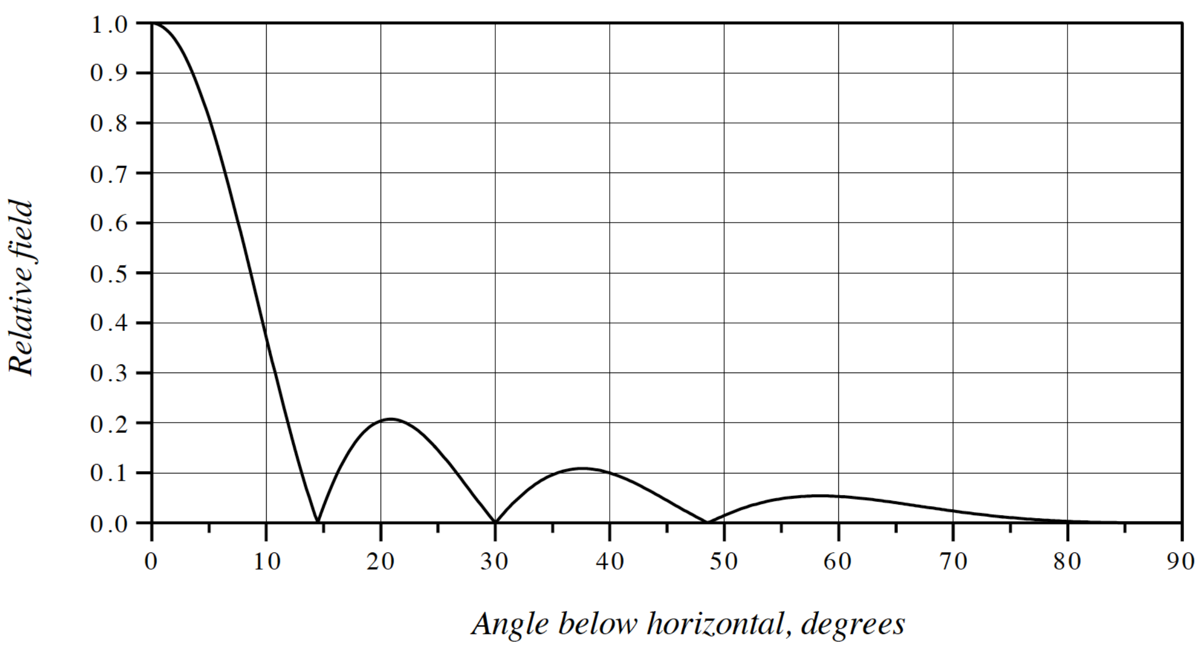

Figure 2 - 8-Bay, Half Wavelength-Spaced ERI Rototiller Antenna Elevation Pattern

The analysis for this study follows the guidance found in FCC OET-65 [2]. The power density of a plane wave will attenuate as the square of the distance from the source. We can write the power density at a distance *d* from the source antenna as

$$S = \frac{EIRP}{4\pi d^2} \tag{2}$$

where EIRP is the effective isotropic radiated power. Equation (2) is valid when the measurement is taken in the far field and in the main lobe of the antenna and there are no reflecting surfaces nearby. In practice, the EIRP must be adjusted to accommodate several factors, including:

- Antenna elevation pattern
- Antenna azimuth pattern
- Near field vs. far field effects
- Ground reflections
- Type of modulation
- Antenna polarization

In this study, we are interested in the power density contributed by two FM broadcast transmitters operating from a single, circularly polarized master FM antenna. We can write the expression for power density for a circularly-polarized broadcast FM station in mW/cm^2 as [2]

$$S = \frac{a_r g_d f_a(\phi)^2 f_e(\phi)^2 (ERP_{hpol} + ERP_{vpol})(1{,}000 mw / watt)}{4\pi d^2 (10{,}000 cm^2 / m^2)} \tag{3}$$

where a_r is the power reflection factor, $a_r = 4$, worst case, $a_r = 2.56$ used in practice
g_d is the gain of a half-wave dipole = 1.64
$f_a(\phi)$ is the relative field strength of the total azimuth antenna pattern (vpol+hpol)
$f_e(\phi)$ is the relative field strength of the total elevation antenna pattern (vpol+hpol)
ϕ is the azimuth angle or the look down angle measured from the horizontal
ERP_{hpol} is the effective radiated power in the horizontal polarization in Watts
ERP_{vpol} is the effective radiated power in the vertical polarization in Watts
d is the slant distance between the radiating source and the observation point in meters

The licensed ERP for an FM station is the ERP in the horizontal polarization. The ERP in the vertical polarization can be as large as the horizontal, but no larger. For the purposes of this study, we made the worst-case assumption that the horizontal and vertical ERP are identical. We also assume that the IBOC ERP is included in the values above. For this study, a worst case values of IBOC ERP equal to 10% of the licensed ERP was used.

A power reflection factor of 4.0 is very conservative because it assumes worst-case reflection geometry and a perfectly conducting ground. For practical sites, the FCC suggests a reflection factor of 2.56 (60% field reflection) [2]. At distant locations, reflection angles are shallow and reflections are weaker regardless of soil conductivity.

We are assuming that the master FM antenna has two combined FM stations, with ERPs of 6.4 kW and 68.3 kW. For exposure purposes, the total FM ERP (hpol+vpol, including IBOC) is 149.5 kW.

Using the digital topographical map provided by the City of Golden, we identified 95 locations in within 500 meters of the Tribune Tower for measurement and analysis. The coordinates (*x, y, z*) of each location were extracted from the topographic map using a rectangular coordinate system to scale. The coordinates were converted to meters for further analysis.

The azimuth and elevation angles from the center of radiation of the prospective antenna to each of the 95 locations were calculated. Then elevation relative field pattern factor were entered at each location using the elevation pattern in Figure 2. The power density was then computed at each location at a height of 1.8 m (6') above ground in units of mW/cm^2, percent of occupational limit and percent of public limit, using the OET-65 method (see Equation 3). The following study parameters were used:

a. Location: Channel 2 Tribune Tower, ASRN 1044149, Ground elevation 2218.6 m (7278.9') AMSL, 39-43-58.0 N, 105-14-10.0 W (NAD 83).
b. Antenna CoR: 56.4 m (185') AGL
c. ERP (CP): 88.1-FM = 6.4 kW, 90.1-FM, 68.3 kW
d. Antenna Type: ERI SHPX-8AC-HW, ERI Rototiller, 8-Bay, Half Wave Spaced
e. Antenna Gain: 2.519
f. Antenna Length, End to End: 15.4 m (50.6'), (38.1' center to center of end bays)
g. Ground power reflection factor = 2.56
h. Observer height = 1.8 m AGL
i. Public exposure limit = 200 $\mu W/cm^2$.

Equation (3) was first calculated for a simplified case of a flat earth to evaluate candidate antenna patterns. Figure 3 shows the power density as a function of distance assuming flat earth with a ground elevation equal to the base of the tower. Note that the peak predicted power density of 12.4 $\mu W/cm^2$ occurs at a horizontal distance of 407 meters from the tower base.

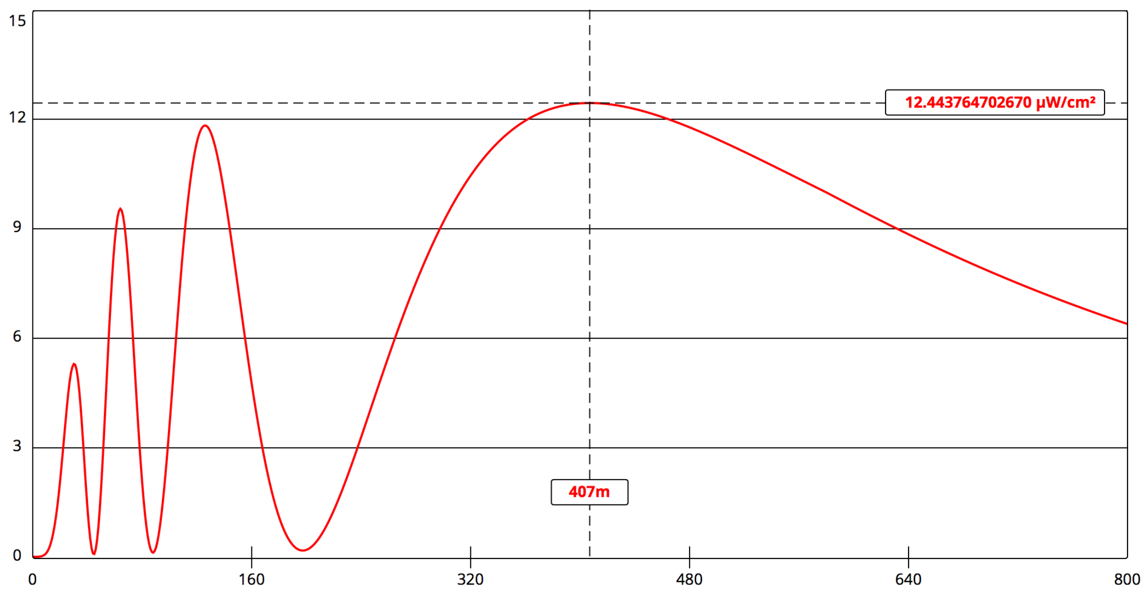

Figure 3 - Power Density Versus Distance Assuming Flat Earth (observer at 1.8 m)

But the top of Lookout Mountain is not flat and the local high point is Buffalo Bill's grave site which is 32.3 m (106') higher than the base of the Tribune Tower. Figure 4 shows the power density as a function of distance assuming flat earth at an elevation equal to the Buffalo Bill grave overlook. The overlook is 190 meters horizontal distance from the base of the tower. At this distance and height the predicted power density is 36 $\mu W/cm^2$. Note that the FCC public exposure limit is 200 $\mu W/cm^2$.

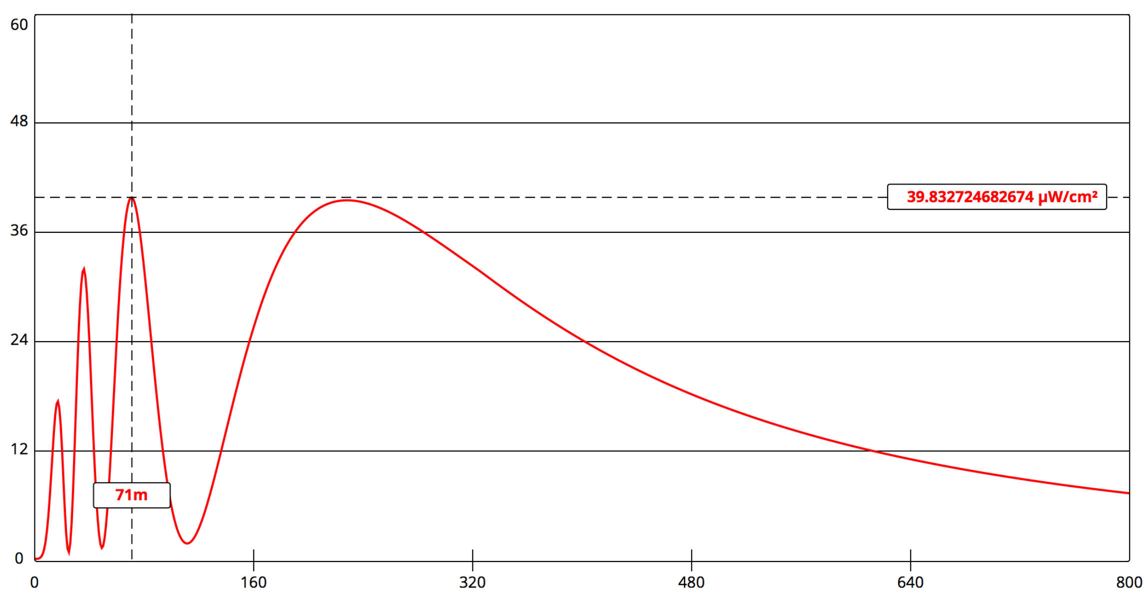

Figure 4 - Power Density Versus Distance Assuming Buffalo Bill Grave Overlook Flat Earth (8 bay, half wave spaced)

We can improve performance at the Buffalo Bill overlook by using an 8 bay, 3/4 wavelength-spaced antenna. This increases the length of the antenna to 70' end-to-end which is a disadvantage, but this antenna does have higher gain. As shown in Figure 5 below, the power density at 190 meters is reduced to 3.2 μW/cm^2, but the power density increases near the tower base with a peak at 39 m horizontal distance. It is unlikely that the 3/4 wavelength-spaced antenna will fit in the available aperture and the tradeoffs are not that favorable, regardless because we increase power densities at and near the tower base. Consequently, we recommend the 8-bay, half wavelength-spaced antenna.

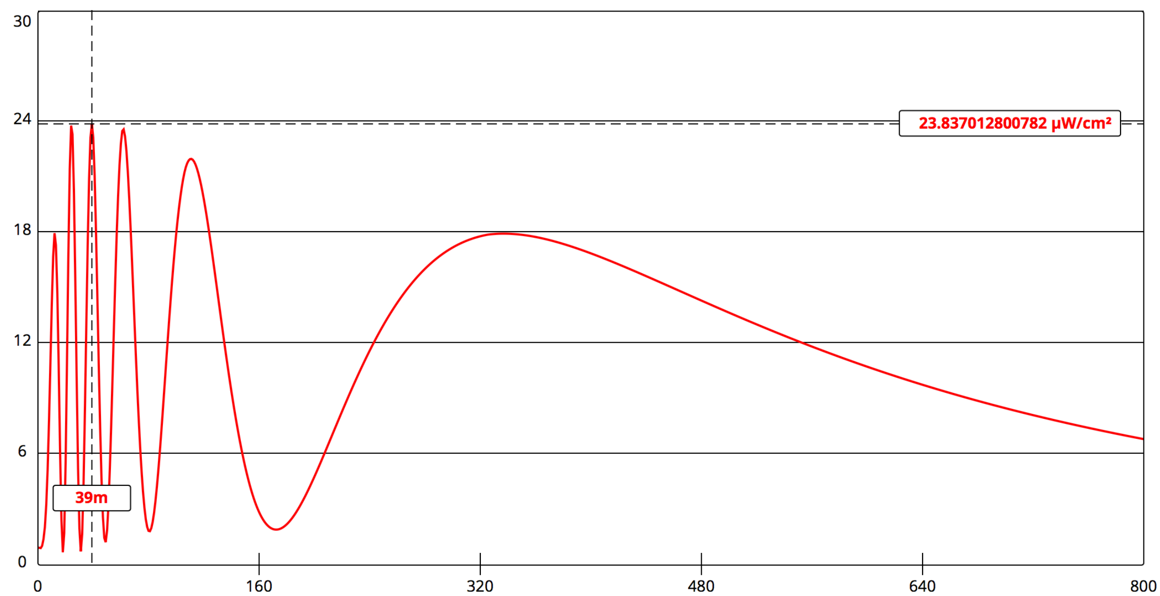

Figure 5 - Power Density Versus Distance Assuming Buffalo Bill Grave Overlook Flat Earth (8 bay, 3/4 wave spaced)

After measurements were collected (see Section 5 below), power densities were calculated at each measurement location, taking into account actual terrain elevations. These values are shown in the spreadsheet in Appendix A.

5.0 Measurements

The MPE survey was accomplished on March 29, 2017 by Bryan Canaan (*Pericle*). Measurements were conducted in accordance with the guidelines published in ANSI C95.3-2002 [3] and FCC Bulletin OET-65 [2]. The survey was accomplished with the test equipment listed in Table 1.

Table 1 - Test Equipment Used in Survey		
Instrument	**Serial Number**	**Last Calibration (2 yr.)**
Wandel & Goltermann (W&G) EMR-300	B-0053	February 24, 2017
Wandel & Goltermann Type 25.1 Probe, 300 kHz - 40 GHz	B-0053	February 24, 2017

Electromagnetic fields on the site are a complex combination of signals from several sources. Reflections from the ground, buildings, towers, and guy wires create standing waves with wide spatial variations. Moving the probe a distance of a few inches can result in significant measured variation. The FCC standard is a whole-body average exposure standard, so the measurements must be taken over a volume comparable to that occupied by a standing adult. The W&G probe and meter record field strength as percent of the FCC controlled environment standard. The W&G meter also performs an automatic average as the user sweeps the volume of interest. To perform a spatial average with the W&G meter, we use either a vertical straight line method (for levels well below FCC limits) or the zig-zag method (for levels approaching the FCC limit) shown in Figure 6.

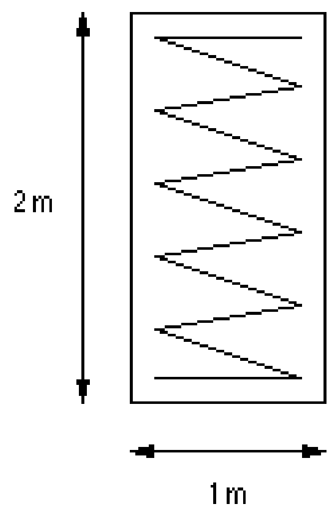

Figure 6 - Zig-zag method for automatic spatial averaging

Measurements are always taken at least 20 cm from reflecting objects in accordance with ANSI C95.3-2002. Magnetic field probes tend to exhibit false readings above 300 MHz. Because sources on Lookout Mountain include both VHF and UHF transmitters, we did not use a magnetic field probe.

Measurement locations were selected to be thorough, but also to focus on locations where terrain and proximity resulted in higher ambient power densities. We see from the contour map of Figure 7 that the local high point is the Buffalo Bill grave site where power densities are likely to