Broadcast Signal Lab

Evaluation of Human Exposure Potential Of Three Utility-pole-mounted Antenna Configurations In The Advanced Wireless Service, Personal Communications Service and Cellular Service For Extenet Systems

1. Introduction

Extenet Systems engaged Broadcast Signal Lab, LLP to evaluate the emissions from three antenna configurations considered for distributed antenna systems in Yonkers and Mount Vernon, New York. Each configuration employs a Comba omnidirectional antenna mounted on streetside poles. Three heights are evaluated in anticipation of three mounting configurations – on a 37-foot utility pole, a 26-foot lamp post, and a 22-foot high side-arm mount on a utility pole. The first configuration (37-foot nominal height) places the antenna above electrical distribution lines where it is anticipated only electrical workers qualified to work on distribution lines and apparatus may ascend to perform work on the power lines or the antenna components within and above the electrical space on the utility pole. The second configuration (26-foot nominal height) places the antenna on a lamp post that does not serve to transport electricity or communications services and is only serviced by individuals maintaining the lights. The third configuration (22-foot nominal height) places the antenna in the so-called communications space of a utility pole where every utility worker, including electrical, cable, and telecom, has an opportunity to be near it.

2. Protocol

We apply the Federal Communications Commission (FCC) criteria for human exposure to radio frequency energy as codified in 47 CFR 1.1310, **Radiofrequency Radiation Exposure Limits**, and amplified in FCC Office of Engineering and Technology Bulletin 65, *Evaluating Compliance* *with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields.* In addition, we rely on additional guidance from the Institute of Electrical and Electronics Engineers (IEEE) standards committee C95 series of standards and the National Council on Radiation Protection and Measurements (NCRP) Report 119, *A Practical Guide to the Determination of Human Exposure to Radiofrequency Fields.*

3. System

The proposed distributed antenna system technology employs low power radiofrequency amplifiers at each point of emission to the environment. The proposed amplifier is a model NEXUS FT manufactured by Powerwave technologies. It is designed to transmit and receive radio communications in three licensed wireless bands – the Advanced Wireless Service ("AWS"), Personal Communications Service ("PCS") and Cellular Service ("Cellular"). Our only concern is for the portions of each band that are transmitted by the Powerwave unit. The radio frequencies employed to receive from the mobile telephone are not relevant because the unit does not generate these frequencies. The Powerwave unit's AWS transmitted ("downlink") band is 2110-2150 MHz. The PCS downlink spectrum extends from 1930 to 1990 MHz. The Cellular downlink spectrum extends from 869 to 894 MHz.

The Powerwave unit is mounted to the utility pole and coaxial cables are installed to link the amplifier to an antenna mounted on the utility pole. By virtue of their relatively low antenna heights and their consequently small, often terrain-limited coverage areas, these installations do not require much radio frequency energy to achieve their coverage objectives. Each amplifier has a maximum output power of 20 watts. Regardless of the number of communications channels transmitted from the unit, the combined power of all channels on a common amplifier can not exceed 20 watts (43 dBm). Each amplifier is connected to the antenna via coaxial cables that waste a small portion of the power. We apply a conservative 1 dB loss figure to the 43 dBm output, achieving a 42 dBm antenna input power.

We approach the analysis in four ways. Each wireless service is treated independently, assuming there is one amplifier handling one service spectrum in the Powerwave unit. The fourth analysis assumes there are three amplifiers and each is carrying the signals belonging to one of the three service bands. This is called the "composite" analysis.

The antenna employed in the current analysis is a dual-band model that may accommodate signals in several wireless communications bands, including the AWS band that also straddles the PCS bands in the 1850 MHz region, as well as the original cellular bands in the vicinity of 850 MHz and.

4. Regulatory Environment

The FCC indicates that radio frequency facilities operating in this spectrum are required to perform a *routine evaluation* of their emissions only if the antennas are less than 33 feet above ground and their emissions are less than 2000 watts effective radiated power (ERP). The system design employs power levels that are significantly lower than the threshold. Based on this, FCC licensees operating on such a system are not obliged to perform any analysis of potential exposure of members of the public on the ground because the emissions are understood to be implicitly compliant. However, this does not exempt the operator from compliance. Nor does it address individuals who would have occasion to work on the poles and lines.

The FCC exposure[1] limitations are divided into two classes: occupational/controlled ("occupational" or "controlled" depending on context) and general population/uncontrolled ("public" or "uncontrolled" depending on context). Uncontrolled areas where people without proper training and supervision may go must adhere to a more stringent exposure limit than controlled areas. In controlled areas, personnel who have access must be provided with necessary knowledge and protocols to control their exposure. This means that if a utility worker who is not properly informed about controlling exposure has access to the antenna level, the public exposure

[1] For the layman reading this analysis, detailed discussion of "exposure" may seem daunting. All individuals are exposed to radio waves continuously in their daily lives. From cell phones to garage door openers, to baby monitors, to radio and TV broadcasts, the airwaves are busy with radio signals, and our bodies are immersed in them all the time. Exposure to radio energy is not a matter of either being exposed or not exposed. Rather, it is a matter of degree—how much exposure? Is it excessive? We offer reassurance that the exposure standards are conservative. That is to say, when individuals are exposed to radiofrequency energy that is compliant with the applicable limit (occupational or public), they are exposed to energy levels that are quite feeble and are not shown to be harmful. The standards avoid excessive levels by invoking a large factor of safety. Excessive levels of radio energy, such as can be found inside a high power TV broadcast transmitter, can be injurious, and significant precautions are necessary when working with such equipment. By comparison, the amplifier unit evaluated in this report operates at very modest power levels requiring minimal precautions to comply with the safety standards. As an analogy, we manage our exposure to excessive amounts of another form of electromagnetic energy, sunlight, to avoid injury but are not concerned with the intensity of moonlight or starlight.

criteria apply. If, however, all workers who have access to a given antenna are trained to avoid or control exposure, the occupational criteria apply.

Above utility poles that have power lines on them one may expect the only personnel who have access are duly authorized electrical workers. (Power lines occupy the upper spaces on the poles.) Such workers would be trained and required to maintain appropriate distances or exert other control over their exposure, including employing such options as maintaining minimum distance limits, employing body monitors or performing power reduction to control exposure. Antennas in the communications space may be more difficult to control. Since a variety of communications services and their contractors have access to the communications space, it would be more difficult to ensure all parties exert the necessary control over their workers to understand and manage their exposure. The public exposure limits might be most appropriate in the communications space, while the option of employing occupational exposure limits above the electrical space has potential, but should be implemented with care.

We evaluated the antenna emissions for the public and the occupational exposure limits. It will be up to the parties in control of access to the utility spaces to determine how to administer any exposure control protocol. At a minimum, it is advisable to provide basic information (labels or signs) on the installation regarding compliant distances to maintain from the antenna and whom to contact if this distance must be violated.

The current state of the radiofrequency energy exposure discipline considers the *whole body average* exposure to the radiofrequency environment. In situations where part of a body is in a higher field than the average, relaxed partial body exposure limits apply. This is likely to be the case with the relatively small and low power antennas considered in this analysis because they are neither large enough nor powerful enough to evenly illuminate an entire human body. However, there is a consensus (e.g IEEE C-95.1) that the eyes and testes are two human organs that are not subject to the relaxed partial body exposure limits. Based on the nature of utility work, individuals climb poles or are hoisted in buckets to fixed positions in order to perform a specific task at a specific point for a period of time. This potentially places the worker in a position with respect to an antenna in which the eyes or testes could be exposed to a peak value of the antenna's field while the whole body exposure remains below the limit. Therefore, we suggest it is prudent to simply employ the public or occupational limits as the guides and not attempt to make allowances for whole body averaging, partial body exposure, or exposure time management. Properly trained and equipped personnel might be permitted to work with higher partial body exposures (with compliant whole-body averages) on a case-by-case basis.

5. Exposure Assessment

Exposure is described by a combination of the strengths of the fields to which the body is exposed and the duration of the exposure. A 6-minute averaging time applies to the occupational/controlled exposure class, while the general population/uncontrolled class is assessed with a 30-minute exposure window. These exposure times are rolling windows. That is to say, any continuous period of 6 or 30 minutes must not result in exposure above the respective limit. In uncontrolled environments it is by definition that individuals are not exerting control over their exposure time, so the only controls to exposure time would be related to the operation of the RF emitter. With a system, such as a wireless facility, that essentially randomly operates when users are communicating through it, there is no reasonable way to limit general population exposure by controlling emission times in half-hour windows. Hence, the exposure levels as written must be applied, irrespective of the exposure time.

In contrast to the public exposure management limitation, in controlled environments where individual have been trained and equipped to manage exposure, it is conceivable that an individual might work for, say, two or three minutes within an exposure area that is up to twice the limit, and exit the over-exposure area for the remaining 3 to 4 minutes to ensure the average exposure is within specification. This is still a complicated affair to manage, but is an option for brief inspectional excursions under well-defined circumstances.

5.1. Emission Regions

The emissions of the antenna are tabulated in Table 1. From left to right are analysis columns with information for the AWS, PCS, Cellular and Composite bands. Starting from the top of the table, we applied an approximate dimension of the height of the antenna, which was used in calculating the threshold between the reactive near field and the radiating near field of the antennas. This is an important first step in exposure analysis when operating antennas at low power levels. In the reactive near field, the closest region to an antenna, the electrical and magnetic fields are not coalesced into a radiating wave and may have significant peaks or nulls that are not predicted by the antenna radiating pattern. The most reliable way to characterize the reactive near field, and the potential exposure to a body within this region, is to perform measurements under controlled conditions, which have not been performed in this study. Hence, it is advisable that the reactive near field region simply be identified as off-limits in the absence of further analysis.

The far field region of the antenna (the Fraunhofer region) is the region most distant from the antenna where the electric and magnetic fields of the electromagnetic emissions are functioning in a fairly fixed relationship that lends itself to customary measurement techniques. The transition region between reactive near field and the far field is the radiating near field—also called the Fresnel region. It has a reactive component, but is primarily a radiating signal. The Fresnel region and the Fraunhofer region are more reliably modeled with conventional power density equations than the near field region.

Using the antenna's physical height[2] and the signal frequencies, we calculated the distance to the Fresnel region with equation 37 from IEEE standard C95.3-2002, Annex B. This distance varies for each service band. Next, using the antenna gain and antenna input power for the respective bands, we calculated the effective power emitted on the main lobe of the antenna.

5.2. Safe-Side Estimation

An antenna acts like a lens. By analogy, the lens of a lighthouse or a flashlight focuses a modest light into a beam that has a bright spot (the main lobe) whose width is measured in degrees. The narrower the beam, the greater the focusing power of the lens, the brighter, and smaller, the bright spot of the beam is. The antenna considered in this analysis has focusing power, called gain, of about 6 to 8 dBi in the AWS and PCS bands. It has a gain of 3.7 to 4.7 dBi in the Cellular band. We applied the gains to determine how "bright" the main lobes of the emitted signals are, known as the Effective Isotropic Radiated Power ("EIRP") levels.

A person directly in front of the lobe of the antenna will be exposed to the highest power density the antenna emits. Since it is often not apparent to workers where the main lobe of the antenna is directed, it is prudent to assume the antenna could be pointed in any direction and employ this main lobe power to determine safety distances for all angles of approach. In practice, however, the focus of the antenna is horizontal or nearly so. Emissions from the antenna downward, toward persons on the ground or to workers positioned below the antenna, are less powerful than the

[2] We employed the mechanical dimension of the antenna, which may not exactly represent the electrical length of the antenna. Our estimates of the distance to the Fresnel region are only slightly conservative in favor of increasing the recommended minimum distance to the antenna.

main lobe of the antenna. Exposure levels at a given distance directly below the antenna will be typically one-tenth to one-thousandth of the exposure levels at an equal distance horizontally in front of the antenna.

Characteristic	Source	Unit	AWS Band	PCS Band	Cellular Band	Combined
Antenna	Given	Make/Type/ Model	Comba, Omni OOA-360V06N0	Comba, Omni OOA-360V06N0	Comba, Omni OOA-360V06N0	Comba, Omni OOA-360V06N0
Largest Dimension of Antenna (Height)	Given	m	0.6	0.6	0.6	0.6
Antenna Frequency	Given	MHz	1710-2500	1710-2500	806-960	composite
Evaluation Frequency			2110	1930	869	composite
Antenna Gain	Given	dBi	7, ±1	7, ±1	4.2, ±0.5	composite
Antenna Input Power	Given	dBm	42	42	42	composite
Antenna Input Power	Calculated	watts	15.8	15.8	15.8	composite
Effective Isotropic Radiated Power	Calculated	watts	100	100	46.7	composite
Exposure Near Antenna						
Occupational Exposure Limit	Calculated	mW/cm^2	5	5	2.9	composite
Public Exposure Limit	Calculated	mW/cm^2	1	1	0.6	composite
Wavelength	Calculated	ft	0.46	0.51	1.1	composite
Minimum Fresnel Distance	Calculated	ft	3.5	3.2	1.4	max case 3.5
% Occupational Limit At Fresnel	Calculated	%	14	16.8	66.9	38.7
% Public Limit At Fresnel	Calculated	%	70	84	334.7	193.7
Distance To Occ Limit [See Text]	Calculated	ft	1.3	1.3	1.1	2.2
Distance To Public Limit [See Text]	Calculated	ft	2.9	2.9	2.6	4.9
Ground Level Analysis						
Antenna Height Above Ground Level	Given	ft	22	22	22	22
Emissions at 2 m AGL (Maximal case)	Calculated	mW/cm^2	.036	0.036	0.017	composite
Emissions at 2 m AGL (Maximal case)	Calculated	% public limit	3.6	3.6	2.9	9.9
Compliant at ground level?			Yes	Yes	Yes	Yes
Antenna Height Above Ground Level	Given	ft	26	26	26	26
Emissions at 2 m AGL (Maximal case)	Calculated	mW/cm^2	.023	.023	0.011	composite
Emissions at 2 m AGL (Maximal case)	Calculated	% public limit	2.3	2.3	1.8	6.2
Compliant at ground level?			Yes	Yes	Yes	Yes
Antenna Height Above Ground Level	Given	ft	37	37	37	37
Emissions at 2 m AGL (Maximal case)	Calculated	mW/cm^2	0.0092	0.0092	0.0043	composite
Emissions at 2 m AGL (Maximal case)	Calculated	% public limit	0.9	0.9	0.7	2.5
Compliant at ground level?			Yes	Yes	Yes	Yes

Table 1 – Antenna Analysis Data

Note: Controlling minimum approach distances (Fresnel and/or MPE) for occupational and public compliance are highlighted yellow in each column.

The results of our analysis are realistic in the horizontal direction from the antenna, and conservatively overestimate the emissions below the antenna. When the antenna is in its normal position, vertical, its main lobe is roughly horizontal. Ground-level exposure estimations are calculated as if the antenna lobe were pointed directly to the ground rather than toward the horizon. The calculations assume the antenna is mounted horizontally with the main lobe pointed directly at the ground.

5.3. Maximum Permissible Exposure

We also applied the FCC controlled and uncontrolled area standards to the frequency of the radio signals under consideration to determine the maximum permissible exposure (MPE) levels. These are presented in units of power density—in this case milliwatts per square centimeter (mW/cm^2). Then, based on the antenna effective power levels, we computed the distance from antenna to the controlled and uncontrolled area MPE levels. This computation applies only if the results are outside the start of the Fresnel region. If the results are less than the minimum Fresnel distance, then the Fresnel distance is the controlling limit (until more detailed reactive near field analysis is conducted).

Table 1 shows the calculated Fresnel distance for the antenna as well as the calculated minimum distance to the occupational and public MPE's. Since for the AWS and PCS bands this antenna's Fresnel region extends farther from the antenna than the calculated MPE distances, the Fresnel distances should be the limit of approach by personnel. The Cellular and Composite columns indicate that the Fresnel distance applies to occupational compliance and the MPE distance applies to public compliance.

Table 1 also shows the predicted power densities and percentages of the public MPE near ground level, based on the three nominal antenna heights above ground – 37, 26, and 22 feet.

6. Analysis

6.1. AWS Amplifier Only

The emissions of a fully-loaded Powerwave amplifier module operating in the AWS spectrum and connected to the Comba antenna are of no regulatory consequence on the ground below or near the pole to which it is attached. In the most extreme case, in which the antenna is 22 feet above ground and the antenna is tilted to focus its main lobe at the ground, the emissions reach

3.6 % of the public MPE. In practice, the emissions at ground level can be expected to be orders of magnitude less than this safe-side estimate. As the antenna height above ground increases, the ground–level exposure decreases further.

For workers approaching the antenna, the minimum Fresnel distance applies. Workers should assume the antenna is emitting the full 100 watts effective power and should remain outside the Fresnel region. This is a radius of 3.5 feet from the antenna.

6.2. PCS Amplifier Only

The emissions of a fully-loaded Powerwave amplifier module operating in the PCS spectrum and connected to the Comba antenna are of no regulatory consequence on the ground below or near the pole to which it is attached. In the most extreme case, in which the antenna is 22 feet above ground and the antenna is tilted to focus its main lobe at the ground, the emissions reach 3.6 % of the public MPE. In practice, the emissions at ground level can be expected to be orders of magnitude less than this safe-side estimate. As the antenna height above ground increases, the ground–level exposure decreases further.

For workers approaching the antenna, the minimum Fresnel distance applies. Workers should assume the antenna is emitting the full 100 watts effective power and should remain outside the Fresnel region. This is a radius of 3.2 feet from the antenna.

6.3. Cellular Amplifier Only

The emissions of a fully-loaded Powerwave amplifier module operating in the Cellular spectrum and connected to the Comba antenna are of no regulatory consequence on the ground below or near the pole to which it is attached. In the most extreme case, in which the antenna is 22 feet above ground and the antenna is tilted to focus its main lobe at the ground, the emissions reach 2.9 % of the public MPE. In practice, the emissions at ground level can be expected to be orders of magnitude less than this safe-side estimate. As the antenna height above ground increases, the ground–level exposure decreases further.

For workers approaching the antenna, the minimum Fresnel distance applies. Workers should assume the antenna is emitting the full 47 watts effective power and should remain outside the Fresnel region. This is a radius of 1.4 feet from the antenna. .

6.4. Composite of Three Amplifiers

The emissions of three fully-loaded Powerwave amplifier modules operating in the AWS, PCS, and Cellular bands respectively and connected to the Comba antenna are of no regulatory consequence on the ground below or near the pole to which it is attached. In the most extreme case, in which the antenna is 22 feet above ground and the antenna is tilted to focus its main lobe at the ground, the emissions reach 9.9 % of the public MPE. In practice, the emissions at ground level can be expected to be orders of magnitude less than this safe-side estimate. As the antenna height above ground increases, the ground–level exposure decreases further.

For workers approaching the antenna, the minimum Fresnel distance applies. Workers should assume the antenna is emitting the full combined effective power and should remain outside the largest Fresnel region. This is a radius of 3.5 feet from the antenna.

6.5. Approach Dynamics

Considering the small size of the antenna, the distances outlined in the above sections are conservative distances that ensure exposure management compliance for public and occupational exposure conditions. Climbers or bucket riders working on pole mechanics or electronics at the elevation of the antenna may find themselves spending extended periods of time within the minimum Fresnel distance, and at the elevation of the antenna main lobe. In such cases, the antennas should be de-energized, or workers should be equipped with (and trained to operate) exposure monitors (that must be effective in the near field), or further analysis of the conditions within the reactive near field should be conducted. At pole-top, the geometry of workers exposed to the main lobe may differ from the manner in which workers in the communications space might be exposed, particularly if the top-mounted antenna were to be mounted on a vertical extension of 2 or 3 feet height above the pole top.

While the analysis suggests maintaining a prudent minimum distance from the antennas as identified in Table 1 and in the absence of further exposure control or analysis, it nevertheless has been our experience that such antennas tend to have significantly less exposure potential below the plane of the antenna base (and above the plane of the antenna top). This is due to their designs that focus energy horizontally. At depression angles below 45 degrees from horizontal, the antenna emissions are substantially less than 10% of the emissions on the main lobes. Such reduced emissions levels, coupled with the low powers of operation, indicate that it is reasonable to expect workers who are completely below or above the antennas will be unable to exceed MPE limits. If close approach is expected from directly below the antenna, this hypothesis should be confirmed with field measurement of the antennas before implementing as policy.

7. Conclusion

The system considered in this analysis emits low power levels and can certainly be approached by workers to distances of 3.5 feet or less, as applicable, without further analysis or controls. Labeling on the antennas or antenna mounts that is legible from 8 feet distance can inform workers to keep their distance or invoke exposure management protocols (such as to shut down, monitor exposure, or seek direction from qualified personnel). Exposure management protocols must be negotiated among all parties in interest (service providers, network developer, and applicable classes of utility workers). Further analysis can be conducted to better predict what occurs within the Fresnel radii, including determining whether the Fresnel distance can be relaxed on the main lobe, and whether a 0-foot limit above and below the tips of the antenna is accessible without exposure controls.

The least administrative burden on all utilities sharing the utility poles would be imposed by attaching antennas to the pole tops, perhaps with short vertical extensions, whose optimum lengths can be determined with further study.

David P. Maxson
Managing Partner
Broadcast Signal Lab, LLP
503 Main Street
Medfield, MA 02052

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