APPENDIX K – SUNZIA PROJECT PRELIMINARY EMF AND CORONA EFFECTS STUDY

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SOUTHWESTERN POWER GROUP

SunZia Project

Preliminary EMF and Corona Effects Study

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- "Prelim" means this document is issued for preliminary review, not for implementation
- "Appvl" means this document is issued for review and approval, not for implementation
- "Impl" means this document is issued for implementation
- "Record" means this document is issued after project completion for project files

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1.0 INTRODUCTION

1.1 Project Discussion

Southwestern Power Group (SWPG) is the project manager for the development of the SunZia Southwest Transmission Project, which includes approximately 500 miles of 500 kV transmission lines. This project would consist of one or two 500 kV lines in parallel running from central Arizona in to central New Mexico to transport primarily renewable energy into areas of demand. The Project is being permitted to accommodate a single 500 kV AC transmission line with an expected capacity of 1,500 MW and a future second 500 kV transmission line that would be either an AC line rated at 1,500 MW or a DC line rated at 3,000 MW.

POWER Engineers, Inc.'s (POWER) engineering service for this study was to perform calculations to determine the field and corona effects of the transmission line(s) and compare the results to applicable standards and guidelines. The analysis included determining predicted electric and magnetic fields, audible noise, and AM radio and television interference.

1.2 Summary

Electric and magnetic fields (EMF) and corona effect levels have been analyzed for a variety of conductor configurations and two structure types for the first AC transmission line. In addition, the effects of increased line voltage and adding a second line in parallel were examined. Electric and magnetic fields were analyzed at a minimum conductor height. Audible noise (AN), radio interference (RI) and television interference (TVI) were analyzed at average conductor height. Values calculated are typically below common limits and guidelines for each effect. Based on the results of the analysis, radio frequency interference from the proposed 500 kV transmission lines is expected to be relatively low within a few miles of the line for frequencies near 1 MHz, and near negligible as the frequency increases. Specific frequencies of concern could be analyzed for more exact values and their behavior with varying distance from the line. Calculations were based on preliminary structure designs that may change as detailed design is performed. Any changes to the characteristics of the conductors or their arrangement could affect the results of the study and should be further investigated.

2.0 DATA

EMF, audible noise, and radio and television interference from a transmission line are based on the electrical and physical characteristics of the transmission line. Specifically, these factors are driven by: the voltage and current loading of the line; the physical conductor characteristics and bundling; relationships of each phase conductor to the other phases and shield wires; and the heights of the conductors from the ground. The following data was used for the analysis. Should any of this data change, the results will also change.

- For the 500 kV line, a maximum operating voltage of 105 % of nominal voltage was used for electric field, audible noise, radio interference and television interference analysis, except where otherwise noted.

  - Additional sensitivity cases were run for a single line to examine the change in effects at 110%, 115%, and 120% of nominal voltage as portions of these lines may experience higher voltage due to reactive compensation installed for the long lines.
- A maximum loading of 1,650 amps per phase (1,500 MVA nominal at 105% of nominal voltage) was assumed for each 500 kV AC line analysis. For DC analysis, a pole current of 3,000 amps was used. Balanced loading was assumed for all cases.
- Three conductor bundling configurations were examined on the base AC horizontal guyed V structure, all with 18 inch bundle spacing:
  - A 3-bundle 1590 kcmil ACSR Lapwing conductor (base case)
  - A 4-bundle 954 kcmil ACSR Rail conductor (as a mitigation option)
  - A 4-bundle 1590 kcmil ACSR Lapwing conductor (as a mitigation option)
- A delta structure was also examined as a mitigation option for the base AC line, using the initial 3-bundle 1590 kcmil ACSR Lapwing conductor.
- There are two shield wires on each structure:
  - One 7/16 inch EHS steel
  - One optical ground wire (OPGW) GW4830 (diameter 0.669)
- The conductor spacing and arrangement was assumed as labeled on the structure drawings provided for reference in Appendix A. The assumed phasing for this first line is A-B-C, left to right, although with one line, the actual phasing has no effect.
- The phasing of the second AC circuit was varied to show the effects of different phasing arrangements between the two circuits. The second AC line was assumed to also be a horizontal configuration as the delta configuration does not provide significant benefit.
- If the second line is DC, the positive pole is assumed to be on the inside side of the ROW (adjacent to the AC line). If the positive and negative poles are swapped, there will be slight changes in the DC fields.
- The Right-of-Way (ROW) width is assumed to be 200 feet centered on the structure. For a second line, it is assumed that an identical ROW would be located immediately adjacent, for a separation of 200 feet from centerline to centerline of the structures.
- A maximum sag value of 57.5 feet was used for the AC phase conductors, while the shield wires sag 85% of this value.
- A maximum sag value of 65 feet was used for the DC pole conductors, while the shield wires sag 85% of this value.
- Calculations were based on an assumed elevation of approximately 5,000 feet, based on the typical elevations in the area of this project of greatest concern (near the White Sands Missile Range (WSMR)). The actual elevation of the line varies from around 2,000 feet in the west to 6,000 feet in the east.

3.0 ANALYSIS

The environmental field effects analysis for AC cases was performed using the Bonneville Power Administration's (BPA) Corona and Field Effects Program (CAFEP) software on the various transmission line structure and conductor configurations. CAFEP uses the electrical and physical

characteristics of the transmission line to calculate resulting fields and interference effects from the transmission lines. It should be noted that the radio interference values calculated by CAFEP are 2 dB greater than would be measured with modern equipment using the standard IEC/CISPR quasi-peak detector; therefore the RI results in this report are adjusted down by 2 dB to account for the change.

For the AC/DC hybrid transmission line corridor SESEnviroPlus (Enviro) by Safe Engineering Services & technologies ltd. was used. This software package was used due to the fact that the CAFEP is incapable of performing analysis on multiple frequencies at the same time. Enviro allows more flexibility in computation of audible noise and radio interference. For consistency BPA methods were used to produce results included in this report.

The electric fields, audible noise, and radio and television interference are all driven by the maximum operating voltage of conductors. Magnetic fields are driven by the line current loading, which varies over time, and not by the sub-conductor size or configuration. The magnetic fields calculations were performed at the maximum line loading and can be scaled down proportionally to the actual loading of the line.

The values of these effects are typically of concern at various points across the ROW. Therefore, values reported include the maximum and average values within the ROW for the given scenarios, along with the calculated values at the edge of the ROW. Also included for reference are plots of the results for all analyzed values across the entire width of the ROW and slightly beyond the ROW. Since this project will be constructed near sensitive sites, plots are also included showing the values extending approximately 5 miles to either side of the corridor.

For the analysis, electric and magnetic fields were analyzed at a minimum conductor height (mid-span, maximum sag), as this location will produce the worst case scenario. Audible noise, radio interference, and television interference were analyzed at the average conductor height along a span, as these effects are generally a concern over a larger area, and not immediately under the mid-span of the line.

Once values are calculated, they can be compared to local, statewide, or national guidelines and/or limits. However, no requirements were presented that would apply to this specific installation. Therefore, typical guidelines are presented for reference at this point. If specific limits for the WSMR or other regulatory agencies are presented at a later time, they can be examined and referenced in future versions of this report.

The two states involved in this project do not have any limits on electric or magnetic fields. However, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) publishes recommended limits (called reference limits) for electric and magnetic fields based on a collaboration of international scientists. The guidelines are non-binding and are more stringent than the guidelines presented by the Institute of Electrical and Electronics Engineers (IEEE). These values are expressed as reference exposure limits for both occupational and general public exposure. These limits are discussed in the results sections.

Nationally and in these states, audible noise from a transmission line has no regulated limit. However, the Environmental Protection Agency (EPA) provides a recommended limit of 55 dBA for outdoors for a day-night average sound level. Radio and television interference is driven by the signal-to-noise ratio, which depends on the broadcast source and frequencies. Some typical guidelines are discussed in the results section.

4.0 RESULTS OF VARIOUS CONDUCTOR CONFIGURATIONS

This section covers the examination of the various sub-conductor bundle configurations, as well as the alternate delta structure design. Typically, increasing the size or number of conductors will increase the electric field, have no effect on magnetic field, and will reduce the audible noise, radio interference, and television interference levels.

4.1 Electric Field

The electric field strength is a measure of the force per unit charge at a given point in space relative to a charged object. It is typically measured in kilovolts per meter (kV/m). Table 1 shows a summary of the values in the ROW for each configuration for a single transmission line. Values are calculated at the minimum conductor height (mid-span) at a height of one meter above the ground per IEEE Standard 644-1994 (R2008).

Table 1: Electric Field Results for Various Configurations [kV/m]

CASE	EDGE OF ROW	MAXIMUM IN ROW	AVERAGE IN ROW*
Horizontal 3-Bundle Lapwing	2.6	8.6	6.2
Horizontal 4-Bundle Rail	2.8	9.2	6.6
Horizontal 4-Bundle Lapwing	2.8	9.3	6.7
Delta 3-Bundle Lapwing	1.1	8.3	4.5

* Average values based on data points calculated every five feet across the ROW width.

ICNIRP reference levels for electric field strength are 8.33 kV/m for occupational exposure and 4.16 kV/m for general public exposure. Values beyond the ROW are below the ICNIRP reference level for general public exposure.

Figure 1 and Figure 2 (on the following page) respectively show plots of the electric field across the ROW and for five miles beyond the ROW for the various configurations. The red line indicates the ICNIRP reference level for the general public (beyond the ROW) as a reference. Increasing the size or number of conductors will increase the maximum electric fields, while using a delta configuration will reduce the electric fields. Once more than a few hundred feet from the edge of the ROW, the values will be practically zero.

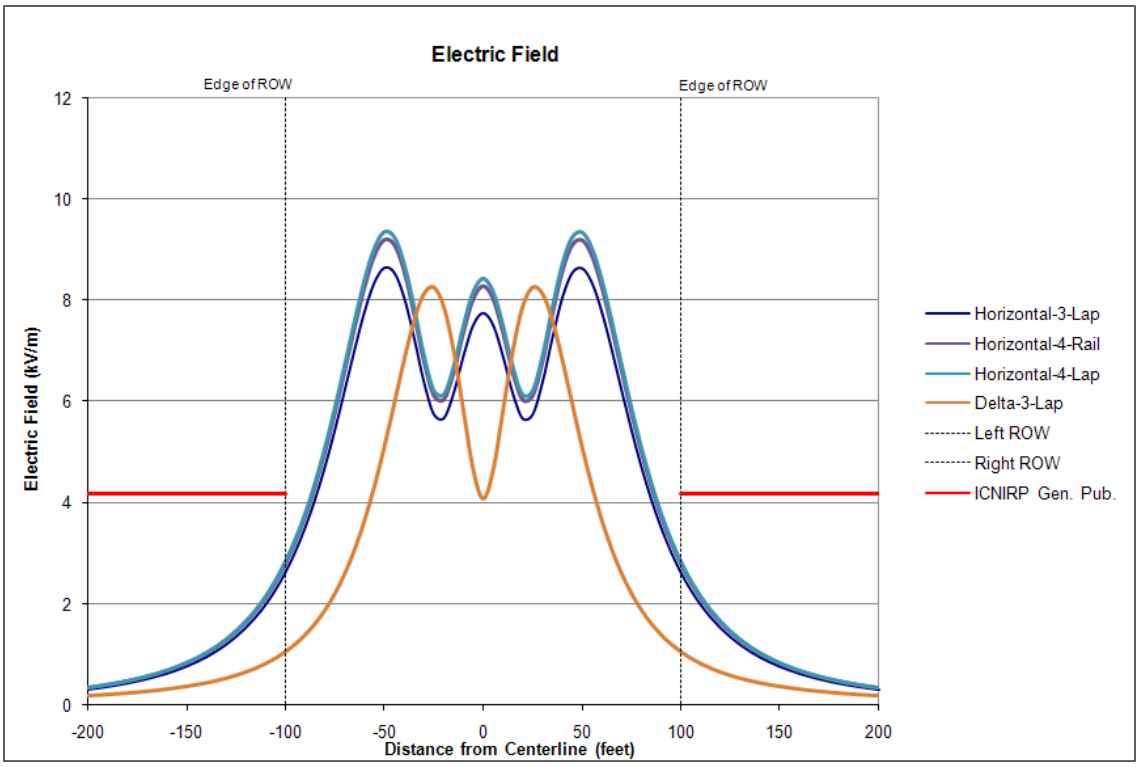

Figure 1: Electric Field Across ROW for Various Configurations

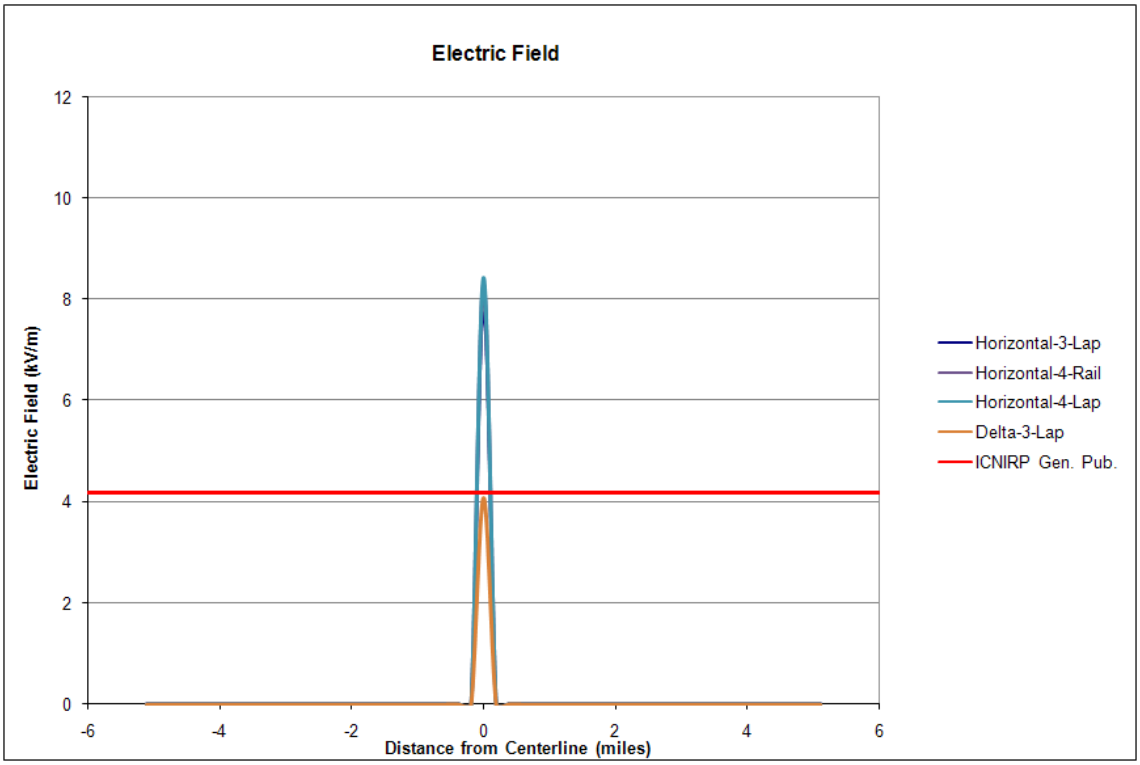

Figure 2: Electric Field for Five Miles Beyond ROW for Various Configurations

4.2 Magnetic Field

The reported magnetic field values are the magnetic flux density at a given point in space. Magnetic flux density is measured in gauss or milligauss (mG) or in micro-Teslas (μT). These values can be easily converted as one tesla equals 10,000 gauss, or simply 10 mG equals 1 μT.

Table 2 shows a summary of the resulting values in the ROW for each configuration for a single transmission line, assuming maximum current loading. All values are calculated assuming balanced loading on all three phases. The magnetic fields will vary if there is unbalance on the system; however, transmission unbalance is typically fairly low. Note that the results are directly proportional to the loading of the line; therefore, 50% loading would be exactly half of the 100% loading condition. Also note that the values are independent of the sub-conductor size. Values are calculated at the minimum conductor height (mid-span) at a height of one meter above the ground per IEEE Standard 644-1994 (R2008).

Table 2: Magnetic Field Results for Various Configurations – 100% Loading [mG]

CASE	EDGE OF ROW	MAXIMUM IN ROW	AVERAGE IN ROW*
Horizontal 3-Bundle Lapwing	89.4	294.5	217.5
Horizontal 4-Bundle Rail	89.4	294.5	217.5
Horizontal 4-Bundle Lapwing	89.4	294.5	217.5
Delta 3-Bundle Lapwing	41.0	265.3	141.3

* Average values are based on data points calculated every five feet across the ROW width.

ICNIRP reference levels for magnetic flux density are 4,167 mG for occupational exposure and 833 mG for general public exposure. None of the configurations in this analysis exceed the ICNIRP limits for general public exposure. The ICNIRP reference level for general public (beyond the ROW) is also included in the associated plots.

Figure 3 and Figure 4 (on the following page) respectively show a plot of the magnetic field at 100% loading across the ROW and extending five miles beyond the ROW, for the two structure configurations. Again, since the magnetic field is directly proportional to the line current loading, values at 50% loading will follow the same plot shape but will be 50% of the magnitude.

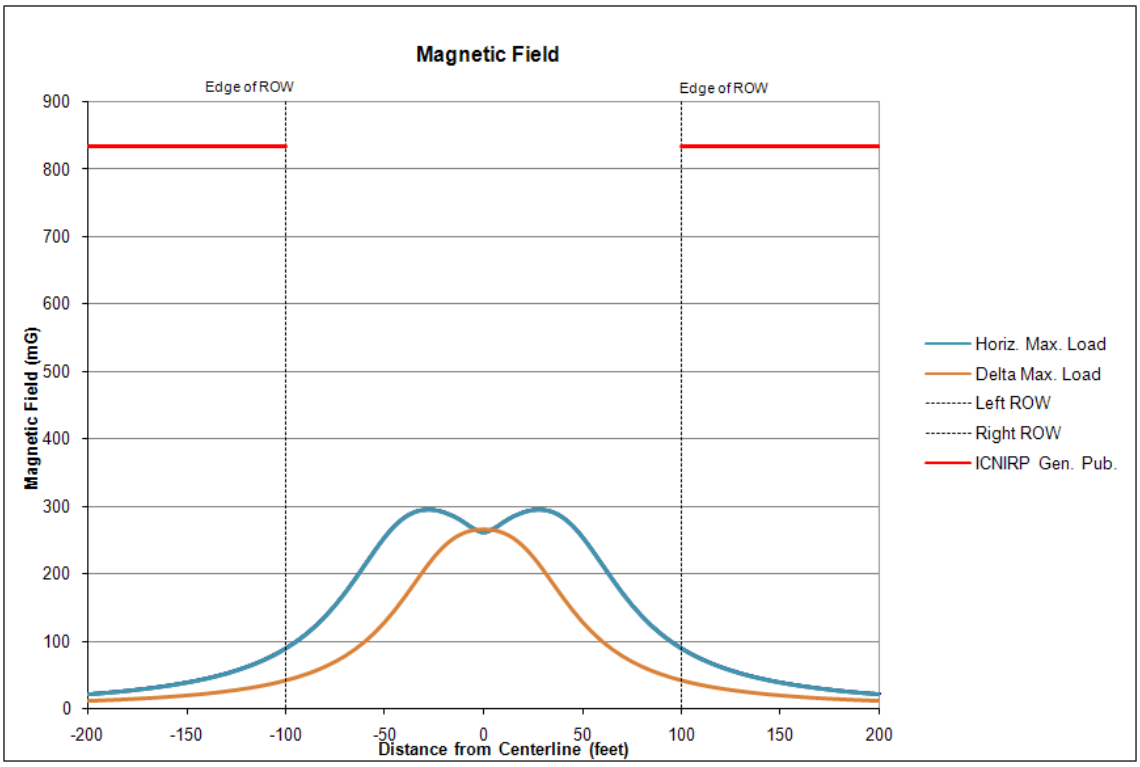

Figure 3: Magnetic Field Across ROW for Various Configurations

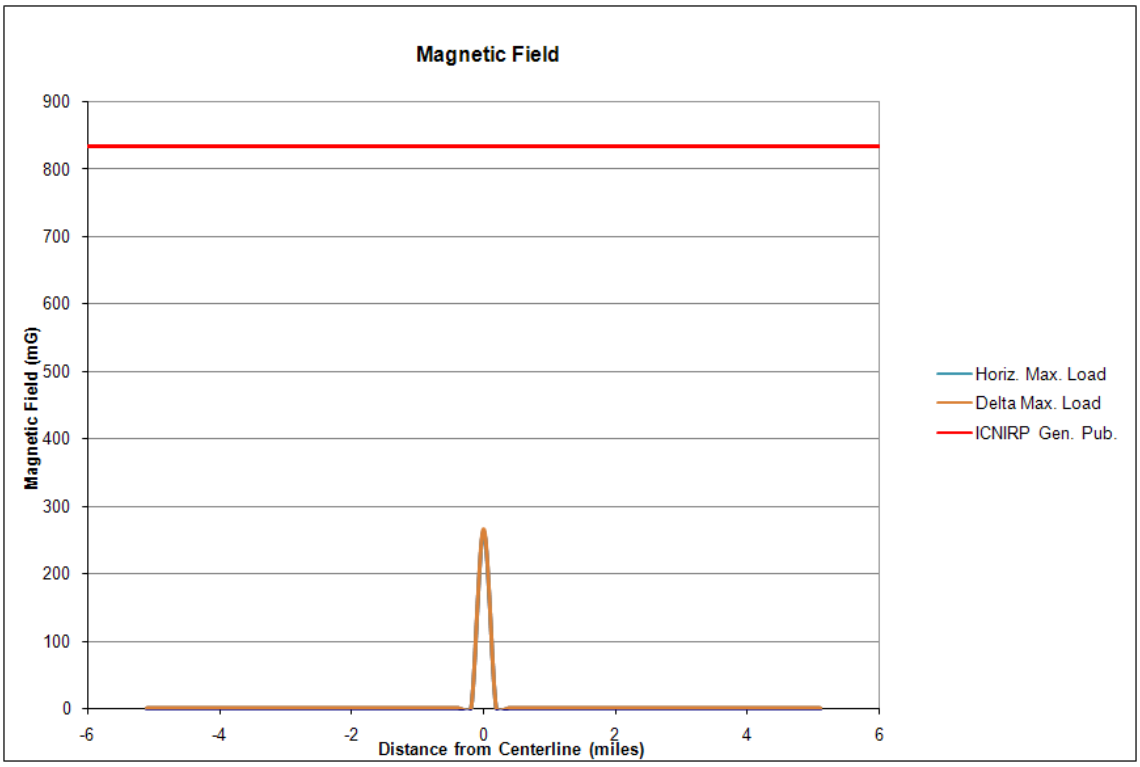

Figure 4: Magnetic Field for Five Miles Beyond ROW for Various Configurations

4.3 Audible Noise

Audible noise is measured as an equivalent A-weighted sound-pressure level in decibels (dBA). The L_{50} Audible Noise (Foul Weather) values represent a predicted average (L_{50}) noise levels present when foul weather conditions cause the conductors to become wet. The actual value is expected to be at or below this calculated L_{50} value 50% of the time, and above the value the other 50% of the time. Values are calculated at a height of five feet above the ground per IEEE Standard 656-1992, using the average conductor height to approximate the average values along the entire line.

Table 3 shows a summary of the audible noise levels in the ROW for each configuration for a single transmission line.

Table 3: L50 Audible Noise Results for Various Configurations (Foul Weather) [dBA]

CASE	EDGE OF ROW	MAXIMUM IN ROW	AVERAGE IN ROW*
Horizontal 3-Bundle Lapwing	45.0	48.1	46.8
Horizontal 4-Bundle Rail	43.3	46.4	45.1
Horizontal 4-Bundle Lapwing	38.7	41.8	40.5
Delta 3-Bundle Lapwing	47.4	50.4	49.1

* Average values based on data points calculated every five feet across the ROW width.

No guidance was provided on limits for audible noise for this line route; however, EPA guidelines recommend levels below 55 dBA for a day-night average in the outdoors. If applied to transmission lines, this is often measured at the edge of the ROW. The values across the entire ROW are all below this EPA recommendation for all configurations.

Figure 5 and Figure 6 (on the following page) respectively show a plot of the audible noise levels across the ROW and extending five miles beyond the ROW for a the various configurations. In addition, these figures show the EPA recommended level as a red line beyond the ROW.

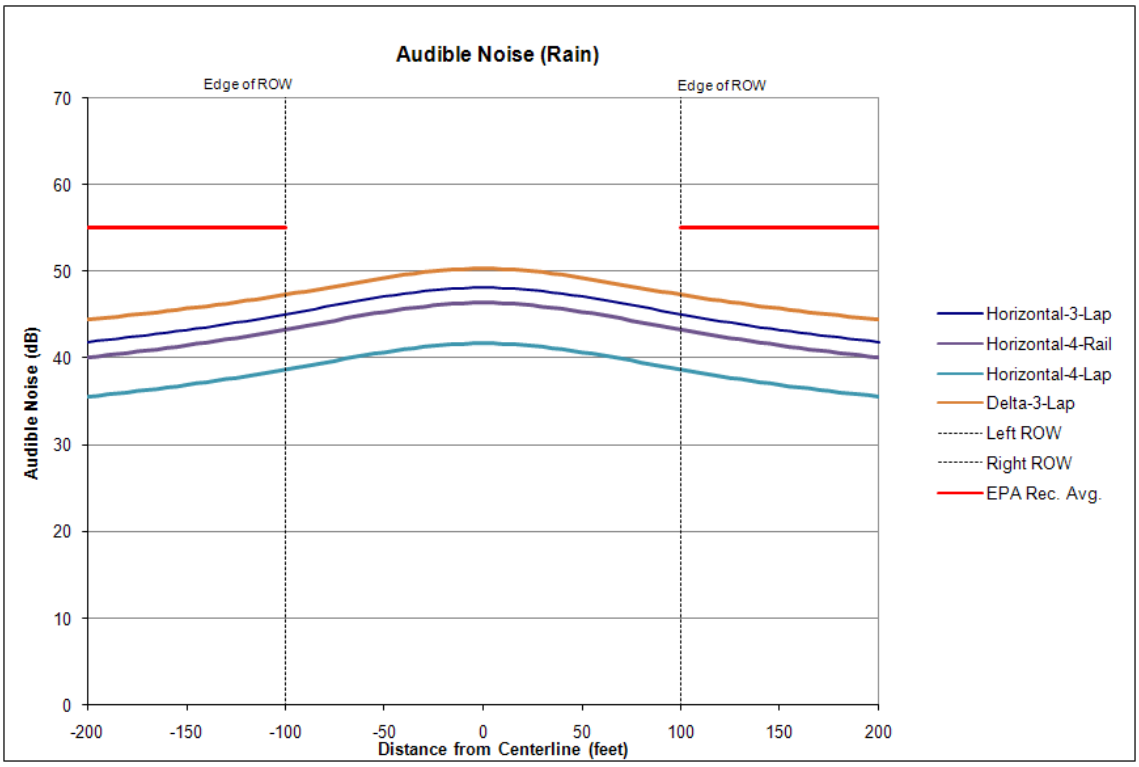

Figure 5: Audible Noise Across ROW for Various Configurations

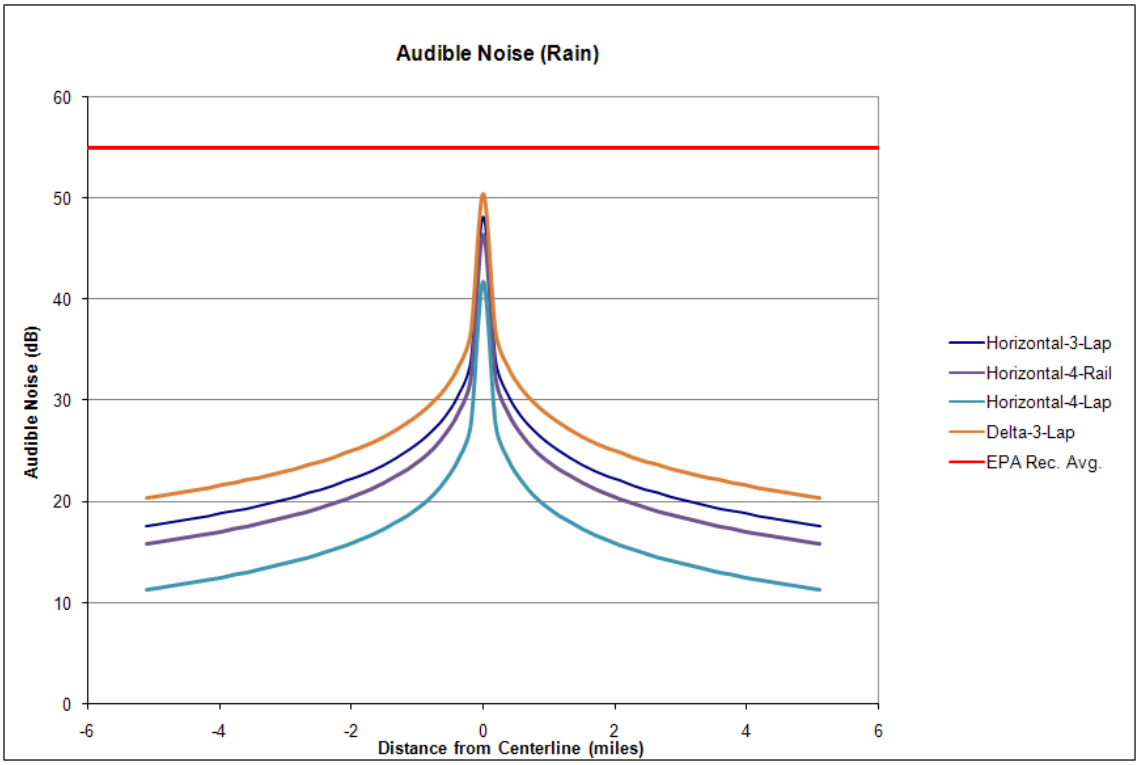

Figure 6: Audible Noise for Five Miles Beyond ROW for Various Configurations

4.4 AM Radio Interference

Radio interference is the degradation of a radio signal by radio frequency electromagnetic disturbances and is reported as the field strength of the interference. It is often measured in decibels (dB) of one microvolt per meter (μV/m), which is a logarithmic scale. The L_{50} Radio Interference (Fair Weather) values represent the predicted average levels present when conductors are dry. Note that interference values will increase during foul weather conditions; however, other atmospheric conditions will typically have a greater degradation of AM radio signals during this scenario.

The actual value of radio interference is expected to be at or below this calculated L_{50} value 50% of the time, and above the value the other 50% of the time. Values are calculated at a height of six feet above the ground and at 1 MHz, using the average conductor height to approximate the average values along the entire line. IEEE Standard 430-1986 suggests that these measurements are taken no greater than two meters above the surface.

Radio frequency and television interference is also dependent on frequency. As the frequency of desired received signal goes up the interference produced by corona goes down. This effect is most prominent in frequencies above 1 MHZ. Figure 7 below (Figure 8.5-2 from the EPRI AC Transmission Line Reference Book, Third Edition) shows the magnitude of the corona decreasing as frequency goes up. As the magnitude of the corona decreases the radio interference effects diminish as well.

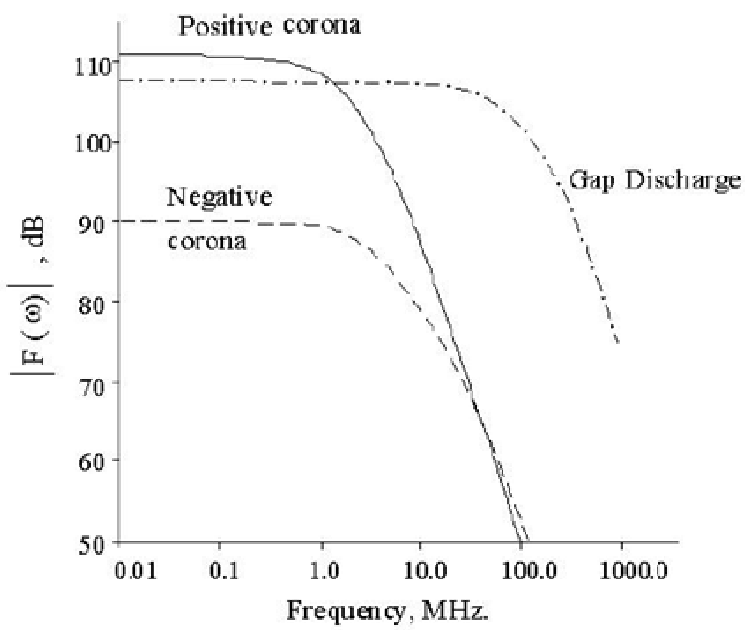

Figure 7: Corona Effects with Increasing Frequency

Radio interference is affected by both the signal strength, as well as the level of interference (noise). The signal-to-noise ratio (SNR) is simply the signal strength in dB minus the calculated interference (noise) level in dB. Depending on location, the signal strength can vary significantly; therefore the amount of interference that is tolerable varies as well. Guidance provided by the EPRI AC Transmission Line Reference Book indicates that the amount of radio interference should be below 38 dB at 100 feet from the outermost conductor (or often examined at the edge of ROW). This is only a rough guideline, and without actual signal strength measurements and data from the FCC on the protected signal contours (within which the signals are protected from interference) for radio stations in the area, can only provide a typical idea of if there may be concerns.

Table 4 shows a summary of the radio interference levels in the ROW for each configuration.

Table 4: L50 Radio Interference for Various Configurations (Fair Weather) [dBµV/m @ 1 MHz]

CASE	EDGE OF ROW	MAXIMUM IN ROW	AVERAGE IN ROW*
Horizontal 3-Bundle Lapwing	37.5	47.7	43.2
Horizontal 4-Bundle Rail	34.5	44.8	40.3
Horizontal 4-Bundle Lapwing	28.2	38.6	34.0
Delta 3-Bundle Lapwing	38.6	47.8	44.3

* Average values based on data points calculated every five feet across the ROW width.

Figure 8 and Figure 9 respectively show a plot of the radio interference levels across the ROW and extending five miles beyond the ROW for the various configurations. All configurations indicate values below the 38 dB recommendation at 100 feet from the outermost conductor, as can be seen in the following figures. In addition, all horizontal configurations are below the limit at the edge of ROW, as shown by the red line on the plots. However, as this is only a guideline, it is possible that some stations that have low signal strength in the area may suffer from some interference. Similarly, these values are calculated at 1 MHz and will decrease with increasing frequency, or increased separation between the line and antenna.

It is important to note that these values are based on a 1 MHz amplitude modulated signal. Most modern communications systems use either frequency modulation or spread spectrum techniques, and broadcast at higher frequencies. In addition, the signals are often digital which are typically more immune to interference. It is anticipated that most other communications signals would be able to function properly even with the effects of these transmission line interference results.

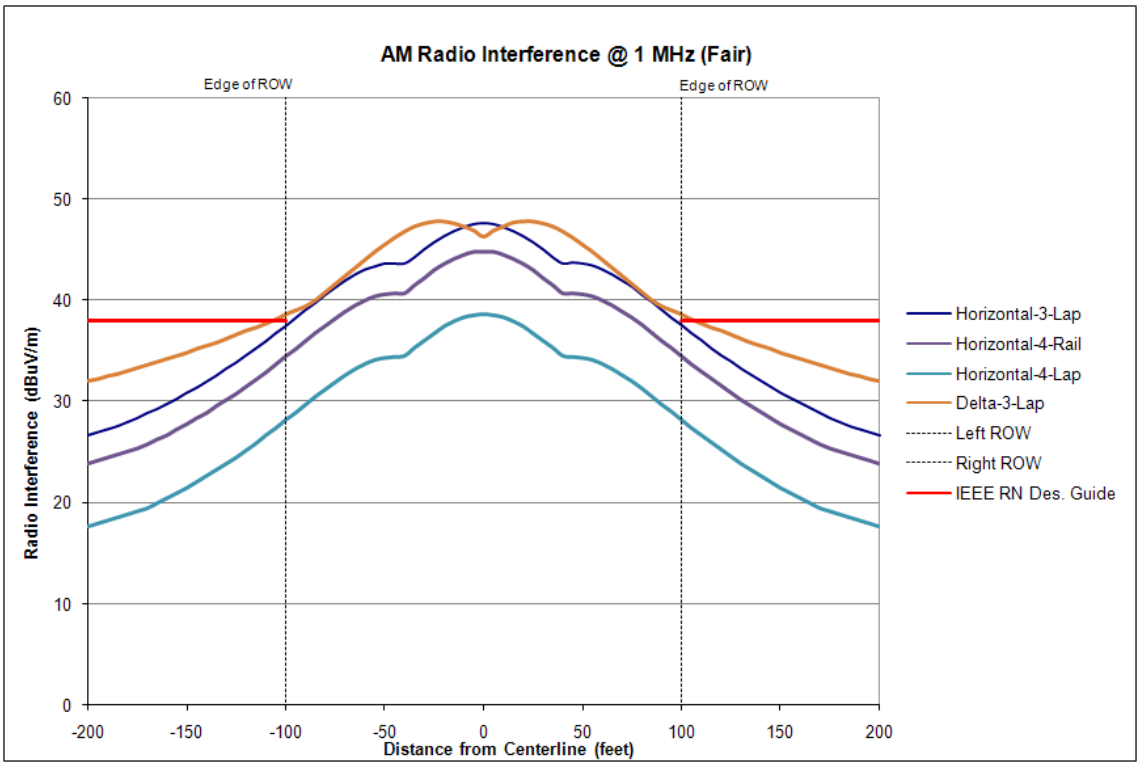

Figure 8: AM Radio Interference Across ROW for Various Configurations

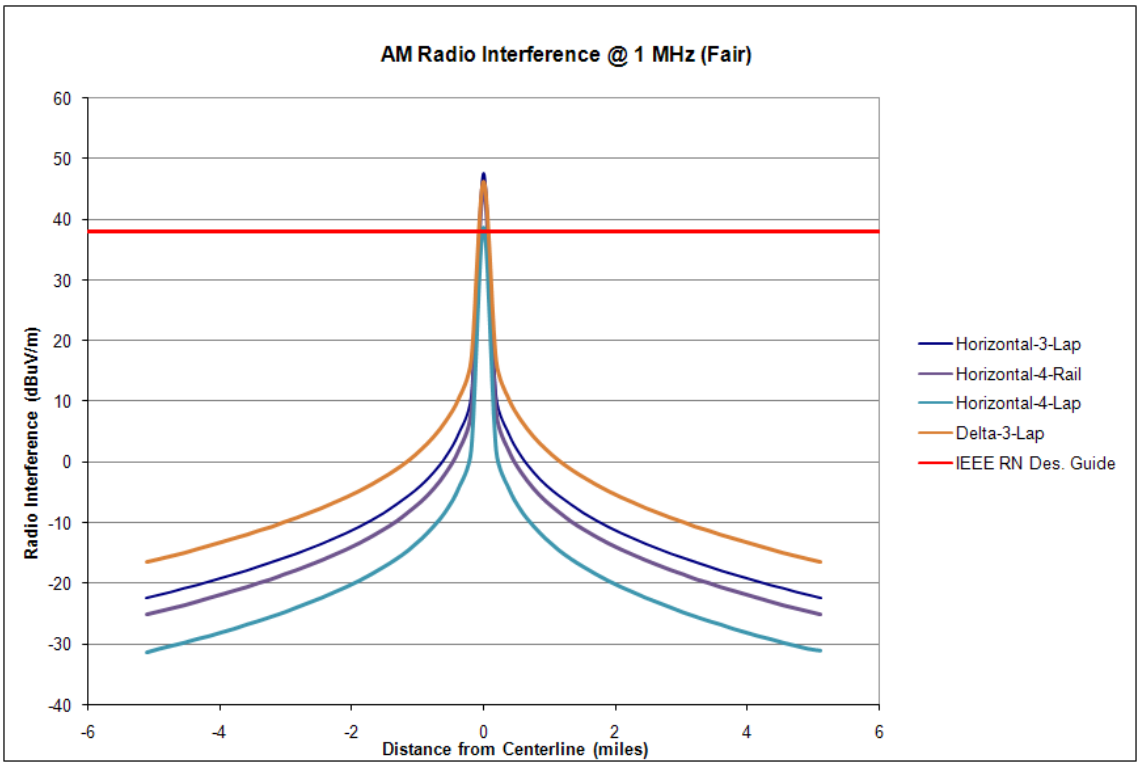

Figure 9: AM Radio Interference for Five Miles Beyond ROW for Various Configurations

4.5 Television Interference

Television interference (TVI) is the degradation of a television signal by television frequency electromagnetic disturbances and is reported as the field strength of the interference. It is often measured in decibels (dB) of one microvolt per meter (µV/m) which is a logarithmic scale. The values are reported for wet conductor conditions, as TVI is negligible during fair weather. Values are calculated at a height of ten meters above the ground per IEEE Standard 430-1986 and FCC measurement guidelines, using the average conductor height to approximate the average values along the entire line. Television signals cover multiple bands and a large range of frequencies. These calculations are made in a dead band (75 MHz) in the lower VHF band (54-88 MHz), and interference effects will decrease moving into the upper VHF (174-216 MHz) and the UHF (470-698 MHz) bands, which are the more commonly used bands.

Television interference is now less of a concern since the recent national switch to digital television. Digital television does not experience the typical TVI noise effects that analog television did, such as shadowing or snow. With digital television, there is either signal or no signal, and the signals are less susceptible to the noise due to their higher operating frequencies. However, the values are reported since there may be a few local low-strength analog stations broadcasting in the area, or for any remaining VHF digital channels on the fringe of their operating range.

There has also been no significant published research on what levels of transmission line corona TVI will cause disruption of digital television signals, therefore there are no guidelines, such as those that apply to analog television. However, the FCC has indicated that a signal-to-random noise ratio of 17 dB or greater should be sufficient for reception. Similar to radio interference, TVI needs both a signal strength and a calculated noise (interference) value to calculate a signal-to-noise ratio, which in turn would provide an idea of reception quality. Using the digital upper VHF (most stations have moved out of the lower VHF band) average signal strength for a channel of 36 dB and the signal-to-random noise ratio above, a rough limit could be approximated at 19 dB of TVI. Note that this limit is not an industry accepted limit and is only a means of rough guidance.

Table 5 shows a summary of the television interference levels in the ROW for each configuration for a single transmission line.

Table 5: Television Interference for Various Configurations [dBµV/m @ 75 MHz]

CASE	EDGE OF ROW	MAXIMUM IN ROW	AVERAGE IN ROW*
Horizontal 3-Bundle Lapwing	18.3	30.4	24.7
Horizontal 4-Bundle Rail	15.2	27.6	21.7
Horizontal 4-Bundle Lapwing	8.9	21.4	15.4
Delta 3-Bundle Lapwing	19.4	30.5	25.7

* Average values based on data points calculated every five feet across the ROW width.

Figure 10 and Figure 11 (on the following page) respectively show a plot of the television interference levels across the ROW and extending five miles beyond the ROW for each of the configurations. The rough guideline mentioned above is indicated by a red line beyond the ROW on these plots.

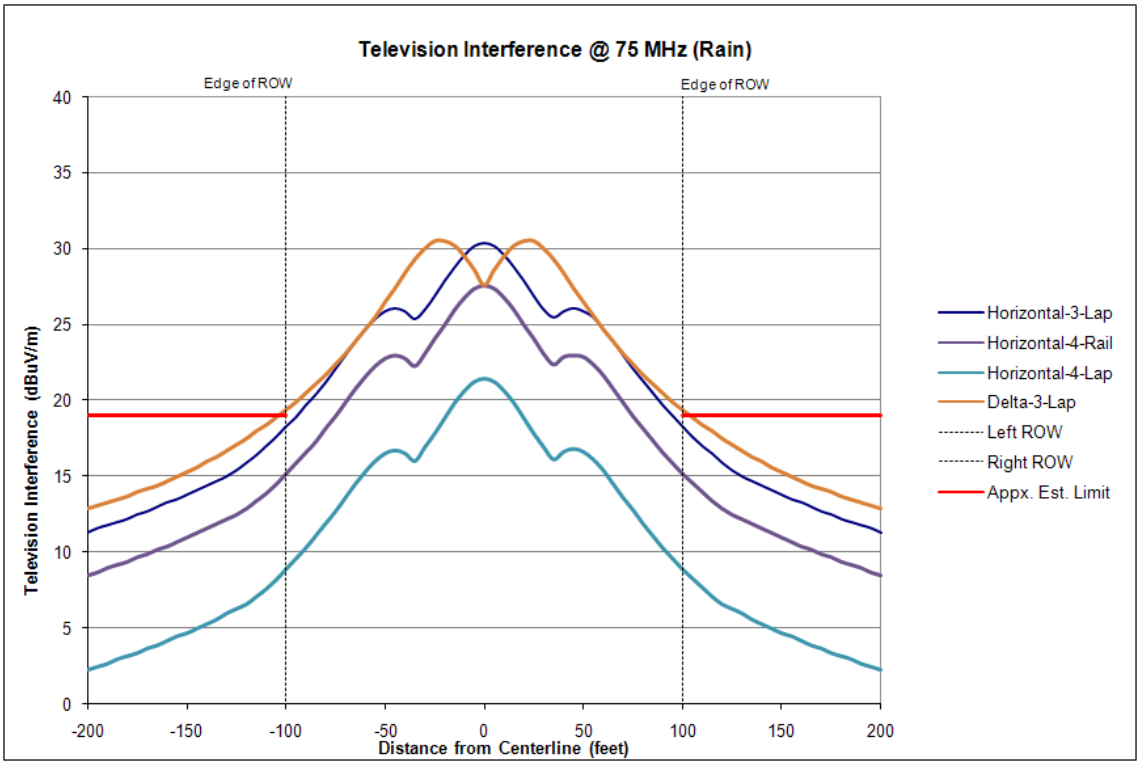

Figure 10: Television Interference Across ROW for Various Configurations

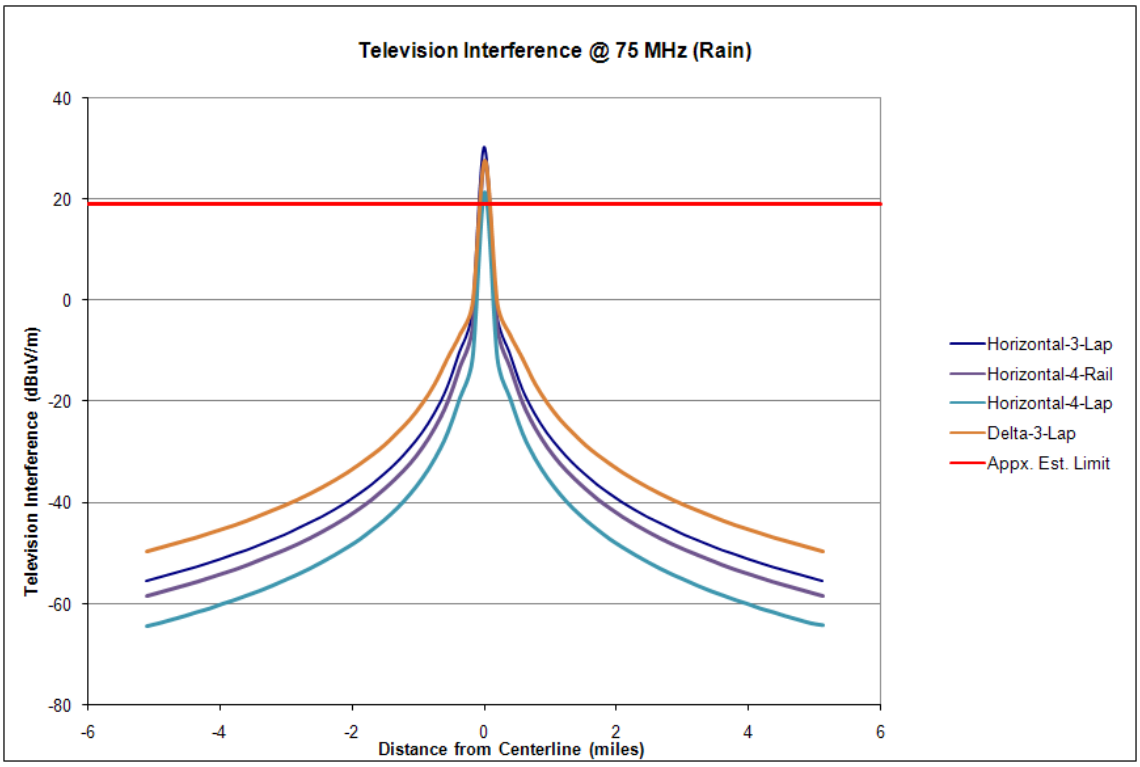

Figure 11: Television Interference for Five Miles Beyond ROW for Various Configurations

5.0 RESULTS OF INCREASING LINE VOLTAGE

This section explores the effects of increasing line voltage along the AC line. Since this transmission line will be heavily compensated with reactive power, there is a high likelihood that portions of the line will far exceed the nominal 500 kV rating. All calculations in Section 4 were based on 105% of the nominal voltage. This section extends to 110%, 115%, and 120% of nominal voltage. Increasing the voltage increases the electric field, which in turn increases the audible noise, radio interference, and television interference. Magnetic fields are driven by current and therefore are not directly affected by the system voltage.

All cases examined in this section are based on the initial design of a three conductor bundle using 1590 ACSR Lapwing conductor in a horizontal configuration. These results can be interpolated into the results of the other configurations presented in Section 4.

5.1 Electric Field

Electric fields are directly proportional to the voltage. Therefore when the voltage goes up 5%, so does the resulting electric field. Table 6 presents the increased electric fields based on the four examined scenarios.

Table 6: Electric Field Results for Different Voltages [kV/m]			
CASE	EDGE OF ROW	MAXIMUM IN ROW	AVERAGE IN ROW*
Max. Voltage = 105% (525 kV)	2.6	8.6	6.2
Max. Voltage = 110% (550 kV)	2.7	9.0	6.5
Max. Voltage = 115% (575 kV)	2.9	9.5	6.8
Max. Voltage = 120% (600 kV)	3.0	9.9	7.1

* Average values based on data points calculated every five feet across the ROW width.

Figure 12 shows a plot of the electric field across the ROW for the various voltages. Again, none of these changes result in exceeding the ICNIRP reference level beyond the edge of the ROW, which is shown as a red line on the plot. Since the values drop to nearly the same value just beyond the edge of the ROW, no plot to five miles was provided as the fields are negligible as before.

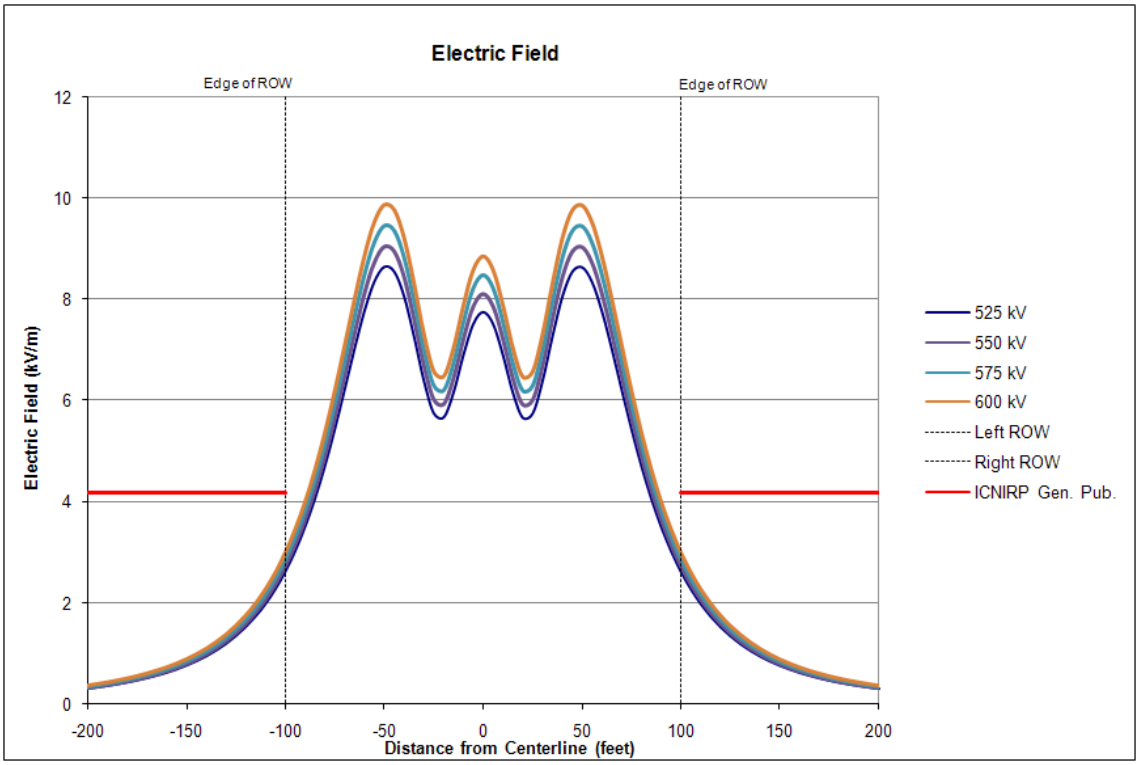

Figure 12: Electric Field Across ROW for Different Voltages

5.2 Magnetic Field

The magnetic field is independent of the system voltage and therefore is not presented in this section.

5.3 Audible Noise

Table 7 shows a summary of the audible noise levels in the ROW as the voltage increases for a single transmission line. The increases in noise are roughly proportional to the increase in voltage.

Table 7: L50 Audible Noise Results for Different Voltages (Foul Weather) [dBA]

CASE	EDGE OF ROW	MAXIMUM IN ROW	AVERAGE IN ROW*
Max. Voltage = 105% (525 kV)	45.0	48.1	46.8
Max. Voltage = 110% (550 kV)	47.4	50.5	49.3
Max. Voltage = 115% (575 kV)	49.8	52.8	51.6
Max. Voltage = 120% (600 kV)	52.0	55.0	53.8

* Average values based on data points calculated every five feet across the ROW width.

Figure 13 shows a plot of the audible noise levels across the ROW for increasing voltages. The EPA recommended average noise level shown as a red line on the plot) is not exceeded within or beyond the ROW for any of these scenarios.

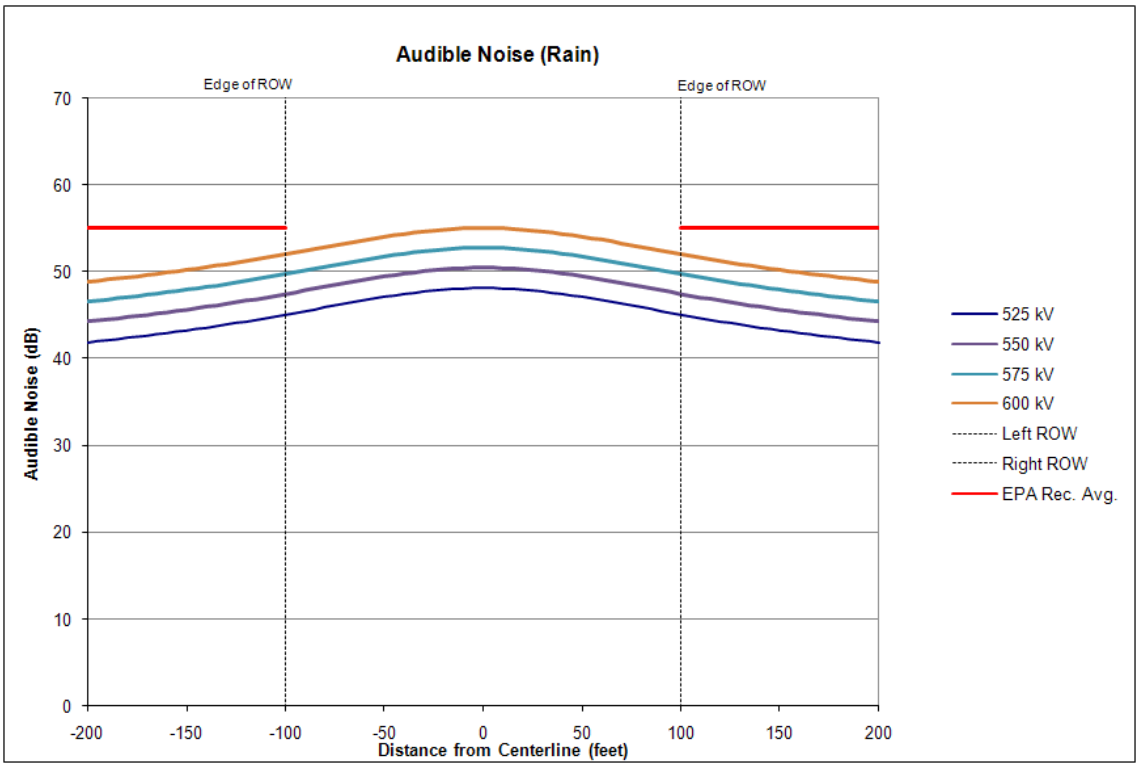

Figure 13: Audible Noise Across ROW for Different Voltages

5.4 AM Radio Interference

Table 8 shows a summary of the radio interference levels in the ROW for the increasing voltages. Again, values increase roughly proportional to the increase in voltage.

Table 8: L50 Radio Interference for Different Voltages (Fair Weather) [dBµV/m @ 1MHz]

CASE	EDGE OF ROW	MAXIMUM IN ROW	AVERAGE IN ROW*
Max. Voltage = 105% (525 kV)	37.5	47.7	43.2
Max. Voltage = 110% (550 kV)	40.0	50.1	45.7
Max. Voltage = 115% (575 kV)	42.3	52.4	48.0
Max. Voltage = 120% (600 kV)	44.5	54.6	50.2

* Average values based on data points calculated every five feet across the ROW width.

Figure 14 shows a plot of the radio interference levels across the ROW for the various voltages. Near the higher voltages, the IEEE Radio Noise Design Guide recommended limit of 38 dB (shown as a red line) is slightly exceeded, but this is only for antennas located within about 50 feet of the edge of ROW.

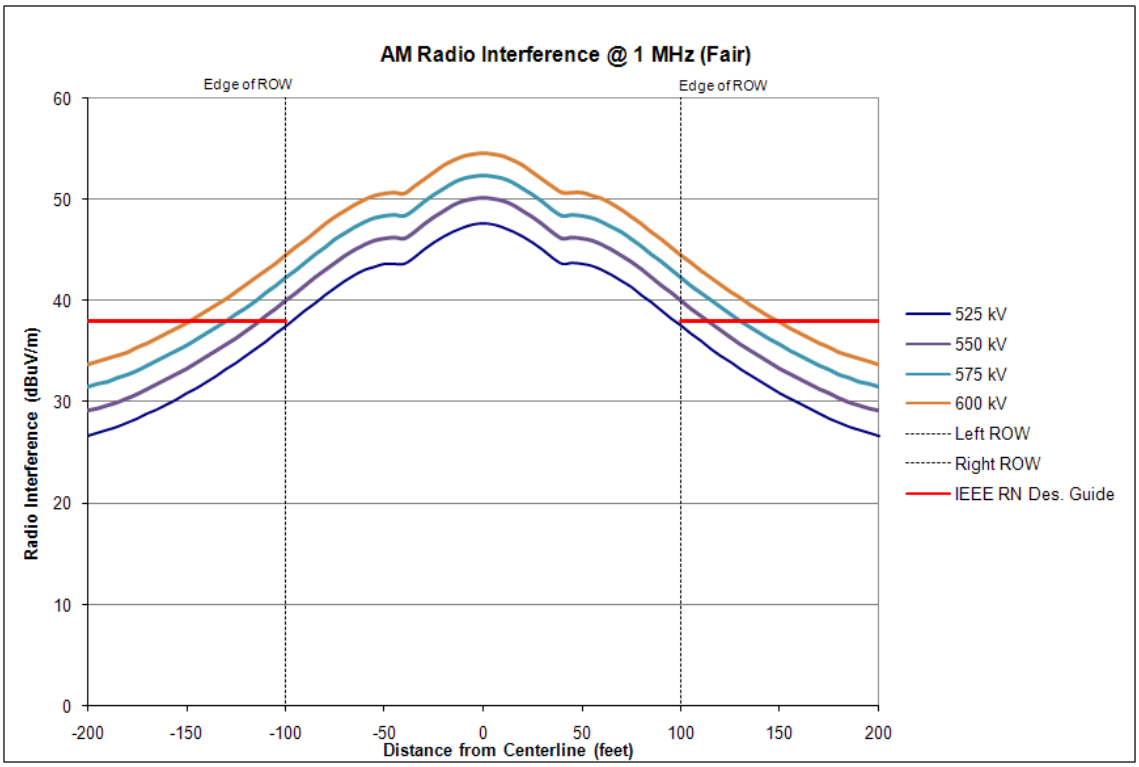

Figure 14: AM Radio Interference Across ROW for Different Voltages

5.5 Television Interference

Table 9 shows a summary of the television interference levels in the ROW for each configuration for a single transmission line. As with the other effects, TVI increases roughly proportional to the voltage.

Table 9: Television Interference for Different Voltages [dBµV/m @ 75 MHz]

CASE	EDGE OF ROW	MAXIMUM IN ROW	AVERAGE IN ROW*
Max. Voltage = 105% (525 kV)	18.3	30.4	24.7
Max. Voltage = 110% (550 kV)	20.7	32.8	27.1
Max. Voltage = 115% (575 kV)	23.0	35.2	29.4
Max. Voltage = 120% (600 kV)	25.2	37.4	31.6

* Average values based on data points calculated every five feet across the ROW width.

Figure 15 shows a plot of the television interference levels across the ROW for each of the voltage scenarios.

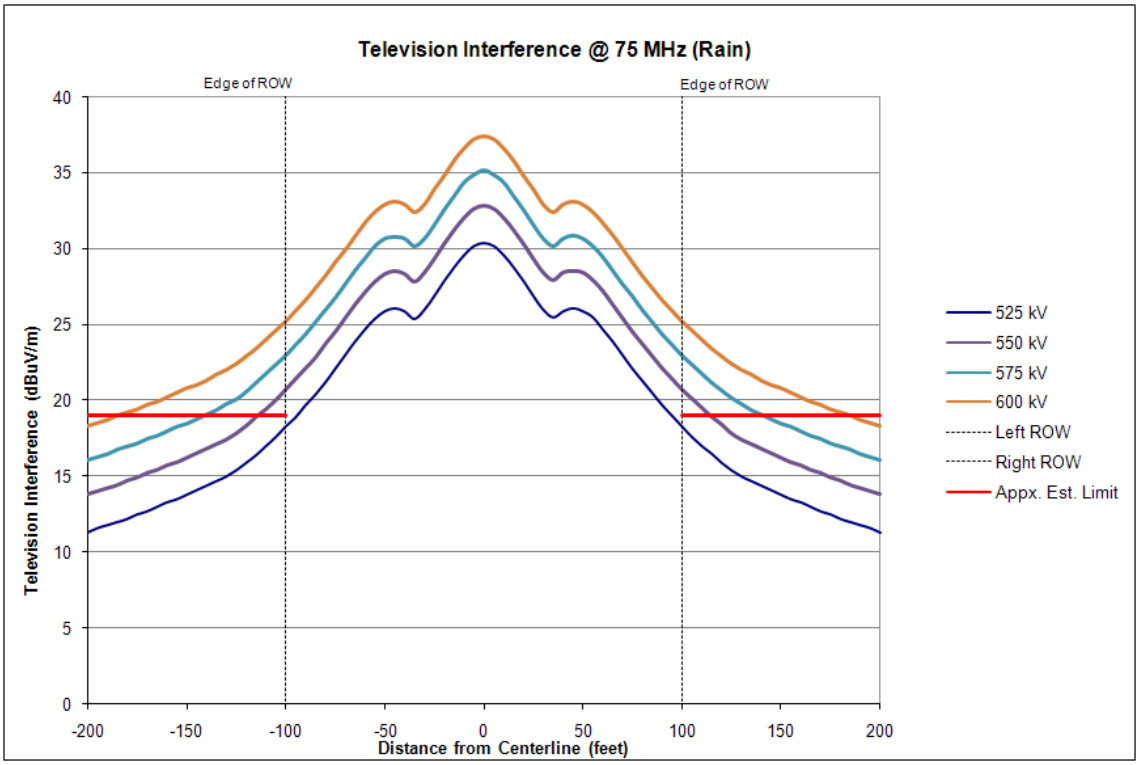

Figure 15: Television Interference Across ROW for Different Voltages

6.0 RESULTS OF ADDING A SECOND LINE

This section examines the effects of adding a second AC or DC line in parallel to the first. In addition, two phasing configurations are examined for the AC cases, the first with the phases A-B-C and A-B-C left-to-right on the two structures, the second with A-B-C and C-B-A. For some aspects one arrangement will present a slightly better configuration, and for others the opposite arrangement will be slightly better.

In general with a second AC line, values at and near the edge of ROW remain similar to that of one line, especially when examining the audible noise and radio and television interference. Values near the center of the ROW differ particularly for the electric and magnetic fields. For cases where the second line is DC, none of the values at the edge of the ROW are significantly higher. The maximum electric and magnetic fields and RI effects in the ROW are higher with DC versus AC, while the audible noise is actually lower. Once far from the line, the values are practically identical for all effects.

All cases examined in this section are based on the initial design of a three conductor bundle using 1590 ACSR Lapwing conductor in a horizontal configuration. These results can be interpolated into the results of the other AC configurations presented in Section 4.

6.1 Electric Field

Table 10 shows a summary of the values in the ROW for different configurations with two transmission lines in the corridor. These values are similar to the single line cases, although the DC values peak higher in the ROW.

Table 10: Electric Field Results for Two Circuits [kV/m]

CASE	EDGE OF ROW	MAXIMUM IN ROW	AVERAGE IN ROW*
Second Line with A-B-C and A-B-C Phasing (L to R)	2.7	8.7	4.7
Second Line with A-B-C and C-B-A Phasing (L to R)	2.6	9.1	5.3
AC-DC Hybrid	2.6	12.0	6.8

* Average values based on data points calculated every ten feet across the ROW width.

Figure 16 shows a plot of the electric field across the ROW for the configurations. Due to the arrangement of the phase conductors, the A-B-C A-B-C configuration presents a cancelation effect, reducing the electric maximum field strength near the center of the ROW. The DC line brings up the field strength on its side of the corridor due to larger phase-to-neutral voltages associated with it. Ion enhanced fields were not considered in the electric field strength of the hybrid line. This is a phenomenon where static pole conductors can actually charge the air particles in the immediate vicinity in fair low wind conditions and could cause field strengths higher than reported. These enhanced fields vary significantly

with weather conditions, and are hard to predict. Other reported values do take these effects into account due to the use of empirical formulas.

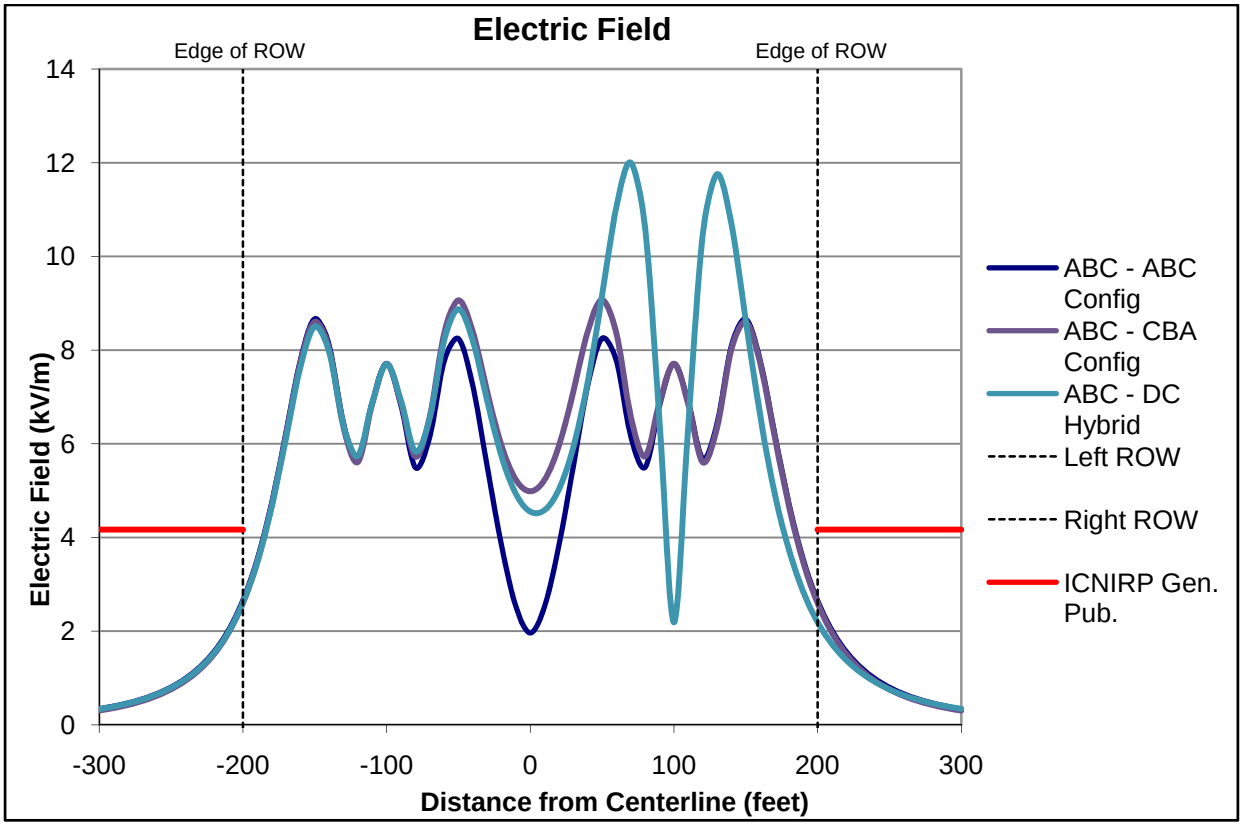

Figure 16: Electric Field Across ROW for Two Circuits

6.2 Magnetic Field

Table 11 shows a summary of the values in the ROW for the different configurations with two transmission lines in the corridor assuming maximum current loading. Again, the results are directly proportional to the loading of the line; therefore, 50% loading would be exactly half of the 100% loading condition. The values presented are similar to a single line case at the edge of ROW.

Table 11: Magnetic Field Results for Two Circuits – 100% Loading [mG]

CASE	EDGE OF ROW	MAXIMUM IN ROW	AVERAGE IN ROW*
Second Line with A-B-C and A-B-C Phasing (L to R)	97.4	284.9	171.4
Second Line with A-B-C and C-B-A Phasing (L to R)	82.1	323.2	188.0
AC – DC Hybrid	102.5	496.6	272.8

* Average values are based on data points calculated every ten feet across the ROW width.

Figure 17 shows a plot of the magnetic field across the ROW at 100% loading for the various configurations. Similar to the electric field, the A-B-C A-B-C configuration presents a cancellation effect near the center of the ROW, although the values near the edge of the ROW and beyond are actually lower with the A-B-C C-B-A configuration. However, the AC – DC hybrid corridor has much higher peak magnetic fields in the ROW due to the fact that the DC has approximately twice the current of the AC line.

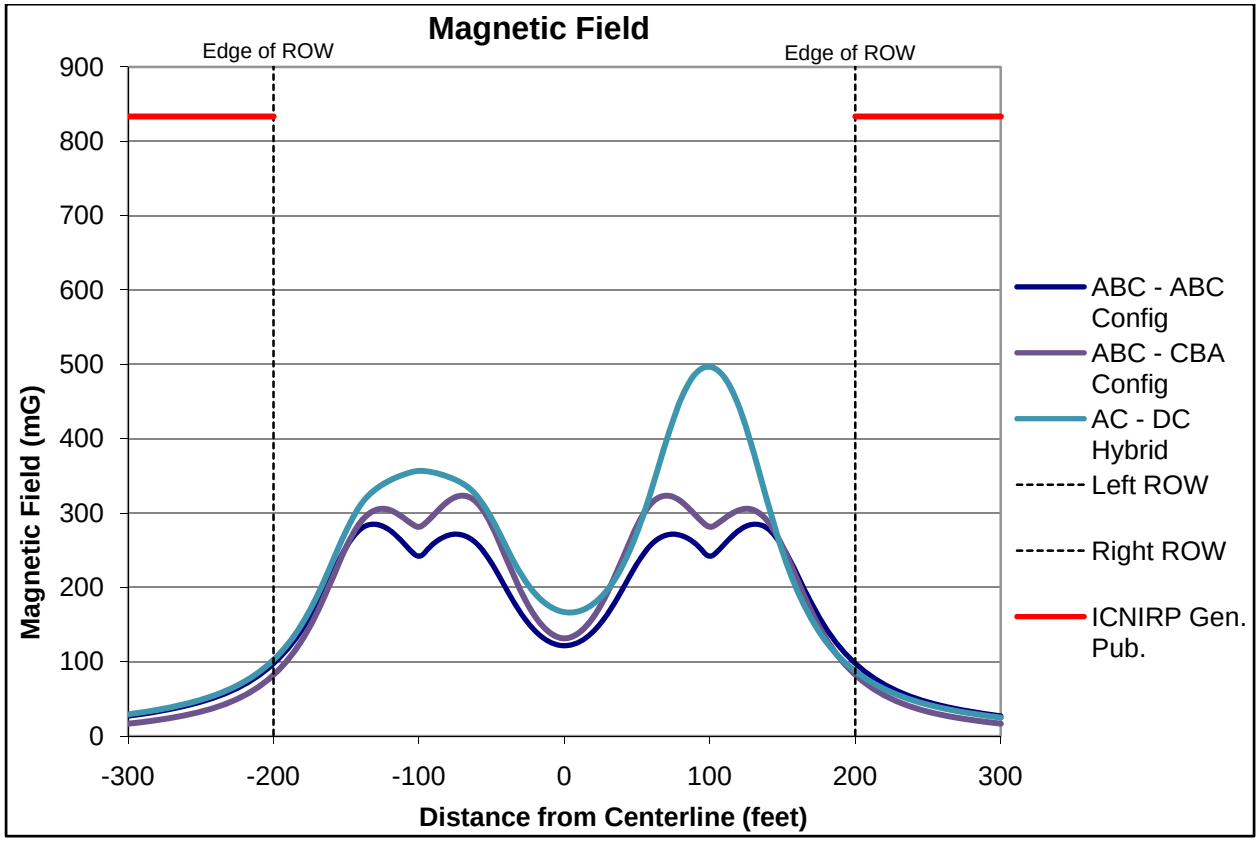

Figure 17: Magnetic Field Across ROW for Two Circuits

6.3 Audible Noise

Table 12 shows a summary of the values in the ROW for the different line configurations with two transmission lines in the corridor. These values are approximately equal to those of a single line for foul weather conditions.

Table 12: L50 Audible Noise Results for Two Circuits (Foul Weather for AC) [dBA]			
CASE	EDGE OF ROW	MAXIMUM IN ROW	AVERAGE IN ROW*
Second Line with A-B-C and A-B-C Phasing (L to R)	46.4	49.3	47.7
Second Line with A-B-C and C-B-A Phasing (L to R)	46.1	48.9	47.2
AC-DC Hybrid (Foul)	46.0	48.8	46.3
AC-DC Hybrid (Fair)	37.2	41.3	38.5

* Average values based on data points calculated every ten feet across the ROW width.

Figure 18 shows a plot of the audible noise levels across the ROW for the various configurations. There is negligible difference between the configurations in areas of close proximity to the AC transmission lines. The DC transmission line is actually nosier during fair weather which is why it is included. However, the noise from the foul weather AC transmission line is greater than that of the fair weather DC line for both weather conditions and all values are below the EPA guidelines.

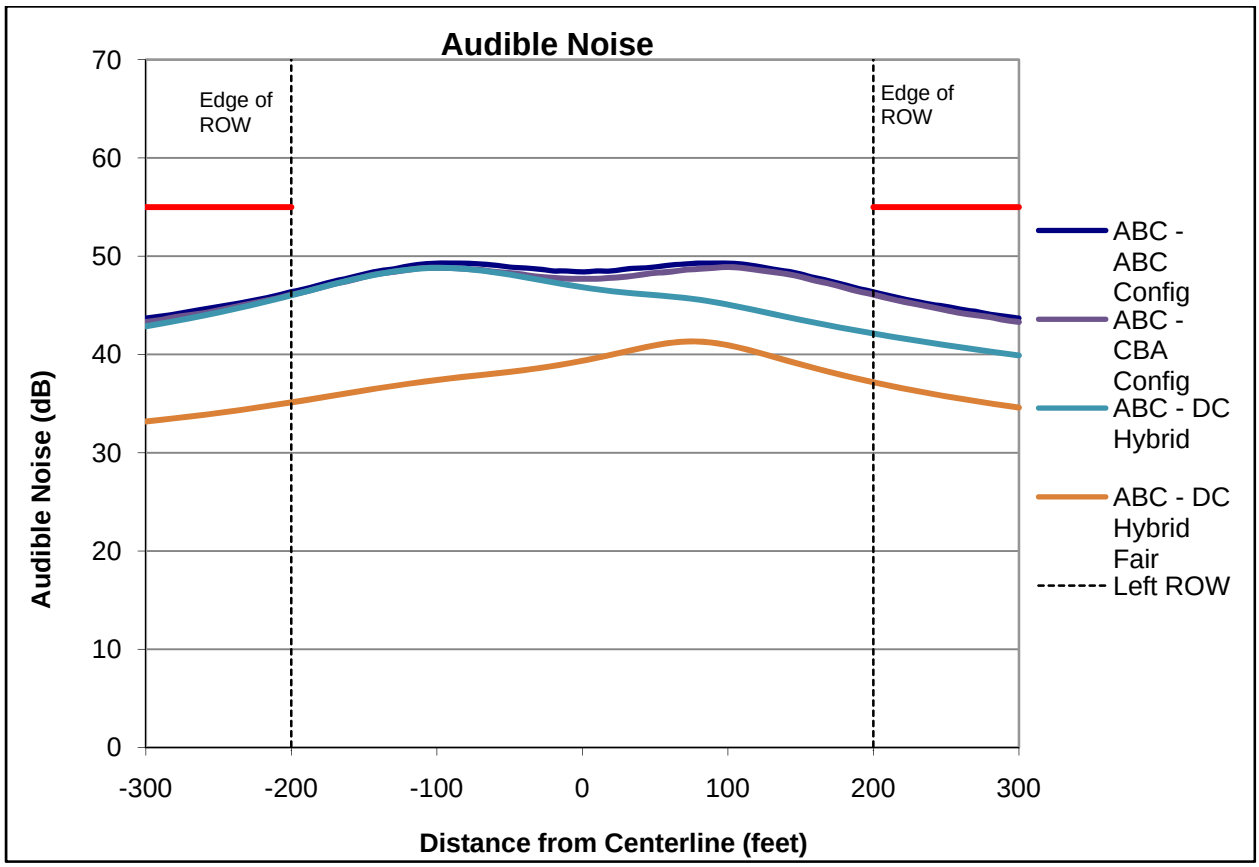

Figure 18: Audible Noise Across ROW for Two Circuits

6.4 AM Radio Interference

Table 13 shows a summary of the values in the ROW with two transmission lines in the corridor. These values are nearly identical to the single transmission line case at the edge of ROW.

Second Line with A-B-C and A-B-C Phasing (L to R)	37.3	47.8	40.6
Second Line with A-B-C and C-B-A Phasing (L to R)	37.6	47.8	40.0
AC-DC Hybrid	38.1	50.0	41.6

* Average values based on data points calculated every ten feet across the ROW width.

Figure 19 shows a plot of the radio interference levels across the ROW for the various configurations. The values of the under the DC line increase slightly, but there is little change outside of the ROW.

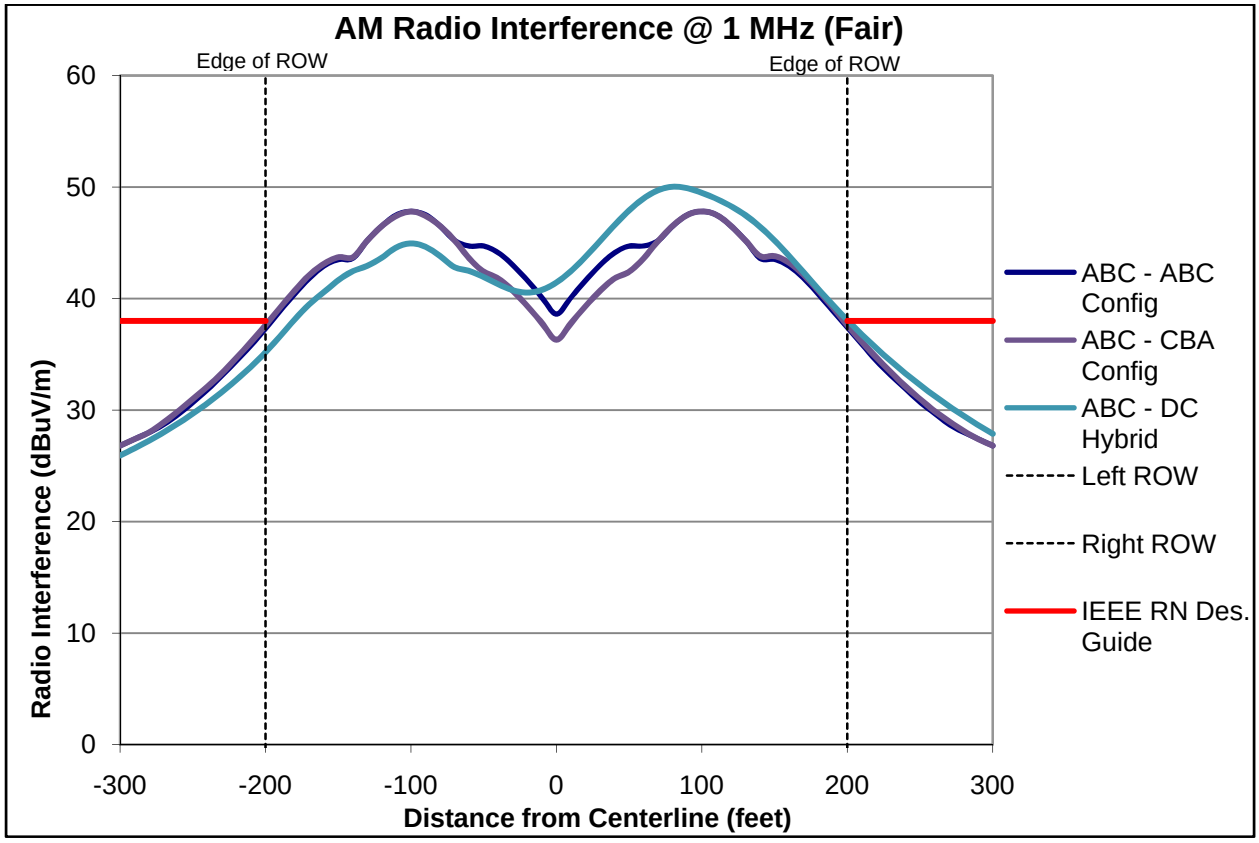

Figure 19: AM Radio Interference Across ROW for Two Circuits

6.5 Television Interference

Table 14 shows a summary of the television interference values in the ROW for the two different AC line phasing configurations with two transmission lines in the corridor. These values are nearly identical to those of a single transmission line. The Enviro software does not produce radio frequency interference results in the television band as it only goes up to 30 MHz. The DC line is not expected to produce significant interference in this frequency range. One quote from the EPRI *Transmission Line Reference Book HVDC to +/- 600 kV*, is "No significant TVI has ever been measured from DC lines during fair or foul weather; therefore, no attempt has been made to develop equations for calculating TVI from DC Lines."

Table 14: Television Interference for Two Circuits [dBµV/m @ 75 MHz]

CASE	EDGE OF ROW	MAXIMUM IN ROW	AVERAGE IN ROW*
Second Line with A-B-C and A-B-C Phasing (L to R)	18.1	30.5	22.4
Second Line with A-B-C and C-B-A Phasing (L to R)	18.3	30.5	21.8

* Average values based on data points calculated every ten feet across the ROW width.

Figure 20 shows a plot of the television interference levels across the ROW for the two configurations. Similar to radio interference, there is negligible difference between the two options outside of the ROW.

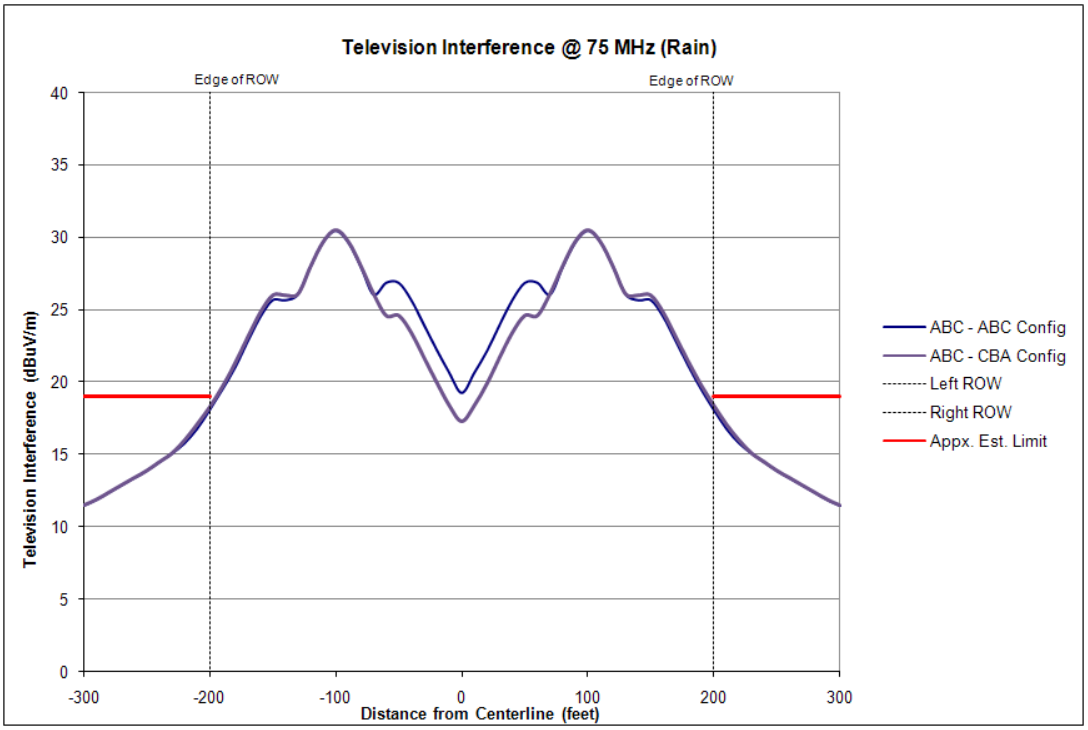

Figure 20: Television Interference Across ROW for Two Circuits

7.0 GENERAL SUMMARY OF RESULTS

This report analyzed EMF and field effects for a base case horizontal guyed V structure with a three conductor bundle, and explored the effects of modifying the bundle or structure type, increases in voltage along the line, and the addition of a second AC or DC line in parallel. In general, it appears that the base case structure and bundle configuration will be acceptable based on the discussion and results in the previous sections. Adding a future second AC or DC line will produce similar results outside of the ROW as compared to a single line.

No guidance was provided on limits that could not be exceeded for any of the field effects. These limits are typically presented by state or municipal requirements; however, Arizona and New Mexico do not have any statewide requirements. All electric and magnetic fields calculated are below the International Commission on Non-Ionizing Radiation Protection (ICNIRP) reference exposure limits for both general public exposure off the ROW. Audible noise levels are below EPA recommended values for outdoor areas. Radio and television interference depend on the signal strength to categorize the effects of the interference on reception quality. Values for AM radio interference are approximately at or below typical guidelines and television interference has no published guidelines for digital television signals, although the interference produced by the lines is likely acceptable. Any additional radio frequency concerns were not presented at this time for other communications systems in the areas.

APPENDIX A – TRANSMISSION LINE STRUCTURE DRAWINGS

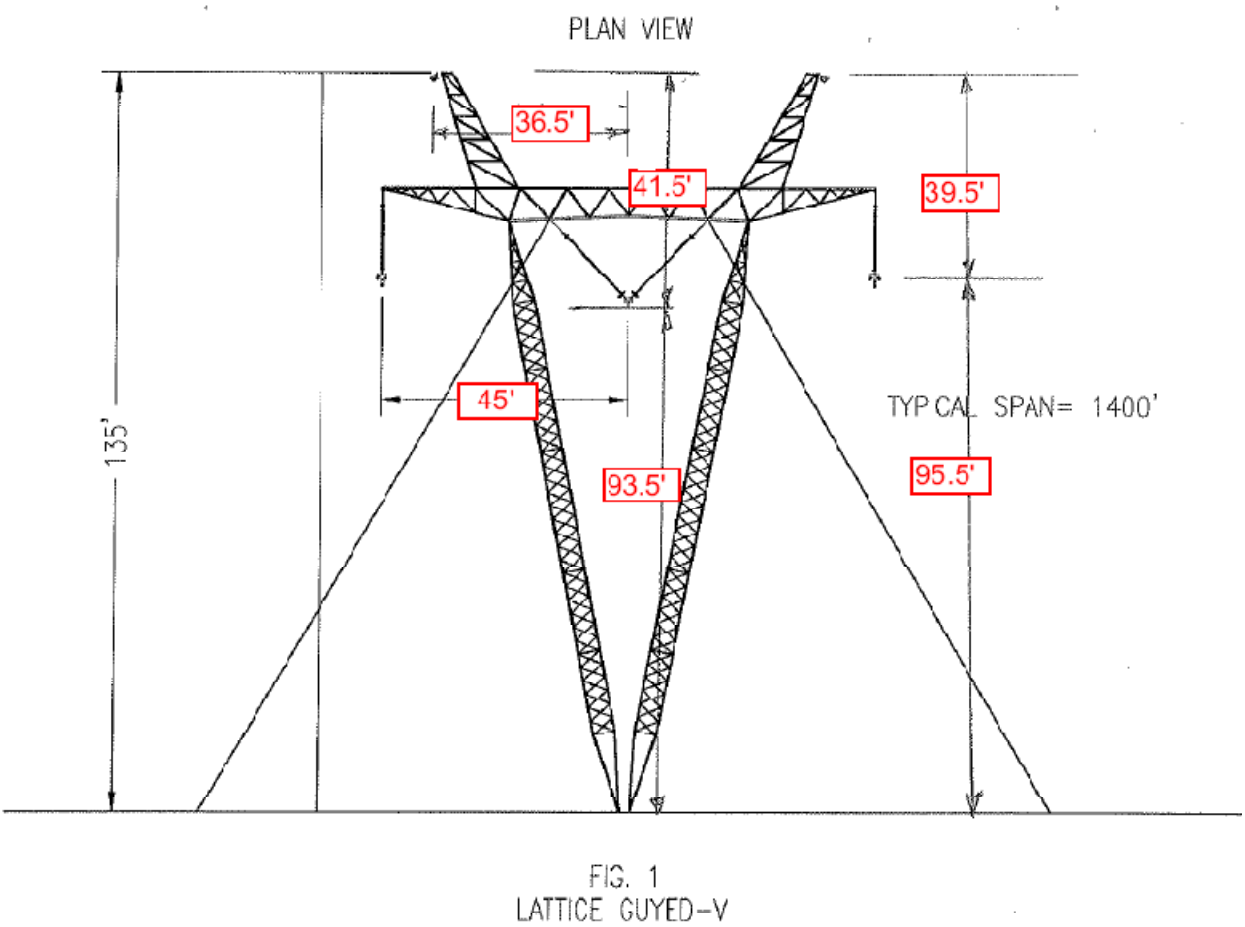

Figure 21: Horizontal Transmission Structure Configuration

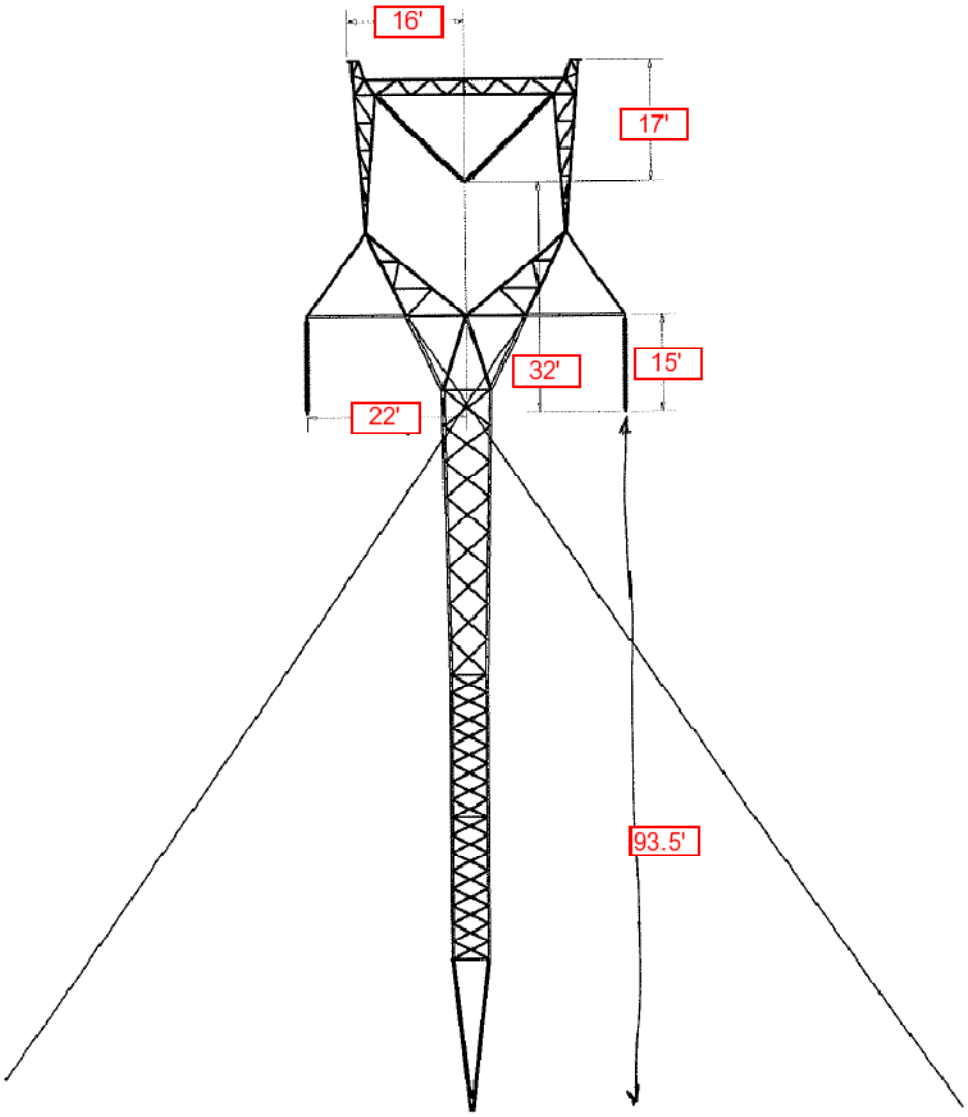

Figure 22: Delta Transmission Structure Configuration

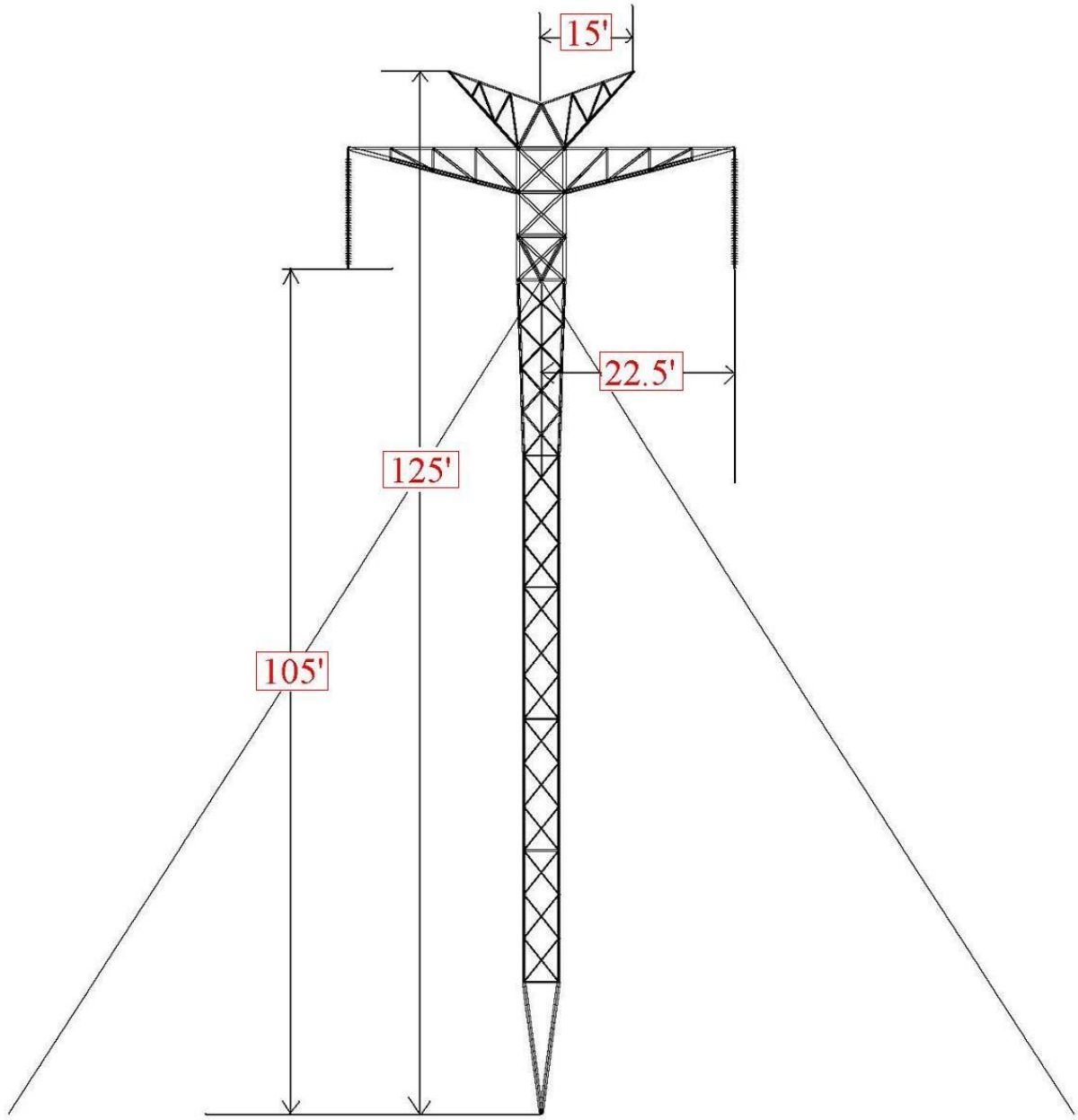

Figure 23: DC Tower Configuration