San Juan Basin Energy Connect Transmission Line Project

Magnetic Fields and Audible Noise

Prepared for

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SAN JUAN BASIN ENERGY CONNECT PROJECT

Introduction

The Tri State Generation and Transmission Association, Inc. (Tri State) is building a new set of electric transmission lines to connect the Ignacio area of Southwestern Colorado to the Shiprock Substation in northwest New Mexico near Farmington. The project is called the San Juan Basin Energy Connect Project.

Four segments of new transmission lines will be built: Shiprock Substation near Farmington to the proposed Kiffen Canyon Substation (also known as Black Glade Substation); Kiffen Canyon to Intermittent Point where final selected route turns northerly; Intermittent Point where final selected route turns northerly to Intermittent Point where route potentially intercepts double circuit La Plata Electric Association (LPEA) line; and Intermittent Point where route potentially intercepts double circuit LPEA line to the proposed Iron Horse Substation near Ignacio.

This report describes the modeling of electric and magnetic fields and audible noise produced from corona for the four segments of the San Juan Basin Energy Connect Project.

Electric and Magnetic Fields from San Juan Basin Energy Connect Project

Electric transmission lines produce EMF when they are in operation. EMF is a term that refers to electric and magnetic fields. These fields are caused by different aspects of the operation of a transmission line and can be evaluated separately.

Electric fields are produced whenever a conductor is connected to a source of electrical voltage. An example of this is the plugging of a lamp into a wall outlet in a home. When the lamp is plugged in, a voltage is induced in the cord to the lamp which causes an electric field to be created around the cord.

Magnetic fields are produced whenever an electrical current flows in a conductor. In the lamp example, if the lamp is turned on allowing electricity to flow to the lamp, a magnetic field is created around the lamp cord in addition to the electric field.

Modeling Methodology

The transmission lines of the San Juan Basin Energy Connect Project were modeled for their resulting electric and magnetic fields using EMF Workstation: ENVIRO (Version 3.52), a Windows-based model developed by the Electric Power Research Institute (EPRI). It is a program that accurately predicts the electric and magnetic fields produced by linear transmission lines such as those in the San Juan Basin Energy Connect Project.

The four segments of lines that will be built were modeled: 230 kilovolt (kV) double circuit line from Shiprock to Kiffen Canyon; 230 kV double circuit line from Kiffen Canyon to Intermittent Point where final selected route turns northerly; 230 kV single circuit line from Intermittent Point where final selected route turns northerly to Intermittent Point where route potentially intercepts double circuit LPEA line; and 230 kV double circuit line with potential for 115 kV circuit on right side from Intermittent Point where route potentially intercepts double circuit LPEA line to Iron Horse Substation.

To perform this modeling, detailed information was received from Tri State on the design of each of these lines, which included projected electrical power flows, operating voltage, tower configuration, conductor size and type, the height and horizontal location of each conductor, conductor sag, and conductor phasing. The modeling was conducted with three cases of power flows for each segment: typical initial minimum, typical initial peak, and typical future peak. Table A-1 of Appendix A shows the three cases of power flows for each circuit in each modeled segment, and the conductor size and type and operating voltage used for each circuit in each modeled segment. Table A-2 of Appendix A presents the height and horizontal location of each conductor, conductor sag, and conductor phasing.

The San Juan Basin Energy Connect Project segments were modeled with the different structural configurations being considered. The segments from Shiprock to Kiffen Canyon and Kiffen Canyon to Intermittent Point where final selected route turns northerly were modeled with a steel monopole structure and a lattice steel structure. The segment from Intermittent Point where final selected route turns northerly to Intermittent Point where route potentially intercepts double circuit LPEA line was modeled with a wood h-frame structure. The segment from Intermittent Point where route potentially intercepts double circuit LPEA line to Iron Horse Substation was modeled with a steel monopole structure.

The design information received from Tri State was identical for the segments from Shiprock to Kiffen Canyon and Kiffen Canyon to Intermittent Point where final selected route turns northerly; therefore the two segments were modeled as one.

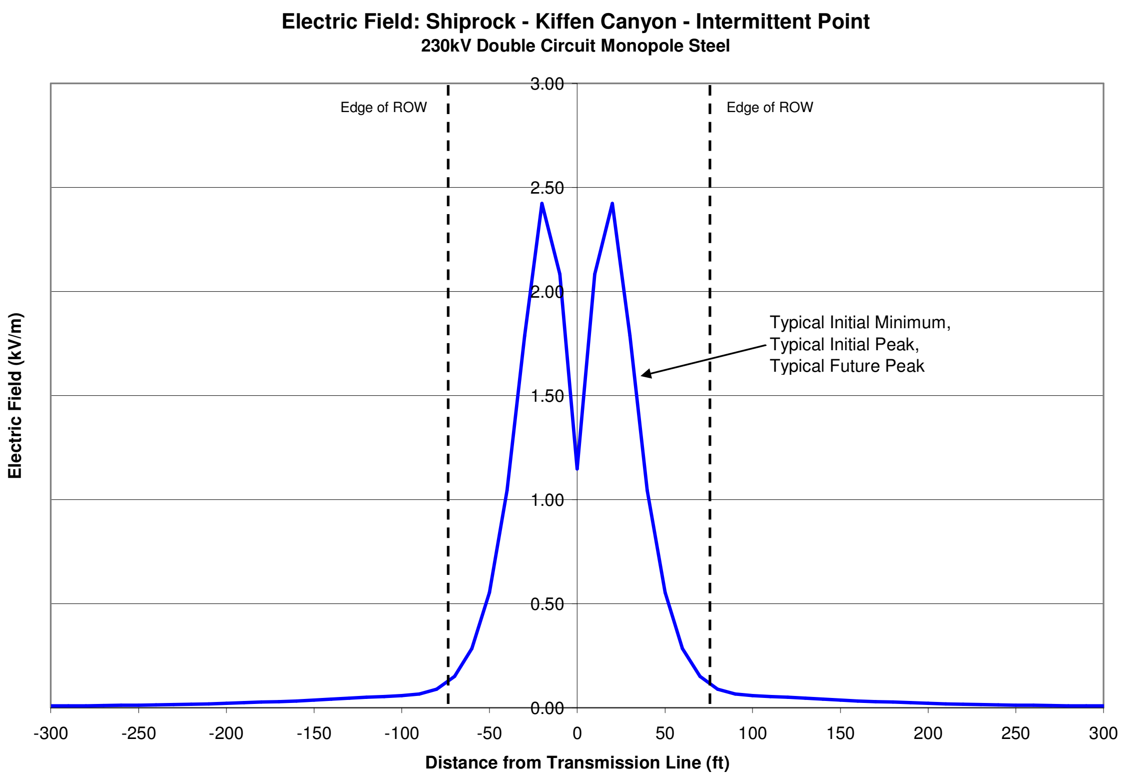
These data were input into the ENVIRO program which produced the lateral profiles of the electric and magnetic fields. These profiles were then plotted to produce the graphs that are presented below. The profiles were calculated with the lowest phase conductor at 28 feet above the ground, the minimum ground clearance per the National Electrical Safety Code (NESC), which coincides with the lowest point of conductor sag, providing the most conservative results. The accuracy of the modeling is dependent on the accuracy of the input data (i.e., if the average phase current is higher than what was modeled, so will the resulting magnetic fields). The resulting field plots are within a few percent of the true value for the conditions modeled.

Modeling Results

Segment from Shiprock to Kiffen Canyon and Segment from Kiffen Canyon to Intermittent Point where final selected route turns northerly

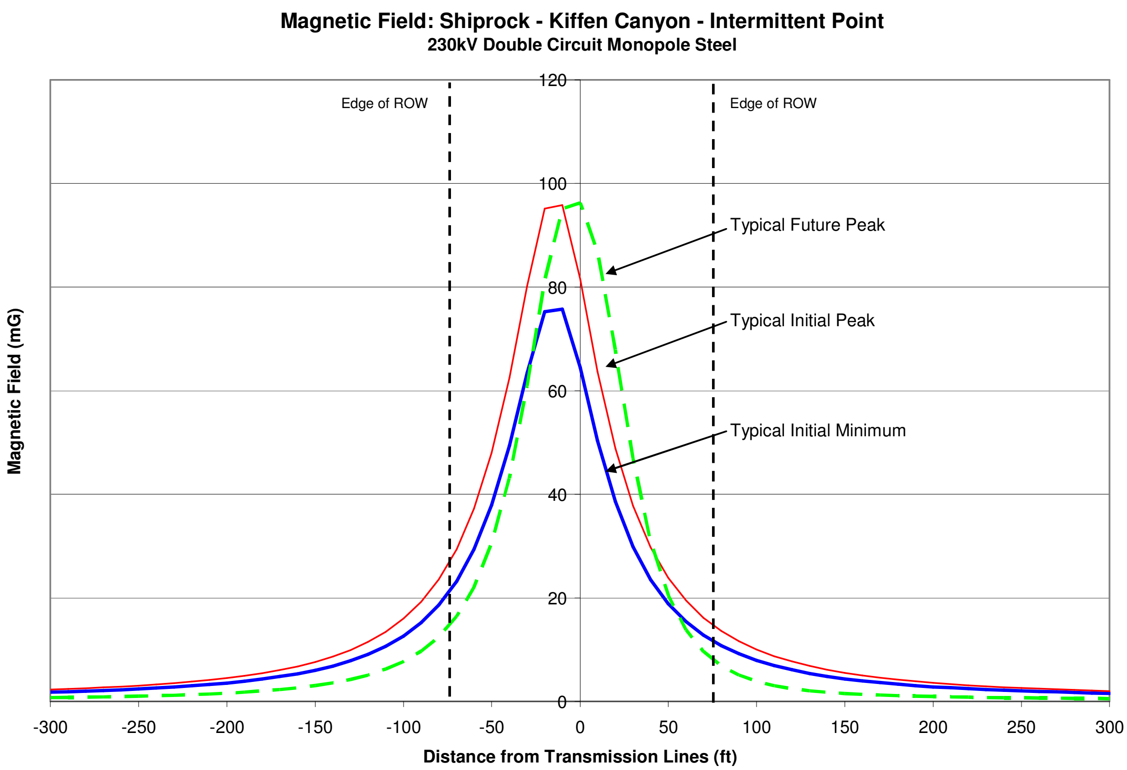
The design information received from Tri State was identical for the 230 kV double circuit segments from Shiprock to Kiffen Canyon and Kiffen Canyon to Intermittent Point where final selected route turns northerly; therefore the two segments were modeled as one. The segments were modeled with the two different structural configurations: steel monopole structure and lattice steel structure. The electric and magnetic field results for these segments with the steel monopole structure are presented in Figures 1 and 2. The electric and magnetic field results for these segments with the lattice steel structure are presented in Figures 3 and 4. All the electric and magnetic field plots show the results of the three cases of power flows (typical initial minimum, typical initial peak, and typical future peak). In all cases, the right of way is 150 feet wide (75 feet either side of the centerline).

Figure 1, Electric field plot for the steel monopole configuration of Segment from Shiprock to Kiffen Canyon and Segment from Kiffen Canyon to Intermittent Point where final selected route turns northerly, with typical initial minimum, typical initial peak, and typical future peak power flows shown. The edges of the 150 foot right of way are shown as vertical dashed lines.



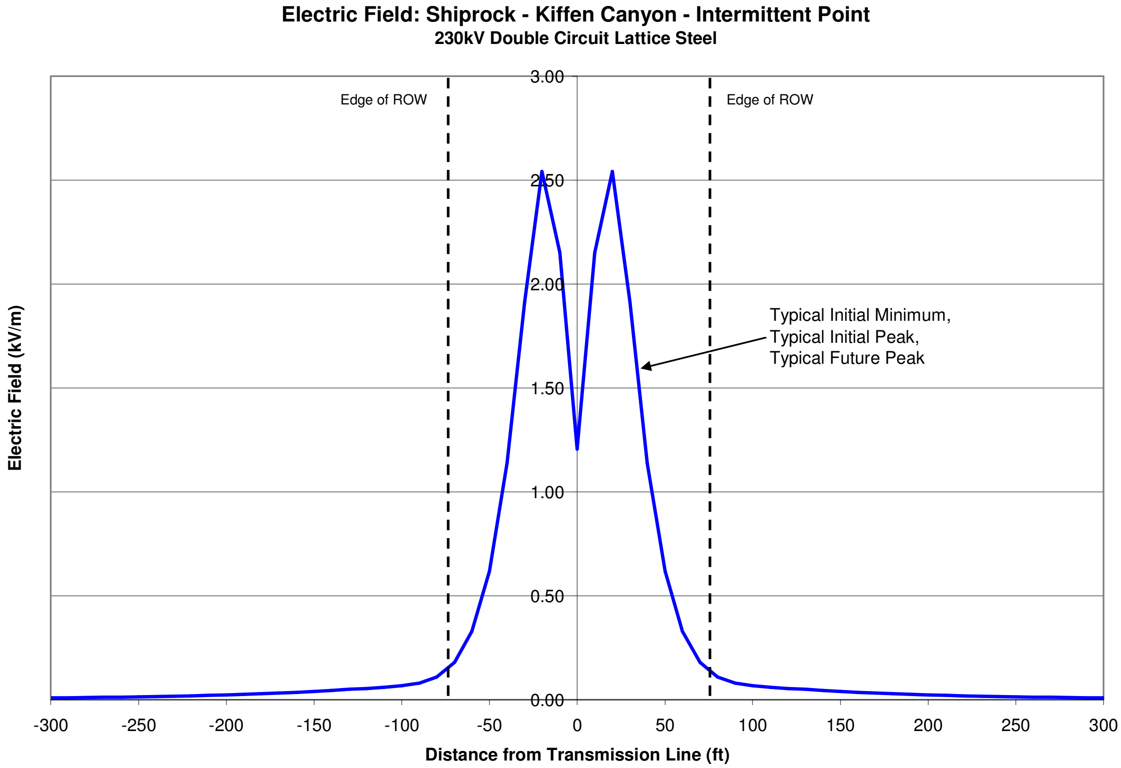
The results of the electric field modeling plotted in Figure 1 show that on both ROW edges the electric field is approximately 0.1 kilovolt per meter (kV/m) for all three power flow cases. This is because electric fields do not vary with power flow. The maximum electric field within the ROW is 2.4 kV/m.

Figure 2, Magnetic field plot for the steel monopole configuration of Segment from Shiprock to Kiffen Canyon and Segment from Kiffen Canyon to Intermittent Point where final selected route turns northerly, with typical initial minimum, typical initial peak, and typical future peak power flows shown.



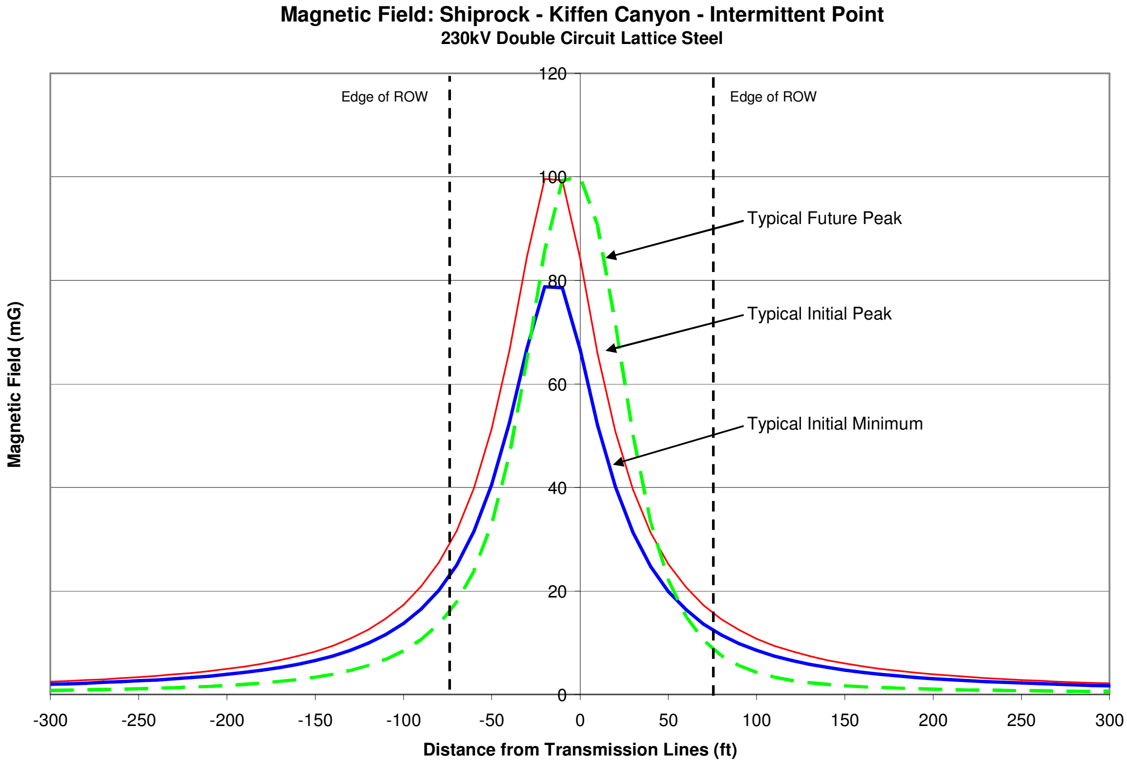
The results of the magnetic field modeling plotted in Figure 2 show that on the left ROW edge the magnetic field is approximately 21 milli Gauss (mG) for typical initial minimum power flow, 26 mG for typical initial peak, and 14 mG for typical future peak. On the right ROW edge the magnetic field is approximately 11 mG for typical initial minimum power flow, 15 mG for typical initial peak, and 8 mG for typical future peak. The reason for this shift is that the circuit on the left side of the structures will carry more current than will the right hand circuit. The maximum magnetic field within the ROW is 75.8 mG for typical initial minimum power flow, 95.8 mG for typical initial peak, and 96.2 mG for typical future peak.

Figure 3, Electric field plot for the lattice steel configuration of Segment from Shiprock to Kiffen Canyon and Segment from Kiffen Canyon to Intermittent Point where final selected route turns northerly, with typical initial minimum, typical initial peak, and typical future peak power flows shown.



The results of the electric field modeling plotted in Figure 3 show that on both ROW edges the electric field is approximately 0.15 kV/m for all three power flow cases. This is because electric fields do not vary with power flow. The maximum electric field within the ROW is 2.5 kV/m.

Figure 4, Magnetic field plot for the lattice steel configuration of Segment from Shiprock to Kiffen Canyon and Segment from Kiffen Canyon to Intermittent Point where final selected route turns northerly, with typical initial minimum, typical initial peak, and typical future peak power flows shown.



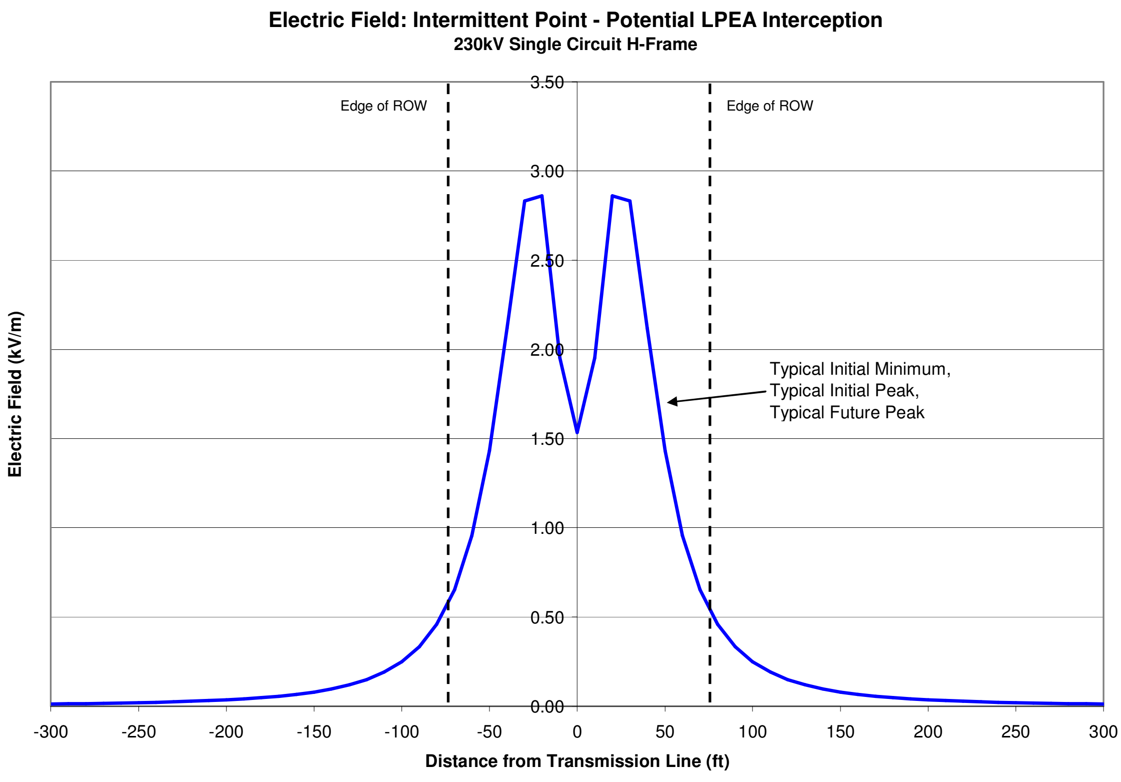
The results of the magnetic field modeling plotted in Figure 4 show that on the left ROW edge the magnetic field is approximately 23 mG for typical initial minimum power flow, 29 mG for typical initial peak, and 16 mG for typical future peak. On the right ROW edge the magnetic field is approximately 13 mG for typical initial minimum power flow, 16 mG for typical initial peak, and 9 mG for typical future peak. As with Figure 2, the reason for this shift is that the circuit on the left side of the structures will carry more current than will the right hand circuit. The maximum magnetic field within the ROW is 78.7 mG for typical initial minimum power flow, 99.6 mG for typical initial peak, and 100.0 mG for typical future peak.

Modeling Results Continued

Segment from Intermittent Point where final selected route turns northerly to Intermittent Point where route potentially intercepts double circuit LPEA line

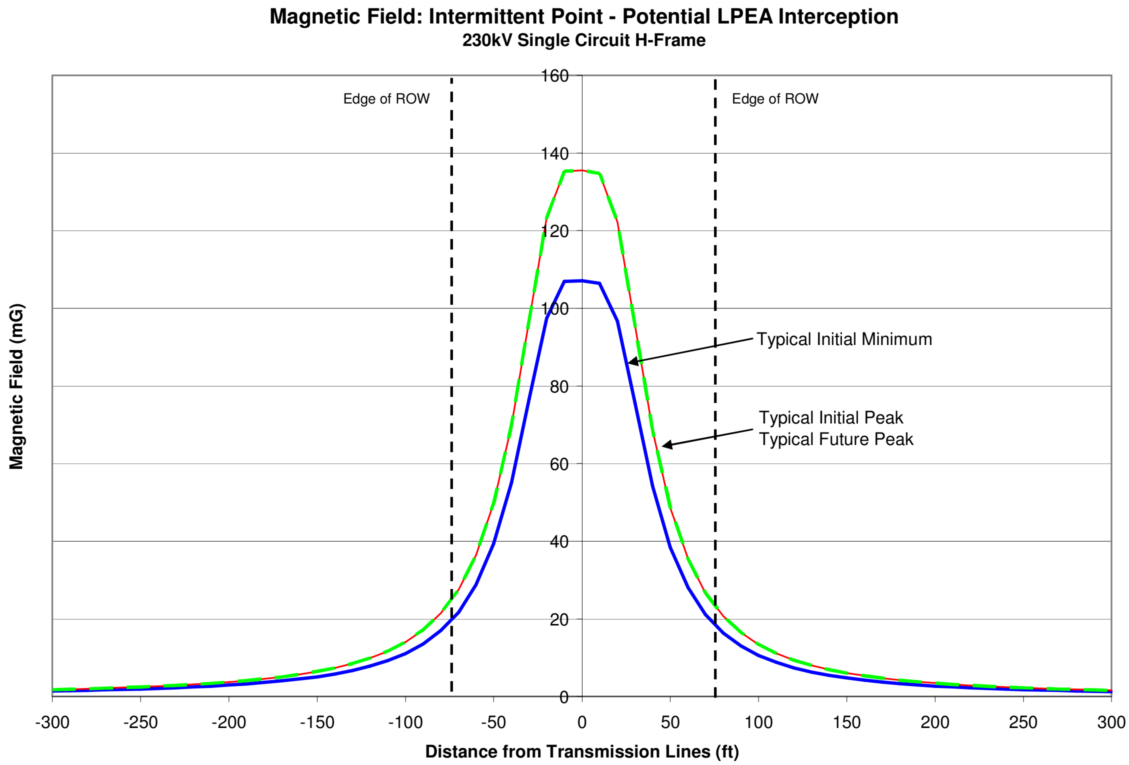
The 230 kV single circuit segment from Intermittent Point where final selected route turns northerly to Intermittent Point where route potentially intercepts double circuit LPEA line was modeled with one structural configuration: wood h-frame structure. The electric and magnetic field results for this segment with the wood h-frame structure and three cases of power flows (typical initial minimum, typical initial peak, and typical future peak) are presented in Figures 5 and 6.

Figure 5, Electric field plot for the wood h-frame configuration of Segment from Intermittent Point where final selected route turns northerly to Intermittent Point where route potentially intercepts double circuit LPEA line, with typical initial minimum, typical initial peak, and typical future peak power flows shown.



The results of the electric field modeling plotted in Figure 5 show that on both ROW edges the electric field is approximately 0.55 kV/m for all three power flow cases. This is because electric fields do not vary with power flow. The maximum electric field within the ROW is 2.9 kV/m.

Figure 6, Magnetic field plot for the wood h-frame configuration of Segment from Intermittent Point where final selected route turns northerly to Intermittent Point where route potentially intercepts double circuit LPEA line, with typical initial minimum, typical initial peak, and typical future peak power flows shown.



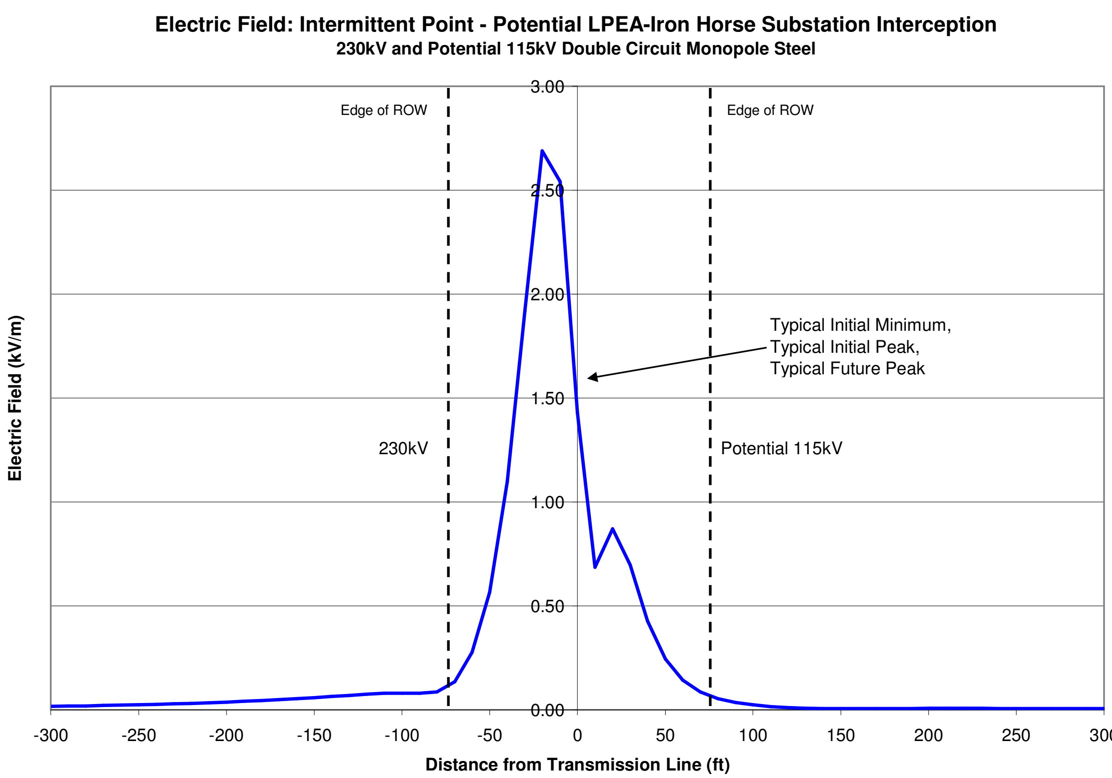
The results of the magnetic field modeling plotted in Figure 6 show that on the left ROW edge the magnetic field is approximately 20 mG for typical initial minimum power flow, and 25 mG for both typical initial peak and typical future peak. This is because the power flows are the same in both cases. On the right ROW edge the magnetic field is approximately 19 mG for typical initial minimum power flow, and 24 mG for both typical initial peak and typical future peak. This is because the power flows are the same in both cases. The maximum magnetic field within the ROW is 107.1 mG for typical initial minimum power flow, and 135.5 mG for both typical initial peak and typical future peak.

Modeling Results Continued

Segment from Intermittent Point where route potentially intercepts double circuit LPEA line to Iron Horse Substation

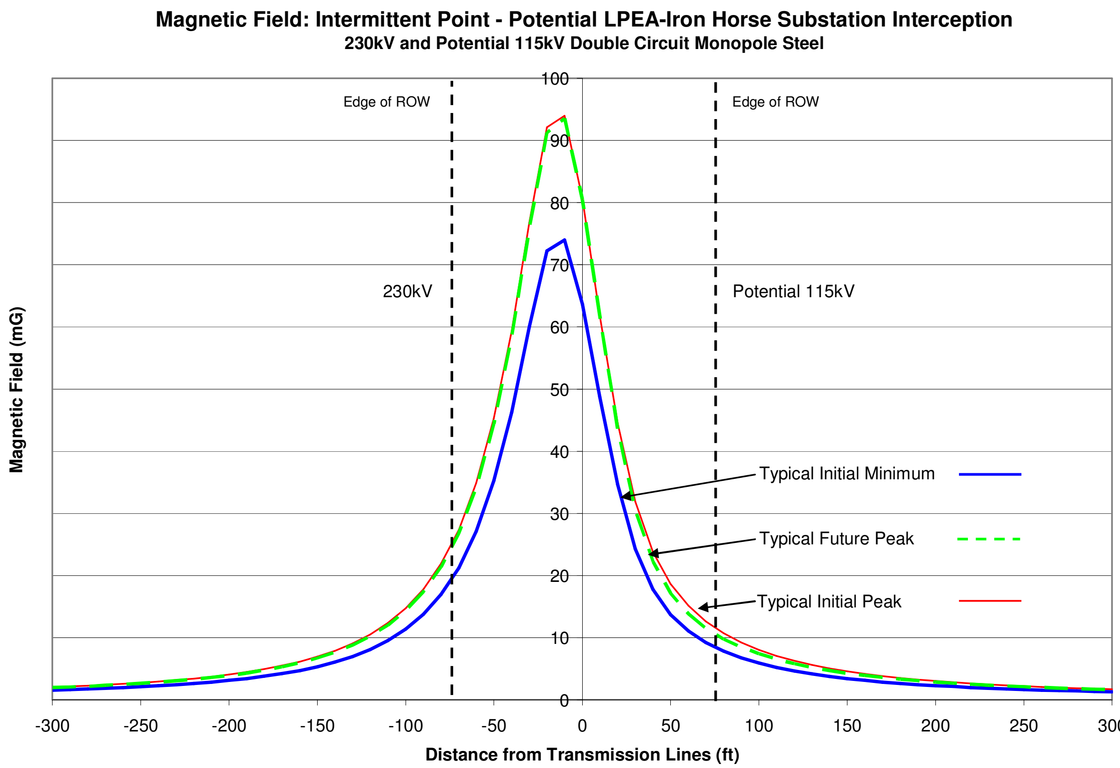
The 230 kV double circuit segment from Intermittent Point where route potentially intercepts double circuit LPEA line to Iron Horse Substation, with potential for 115 kV circuit on right side, was modeled with one structural configuration: steel monopole structure. The electric and magnetic field results for this segment with the steel monopole structure and three cases of power flows (typical initial minimum, typical initial peak, and typical future peak) are presented in Figures 7 and 8.

Figure 7, Electric field plot for the steel monopole configuration of Segment from Intermittent Point where route potentially intercepts double circuit LPEA line to Iron Horse Substation, with typical initial minimum, typical initial peak, and typical future peak power flows shown.



The results of the electric field modeling plotted in Figure 7 show that on the left ROW edge the electric field is approximately 0.11 kV/m for all three power flow cases. Figure 7 shows that on the right ROW edge the electric field is approximately 0.07 kV/m for all three power flow cases. The reason for this shift is that the 230 kV circuit on the left side of the structures will produce a higher electric field than will the 115 kV circuit on the right. Electric fields do not vary with power flow; therefore the electric fields are identical for all three power flow cases. The maximum electric field within the ROW is 2.7 kV/m.

Figure 8, Magnetic field plot for the steel monopole configuration of Segment from Intermittent Point where route potentially intercepts double circuit LPEA line to Iron Horse Substation, with typical initial minimum, typical initial peak, and typical future peak power flows shown.



The results of the magnetic field modeling plotted in Figure 8 show that on the left ROW edge the magnetic field is approximately 19 mG for typical initial minimum power flow, 25 mG for typical initial peak, and 24 mG for typical future peak. Figure 8 shows that on the right ROW edge the magnetic field is approximately 8 mG for typical initial minimum power flow, 12 mG for typical initial peak, and 11 mG for typical future peak. The reason for this shift is that the 230 kV circuit on the left side of the structures will carry more current than will the 115 kV circuit on the right hand side. The maximum magnetic field within the ROW is 74.0 mG for typical initial minimum power flow, 94.0 mG for typical initial peak, and 93.5 mG for typical future peak.

Corona Audible Noise from San Juan Basin Energy Connect Project

Corona is the electrical ionization of the air that occurs near the surface of the energized conductor and suspension hardware due to very high electric field strength. Corona may result in audible noise being produced by the transmission lines.

The amount of corona produced by a transmission line is a function of the voltage of the line, the diameter of the conductors, the locations of the conductors in relation to each other, the elevation of the line above sea level, the condition of the conductors and hardware, and the local weather conditions. Power flow does not affect the amount of corona produced by a transmission line therefore only one set of corona results is predicted for each modeled segment and structural configuration. The 230 kV double circuit segments from Shiprock to Kiffen Canyon and Kiffen Canyon to Intermittent Point where final selected route turns northerly (modeled together due to identical design information) were modeled for corona audible noise with two different structural configurations: steel monopole structure and lattice steel structure. The 230 kV single circuit segment from Intermittent Point where final selected route turns northerly to Intermittent Point where route potentially intercepts double circuit LPEA line was modeled for corona audible noise with a wood h-frame structure. The 230 kV double circuit segment from Intermittent Point where route potentially intercepts double circuit LPEA line to Iron Horse Substation, with potential for 115 kV circuit on right side, was modeled for corona audible noise with a steel monopole structure. Corona typically becomes a design concern for transmission lines at 345 kV and above and is less noticeable from lines like these that are operated at lower voltages.

The electric field gradient is greatest at the surface of the conductor. Large-diameter conductors have lower electric field gradients at the conductor surface and, hence, lower corona than smaller conductors, everything else being equal. The conductors chosen for the San Juan Basin Energy Connect Project transmission lines were selected to have large diameters and thus a reduced potential to create audible noise.

Irregularities (such as nicks and scrapes on the conductor surface or sharp edges on suspension hardware) concentrate the electric field at these locations and thus increase the electric field gradient and the resulting corona at these spots. Similarly, foreign objects on the conductor surface, such as dust or insects, can cause irregularities on the surface that are a source for corona.

Corona also increases at higher elevations where the density of the atmosphere is less than at sea level. Audible noise will vary with elevation with the relationship of A/300 where A is the elevation of the line above sea level measured in meters (EPRI 2005). Audible noise at 600 meters elevation will be twice the audible noise at 300 meters, all other things being equal. The San Juan Basin Energy Connect Project transmission lines were modeled with an elevation of 6,500 feet (1,981 meters), which is approximately the highest elevation to be encountered, at Ignacio, Colorado.

Raindrops, snow, fog, hoarfrost, and condensation accumulated on the conductor surface are also sources of surface irregularities that can increase corona. During fair weather, the number of these condensed water droplets or ice crystals is usually small and the corona effect is also small. However, during wet weather, the number of these sources increases (for instance due to rain drops standing on the conductor) and corona effects are therefore greater. During wet or foul weather conditions, the conductor will produce the greatest amount of corona noise. However, during heavy rain the noise generated by the falling rain drops hitting the ground will typically be greater than the noise generated by corona and thus will mask the audible noise from the transmission line.

Corona produced on a transmission line can be reduced by the design of the transmission line and the selection of hardware and conductors used for the construction of the line. For instance the use of conductor hangers that have rounded rather than sharp edges and no protruding bolts with sharp edges will reduce corona. The conductors themselves can be made with larger diameters and handled so that they have smooth surfaces without nicks or burrs or scrapes in the conductor strands. The transmission lines proposed here are designed to reduce corona generation.

Modeling Methodology

The Colorado Public Utility Commission (CPUC) Rule 3102 requires that the applicant for a certificate of public convenience and necessity (CPCN) for a new transmission line model the potential noise levels that the line could produce.

The audible noise from the proposed transmission lines was predicted using EMF Workstation: ENVIRO (Version 3.52), a Windows-based model developed by the Electric Power Research Institute (EPRI).

The data presented in Tables A-1 and A-2 of Appendix A were input into the ENVIRO program to calculate the corona audible noise, with the addition of elevation of the line above sea level. The San Juan Basin Energy Connect Project transmission lines were modeled with an elevation of 6,500 feet (1,981 meters), which is approximately the highest elevation to be encountered, at Ignacio, Colorado. Because the equations that predict audible noise were created from empirical measurements, the accuracy of the model is as good as these measurements that produced the original equations. In addition, the model is as good as the accuracy of the parameters input to the model (e.g. the actual elevation of the transmission line at a particular location rather than the average elevation of the entire project). Therefore given these potential uncertainties, the resulting field plots are within a few percent of the true value for the conditions modeled.

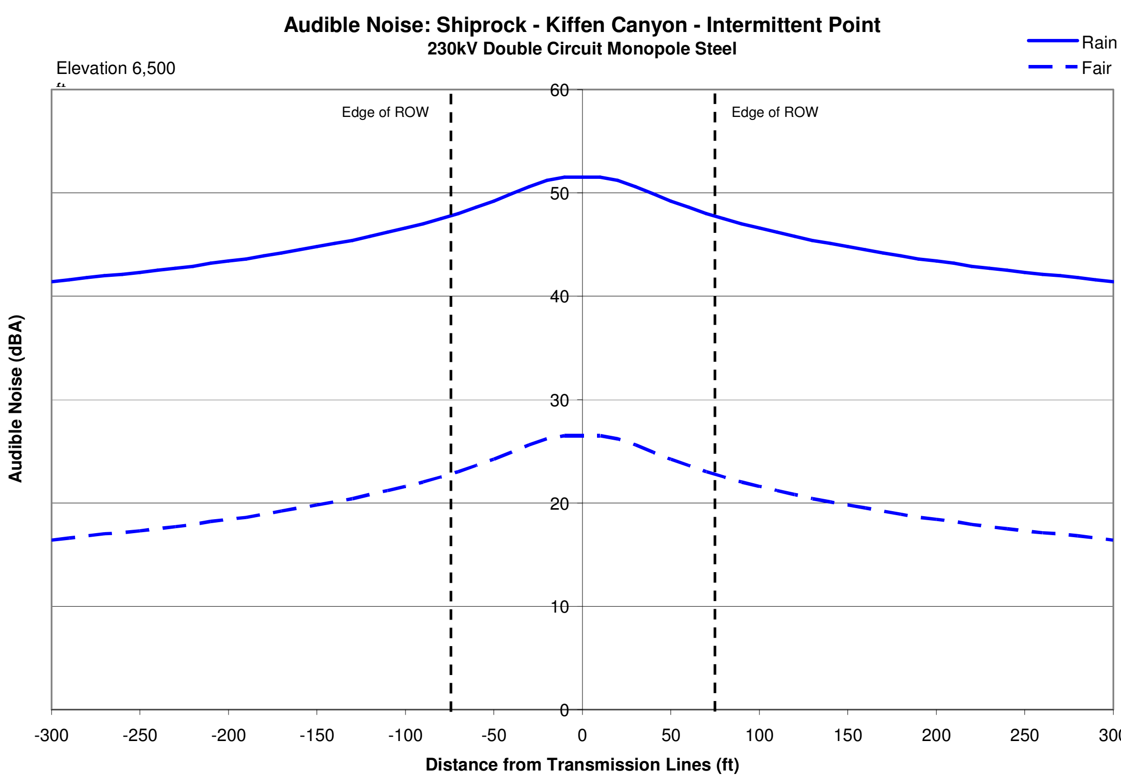
Modeling Results

Segment from Shiprock to Kiffen Canyon and Segment from Kiffen Canyon to Intermittent Point where final selected route turns northerly

The 230 kV double circuit segments from Shiprock to Kiffen Canyon and Kiffen Canyon to Intermittent Point where final selected route turns northerly (modeled together due to identical design information) were modeled for corona audible noise with two different structural configurations: steel monopole structure and lattice steel structure. The corona audible noise plot for these segments with the steel monopole structure is presented in Figure 9. The corona audible noise plot for these segments with the lattice steel structure is presented in Figure 10.

The figures show two conditions, fair and rain. This is to show the range in corona effects due to changing weather.

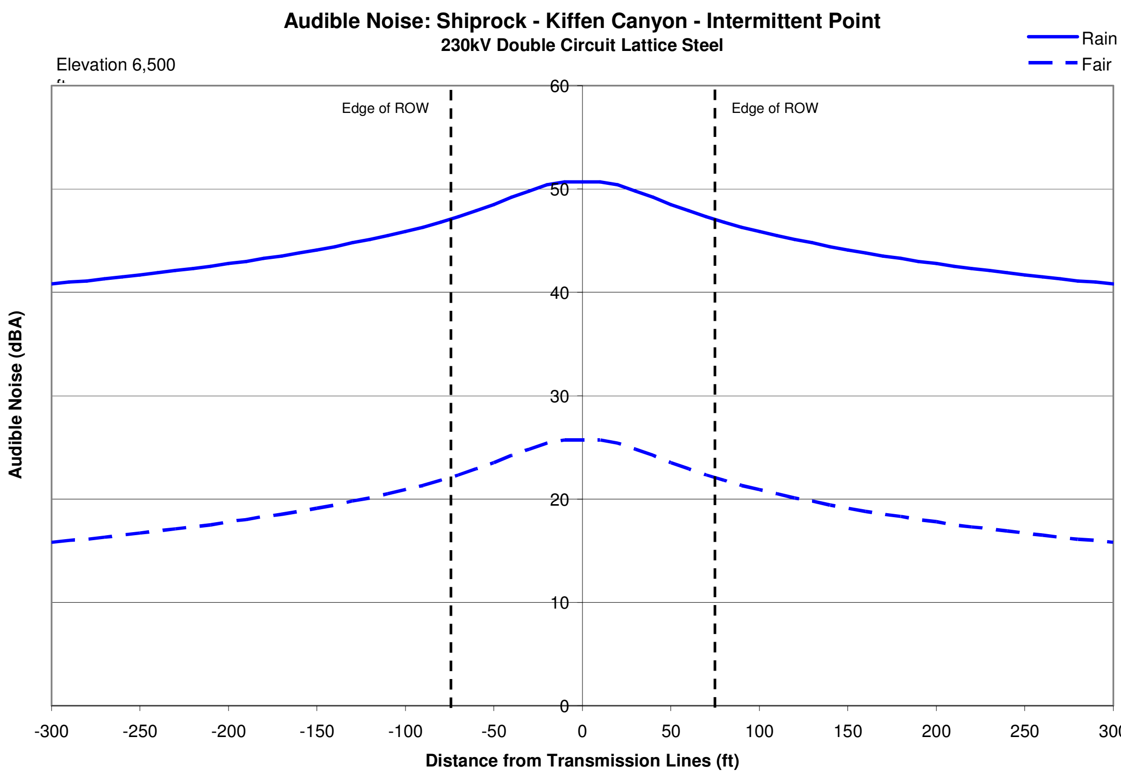
Figure 9, Corona audible noise plot for the steel monopole configuration of Segment from Shiprock to Kiffen Canyon and Segment from Kiffen Canyon to Intermittent Point where final selected route turns northerly.



The results of the corona audible noise modeling plotted in Figure 9 show that on both ROW edges the audible noise is approximately 23 dBA in fair weather and 48 dBA in wet weather.

The maximum noise that occurs within the ROW is 26.5 dBA in fair weather and 51.5 dBA in wet weather.

Figure 10, Corona audible noise plot for the lattice steel configuration of Segment from Shiprock to Kiffen Canyon and Segment from Kiffen Canyon to Intermittent Point where final selected route turns northerly.



The results of the corona audible noise modeling plotted in Figure 10 show that on both ROW edges the audible noise is approximately 22 dBA in fair weather and 47 dBA in wet weather. The maximum noise that occurs within the ROW is 25.7 dBA in fair weather and 50.7 dBA in wet weather.

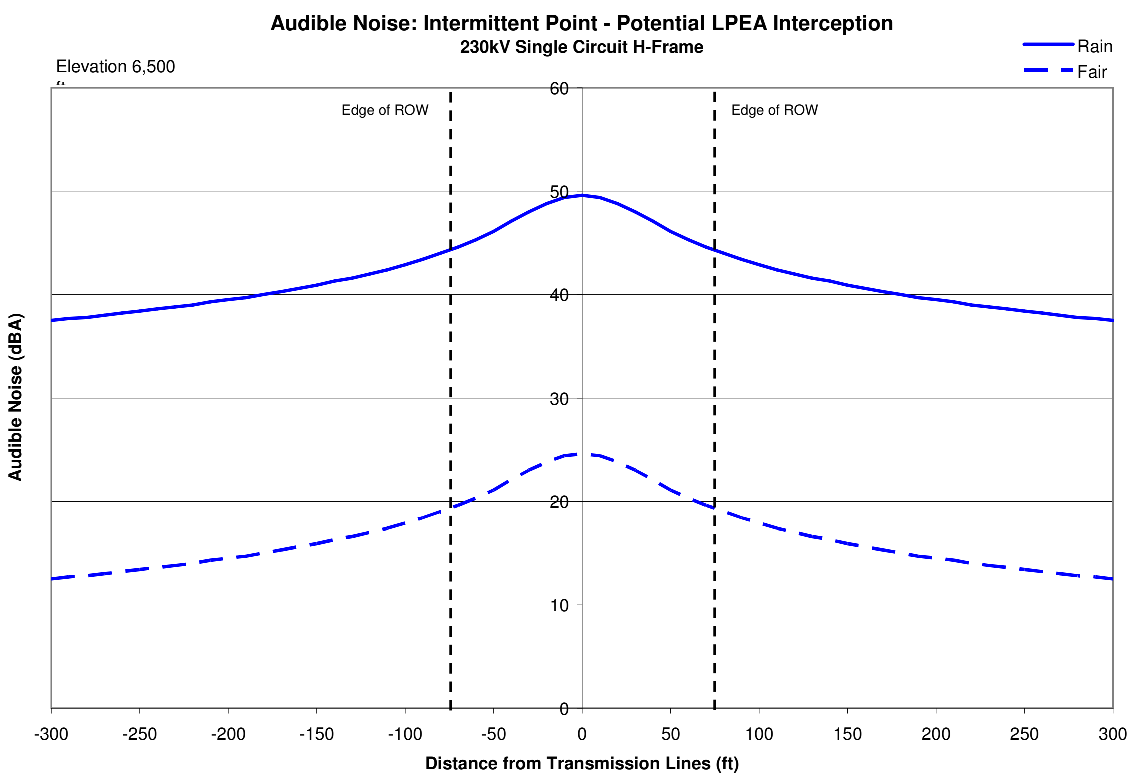
Modeling Results Continued

Segment from Intermittent Point where final selected route turns northerly to Intermittent Point where route potentially intercepts double circuit LPEA line

The 230 kV single circuit segment from Intermittent Point where final selected route turns northerly to Intermittent Point where route potentially intercepts double circuit LPEA line was modeled for corona audible noise with one structural configuration: wood h-frame structure. The corona audible noise plot for this segment with the wood h-frame structure is presented in Figure 11.

The figures show two conditions, fair and rain. This is to show the range in corona effects due to changing weather.

Figure 11, Corona audible noise plot for the wood h-frame configuration of Segment from Intermittent Point where final selected route turns northerly to Intermittent Point where route potentially intercepts double circuit LPEA line.



The results of the corona audible noise modeling plotted in Figure 11 show that on both ROW edges the audible noise is approximately 19 dBA in fair weather and 44 dBA in wet weather. The maximum noise that occurs within the ROW is 24.6 dBA in fair weather and 49.6 dBA in wet weather.

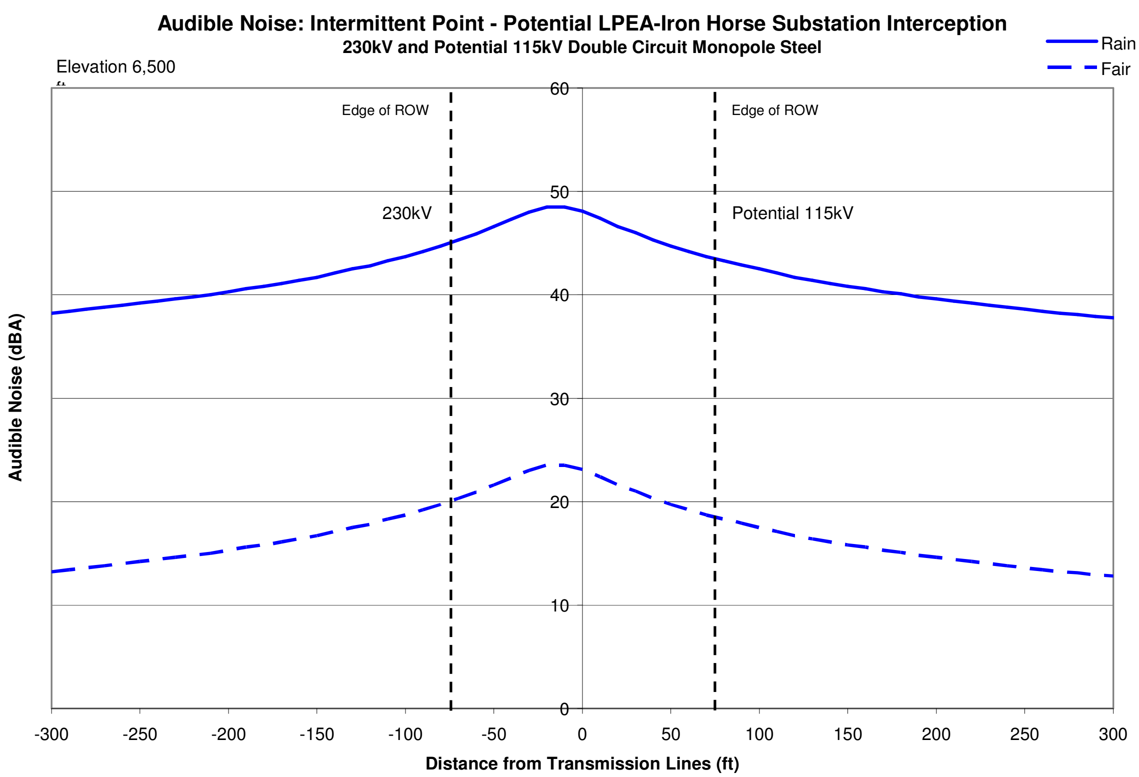
Modeling Results Continued

Segment from Intermittent Point where route potentially intercepts double circuit LPEA line to Iron Horse Substation

The 230 kV double circuit segment from Intermittent Point where route potentially intercepts double circuit LPEA line to Iron Horse Substation, with potential for 115 kV circuit on right side, was modeled for corona audible noise with one structural configuration: steel monopole structure. The corona audible noise plot for this segment with the steel monopole structure is presented in Figure 12.

The figures show two conditions, fair and rain. This is to show the range in corona effects due to changing weather.

Figure 12, Corona audible noise plot for the steel monopole configuration of Segment from Intermittent Point where route potentially intercepts double circuit LPEA line to Iron Horse Substation.



The results of the corona audible noise modeling plotted in Figure 12 show that on the left ROW edge the audible noise is approximately 20 dBA in fair weather and 45 dBA in wet weather. Figure 12 shows that on the right ROW edge the audible noise is approximately 19 dBA in fair weather and 43 dBA in wet weather. The curves are shifted slightly to the left because the 230 kV circuit on the left side will produce slightly more corona noise than will the 115 kV circuit on the right. The maximum noise that occurs within the ROW is 23.5 dBA in fair weather and 48.5 dBA in wet weather.

APPENDIX A
ENVIRO Modeling Inputs

Table A-1 – Projected Electrical Power Flows, Conductor Size and Type, and Operating Voltage

Segment/Circuit	From Shiprock to Kiffen Canyon; and From Kiffen Canyon to Intermittent Point where final selected route turns northerly		From Intermittent Point where final selected route turns northerly to Intermittent Point where route potentially intercepts double circuit LPEA line	From Intermittent Point where route potentially intercepts double circuit LPEA line to Iron Horse Substation	
	Double Circuit		Single Circuit	Double Circuit	
	230 kV Circuit 1	230 kV Circuit 2	230 kV	230 kV Circuit 1	Potential 115 kV Circuit 2
Conductor Number/Type	One conductor 1272 MCM 45/7 ACSR Bittern[1]	One conductor 1272 MCM 45/7 ACSR Bittern[1]	One conductor 1272 MCM 45/7 ACSR Bittern[1]	One conductor 1272 MCM 45/7 ACSR Bittern[1]	One conductor 477 MCM 26/7 ACSR Hawk[2]
Typical Initial Minimum (Amperes)	502	0	502	502	80
Typical Initial Peak (Amperes)	635	0	635	635	80
Typical Future Peak (Amperes)	635	535	635	635	105

[1] 1272 MCM 45/7 ACSR Bittern conductor has a diameter of 1.345 inches. Conductor Type is used for Shielding Type because Shielding Type received from Tri State (single 0.654" diameter 48 fiber OPGW with a short circuit rating of 167 kA^2*s for first circuit, and single 7/16-inch diameter shield wire for any second or future circuit) is not available in ENVIRO database.

[2] 477 MCM 26/7 ACSR Hawk conductor has a diameter of 0.858 inches. Conductor Type is used for Shielding Type because Shielding Type received from Tri State (single 0.654" diameter 48 fiber OPGW with a short circuit rating of 167 kA^2*s for first circuit, and single 7/16-inch diameter shield wire for any second or future circuit) is not available in ENVIRO database.

Table A-2 – Conductor Height and Horizontal Location, Conductor Sag, and Conductor Phasing

Segment/Configuration/Circuit/			Phase (top to bottom/ left to right)	Horizontal Location (ft)	Vertical Location (ft)
From Shiprock to Kiffen Canyon; and From Kiffen Canyon to Intermittent Point where final selected route turns northerly	Steel Monopole	Circuit 1	A	-14.5	66.2
			B	-16	46.7
			C	-14.5	28
			Ground	-10	77
		Circuit 2	C	14.5	66.2
			B	16	46.7
			A	14.5	28
			Ground	10	77
From Shiprock to Kiffen Canyon; and From Kiffen Canyon to Intermittent Point where final selected route turns northerly	Lattice Steel	Circuit 1	A	-15	70
			B	-16.5	49
			C	-15	28
			Ground	-10	80
		Circuit 2	C	15	70
			B	16.5	49
			A	15	28
			Ground	10	80
From Intermittent Point where final selected route turns northerly to Intermittent Point where route potentially intercepts double circuit LPEA line	H-Frame Wood	Circuit	A	-20	28
			B	0	28
			C	20	28
			Ground	-9.75	37.5
			Ground	9.75	37.5

Segment/Configuration/Circuit/			Phase (top to bottom/ left to right)	Horizontal Location (ft)	Vertical Location (ft)
From Intermittent Point where route potentially intercepts double circuit LPEA line to Iron Horse Substation	Steel Monopole	Circuit 1	A	-14.5	66.2
			B	-16	46.7
			C	-14.5	28
			Ground	-10	77
		Circuit 2	C	14.5	66.2
			B	16	46.7
			A	14.5	28
			Ground	10	77