California High-Speed Train Project

TECHNICAL MEMORANDUM

Radio Frequency Propagation Simulations
TM 300.06

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ABSTRACT

The purpose of the RF propagation simulation activity was to determine the propagation characteristics of suitable radio technologies deployed at different frequencies to meet CHSTP requirements. The information gathered during the simulation activity is used to determine radio tower site needs to support the 15% and 30% designs, site identification, and environmental clearance efforts. Based on the propagation simulations conducted, the EMT has determined that a 2.5 mile spacing of radio sites with a planned100' tall radio tower will provide the available space to support suitable and probable radio technologies to be supplied to the CHSTP.

Furthermore, the 2.5 mile spacing determination is consistent with the Program goals during the preliminary engineering phase in the following ways:

- Multiple likely-to-be-bid radio technologies at multiple frequencies (including greater than 925 MHz) can be deployed (some more compliant to project and technical requirements than others) with minimal additional tower site acquisition by the final designer.
- Risk and uncertainty for the final designer is reduced - thereby leading to lower and more accurate bids and less schedule risk.
- A redundant radio system may be designed within the identified locations such that continuous radio coverage can be maintained despite a single site failure.

If a radio system requiring the use of frequencies in higher microwave bands (greater than approximately 2 to 4 GHz) is deployed to support the CHSTP, that radio system will likely require a different, shorter-path antenna infrastructure which can easily be supported by shorter trackside-mounted antennas which require less physical space and environmental clearance

1.0 INTRODUCTION

Radio Frequency (RF) propagation simulations are used by radio system designers to model the expected geographic radio coverage of a theoretical or real radio system. As part of preliminary design, the Engineering Management Team (EMT) is conducting feasibility design and investigation for desired and alternative radio technology solutions. Part of the feasibility investigation includes RF propagation simulations which allow the EMT to plan preliminary tower site locations and other characteristics without the need to acquire experimental licenses, build a test system and conduct field measurements.

Because RF spectrum is scarce and there is not an identified band that the California High-Speed Rail Authority (Authority) can readily acquire, the EMT has reviewed multiple radio systems and appropriate frequency spectrum to support the requirements of the California High-Speed Train Project (CHSTP). Global System for Mobile Communications - Railway (GSM-R) is the primary technology that meets the CHSTP technical and project requirements and is therefore the primary focus of the RF propagation simulations. After researching and reviewing all known radio technologies, the EMT determined that GSM-R was the most suitable and began research into adaptations to port GSM-R away from its “native” band of operation to bands possibly more accessible to the Authority. The EMT is also investigating alternative radio technologies at different spectrum bands including, International Association of Public Safety Communications Officials Project- 25 (APCO P-25 or P-25), Terrestrial Trunked Radio (TETRA), Long Term Evolution (LTE), Telefunken TRainCom, Mitsubishi Shinkansen Leaky-Coax. Furthermore, the EMT has commissioned research into likely available spectrum to support likely radio technologies and reached out to public and private spectrum holders, government agencies (FCC, FRA, and NTIA) and frequency coordinators to attempt to identify acquirable spectrum.

This report provides an overview of five selected RF simulations for CHSTP. Four simulations depict GSM-R radio technology at different frequency bands and one simulation depicts APCO P-25 Land Mobile Radio (LMR) technology in the 450-470 MHz band. Of the five RF Radio simulations presented and the brief discussion of each application highlights the impacts to the CHSTP. The RF propagation simulation task was undertaken to:

1. Determine tower spacing suitable to support likely-to-be-bid radio systems deployed at likely-to-be-used frequencies and support a single-site failure.
2. Develop and validate a radio tower infrastructure preliminary design which will accommodate likely-to-be-bid radio systems at likely-to-be-used frequencies.
3. Provide input to 30% civil design and environmental clearance
4. Reduce risk and uncertainty for the final designer thereby leading to lower and more accurate bids and less schedule risk due to tower site acquisition.
5. Create a simulation environment to more easily evaluate and critique design-builders' proposed and final radio system designs.

2.0 ASSESSMENT / ANALYSIS

The CHSTP is an 800-mile high-speed rail transportation network that will serve the present and future transportation needs of California, using proven high-speed passenger train technology to achieve the same transportation benefits as current Asian and European systems. When complete, the CHSTP will connect cities, including San Francisco, San Jose, Sacramento, Los Angeles, Anaheim, San Diego, and the cities in the Central Valley region. High-speed trains will travel at speeds up to 220 mph and provide reduced travel times for passengers. The CHSTP infrastructure and systems will have a 220 mph nominal operating speed while being designed for 250 mph capability.

2.1 ANTENNA TOWER SITE LOCATIONS

Along the right-of-way, there will be several wayside sites and facilities which will house CHSTP support systems and equipment. It is planned that many of these sites and facilities will also accommodate radio equipment and antenna towers. Part of the EMT's preliminary design effort involves ensuring that suitable site acquisition for a radio tower infrastructure is accommodated in the civil design and environmental clearance is performed such that the final design-builder can arrive later in the project schedule to design and build a compliant radio system with minimal added or unused sites. It was initially proposed that radio towers share space at non-communications sites: traction power facilities (supply, paralleling and switching stations), signaling equipment houses, stations and facilities (including yards) and tunnel portal sites. The EMT found early in the simulation task that additional towers would be needed, and therefore placed Standalone Radio Sites at locations roughly between the above non-communications sites. Radio towers are located at the following:

- Traction Power Facilities (Supply, Paralleling and Switching Stations)
- Signaling Equipment Houses
- Stations and Facilities (including Yards)
- Tunnel Portal Sites
- Standalone Radio Sites

Detailed discussion of the Standalone Radio Sites is included in Section 4.1.

2.2 Radio Requirements and Suitable Radio Technologies

CHSTP trains and personnel are mobile; therefore, radio systems must be deployed to provide voice and data communications to mobile users. As part of the preliminary engineering task, the EMT is investigating multiple radio technologies to support the variety of CHSTP radio requirements. Based on technology limitations, the EMT has defined separate radio systems to support the CHSTP radio requirements. These systems are:

- Operations Radio System (ORS): voice and low-bandwidth data radio system for radio communications between train-borne equipment, mobile and portable users, fixed users and systems (if ETCS Level 2 / GSM-R technology is deployed for the ORS, the data carried by the ORS will include safety-critical train control data)
- Broadband Radio System (BRS): high-bandwidth data radio system for radio communications between train-borne high-bandwidth systems and fixed systems while trains are in motion including at 220+ mph.

The EMT focused the RF propagation simulation task on the technologies and spectrum to meet the requirements of the ORS system. The ORS is the mission-critical voice and data radio system and without this radio system, the CHSTP will not be able to operate.

Conducting propagation simulations to support technologies meeting BRS requirements have not be undertaken at this stage of the engineering development. The EMT estimates that the infrastructure necessary to support a suitable technologies to meet the BRS requirements will have a minimal physical footprint. In particular, it is estimated that land to support BRS antenna infrastructure will not be required and therefore site identification and environmental clearance for BRS are not critical activities during preliminary engineering. Furthermore, the likely-to-be-bid technologies to support the requirements of the ORS will require physical site locations which need to be accommodated early in the civil design.

Several candidate radio technologies are suitable to fully or partially fulfill the requirements of the ORS. These radio technologies include:

1. GSM-R
2. APCO P-25
3. TETRA

GSM-R, APCO P-25 and TETRA have been successfully used in high-speed train environments and all three were simulated by the EMT. Radio technologies were simulated at native frequencies and also at alternative frequencies when sufficient evidence or vendor support indicated that the technology could operate at the alternative frequency. As each radio technology was simulated, the EMT would review and discard each unacceptable technology based on non-availability of equipment or non-availability of spectrum. Radio frequency propagation simulations involving suitable radio technologies at multiple frequencies were conducted, however, since GSM-R is the radio system that meets the project and technical requirements, GSM-R is the primary focus of this document.

2.2.1 Global System for Mobile Communications - Railway

Global System for Mobile Communications - Railway (GSM-R) is an international wireless communications standard for railway communication and applications. GSM-R is built on GSM technology and benefits from the economies of scale of its GSM technology heritage. GSM-R is a subsystem of European Rail Traffic Management System (ERTMS) and is used for mobile communications for trains and personnel. GSM-R also carries the train signaling data, enabling higher train speeds and traffic density with a high level of safety.

2.2.2 Land Mobile Radio (LMR)

Federal Communication Commission (FCC) rules define a land mobile radio (LMR) system as a regularly interacting group of base, mobile, and associated control and fixed relay stations intended to provide land mobile radio communications service over a single area of operation. Land mobile radio systems are used by companies, local governments, and other organizations to meet a wide range of voice and low speed data communication requirements.

2.2.3 APCO Project 25 (P-25)

APCO Project 25 (P-25) is the U.S. public safety industry standard adopted by the International Association of Public Safety Communications Officials (APCO) to provide a radio solution so that agencies using radio systems from different manufacturers can interoperate per an open and non-proprietary public safety industry standard.

2.3 SIMULATING RF PROPAGATION

RF propagation is the transmission of radio waves from a transmitter to a receiver through the atmosphere. RF propagation is affected by distance, physical obstructions like terrain, buildings and foliage, and atmospheric and weather conditions. RF propagation is a known physical phenomenon which can be accurately predicted by mathematical models. Simulating RF radio propagation incorporates mathematical modeling and geographic information system (GIS) data. GIS data is a compilation of terrain features and building densities which is used by the simulation tool to calculate expected coverage and display results.

RF propagation simulations focus the analysis only on the transmitters, receivers, antennas, radio channel and cabling as shown in red in Figure 1. All details about the network and processing are not under consideration in RF propagation simulations.

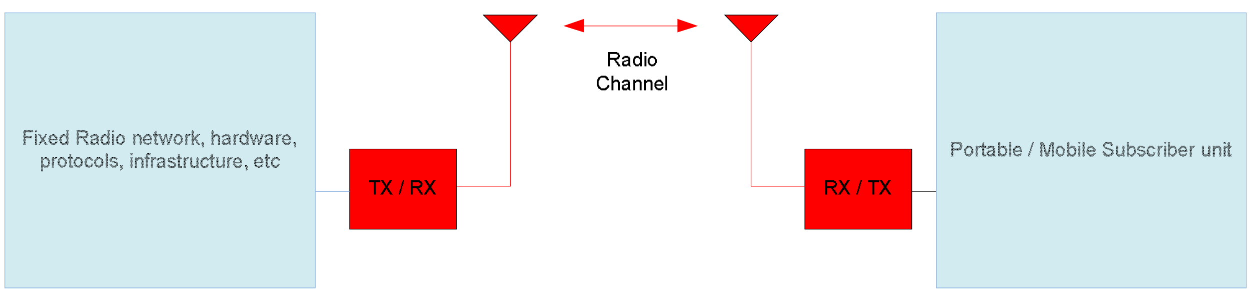

Figure 1: Scope of RF Propagation Simulations

The CHSTP engineering team selected RCC ComSite Design Software to conduct the RF simulations. ComSite Design software is capable of providing RF simulation covering the total 800+ miles of the CHSTP as a whole or in sections.

RF propagation simulations require input about the technical characteristics of the radio system under consideration. The output of a propagation simulation graphically shows the expected received signal level at the receiver. These output plots can be done for the two directions of radio traffic: Forward and Reverse links. Forward link (also known as downlink) analysis evaluates the signal level at the mobile receiver that is transmitted from a fixed base station. Reverse link (also known as uplink) analysis evaluates the signal level at the fixed receiver, transmitted from the mobile transmitter. Typically, in radio system design, the radio engineer evaluates both links to evaluate all aspects of the radio system's expected performance.

2.3.1 RCC ComSite Design Tool

The RCC ComSite Design Tool is capable of creating RF propagation simulations providing instant analysis of the following:

- Site Selection and Search Ring Analysis
- Forward and reverse Link engineering
- Frequency Planning and Cellsite Splitting
- Capacity Planning and Traffic Engineering
- Propagation Model Calibration
- Networking Engineering

RCC ComSite Design is an industry-standard RF propagation simulation tool developed for radio, microwave and cellular engineers for wireless system analysis and planning, and the design and optimization of wireless networks. ComSite Design performs multi-radio site propagation analysis, interference analysis, multiple point-to-point and point-to-multipoint analyses using empirical and deterministic propagation algorithms and terrain, clutter, building, demographic, traffic and other GIS databases.

RCC ComSite Design also makes use of a database containing manufacturers' antenna details including gain, pattern and other technical characteristics of multiple real-world antennas and therefore RF propagation simulations within RCC ComSite design based upon real-world antenna data.

RCC ComSite Design can create a .KML file which allows the user to overlay expected RF coverage on a Google Earth map for viewing.

2.4 SIMULATING RF PROPAGATION

RF propagation simulations were created for the CHSTP to study existing technologies at different frequencies to satisfy radio requirements. The RF propagation simulations were conducted within the Central Valley region using actual latitude and longitude of traction power facility sites. The Central Valley was chosen because it is the location of the initial construction of the CHSTP. While the terrain in the Central Valley is relatively flat with low amount of foliage, it is understood that as part of final design and implementation, the final designer will tweak the radio design and infrastructure to meet the functional and performance requirements by adding additional sites, leaving sites unused, or modifying the technical implementation.

Based on data gathered from European GSM-R deployments, anticipated environmental clearance issues, the EMT settled on a standard radio antenna height of 100' (31 meters) and resulting antenna height 100' above ground.

This RF simulation task investigation is intended to:

1. Determine tower spacing suitable to support likely-to-be-bid radio systems deployed at likely-to-be-used frequencies.
2. Determine tower spacing necessary to provide a redundant radio system layout able to support a single site failure without any effect on coverage or service quality.
3. Develop and validate a radio tower infrastructure preliminary design which will accommodate likely-to-be-bid radio systems at likely-to-be-used frequencies.
4. Provide input to 15% and 30% communications and civil designs and environmental clearance activities.
5. Reduce risk and uncertainty for the final designer thereby leading to lower and more accurate bids and less schedule risk due to tower site acquisition.
6. Create a simulation environment to more easily review and evaluate design-builders' proposed and final radio system designs.

Using the RF propagations simulations, the EMT is able to evaluate different technologies, frequencies and whether or not a radio site configuration can maintain coverage despite the loss of a single tower or site. With RF simulation environments created and available, future time spent engaged in review and critique of radio design submittals from the eventual design builder will be greatly reduced.

2.4.1 Antenna Tower Spacing

Traction Power Facility sites are located approximately every five miles throughout the right-of-way. The Traction Power facilities are the most frequent, numerous and regularly spaced wayside sites within the CHSTP. Initial propagation simulations at 800 MHz found that a tower infrastructure based on the five-mile spaced Traction Power Facility sites was not sufficiently close together to maintain coverage if a single radio site failed. Furthermore, if a higher frequency was eventually selected and used, the five-mile spaced tower infrastructure was not close enough to support the reduced propagation characteristics at higher frequencies. Therefore, the EMT decided that Standalone Radio Sites, housing only a communications shelter and antenna tower would be placed between the other disciplines' sites to create a tower infrastructure spaced at approximately 2.5 miles. Therefore, radio towers will be located at the following locations.

- Traction Power Facilities (Supply, Paralleling and Switching Stations)
- Signaling Equipment Houses
- Stations and Facilities (including Yards)
- Tunnel Portal Sites
- Standalone Radio Sites

Further propagation simulations were done using this tower infrastructure.

2.4.2 Evaluation Criteria

The RF engineer evaluates the RF propagation simulation plots produced against the required signal level at the receiver for the desired quality of service. The following criteria were used to evaluate the results of the RF propagation simulations.

(1) GSM-R Criteria

For GSM-R, the European Integrated Radio Enhanced Network (EIRENE) functional specifications that govern the GSM-R technology define the forward link requirements as follows:

> *For network planning, the coverage level is defined as the field strength at the antenna on the roof of a train (nominally a height of 4m above the track). An isotropic antenna with a gain of 0dBi is assumed. This criterion will be met with a certain probability in the coverage area. (The target coverage power level is dependent on the statistical fluctuations caused by the actual propagation conditions.)*

The following minimum values are recommended:

> *Coverage probability of 95% based on a coverage level of 44.5 dBµV/m (-92 dBm) on lines with ETCS levels 2/3 for speeds above 280km/h.*

(2) Land Mobile Radio Criteria

Telecommunications Industry Association (TIA) standard TSB-88-B provides a standard for measurement and characterization of Delivered Audio Quality (DAQ) on both uplink and downlink for LMR radio systems. DAQ or Desired Audio Quality is the minimum acceptable speech intelligibility. Measured DAQ ranges from a 1 to 4. Many factors impact DAQ including modulation, bandwidth, channel spacing, and receiver signal strength. The ability of a radio receiver to capture the desired signal in the presentence of interfering signals and noise is designed as the manufacturer's Standard Level of Receiver Sensitivity. The minimum standard level of Receiver Sensitivity is 12dB SINAD (dBs) equates to a DAQ of 1.6.

Public Safety Radio system designers generally target a minimum DAQ of 3.4 based on TSB-88-B. The EMT team used the same desired DAQ to evaluate the output of the RF propagation simulations. To deliver a DAQ of 3.4 a receiver signal strength greater than -113.5 dBm was required for P-25.

2.5 SELECTED RF PROPAGATION SIMULATIONS

The following sections present selected RF propagation simulation outputs and evaluations conducted by the EMT. All simulations were done using predicted latitude-longitude of radio towers (at traction power facilities and standalone radio sites) along the right-of-way and GIS terrain profiles in the Central Valley of California. The labeled locations in the figure indicate a radio tower located either at a traction power facility or a standalone radio site. The planned rail track is located roughly along the line of sites. In general, the colored regions indicate an area of geography where a located transceiver will receive signal strength according to the legend. Propagation plots included herein show the forward link, the reverse link was simulated in all cases, however is not shown here.

2.5.1 GSM-R at 860-920MHz RF Propagation Simulation

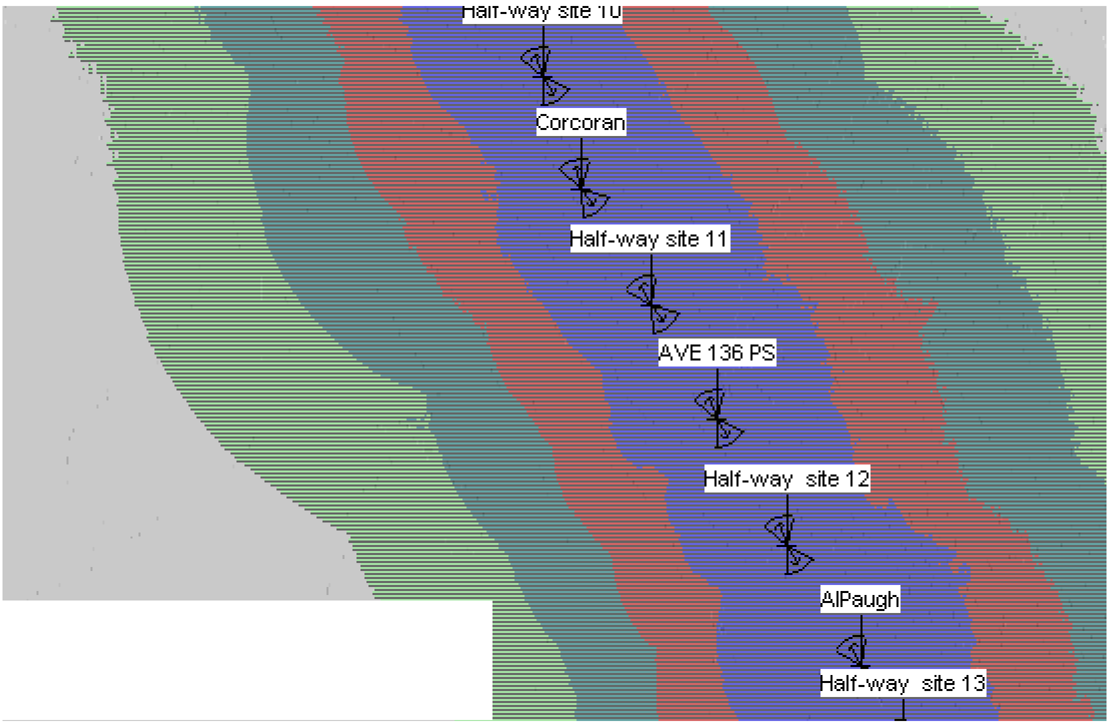

Figure 2: RF propagation plot for GSM-R at 860-920 MHz

The RF propagation plot shown in Figure 2 shows the expected RF coverage pattern of GSM-R propagation at the “native” frequency of 860-920MHz for a forward link.

In the plot above, the area covered by blue and red colors (greater than -95 dBm) is roughly acceptable for GSM-R transmission as EIRENE calls for minimum signal strength of -92 dBm. The lateral area covered by blue and red colors is an average of 7.5 miles. Blue and red colored regions (-95dBm and stronger) depicts the primary radio signal which is required for reliable communications from the fixed Radio system to the mobile system. The shades of green provide signal strength as low as -110 and below and covers some 15+ miles. Radio coverage in the light and dark green areas is not reliable for radio communications.

The technical data used to create this simulation plot was:

Mobile unit:

- Transmit Power: 3 Watts
- Receiver Sensitivity: -95dBm
- Antenna gain: 0 dBi
- Antenna height: 14’ (4 m) above ground level (AGL)

Base Transceiver Station:

- Transmit Power: 5 Watts
- Receiver Sensitivity: -104.49 dBm
- Antenna Gain: 12.6 dB
- Antenna height: Above Ground Level (AGL) 100' (31 m)

2.5.2 GSM-R at 746-869MHz RF Propagation Simulation

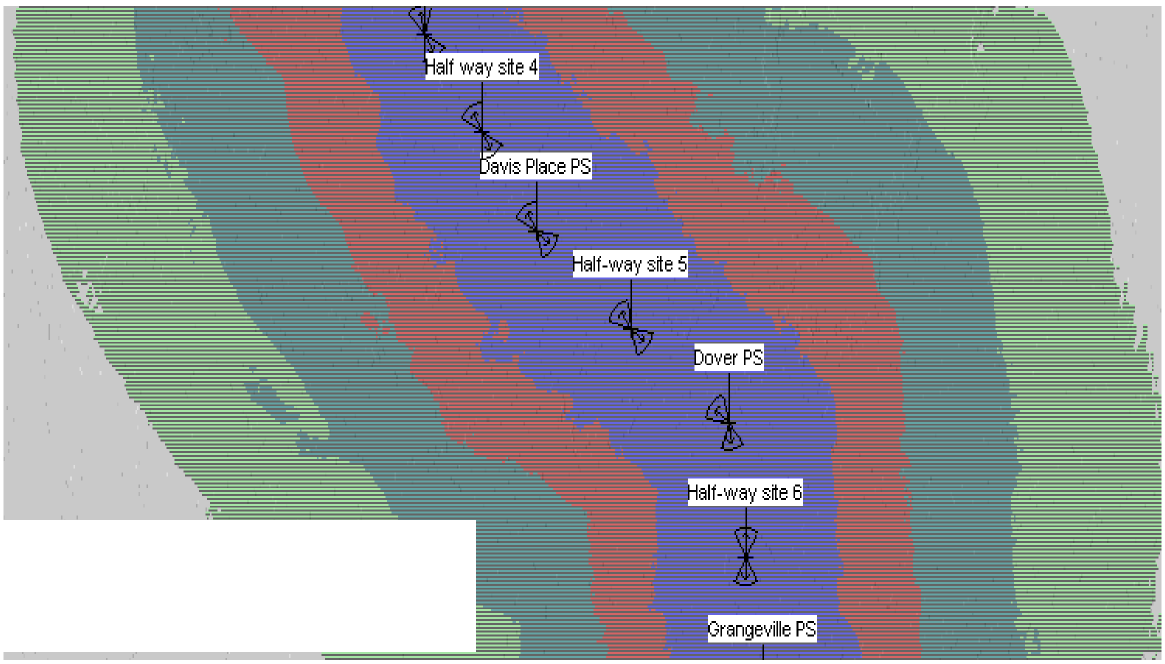

Figure 3: RF propagation plot for GSM-R at 746-869 MHz

The RF propagation plot shown in Figure 3 shows the expected forward link RF Coverage pattern of the GSM-R propagation if deployed in 700 MHz Public Safety Band. The lateral area covered by blue and red colors is an average of seven (7) miles wide. The explanation for the wide propagation pattern is simply that only one antenna is available within RCC ComSite Design in the 700MHz range and it transmits an Omni-directional pattern (360 degrees). The RCC ComSite design tool did not contain a diverse selection of 700MHz antennas allowing the EMT to thoroughly simulate propagation at 700MHz. This is only a limitation of the RCC ComSite tool and a customized antenna could be designed in practice to achieve a suitable propagation pattern at 700 MHz.

The technical data used to create this simulation plot was:

Mobile unit:

- Transmit Power: 3 Watts output
- Receiver sensitivity: -95dBm
- Antenna Gain: 0 dBm
- Antenna Height: 14' (4 m) Above Ground level (AGL)

Base Transceiver Station

- Transmit power: 5 Watts output
- Receiver Sensitivity: -104.49 dBm
- Antenna Gain: 12.6 dB

- Antenna Height: Above Ground Level (AGL) 100’ (31 m)

2.5.3 GSM-R at 450-470 MHz RF Propagation Simulation

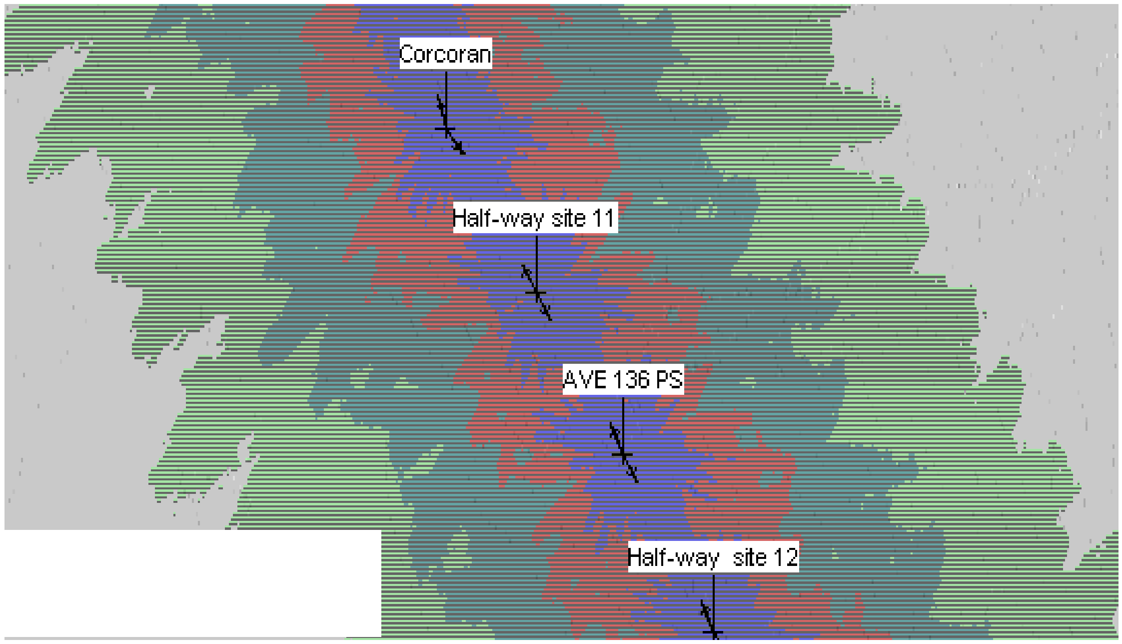

Figure 4: RF propagation plot for GSM-R at 450-470 MHz

The RF propagation plot shown in Figure 4 shows the expected forward link RF coverage pattern of a GSM-R system deployed in the 450-470 MHz bands with a different antenna system suited to the lower frequencies. Note the width of the propagation (blue and red) is approximately 3.5 miles wide with the primary (blue) (-85dBm and greater) approximately 1.37 miles wide. Because this lateral propagation coverage area is relative smaller than shown at the prior simulations at other frequencies, this 450- 470 MHz band antenna system will have much less of an interference impact to other 450 – 470 MHz systems in the region such as industrial and business trunked radio systems in the private sector.

The technical data used to create this simulation plot was:

Mobile unit:

- Transmit Power: 3 Watts output
- Receiver: -95dBm
- Antenna Gain: 0 dBi
- Antenna Height: 14’ (4 m) above Ground Level (AGL)

Base Transceiver Station

- Transmit Power: 5 Watts Output
- Receiver Sensitivity: 100.4 dBm
- Antenna Gain: 8.25 dB
- Antenna Height: Above Ground Level (AGL) 100’ (31m)

2.5.4 P-25 Land Mobile Radio at 450 –470 MHz RF Propagation Simulation

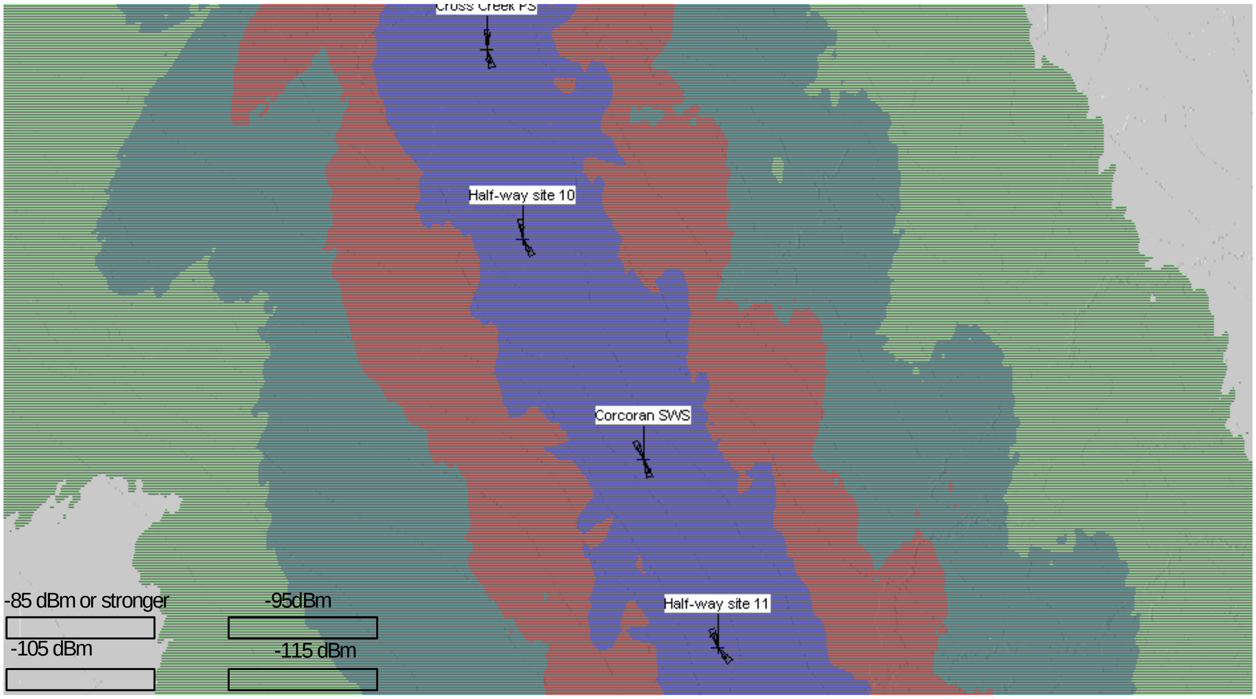

Figure 5: RF propagation plot for P-25 LMR at 450 -470 MHz

The RF propagation plot shown in Figure 5 shows the expected forward link RF coverage pattern of a P-25 LMR system deployed in the 450 -470 MHz Bands Note the width of the propagation (blue and red) is approximately 3.7 miles wide with the primary (blue)(-85dBm) approximately 1.7 miles wide.

The technical data to create this simulation plot was:

Mobile Unit:

- Transmit Power: 3 Watts Output
- Receiver Sensitivity: 95 dBm
- Antenna Gain: 0 dB
- Antenna Height: Above Ground Level (AGL) 14' (4 m)

Base Transceiver Station:

- Transmit Power: 5 Watts Output
- Receiver Sensitivity: 105.982 dBm
- Antenna Gain: 15 dB
- Antenna Height: above Ground level (AGL) 100'

2.5.5 GSM-R at 1900 MHz RF Propagation Simulation

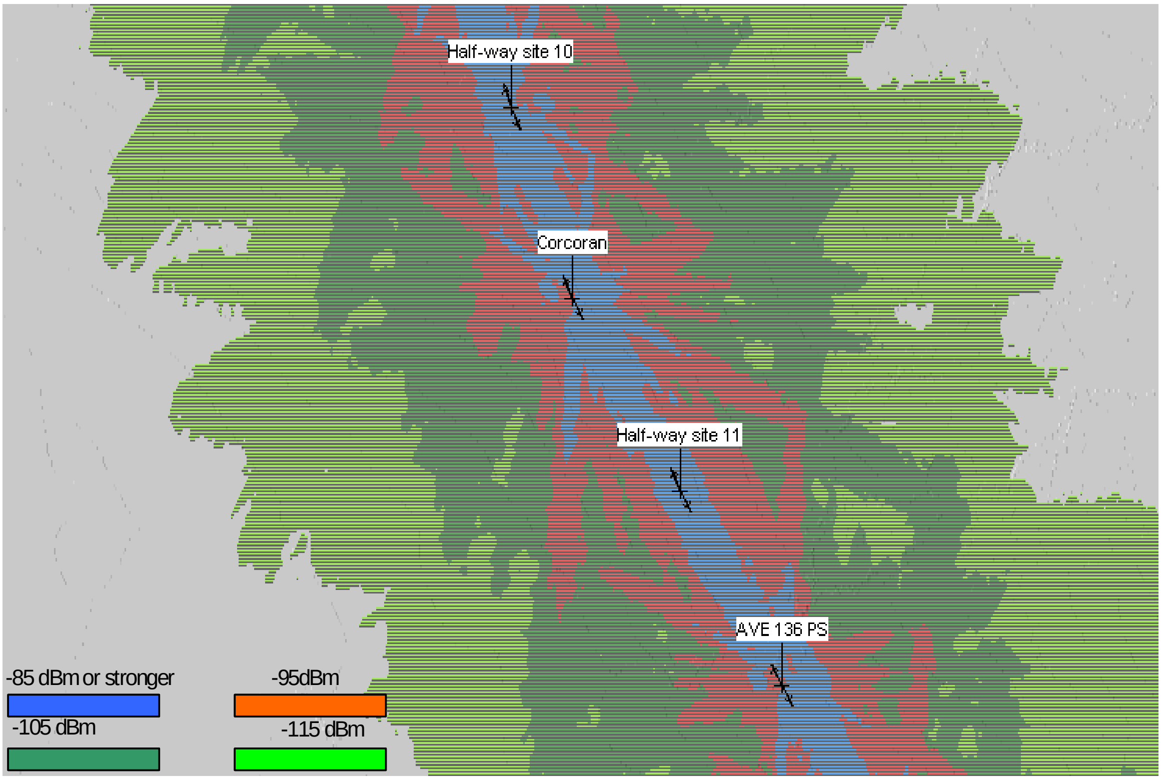

Figure 6: RF propagation plot of GSM-R at 1900 MHz

The RF propagation plot shown in Figure 6 shows the expected forward link RF coverage pattern of a GSM-R system deployed in the 1900 MHz Band with an antenna system suited to the higher frequencies. Note the width of the propagation (blue and red) is approximately 2.5 miles wide with the primary (blue) (-85dBm and greater) approximately 0.725 miles wide. This lateral propagation coverage area is relatively smaller than the prior simulations at other frequencies.

The technical data to create this simulation plot was:

Mobile Unit:

- Transmit Power: 3 Watts Output
- Receiver Sensitivity: 95 dBm
- Antenna Gain: 0 dB
- Antenna Height: Above Ground Level (AGL) 14' (4 m)

Base Transceiver Station:

- Transmit Power: 5 Watts Output
- Receiver Sensitivity: 106.4 dBm
- Antenna Gain: 15 dB
- Antenna Height: above Ground level (AGL) 100' (31 m)

3.0 SUMMARY AND RECOMMENDATIONS

The purpose of the RF propagation simulation activity was to determine the propagation characteristics of suitable radio technologies deployed at different frequencies to meet CHSTP requirements. The information gathered during the simulation activity is used to determine radio tower site needs to support the 15% and 30% design and environmental clearance effort. Based on the propagation simulations conducted and using the five selected simulations presented, the EMT is confident that with a 2.5 mile spaced, 100' tall radio tower infrastructure:

- Multiple likely-to-be-bid radio technologies at multiple frequencies (including greater than 925 MHz) can be deployed (some more compliant to project and technical requirements than others) with minimal additional tower site acquisition by the final designer.
- Risk and uncertainty for the final designer is reduced - thereby leading to lower and more accurate bids and less schedule risk.
- A redundant radio system may be designed within the identified locations such that continuous radio coverage can be maintained despite a single site failure.

If a radio system requiring the use of frequencies in higher microwave bands (greater than approximately 2 to 4 GHz) is deployed to support the CHSTP, that radio system will likely require a different, shorter-path antenna infrastructure which can easily be supported by shorter trackside-mounted antennas which require less physical space and environmental clearance

With this RF propagation simulation task the EMT team has:

- Validated a radio system infrastructure which will accommodate likely-to-be-bid radio systems and support final designers' likely final designs.
- Created a simulation environment to more easily evaluate and critique design builders' proposed and final radio system designs.