# Modeling RF Attenuation in a Mine Due to Tunnel Diameter and Shape

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***Abstract*—We use Wireless InSite® to calculate the attenuation of an RF signal at GHz for various tunnel diameters and shapes. The attenuation is calculated at 2.4 GHz and a Weibull distribution is found that fits the propagation model. The propagation characteristics in our examples follow a Rician distribution.**

## I. Introduction

Accurately characterizing the propagation of RF signals in tunnels is important for rescue, safety, and military purposes. The material composition of the tunnel, the tunnel shape and size, obstructions, and tunnel bends are challenges facing the computational electromagnetic modeler [1-2]. In a previous paper, we looked at how the material composition of the tunnel affects the propagation characteristics [3]. As in [4-7], we used a Weibull distribution to characterize the tunnel propagation.

In this paper, we extend the analysis of tunnel propagation using Wireless InSite [8] to tunnel diameter and tunnel shape. We extend the results reported by others by fitting the propagation characteristics to a Weibull distribution.

## II. Computer Model

The shooting and bouncing ray technique in Wireless InSite is used to model the propagation of 2.4 GHz CW signals in tunnels in the Edgar Mine in Idaho Springs, Colorado. The transmitter is a vertically polarized resonant dipole transmitting 30 dBm of power. The receiver is an isotropic antenna. Both antennas are placed at the center of the tunnel cross section. The software calculates the loss in the center of the tunnel over a path of 1 to 6 m from the transmitter. Then a linear fit of the data is performed.

We assume that the received power follows an inverse power law with respect to range. Therefore, the received power can be written in terms of the transmitter power, $P_t$, the antenna constant, $\alpha$ (which is determined by the antenna gain, wavelength, and position and orientation within the tunnel), the range $d$, the path loss exponent, $n$, and the amplitude fading gain, $\kappa$, as

$$P_r = \frac{\kappa^2 \alpha^2}{d^n} P_t \tag{1}$$

We also define the mean received power is given by

$$P_{r,mean} = \frac{\alpha^2}{d^n} P_t \tag{2}$$

which is the received power fitted to an inverse power law. The ratio between the actual received power in (1) and the mean (fitted) power in (2) gives the power fading gain, $\kappa^2$ vs. range.

We model the fading gain $\kappa$ with a Weibull distribution, since it can be used to represent both a Rayleigh and a Rician distribution. The Weibull probability density function of the amplitude fading gain, $\kappa$, is given by

$$f_\kappa = \begin{cases} \frac{p}{q}\left(\frac{\kappa}{q}\right)^{p-1} e^{-(\kappa/q)^p} & \kappa \geq 0 \\ 0 & \kappa < 0 \end{cases} \tag{3}$$

The parameter $p$ is the shape parameter, where $p$=2 represents Rayleigh fading, and $p$>2 represents Rician fading.

An inverse power law model is useful for developing a system model of the tunnel. This type of modeling offers a method to model the wireless coverage within a tunnel environment using a finite number $N$ of autonomous mobile radio nodes [4]. Using this method, a model of an interconnected tunnel network with different values of $n$, $p$ and $q$ could be generated, and the wireless availability of a network of $N$ nodes could be calculated.

We compare the path loss exponent for various tunnel diameters and cross-sectional shapes. The path loss exponent is a measure of how fast the received power drops off as the receiver moves away from the transmitter.

## III. Effects of Tunnel Diameter and Shape

First, we study the effects of tunnel diameter on the propagation characteristics. Dry granite tunnels of length 5 m will be used for all simulations. The relative dielectric constant of dry granite is 5 and the conductivity is 0.01 S/m. The tunnels have square cross-sections with diameters are 1, 2 and 3 m. Figure 1 shows the received power variation with range, for the three diameters. As the tunnel becomes wider, there is more fading, as evidenced by the smaller distance between the peaks and valleys in the power curve. The path loss exponent takes on the values 1.72, 1.387, and 1.823 for the three diameters, in order of increasing diameter. Since this does not show a definite trend, it is necessary to re-run these cases for longer tunnel lengths so that the least-squares curve-fit can be performed over a longer range, giving greater accuracy for *n*.

Figure 2 shows the fading characteristics of the three tunnels. The shape factor of the three cases, *p*=2.6, 2.9 and 3.2 for increasing diameter. This indicates that there is a strong LOS component to the propagation, and that this LOS component grows more dominant as the diameter increases. Note that for the 1 m diameter tunnel, the Weibull distribution is relatively flattened compared to the other distributions. This is consistent with the fact that the received power curve shows fewer peaks and valleys for this diameter. Additionally, the peak at $\kappa$~1 indicates that there is a strong LOS component without much fading. For the 2 m diameter, the Weibull distribution shows a definite gradual peaking, but for the 3 m tunnel, there is again a bias towards the center of the curve near $\kappa$~1.

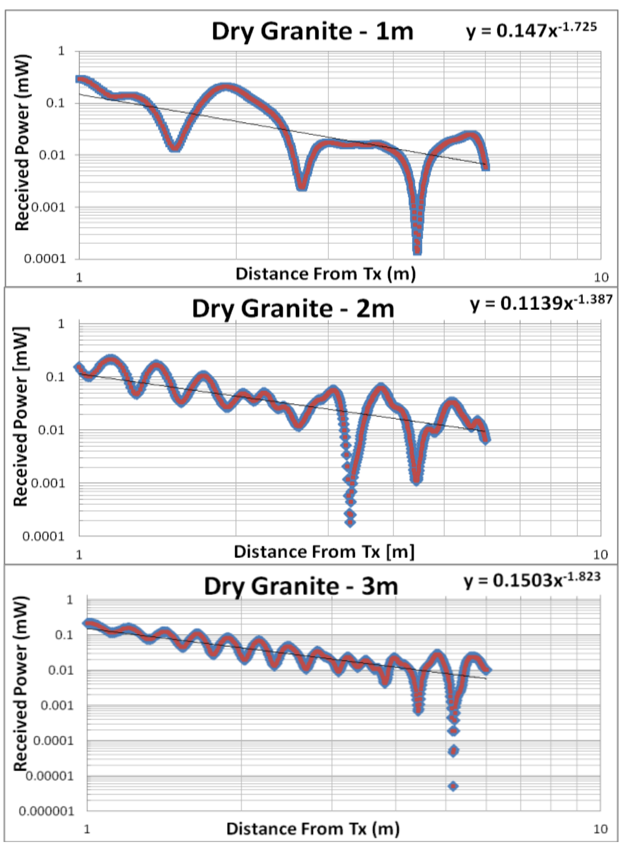


Figure 1. Received power variation vs. range, as a function of tunnel diameter. (Please note the vertical scale differences.)

We also studied the effects of tunnel shapes. In the shape studies, the tunnel cross section is made progressively more circular by increasing the number of sides: 4, 8 and 16. The path loss exponent decreases as the roundness increases, indicating that the half-wavelength vertical dipole couples more efficiently into a low loss mode for rounder tunnels. The path loss exponent takes are 1.82, 1.12, and 0.17 while the shape factors are *p*=3.65, 4.30 and 2.27 for 4, 8, and 16 sides, respectively

## IV. Conclusions

We characterize the propagation of RF signals in tunnels using Wireless InSite. Fading characteristics for several different examples of tunnel diameter and shape are Rician, which agrees with previously published results.

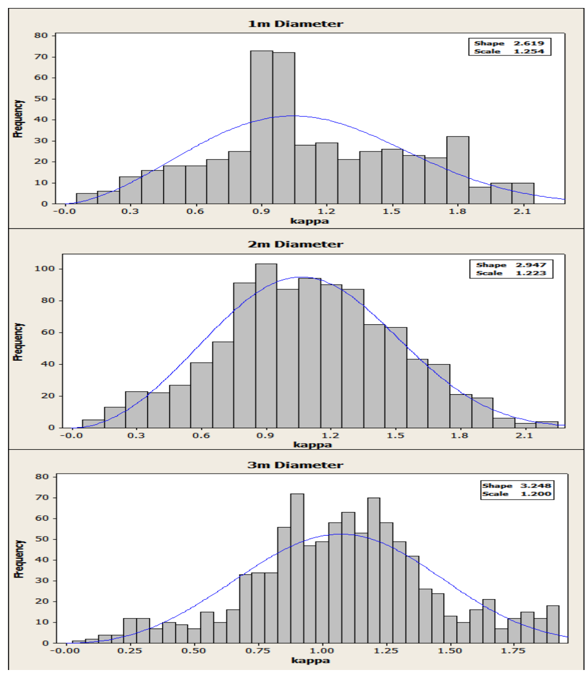


Figure 2. Fading statistics for tunnels of different diameters. (Please note vertical scale differences.)

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