Radiation of a Dipole Antenna inside a Finite Tunnel at Low Frequencies Simulation and Measurement Result

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Abstract

The applications of radio and TV broadcasting often operate at a frequency range below 100 MHz. The receiving antennas of the terminal are generally mobile and may move from a location to another. In particular, as the receiving antennas move into a tunnel environment, the signals will experience degrade and result in poor reception. Thus it is desired to study the radio wave propagation characteristics along the tunnel environment and seek for solutions that may improve the signal reception, which motivates the works presented in this paper. A numerical study based on method of moment (MoM) is thus performed to investigate and compare the signal levels for various situations of tunnel environments and antenna related parameters. Comparative results will be presented. And make two small scale tunnels to measuring simulation result.

1. Introduction

The applications of radio and TV broadcasting often operate at a frequency range below 100 MHz. The receiving antennas of the terminal are generally mobile and may move from a location to another. In particular, as the receiving antennas move into a tunnel environment, the signals will experience degrade and result in poor reception. Thus it is desired to study the radio wave propagation characteristics along the tunnel environment and seek for solutions that may improve the signal reception, which motivates the works presented in this paper.

A numerical study based on method of moment (MoM) is thus performed to investigate and compare the signal levels for various situations of tunnel environments and antenna related parameters. MoM is used here because it may accurately predict the propagation and also include the coupling effects between the tunnel's surfaces especially at low frequencies where the tunnel's internal surface appears in the near zone of the antenna's radiation. In this study, dipole antenna is considered because it exhibits distinguished polarization characteristics of radiating fields, and are thus very useful in characterizing the propagation effects.

In this paper, two commonly seen tunnel's structures with rectangular and half-circular cross-sections are first investigated to exhibit the characteristics. Then, measure the small scale of these tunnels and compare with the simulation result.

This paper is organized in five parts. In Section Ⅱ, the MoM modeling on the tunnel's scattering due to the antenna radiation is presented, in which the criterions to justify the propagation effects are also described. Section III presents the simulation results with respect to various common tunnel structures. Section IⅤ shows the measurement result of two small scale tunnels. Section Ⅴ presents some conclusive discussions for further studies.

2 Review of MoM Modeling

Method of moment (MoM) based on electric field integral equation (EFIE) is employed to model the antenna radiation inside the tunnel. In this case, a dipole antenna is assumed and modeled by thin wires excited by imposing a constant voltage on the central gap of the wires. The antenna can be oriented vertically or horizontally according to the need of the case studies. The surface of the tunnel is assumed to be perfectly electrically conducting. Thus the

tunnel can be replaced by equivalent electrical currents induced on the tunnel surface. These induced currents polarized tangentially to the tunnel surface are represented by sinusoidal basis functions, which transform EFIE into a set of matrix equation where the coefficients of the basis functions are the unknowns to be solved from the matrix equation. The fields scattered from the tunnel are therefore found by computing the fields radiated from the induced currents. The total fields received at an observation point are the sum of the field radiated from the antenna in a free space and the fields radiated from the induced currents.

The characteristics of the antenna radiation inside the tunnel are quantized by considering the shielding effectiveness defined by

$$SE_{dB} = 20\log\left(\frac{E_b}{E_a}\right) \tag{1}$$

for electrical, respectively. The subscripts “a” and “b” indicate whether the tunnels are present or not. The shielding effectiveness provides an index to justify the radiation characteristics. In this case, a larger and positive value indicates poor energy propagating in the tunnels while a larger and negative value indicates power increased in the tunnel, where 0dB indicates propagation in a free space.

3. Simulation Results

The tunnel structures under consideration are illustrated in Figure 1, which are commonly seen in a real world except the sizes are reduced for the purpose of numerical simulation. All dimensions are indicated by parametric variables shown in Figure 1, where L=20m, W=4m and H=6m.

(A)Vertically polarized dipole’s radiation.

In this case, both the TX and RX antennas are placed in the middle of the tunnel (height h=2m). Since dipole antennas are used, the electrical fields dominate in the near zone . The shielding effectiveness is shown in Figure 3. It is observed that the electrical fields exhibit large variations in the shielding effectiveness, which indicates that inside the tunnel the electrical fields may increase significantly to a large value or attenuate to a very low value. In particular, at lower frequencies the radiating field attenuates significantly as the frequency increases up to a frequency of threshold where the field suddenly increases to a very large value. Note that because the separation distance in terms of wavelengths between TX and RX decreases with the decrease of frequency, at very low frequencies (such as less than 20MHz) the fields radiated directly from the antenna dominate and result in nearly 0 dB shielding effectiveness. However, in the frequency range less than 37 MHz, which is below the cutoff frequency of the tunnel and cause wave attenuations along propagation, the electrical length of the separation distance increases with the increase of the frequency, and will cause more attenuation. Also as the frequency continues to increase beyond the cutoff frequency, the waves start propagating. Below 65 MHz, the fundamental mode propagates while the higher order modes attenuate with the increases of electrical lengths (or frequencies).

(B)Horizontally polarized dipole’s radiation

Similar to Subsection (A), the dipole is located in the middle of the tunnel shown in figure 4. The electrical field also exhibits strong effects in the shielding effectiveness. The results corresponding to the cases in Figure 3 are shown in Figure 5, respectively. It is observed that the phenomena remain similar except the switching points of cutoff frequency are slightly lower than that in Subsection (A), and moves from 37MHz down to 27MHz.

3. Measurement Result

In this case, two commonly seen tunnel’s structures with rectangular and half-circular are made by Styrofoam and aluminum foil, and change their scale into 1/22, the length, height and width become L = 90 cm, H = 27 cm , W = 18 cm. the end items are shown in Figure.6 and 7. Now puts two dipole antennas inside these tunnels and measure their S21 values, then observe the shielding effectiveness of two structures. Notice that the observing frequency is up scale to 100MHz~1500MHz because the tunnels size is changed.

First case , puts dipole antennas inside vertically and measure In Figure 8, although there has some oscillation at some frequencies, but at 800MHz~1.4GHz is clearly under 0dB, and the results of two structures are very close just like simulation result, Totally, the measurement result is similar to simulation result. Next case, the dipole antennas inside the tunnels are replaced horizontally, and the measurement result is shown in Figure 9, just like above case, there has some oscillation at some frequency, but at 600MHz~900MHz and 1GHz~1.3GHz are clearly under 0dB, and the results of two structures are very close just like simulation result. Totally, the measurement result and simulation result are similar.

4. Conclusion

This paper studies the propagation of radio wave inside a tunnel environment at low frequencies. Numerical simulations show that the power strengths of the radio waves may appear positive construction or negative destructions with respect to the operational frequencies and locations of observation. However, as the frequency decreases to a certain cutoff value, destructive interferences appear. However, the destruction may be reduced if the internal surfaces of the tunnel appear as a periodic structure, which allows the shielding effectiveness tends approaching to low level. An example is proposed and demonstrates the effects.

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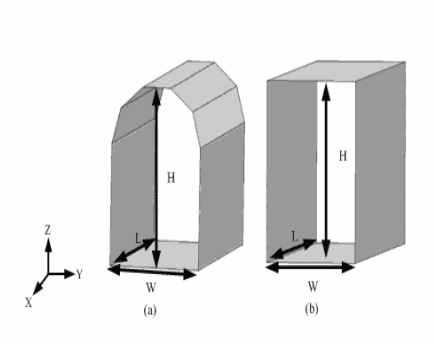

Figure 1: Common tunnel structures for the simulation

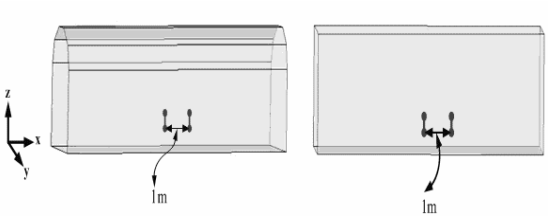

Figure 2: Locations of TX and RX antennas in case1

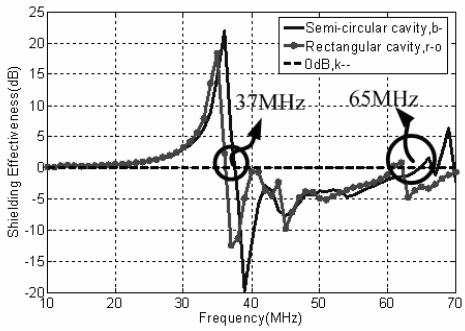

Figure 3: Comparisons of propagation effects for a vertically polarized dipole between two different tunnel types.

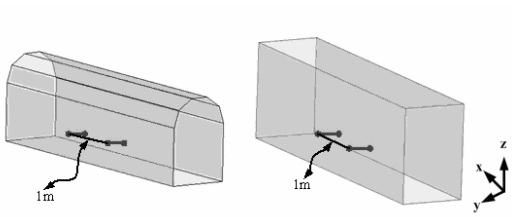

Figure 4: Locations of TX and RX antennas in case2

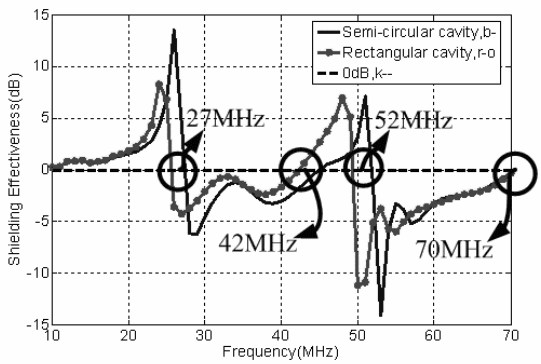

Figure 5: Propagation effects of a horizontally polarized dipole.

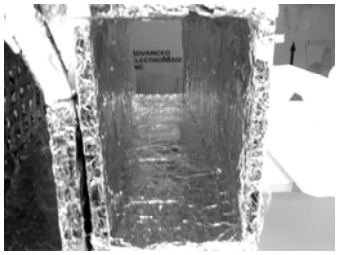

Figure 6: Small scale of rectangular tunnels

Figure 7: Small scale of half-circular tunnels

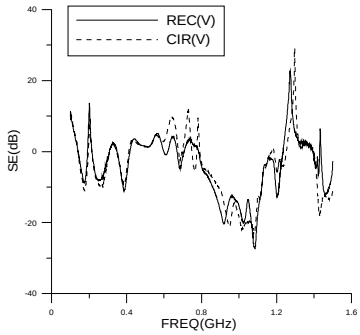

Figure 8: Measurement result (vertically) (a) REC(V): rectangular cavity (b) CIR(V): half-circular cavity

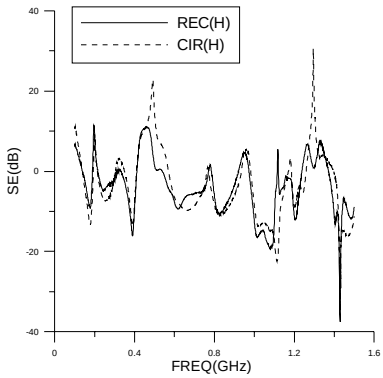

Figure9: Measurement result (horizontally) (a) REC(H): rectangular cavity (b) CIR(H): half-circular cavity