An Experiment Study of the Propagation of Radio Waves in a Scaled Model of Long-Wall Coal Mining Tunnels

Guorui Han, Wenmei Zhang, and Y. P. Zhang

Abstract—**A long-wall coal mining tunnel is the most important working area in a coal mine. It has long been realized that radio communications can improve both productivity and safety in this dangerous area. Hence, many attempts to use radio communications in such an environment have been made. Unfortunately, no radio system has satisfactorily provided communication services there, which, we believe, is partially due to poor understanding of the propagation characteristics of radio waves in the long-wall mining tunnel. To have deeper physical insight into the propagation problem, a scaled model of the long-wall mining tunnel was built, and the propagation characteristics of UHF radio waves were measured. The experiment and the measured results are presented and discussed.**

Index Terms—**Long-wall coal mining tunnel, radio propagation, waveguide.**

I. Introduction

THE LONG-WALL coal mining tunnel is the most important working area in a coal mine. It is also the most dangerous area due to potential hazards from explosions and fires. The coal mining industry has long realized that reliable radio communications can improve both productivity and safety in this area. Hence, many attempts to use radio communication systems in this area have been made. Unfortunately, it is found that no radio system has satisfactorily provided communication services there, which, we believe, is partially due to poor understanding of the propagation characteristics of radio waves in the long-wall mining tunnel. The distinct feature of a long-wall coal mining tunnel is that there are a lot of metallic supports periodically placed along the tunnel axis. Obviously, the actual physical existence of these metallic supports effects a change in both distribution and propagation of natural electromagnetic modes, making them different from those in an empty tunnel or a tunnel containing axial conductors [1]–[11]. For instance, a quasi-TEM mode may exist in an empty tunnel or a tunnel containing axial wires. However, such a mode is destroyed by the existence of metallic supports. Therefore, the influences of these metallic supports on natural propagation of radio waves have drawn our attention. Zhang *et al.* conducted an experiment on the propagation of radio waves in coal mines [12]. Limited by the availability of intrinsic safety potable radio equipment, they only measured the propagation of radio waves at 900 MHz in two long-wall mining tunnels. It is found that the collected data is insufficient to understand the propagation characteristics of radio waves in long-wall mining tunnels.

In order to provide an approach for the generation of enough data sets for better understanding of the propagation of radio waves in long-wall coal mining tunnels or to verify the predicted results by wave-propagation simulators, we designed and fabricated a scaled model of long-wall coal mining tunnels. It is shown that the scaled model allows for accurate propagation measurement in a fully controlled environment with much lower cost and time than propagation measurements in the actual environment. In what follows, the experiment is described in Section II, the measured results are discussed in Section III, and the conclusion is drawn in Section IV.

II. Description of Experiment

A long-wall coal mining tunnel is approximately rectangular in cross section. Its width may vary from 3 to 5 m, height from 1.3 to 3 m, and length from 100 to 300 m. The shield top, bottom, and left-side walls are metal. The right-side wall is the mine body to be cut. The interior of the tunnel is filled with air, in which there are a lot of metallic hydraulic pressure supports periodically placed along the tunnel axis. Fig. 1 shows the scaled model of long-wall coal mining tunnels. Its three sides are aluminum sheets. The fourth side is left open, which allows the model placed either on a floor or on earth to simulate the mine body to be cut. Aluminum cylinders are used to model the metallic hydraulic pressure supports.

The scaled model is 0.28 m wide, 0.21 m high, and 2.4 m long. The diameter of the cylinders is 1.7 cm. Along the ceiling of the scaled model, holes of 0.5 mm in diameter are drilled at an interval of 50 mm. The hole drilled at the beginning of the scaled model is used to insert the transmitting antenna, while the other holes are used to insert the receiving antenna to collect the data.

For the scaled model, four internal cases are considered: 1) empty, 2) loaded with a row of vertical cylinders along the z direction with the period of 5 cm, 3) loaded with a row of vertical cylinders along the z direction with the period of 10 cm,

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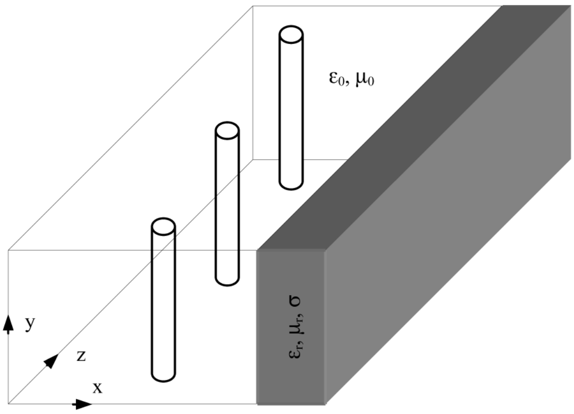

Fig. 1. The scaled model.

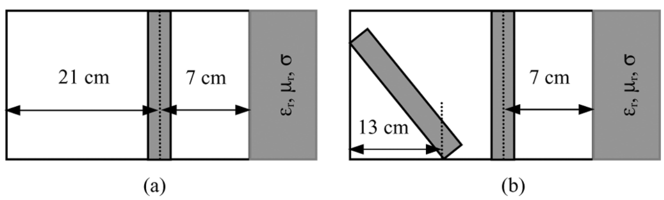

Fig. 2. Cross-sectional views of the scaled model due to different loading conditions.

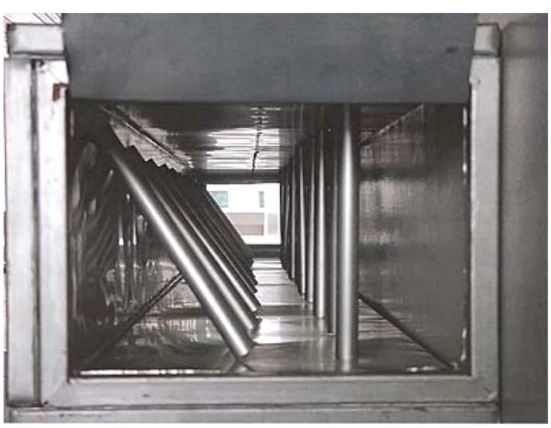

Fig. 3. Photograph of the scaled model with the fourth internal case.

and 4) loaded with both vertical and inclined rows of cylinders along the z direction with the period of 10 cm. The empty case is for reference only. The three loaded cases represent typical arrangements of metallic supports in long-wall coal mining tunnels to match different pressure from the top or side walls. Fig. 2 illustrates the cross-sectional views of the scaled model due to different internal loadings. The photograph of the scaled model with the fourth internal case is shown in Fig. 3.

In our experiment, the scaled model was placed on a thick wall with the electromagnetic properties $\varepsilon_r = 10, \mu_r = 1$, and $\sigma = 0.01$ m/S. The signal generator HP 44233E was used as the transmitter. The transmitting antenna was a monopole inserted into the scaled model from the hole at the beginning. The input power to the transmitting antenna was fixed at 0.0 dBm. The spectrum analyzer HP 8563E was used as the receiver. The receiving antenna was another monopole. A data set was composed of 48 received power levels taken from the 48 holes. The same procedure was repeated for different frequencies from 600 to 3000 MHz at an interval of 300 MHz. Both the transmitting and receiving monopole were changed for measurements at different operating frequencies.

TABLE I
CUTOFF FREQUENCY OF THE SCALED WAVEGUIDE MODEL

Mode	f_c
TE_{10}	535.71MHz
TE_{20}	1110MHz
TE_{01}	714.29MHz
TM_{11}	904.9MHz

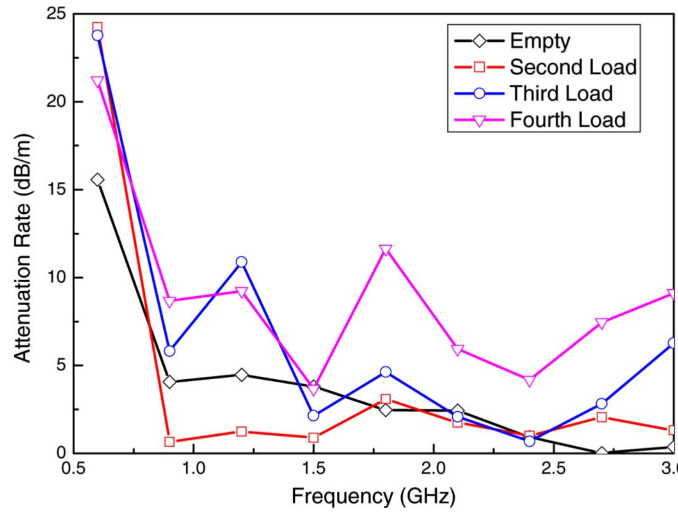

Fig. 4. Attenuation rate as a function of frequency for the closed scaled model.

III. RESULTS AND DISCUSSION

The scaled model can be considered as a periodically loaded oversized imperfect waveguide. Assuming that the open-side wall is also covered with the aluminum sheet, one can estimate the cutoff frequencies of a few modes of the empty scaled model as listed in Table I. Based on our experimental setup, the dominant TE_{10} mode is always well excited and can propagate in the empty scaled model. This is because the lowest operating frequency of 600 MHz is higher than the cutoff frequency of 535.71 MHz of the dominant TE_{10} mode. As the operating frequency increases, more modes are excited and contribute to propagation.

Linear regression analysis was employed to study the variation of received power over the distance from the transmitter to the receiver. It was found that a straight-line estimation was sufficient for the data obtained. The slope of the straight-line yielded the attenuation rate of the propagation of radio waves in the scaled model. Fig. 4 shows the propagation attenuation rates as a function of frequency under different loading conditions when both ends of the scaled model were covered with aluminum sheets. Note that under the condition of no loading, the propagation attenuation rate decreases as the frequency increases, which agrees with the waveguide theory. Also, note that under the conditions of periodical loading, the propagation attenuation rates fluctuate with the frequency. This is because the periodical loading introduces the passband and stopband characteristics to the propagation of radio waves in the scaled

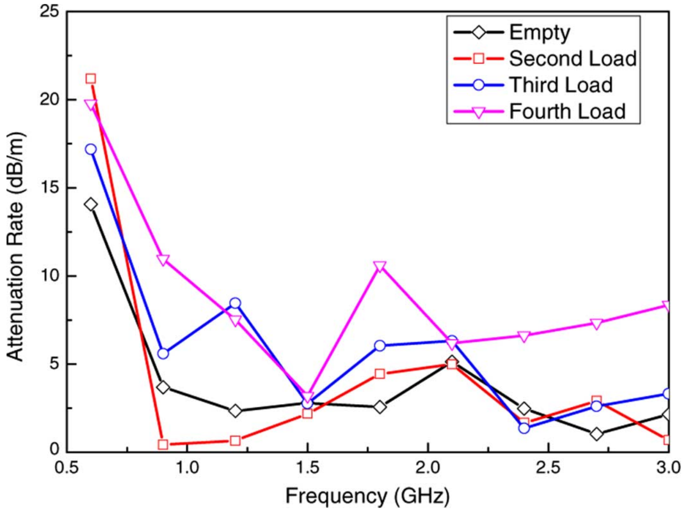

Fig. 5. Attenuation rate as a function of frequency for the open scaled model.

model [13]. Furthermore, note that the fourth loading condition causes the largest propagation attenuation due to the largest reduction of the cross-sectional area. It is unexpected that the second loading condition generally yields a lower attenuation than that of the third one. This could attribute to the fact that more aluminum cylinders produce additional standing waves. The interaction of standing waves and multimode propagation reduces the attenuation.

Fig. 5 shows the propagation attenuation rates as a function of frequency under different loading conditions when both ends of the scaled model were open. It can be seen that the results are similar to those in Fig. 4, indicating the closure or opening of both ends had little effect on the propagation attenuation in the scaled model. The results in Figs. 4 and 5 can be interpreted as the propagation attenuation rates over the frequency range from 40 to 200 MHz for the real environment. It is known from our experience that radio systems operating at such frequencies cannot provide wireless communication services in long-wall coal mining tunnels because of very high propagation attenuation.

In addition, the experiment also revealed that the propagation attenuation rate depends on the locations of cylinders. As expected, the propagation attenuation rate increases as the location of the metallic supports moves to the center.

IV. Conclusion

In this letter, the experimental study of the propagation of radio waves in a scaled model of long-wall coal mining tunnels was conducted and reported for the first time. It was found that the propagation of radio waves in the scaled model loaded periodically with metallic supports exhibits cutoff characteristics and favors a higher frequency and larger unobstructed cross-sectional area. More importantly, it was also found that the propagation attenuation rates fluctuate with the frequency due to the periodical loading. These significant findings not only help us better understand the propagation characteristics of radio waves in long-wall mining tunnels, but also guide us to develop better radio systems to operate more effectively in such working environments. For example, a radio system designed for use in long-wall coal mining tunnels should have multiple channels over a broad frequency range. The radio system can automatically lock and operate on the frequency channel, which results in the least attenuation to the propagation of radio waves.

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