# Radar in Underground Coal Mine Goaf Detection Application

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## Abstract

Ground penetrating radar technology used in underground coal mine under complex geological conditions, the radar profile is difficult to judge abnormal bodies. In this paper, combined with geological information detection field of coal mine goaf on the forward numerical simulation, and then the ground penetrating radar technique applied in coal mine detection work, through numerical simulation and preliminary judgments reflect the underground mined-out area in the radar image, and then analyzes the collected data, and achieved good results.

## Keywords

Ground Penetrating; Radar; numerical simulation; goaf.

## 1. Introduction

At present, the domestic has been carried out for many years of theoretical research and coal mine ground penetrating radar detection application, and summarizes some valuable experiences. The ground penetrating radar has the advantages of simple operation, exploration data without too much processing, results are very intuitive, so the application scope to develop unceasingly, but the new problems are also many [1]. Faced with these problems, if only rely on field work experience to handle is not enough. The development of modern mathematics and electronic technology to provide a virtual platform, namely the use of computer numerical simulation[2], forward calculation of through the abnormal geological structure of the hypothesis, according to the results of a preliminary understanding of underground abnormal structure characteristics in the radar image, and then better guide the coal mine detection work.

## 2. Numerical Simulation Methods and Theory

The finite difference time domain method (Finite-Domain Finite-Time Method, FDTD) based on difference principle, starting from the Maxwell equation, and convert it into a difference equation, in a certain volume and a period of continuous electromagnetic field data sampling [3]. Therefore, it is the numerical simulation of electromagnetic field problems, the essence of the original, the most complete has the widest applicability.

The electromagnetic field changes occurred over time can be spread to the surrounding space, formed from the near to the distant transfer of electromagnetic field, the electromagnetic field which varies with time and space with the wave equation[4]. In an infinite isotropic medium, Maxwell differential equation group will follow:

$$\begin{Bmatrix} \nabla \times E = -\dfrac{\vartheta B}{\vartheta t} - J_{\mathrm{m}} \\ \nabla \times H = J + \dfrac{\vartheta D}{\vartheta t} \\ \nabla \cdot D = \rho \\ \nabla \cdot B = 0 \end{Bmatrix} \tag{1}$$

Among them, E as the electric field strength, B as the magnetic flux density, H as the magnetic field strength, Jmmagnetic flow density, J current density, D as the electric flux density, ρas the volume charge density.

The FDTD method is to replace the partial differential equations solution to differential equations, discrete difference solution to convergence and stability equations. Otherwise, the explicit solutions of differential equations, with increasing the number of time steps, the calculation will be infinite increase [5]. After that, differential equations of the convergence and stability of discrete time , discrete step from T and space walk long Δx, Δy and Δz to satisfy the formula:

$$\Delta t \le \frac{1}{c\sqrt{\dfrac{1}{(\Delta x)^2} + \dfrac{1}{(\Delta y)^2} + \dfrac{1}{(\Delta z)^2}}} \tag{2}$$

In the process of numerical calculation, but also need to set the absorbing boundary conditions, the forward modeling and reflection phenomenon in section will not be carried out in a limited area [6].

## 3. Forward Simulations

This paper uses the two-dimensional radar image simulation software GprMax2D, the finite difference time domain method in the mine goaf are typically based on GPR forward simulation [7], and generates a binary radar image file, display of radar image by Matlab programming.

(1) In the mine goaf, the mechanism and process of formation, its shape is irregular, profile by using spherical, triangular and square approximate simulation of mine goaf, establish goaf whole model as shown in figure 1.

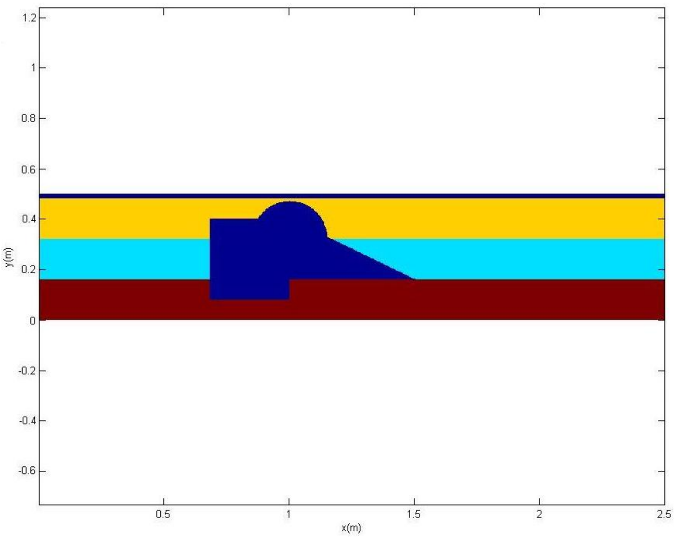


Fig 1. Model of forward simulation

The model adopts the antenna frequency GPR forward simulation for 200MHz. The regional model 2500mm × 500mm, the first layer of yellow region of siltstone rock chart, dielectric constant is 18, the electrical conductivity is 0.01S/m; second layers of blue area for coal seam is 3, dielectric constant, conductivity is 0.00001S/m; third layer brown clay rock in coal seam area, dielectric constant is 30, the electrical conductivity is 0.001S/m; intermediate blue area empty. Simulation of mesh size is x=y=2.5mm, simulation time window is 20 * s, the profile along the lateral line collection 105 radar data signal transmitting antenna initial position (0.3675,0.4825), receiving antenna for initial position (0.4075,0.4825), step size for the 20mm antenna.

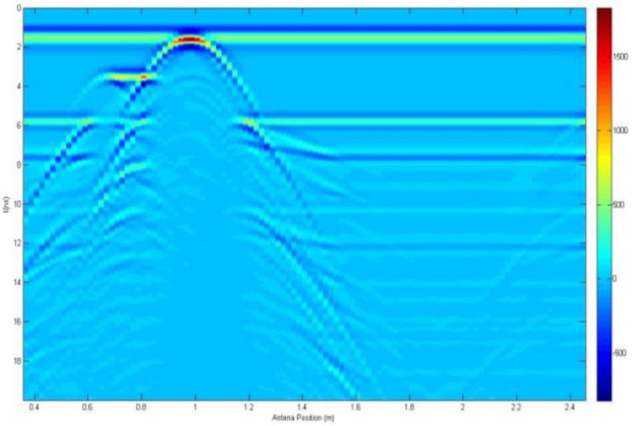

Fig 2. Forward modeling results

(2) According to the roof is falling, not falling, respectively for the coal mine underground goaf forward numerical simulation. Coal is mined, the overlying strata appear crack even roof collapse, rock damage. The establishment of gob local model, as shown in figure 3:

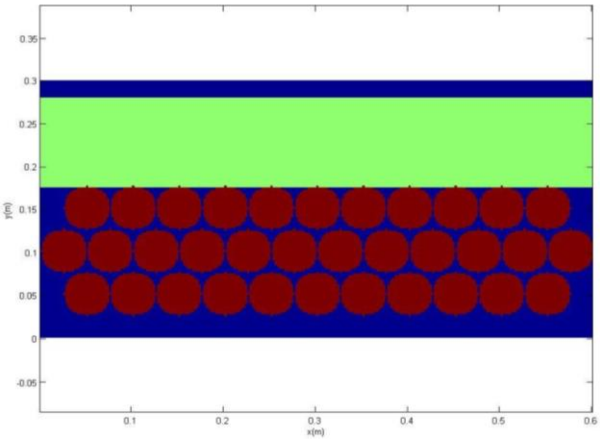

Fig 3. Model of forward simulation

The radar antenna center frequency of the model used for 200MHz. The regional model 600mm × 300mm, map light green areas for coal seam, the dielectric constant is 3, the electrical conductivity is 0.00001S/m; the blue area of goaf; brown small circular area for caving in sandstone. Mined-out area structure the model to simulate the detection driving in front of coal and rock roadway. Simulation of mesh size is x=y=2.5mm, simulation time window is =8 * s, the profile along the lateral line collection 41 radar data signal transmitting antenna initial position (0.075,0.2825), receiving antenna for initial position (0.125,0.2825), step size for the 10mm antenna. The simulation results as figure 4.

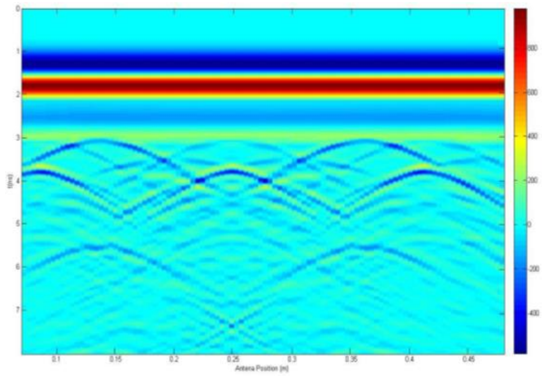

Fig 4. Forward modeling results

(3) If the coal mining with room and pillar mining, is basically not caving roof subsidence, the gob area is filled with water (or air). The establishment of gob local model as shown below:

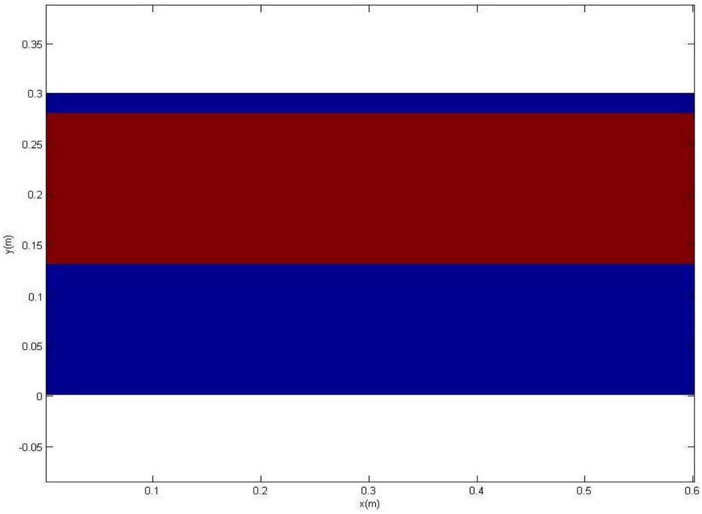


Fig 5. Model of forward simulation

The model uses radar antenna with center frequency of 200MHz. The regional model 600mm × 300mm, brown area of coal and rock, the dielectric constant is 3, the electrical conductivity is 0.00001S/m; the blue area for air. Mined-out area structure the model to simulate the detection driving in front of coal and rock roadway. Simulation of mesh size is x=y=2.5mm, simulation time window is 8 * s, along the line collecting 41 radar data signal using the profile method, the initial position for transmitting antenna, receiving antenna (0.075,0.2825) initial position (0.125,0.2825), step size for the 10mm antenna. The simulation results as below:

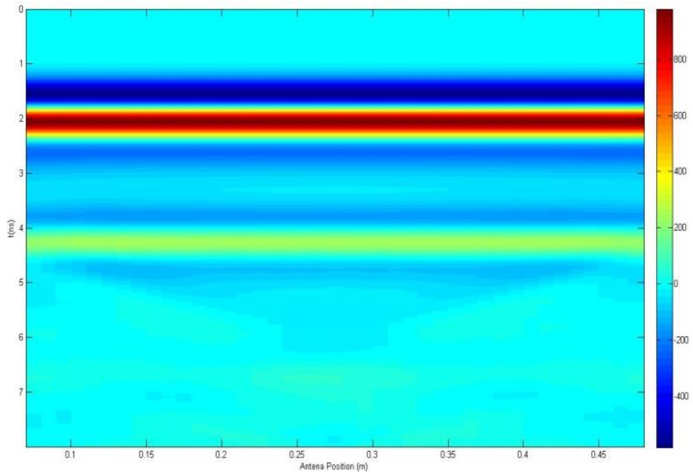


Fig 6. Forward modeling results

Analysis of simulation results, as shown in Figure 2, mined-out area is filled with a lot of air, groundwater. Because of the differences between dielectric properties, strong reflection occurs at the surface of the cave, the reflection coefficient is positive, the amplitude is. Due to irregularity of the cave, on the radar image is more chaos. But for the square cave appears at the top of the approximate level of reflection wave, and obvious features; triangular cave right corner shows the reflected wave converged state; echo on the interface spherical cave significant parabolic shape. Due to the high frequency electromagnetic wave radar with nature and medium high attenuation of electromagnetic wave absorption of energy, cave beneath the echo energy of weak [8]. As shown in Figure 4, the mined-out area is squeeze broken rock filling, and accompanied by water filling phenomenon. Radar wave enters from the coal face caving zone, because of differences in the appearance of coal and rock medium echo. Electromagnetic wave phase axis line in the radar image yellow stripe represents a certain amplitude, due to falling between the area and the coal wall with air layer, the reflection wave from the coal wall into the air layer radar, the reflection coefficient is positive[9]. In the lower part of radar image has a lot of clutter echo, local emission wave distortion, phase axis staggered discontinuous, but also accompanied by a diffraction wave. This is because the caving zone rock crushing after the formation of fracture zone, and the internal containing groundwater, the radar wave absorption, loss and magnetic relaxation effect caused by. As shown in Figure 6, according to the definition of medium, radar wave from the rock into the empty area. Because of the difference of dielectric is obviously reflected in the interface, the reflection coefficient is positive, the amplitude is. Due to the flat interface, event reflection wave is continuous and homogeneous.

## 4. Conclusion

Through the forward numerical simulation method to reflect the image characteristics of coal mine goaf mining structure in the radar profile, contribute to the radar measured data judgment and interpretation, improve the work efficiency and the interpretation precision. But the forward numerical simulation in most cases is a model in the ideal condition is calculated, the measured data and simulation results are not exactly the same, this is the need to pay attention to this.

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