Introduction

Permittivity plays a huge role in distinguishing oil or gas from water, as permittivity of oil/gas is about 1–3 while permittivity of pure water is about 70, but logging response is sensitive to permittivity only in ultra-high frequency (1GHz). A dielectric logging tool was first developed in 1980s, which operates at single frequency (1G or 1.1G Hz), it has not been widely used in oil and gas prospecting due to the limitation of depth of investigation and measurement accuracy. Nowadays, new generation of dielectric tools are developed based on multi-spacing and wide range of frequency like dielectric scanner, this tool have considered the dielectric dispersion effect, multi frequencies (20MHz~1GHz) are set based on physical mechanisms of permittivity at different frequency. Multi-frequency dielectric logging has been widely used in exploration of carbonate reservoir, shale oil, tight oil or gas reservoir and so on.

Coil array of dielectric scanner are placed on a metal pad and that is pushed against the well wall. Eccentric tool pad, borehole, and formation construct complicated three dimensional (3D) downhole environment, forward modelling methods like finite element method, finite difference method could be applied to the simulation, but it could not meet oil field requirement for data processing since they are time consuming. Fast and efficient forward simulation is the basis for inversion or data processing of dielectric scanner measurements.

In this paper, the complicated formation model was first simplified into one dimensional cylindrical layered medium, an improved pseudo analytical method is applied to solve the problem, the spatial sensitivity of different measurements are compared based on response function, and response charts of dielectric scanner with different spacing and frequency are simulated using pseudo analytical solution based on this simplified formation model. This strategy is prove to be feasible and efficient for fast simulation of dielectric logging against several examples.

Logging principle of dielectric scanner

The metal pad of operating dielectric scanner (developed in 2008, Schlumberger) is pushed against the wall as illustrated in Figure 1(a), formation model can be simplified due to following reasons: (1) Spacing of multi-sensors is short and frequency is high, that account to small detection range, and the effect of horizontal formation boundary can be neglected when thickness is larger than the length of tool pad; (2) due to the shield of metal pad, it could be taken as a metal cylinder at high frequency and compact antennas layout. And a 1D cylindrical layered medium is established as Figure 1(b). This kind of problem can be solved by pseudo analytical solution. Thus computing speed will be greatly improved and it is a huge advantage for inversion and data processing.

Figure 1 Formation model and tool configuration. (a) Dielectric scanner in downhole environment. (b) simplified formation model. (c) tool pad layout.
The pad antennas configuration are showed in Figure 1(c). Each antenna is a cross-dipole offering collocated normal magnetic dipoles, two transmitter are in the middle and four pair of receivers are symmetrically mounted around the center. It showed that this symmetrical layout improves the vertical resolution by comparing Figure 2(c) and 2(d), and reduces the influence of borehole rugosity. Figures 2 are simulated based on response function, ant it represent spatial sensitivity or relative contribution of formation region. Comparing figure 2a, b with c, d, contribution between transmitter and receiver is cancelled out by antennas combination, and sensitivity area is focused in between the two transmitters.

![Figure 2](image)

**Figure 2** Response function of different measurements.

Operating frequencies of dielectric scanner are from 20MHz to 1GHz, allowing a full span of the dielectric dispersion. And permittivity become dominated at such high frequency, complex permittivity can be expressed as \( \varepsilon^* = \varepsilon + i\sigma/\omega \), \( \omega = 2\pi f \), The measured signals are calibrated into amplitude ratio (AT) and phase shift (PS):

\[
AT + iPS = \frac{1}{2} \ln \left( \frac{F_{T^*R^*}}{F_{T^0R^*}} \right) + i\Delta\phi
\]

where \( F^* \) are the measured complex valued signals. In formation model showed in Figure 1(b), it can be simplified into equation (2) because of up and down symmetry.

\[
AT + iPS = \ln \left( \frac{F_{T^*R^*}}{F_{T^0R^*}} \right) = \ln \left( \frac{F_{T^*R^*} e^{i\phi}}{F_{T^0R^*} e^{i\phi}} \right) = \ln \left( \frac{F_{T^*R^*}}{F_{T^0R^*}} \right) + i\Delta\phi
\]

**Response charts**

We have constructed a homogeneous formation model and a simplified downhole environment formation model, responses of different situations for the transverse polarization are simulated via pseudo analytical method and are calibrated into phase shift and amplitude ratio, as illustrated in figure 3.

Comparing the response charts of different frequency (left parts are 200MHz and right parts are 1GHz), the response variation range at higher frequency is much larger than that of lower frequency, response are more sensitive to permittivity than resistivity in high frequency.

Comparing response charts of different spacing, a(b) at long spacing and c(d) at short spacing, calibrated attenuation changes a lot and phase shift keep the same. It is because that attenuation is most dominated by the distance between transmitter and receiver, while phase shift is mainly influenced by the distance of two transmitters.

Figure 3e and f show that response charts at short spacing when there is a metal cylinder, noted that response charts of homogeneous medium are denser compared to those with metal pad. From the
comparison of figure c(d) and e(f), we can clearly see that attenuation are different from each other due to the presence of metal pad, but phase shift has equivalent performance with or without a metal pad.

This algorithm is also capable of simulating responses at different downhole environment, including mud cake, wellbore diameter and invasion, these factors are crucial for response in dielectric logging measurement especially in high frequency, and they need to be considered when calibration plates are established based specific geological parameter of oil field, and inversion and data processing.

**Figure 3** Comparison of response charts at a lower and higher frequency. (a) f=200MHz, l=5in, homogeneous medium; (b) f=1GHz, l=5in, homogeneous medium. (c) f=200MHz, l=2 in, homogeneous medium. (d) f=1GHz, l=2in, homogeneous medium. (e) f=200MHz, l=2in, with metal cylinder. (f) f=1GHz, l=2in, with metal cylinder.

**Conclusions**
A simplification strategy of complicated formation model of dielectric logging is proposed in this paper, and a fast pseudo analytical solution is applied to address this problem. We have showed some examples of dielectric scanner and simulated the response of different conditions, we can conclude:

(1) this model simplification strategy are suitable for the simulation of dielectric logging, since it has analytical solution, it has huge advantage for inversion and data processing of dielectric scanner.

(2) the antennas configuration of dielectric scanner could achieve better vertical resolution and reduce the effect of borehole rugosity.

(3) response charts are simulated based on the algorithm, permittivity become dominated when frequency increases, attenuation is more influenced by spacing compared with phase shift, and phase shift stays almost the same with or without a metal pad.

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References