HIGH PRECISION CALCULATION OF MOVE OUT CORRECTION IN GPR MEASUREMENTS

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Abstract

Ground penetrating radar (GPR) is a non-invasive geophysical method that can be used in shallow subsurface exploration. Using GPR it is possible to make high precision measurements of thickness of deposit layer and its distribution in research area. In cases when GPR measurements are performed by bistatic antenna system, time intervals after which reflected signals are received usually are measured relatively to arrival of direct signal. As a result the precise time interval that is necessary for signal to travel from antenna system to reflector is unknown. This paper provides description of precise *move out correction* value determination experiment and calculation method. Recommended method was tested on 3 different bogs in Latvia (Cenas tīrelis bog, Dzelves bog and Ķūķi bog). The main conclusions of described research are: Traditional method of *move out correction* calculation is inaccurate in cases when GPR antenna systems in process of radiolocation profiling are in direct contact with the ground surface. Suggested method of *move out correction* calculation is easy performable and gives accurate results.

Keywords: Ground penetrating radar, electromagnetic wave propagation speed, move out correction

Introduction

Ground penetrating radar (GPR) is a non-invasive geophysical method that can be used in shallow subsurface exploration (Daniels, 2004). GPR generates short electromagnetic impulses that are transmitted into the ground by transmitter antenna and reflected from buried objects or deposit layer with different electromagnetic properties boundaries. These reflections are detected by receiver antenna and recorded as GPR profile that contains information about time intervals after which reflected signals are received. Using GPR it is possible to make high precision measurements of thickness of deposit layer and its distribution in research area. Nevertheless to achieve mentioned precision it is necessary to determine time intervals after which GPR signals are detected with high accuracy.

In cases when GPR measurements are performed by bistatic antenna system, time intervals after which reflected signals are received usually are measured relatively to arrival of direct signal (signal that travels direct from transmitter antenna to receiver antenna). As a result the precise time interval that is necessary for signal to travel from antenna system to reflector is unknown. This problem is well known and usually is solved with addition of *move out correction* (Neal, 2004). In general application of *move out correction* is addition of extra time that was necessary for traveling of direct signal from transmitter antenna to receiver antenna to measured time interval after which reflected signal is received (Equation 1).

$$t = t_m + t_k \qquad (1)$$

where t is the time after which reflected signal is received, t_m is the measured time after which reflected signal is received relatively to direct signal and t_k is the time that was necessary for direct signal to travel from transmitter antenna to receiver antenna.

Time that is necessary for signal to travel from transmitter antenna to receiver antenna for set antenna system can be calculated with equation 2:

$$t_k = \frac{S}{v} \qquad (2)$$

where t_k is the time that is necessary for direct signal to travel from transmitter antenna to receiver antenna, S is the distance from transmitter antenna to receiver antenna and v is the speed with which GPR signal travels between antennas. Usually it is assumed that direct signal travels through the air thereby the signal propagation speed is equal to electromagnetic wave traveling speed in the air (0,2998 m ns^{-1}) (Neal, 2004). This is correct for cases when used GPR antenna system in process of radiolocation profiling is not in direct contact with the ground surface.

Nevertheless many GPR antenna systems in process of radiolocation profiling are in direct contact with the ground surface. In such configuration of GPR antenna direct signal consists of sum of air signal and signal that travels along ground surface (Figure 1) (Daniels, 2004).

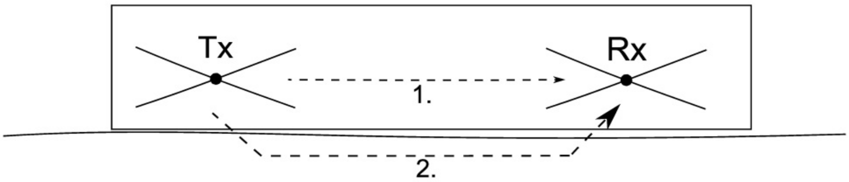

Figure 1. Individual components of direct signal. Where Tx is transmitter antenna, Rx is receiver antenna, 1. – signal that travels through air and 2. – signal that travels along ground surface.

Accordingly to above outlined thee is the hypothesis that the calculation of the time that is necessary for direct signal to travel from transmitter antenna to receiver antenna can not be based on the assumption that direct signal travels through the air nor calculated with equation 2.

This paper provides description of precise *move out correction* value determination experiment and calculation method.

The calculation metho

It is possible to calculate precise time interval what is necessary for direct signal to travel from transmitter antenna to receiver antenna using data that can be obtained in comparatively simple experiment.

In the beginning of the experiment GPR antenna should be placed on ground surface and then recording of GPR profile should be started (Figure 2, A). After acquisition of several traces GPR antenna should be lifted from ground surface in height of at least 50 cm (Figure 2, B). During experiment it is crucial to identify the traces that are recorded when GPR antenna system is in direct contact with ground surface and the traces that are recorded when GPR antenna system is lifted in the air.

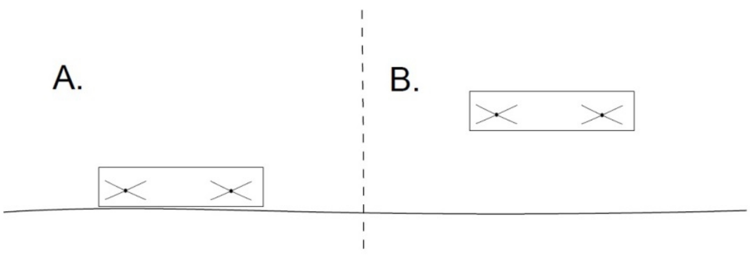

Figure 2. *Move out correction* determination experiment. A – initial pozition of antenna. B – antenna pozition in the end of experiment.

In Figure 3 is shown in such experiment obtained GPR profile. As one can see when antenna system is lifted direct signal is received several nanoseconds earlier.

In the end of the experiment antenna system is lifted in the air and it can be assumed that direct signal travels through the air and there is no component of ground surface signal. Thereby it is possible to calculate time interval that is necessary for signal to travel from transmitter antenna to receiver antenna by equation 2 using electromagnetic wave traveling speed in the air. Afterwards using in above described experiment obtained GPR profile there can be measured the time difference between time when direct signal was detected in position A. (antenna system is on the ground) and position B. (antenna system is lifted in the air).

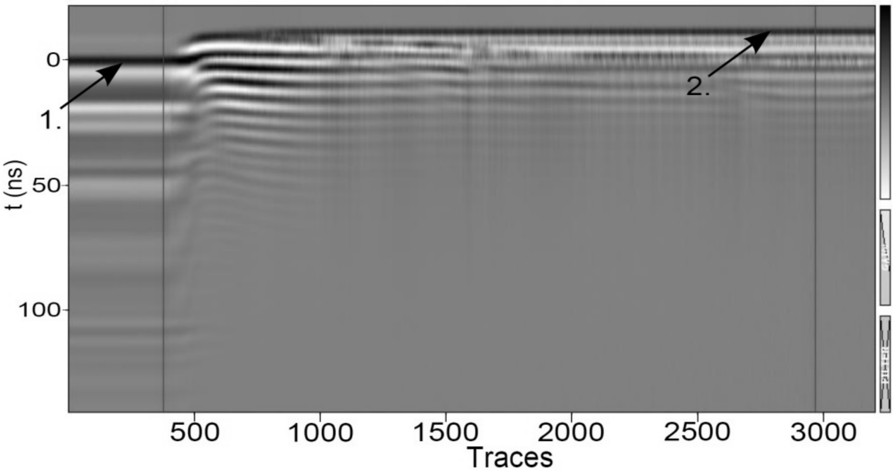

Figure 3. In experiment obtained GPR profile. 1. – identified direct signal when GPR antenna is on ground (corresponds to figure 2A). 2. – identified direct signal when GPR antenna is lifted in the air (corresponds to figure 2B).

Finally the addition of the time difference to calculated time interval that was necessary for direct signal to travel from transmitter antenna to receiver antenna in position B gives the time interval that is necessary for direct signal to travel between antennas in direct contact with the ground surface (Equation 3).

$$t_k = \frac{S}{c} + t_d \qquad (3)$$

where t_k is precise value of move out correction, S is the distance from transmitter antenna to receiver antenna, t_d is the measured time difference and c is electromagnetic wave traveling speed in the air.

Experiment results

Recommended method was tested on 3 different bogs in Latvia (Cenas tīrelis bog, Dzelves bog and Ķūķi bog). For determination of the depth of bog in all three research areas common midpoint measurements (Comas et al., 2011; Musgrave and Binley 2011, Lowry et al., 2009; Neal, 2004; Reynolds, 1997) were done. To evaluate precision with which depth of these bogs were determined using only GPR measurements the exact depths of bogs were determined directly using hand drill.

In the process of the depth calculation with data that are obtained during CMP experiment *move out correction* need to be applied. As a result precision of calculated depth values depends on precision with which *move out correction* values are determined. Thereby using accuracy of calculated bog depths above suggested method of *move out correction* calculation can be evaluated. For comparison also bog depth values were calculated applying *move out correction* values that are calculated assuming that direct signal travels through air (Table 1).

Table 1. The experimental results of the bog depth determination.

	Directly determined depth of bog (m)	With Equation 3 calculated *move out correction* values (ns)	Determined bog depth during CMP experiment (traditional approach of *move out correction* calculation) (m)	Determined bog depth during CMP experiment (suggested approach of *move out correction* calculation) (m)
Cenas tīrelis bog	4,52	10	4,38	4,57
Dzelves bog	3,82	3,8	3,80	3,85
Ķūķi bog	6,48	4,6	6,47	6,52

As obtained results show in most of the cases it is possible to calculate bog depth with high precision using traditional approach of *move out correction* calculation. Nevertheless as it is shown in Table 1 in some cases application of traditional approach of *move out correction* calculation can induce inaccuracies. For example calculated depth of Cenas tīrelis bog strongly depends on calculation methodology of *move out correction*. It can be explained by the fact that ground surface in Cenas tīrelis bog was humid and as a result electromagnetic wave propagation speed along it was noticeably slower than in air. Therefore suggested *move out correction* calculation method was essential for accurate depth value calculation in particular research area.

As ground surface was relatively dry in Dzelves bog and Ķūķu bog, electromagnetic wave propagation speed values along them were close to electromagnetic wave propagation speed value in the air. Therefore traditional approach to *move out correction* calculation provided relatively precise results.

Conclusions

Traditional method of *move out correction* calculation is inaccurate in cases when GPR antenna systems in process of radiolocation profiling are in direct contact with the ground surface.

Suggested method of *move out correction* calculation is easy performable and gives accurate results.

If electromagnetic wave propagation speed along ground surface in research area is presumably slow it is recommended to use suggested method of *move out correction* calculation.

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