DIRECTION ESTIMATION WITH CONFORMAL ARRAYS FOR A BOREHOLE RADAR

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INTRODUCTION

Borehole radars, (Ground Penetrating Radar in a drilled hole) have been utilized in various fields such as resources exploration and tunnel detection[1]. Borehole radars are normally operated in 10MHz-100MHz range, corresponding the wavelength of roughly 10m-1m. The borehole diameter used for radar measurements is usually less than 10cm, therefore dipole antennas polarized along to the borehole axis are commonly used. More recently, directional borehole radars have been developed for 3-D determination of water-filled fractures and geological boundaries[2][3][4]. In the previous paper, the authors proposed a conformal array for a directional borehole radar antenna[5]. In this paper, we show some examples of direction estimation with the new antenna through laboratory experiments.

CONFORMAL ARRAYS FOR A BOREHOLE RADAR

Fig.1 is the antenna configuration presented in [5]. This antenna is constructed of several current probes mounted on a thick conducting borehole sonde. The surface current is induced by incident electromagnetic field, and its incident angle is estimated from relative arrival time and amplitude among current probes. Since the current probe is electrically small, it is broad-band and the sensitive polarization can be chosen by rotating the probe.

POLARIMETRIC MEASUREMENTS IN A BOREHOLE

The choice of polarization of electromagnetic wave used for measurements are quite significant in designing radar systems. Circular polarization has advantages for Ground penetrating radars (GPR), because the reflection efficiency is independent of target orientation to antenna arrangements[6]. Another important role of polarization in GPR is isolation of transmitting and receiving antennas.

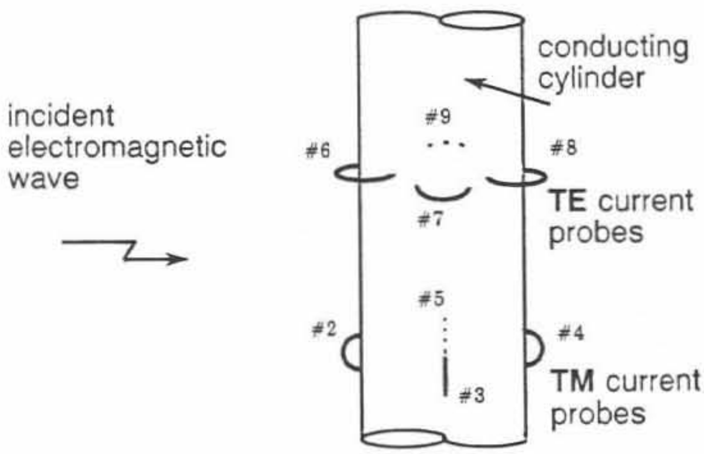

Fig.1 Conformal arrays for a directional borehole radar

GPR measurements normally use two antennas set closely to each other. Direct coupling often shades small reflection from targets. A set of cross-polarized antennas increases the antenna isolation and enhances radar reflection. Further possibility of radar signal processing with polarization characteristics are known as radar polarimetry [7].

The polarization of the new directional antenna is only dependent on the orientation of small current probes mounted on the sonde surface. Therefore, cross-polarization arrangement can be easily achieved.

EXPERIMENTS

The advantage of cross-polarized measurements were shown in laboratory experiments. Fig.2 shows a measuring system. A conical antenna radiates vertically polarized impulsive wave and reflected wave from a rectangular conducting plate(30cm x 30cm) is measured with the new sonde. Probe location on the cylinder is illustrated in Fig.1. Probe #2 and 6 are facing the transmitting conical antenna and reflector locates at 26.5° measured from probe #9 and 5. Probes #2-5 are TM polarized and #6-9 are TE polarized. Fig.3 shows the measured voltage at each probe. Fig.3(a) is co-polarized to the transmitted wave(TM) and Fig3(b) is the cross-polarized signal(TE). In both figures, the waveform with and without the reflector were compared. Fig.4 shows the received signal at each probe after reducing the direct coupling. The direct coupling was estimated by averaging 5 signals from a moving reflector.

DISCUSSION

Both in TM and TE cases in Fig.3, direct coupling appears at 1.5 ns, and in TE case, strongest reflection is observed at 4 ns. Reflection appears also in TM case, but it is not clear due to the strong direct coupling. Reflection strength is smaller in TE case, however, direct coupling was more reduced in TE case and the reflection was relatively enhanced. This is more clear in Fig.4. Direct coupling reduction is quite well in TE case, but is insufficient in TM case.

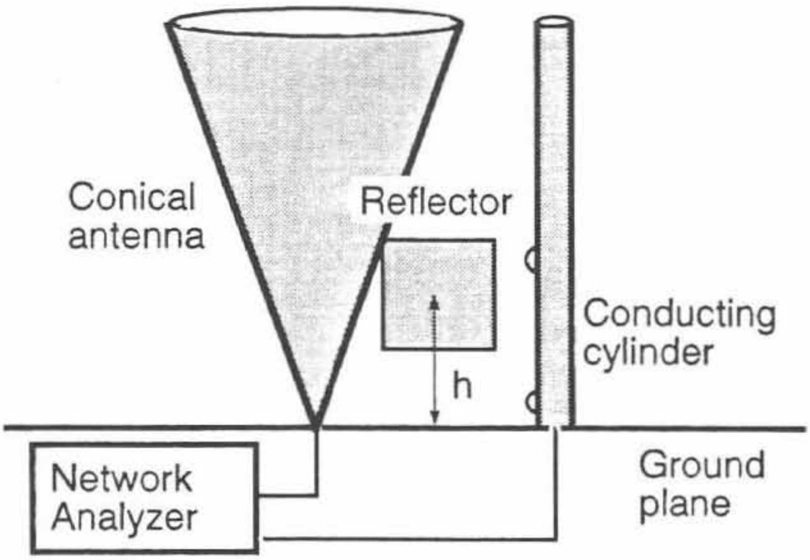

Fig.2 Measuring System

Relative arrival at each probe is picked up in Fig.4 and plotted in Fig.5. Apparent velocity along conductor surface is different in TM and TE case. This is due to the difference of TM and TE pulse deformation along the surface. By fitting a parabolic curve to the plots, the center was determined as the angle of incidence. The agreement is within 10 degrees.

CONCLUSION

The possibility of estimation of incident angle with a conformal arrays for a borehole radar were shown. Laboratory experiments showed that, reflection was clearly detected with a cross-polarized antenna arrangement, because the direct coupling between transmitting and receiving antennas is reduced.

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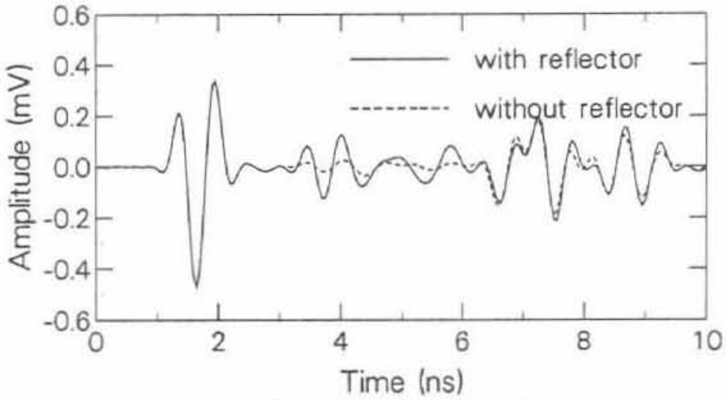

Fig.3(a) Measured receiving voltage. probe #2; TM mode, h = 450mm.

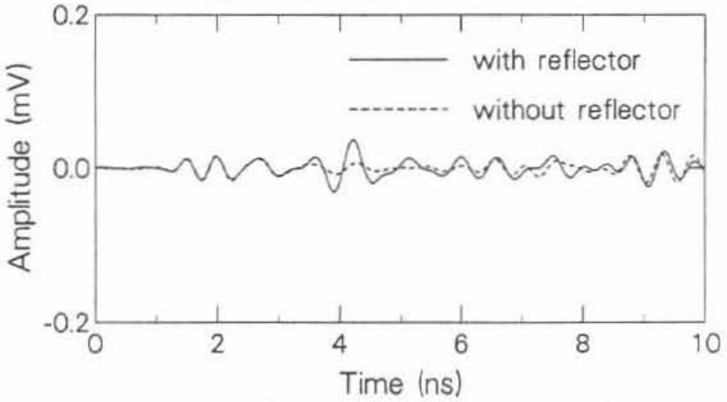

Fig.3(b) Measured receiving voltage. probe #6; TE mode, h = 450mm.

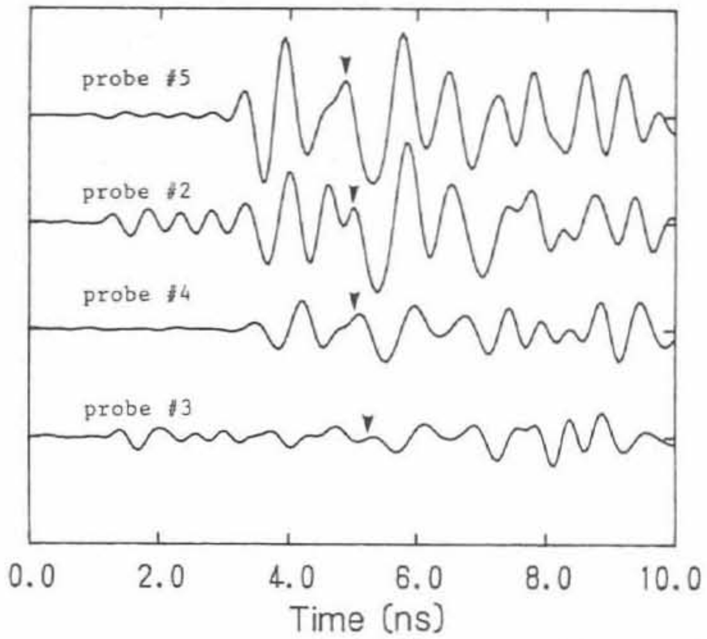

Fig.4(a) Received signal after reduction of direct wave. TM mode, h = 450mm.

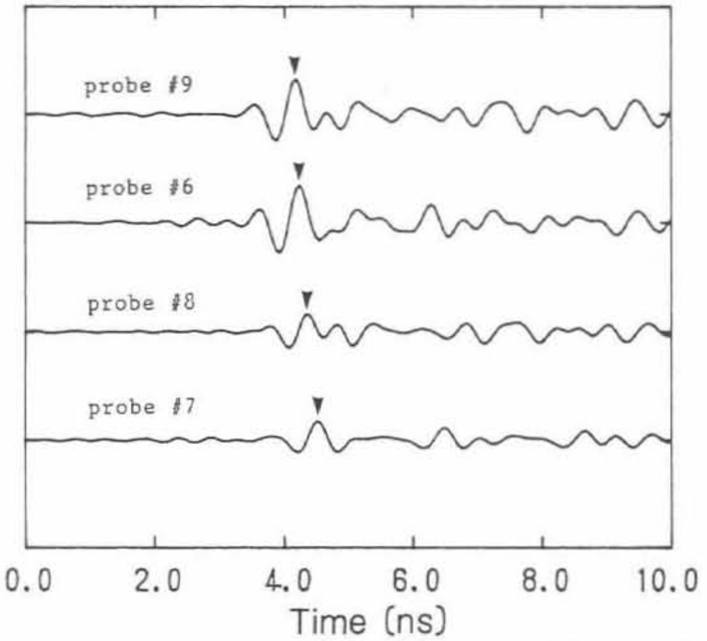

Fig.4(b) Received signal after reduction of direct wave. TE mode, h = 450mm.

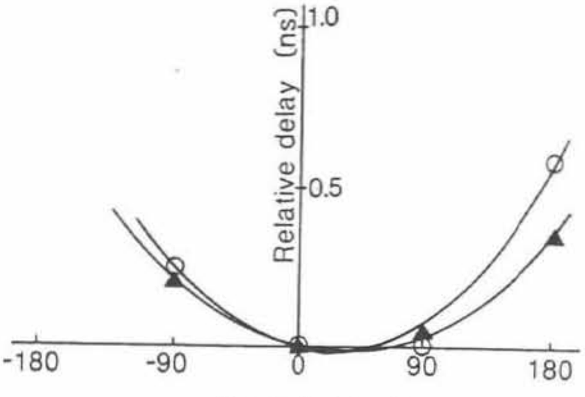

Fig.5 Relative arrival time and estimated incident angle of reflection from a plate.
(○:TM ▲:TE, Actual incidence = 26.5°, Estimated: TM = 16.4°, TE = 27.0°)