SYNTHETIC APERTURE FOR SUBSURFACE RADAR

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1. Introduction

Several types of subsurface radars using VHF and UHF frequencies have been recently developed to profile the underground or to detect buried targets. Imaging systems such as subsurface radar are required to yield high resolution enough to enable the observer to identify the objects.

This paper describes on the principle of a new synthetic aperture technique for base-band pulse radar to improve the horizontal resolution to the extent that it is four times higher than that of a single antenna. The signal processing for base-band pulse radar is different from the signal processing technique using in SAR because the former uses a non-carrier pulse.

The experimental results are also shown in this paper.

2. Principle of synthetic aperture for base-band pulse radar

The cross-sectional geometry of a subsurface (underground) is shown in Fig.1. Let x axis take along the ground surface and y along the depth, then an antenna is moving on the ground surface to detect a target located at point $P_0(x_i, y_j)$. On a B-mode display echoes from a point target may be appeared as an arched shape shown in Fig.1. It means that the azimuthal resolution is degraded.

Leading edges of the echoes are distributed along a trajectory given by

$$y^2 = (x - x_i)^2 + y_j^2 \tag{1}$$

The synthetic aperture for the signal received may be understood as collecting inversely the spreaded echoes P(x,y) at the original point $Po(x_i, y_j)$ in the way shown in

$$Q(x_i, y_j) = \sum_{m=-M}^{M} D_m \cdot P(x_{i+m}, y_m) \tag{2}$$

where $y_m = \sqrt{(x_{i+m} - x_i)^2 + y_j^2}$ and D_m is weighting function.

However, the waveforms actually received have a few ringing cycles due to unsatisfactory antenna bandwidth. Therefore signal processing based on eq.(2) will fail to gather entire signals in phase except for the leading edges of the echoes. Here, a revised signal processing procedure is proposed as follows: for $k = 0, 1, \cdots, K$

$$Q(x_i, y_j + k\cdot\Delta y_0) = \sum_{m=-M}^{M} D_m \cdot P(x_{i+m}, y_m + k\cdot\Delta y_0) \quad (3)$$

where Δy_0 is the minimum spacing along the y coordinate and $K\cdot\Delta y_0$ is selected so as to cover the pulse duration. Signal processing based on eq.(3) is able to gather not only the leading edges but also the remainders of the signal waveforms. Resultant synthetic aperture image is obtained by performing the calculation of eq.(3) for all combinations of (i,j). The horizontal resolution attained by eq.(3) would be equivalent to (2M+1) antenna array being spaced equally over a synthetic aperture length L.

Two patterns, before and after processing, is shwon in Fig.2. By comparing the two patterns, it can be seen that horizontal resolution improvement by a factor of about 4 has been achieved.

3. Detection of pipes in the ground by the synthetic aperture

A cross-sectional view of buried pipes displayed on a subsurface radar CRT is shown in Fig.3(a). A couple of metallic pipes 0.75 m apart is located at 1.5 m depth. Signal processing based on eq.(3) was applied to the original image (a) and improved images, as shown in (b) and (c), was obtained. Two pipes can be separated clearly in (b) and (c) though the original image (a) is not so clear.

Difference between (b) and (c) is from the estimation of wave velocity in the ground which mostly relates to relative permittivity , ε_r , of the soil. Relation between resultant beam width and estimation error of permittivity is shown in Fig.4. It is clear that over-estimation of ε_r may lead to less error.

4. Conclusion

(1) Using the synthetic aperture method proposed here for subsurface radar, improvement in horizontal resolution by a factor of 4 can be achieved.

(2) Over-estimation of ε_r may not lead to serious error in the synthetic aperture.

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I.ARAI and T.SUZUKI "Subsurface Radar-Signal Processing for Noise Reduction and High Resolution" ISNCR-84 Oct.22-24,1984.

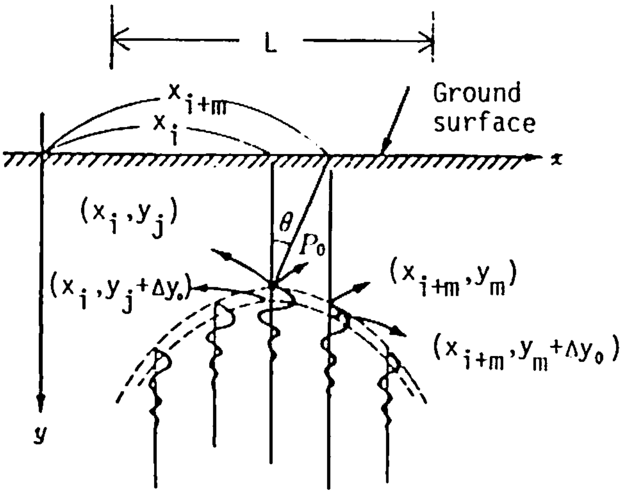


Fig.1 Distribution of the received echo signals.

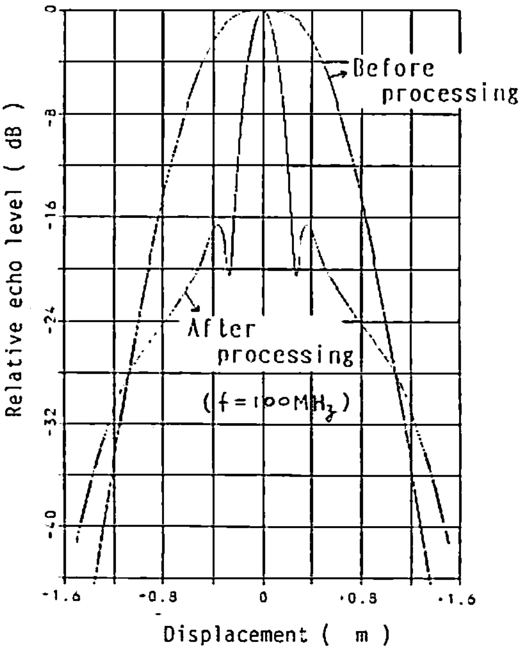
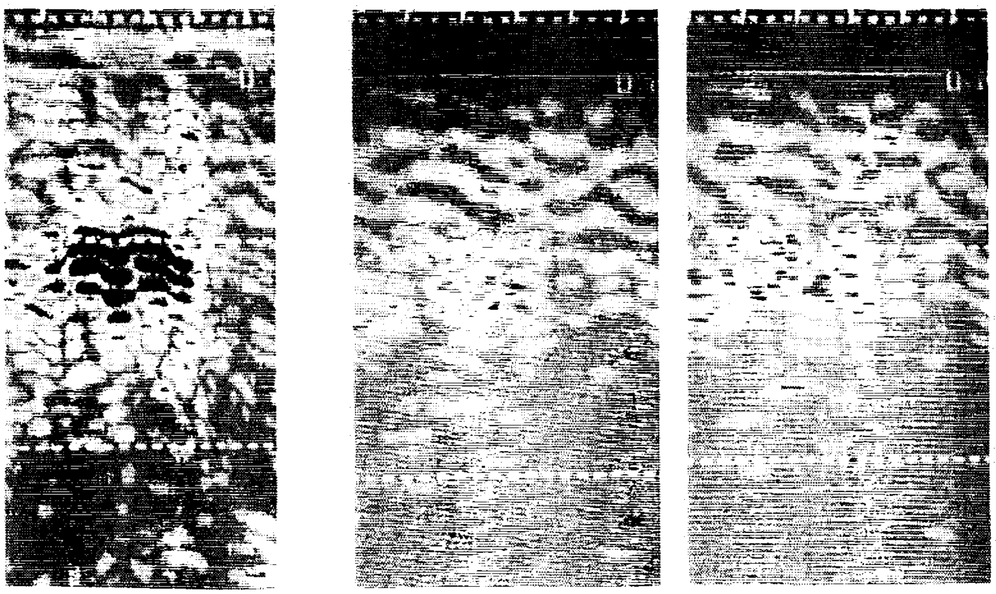


Fig.2 Antenna pattern at 1 m below the ground and it's compressed pattern after signal processing based on eq.(3). (ε_r =30, L=1.5 m, 2M+1=101, Dm =1)



(a) Before processing (b) $\hat{\varepsilon}_r$ =25 (c) $\hat{\varepsilon}_r$ =36

After processing (L=1.5 m)

Fig.3 Subsurface radar images of two parallel metallic pipes(10 cmφ) 0.75 m apart and 1.5 m below the ground. ($\hat{\varepsilon}_r$:estimation value of relative permittivity)

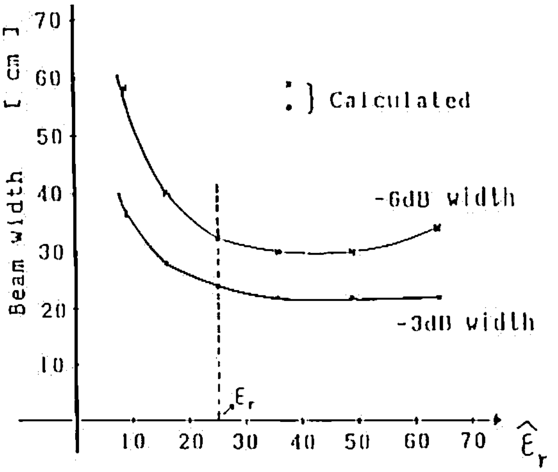


Fig.4 Resultant beam width vs. estimation error of relative permittivity. (True value : $\varepsilon_r = 25$)