PROCEEDINGS OF ISAP '96, CHIBA, JAPAN

AN EQUIVALENT TIME SENSITIVITY CONTROL TECHNIQUE FOR POLARIMETRIC FM-CW RADAR

Toshifumi MORIYAMA, Hajime KASAHARA, Yoshio YAMAGUCHI,
Hiroyoshi YAMADA
Dept. of Information Engineering, Niigata University
Ikarashi 2-8050, Niigata-shi 950-21, Japan

1. Introduction

The typical problems for a subsurface radar are; 1) strong clutter which exhibits radar wave penetration into underground and sometimes masks a target beneath the surface, 2) severe attenuation of wave within the lossy medium which degrades the radar capability in deep sounding, and so on. We have been engaged in the development of a subsurface FM-CW radar. In this paper, we present countermeasures against these problems for the radar. The solution to the problem 1) is a use of radar polarimetry [1]. For the problem 2), we propose an equivalent time sensitivity control technique especially suited for the FM-CW radar, based on the characteristics of Fourier transform in the signal processing [2]. The combined use of these two techniques is expected to enhance the FM-CW radar performance. In the following, brief principles together with an experimental result which supports the validity and the usefulness of an advanced FM-CW radar system are given.

2. Polarimetric FM-CW Radar

2.1 Equivalent Sensitivity Time Control Technique

The FM-CW radar measures a distance from an antenna to an object by the beat signal of transmitted signal and reflected signal from the object. If the object is located at distance r_b from the antenna in a medium of permittivity ε_r, the beat signal can be expressed as a function of time as follows;

$$s_b(t)=g\,A(r)\exp\left[2\pi\left(f_b\,t+\theta\right)\right], \tag{1}$$

g is a reflection coefficient and f_b is the beat frequency which is proportional to the distance r_b. $A(r)$ is an amplitude factor which is essentially identical with attenuation coefficient due to path length. This amplitude factor decreases rapidly with increasing r_b. In order to enhance the deep sounding capability, it is necessary to compensate the amplitude factor.

Since the beat signal f_b in FM-CW radar system can be obtained by a use of Fourier transform to (1), we may go back to (1) and use the property of Fourier transform as follows;

$$\mathrm{FT}\left[s_b(t)\right]=g\,A(r_b)\delta(f-f_b)\exp(j2\pi\theta), \tag{2}$$

$$\mathrm{FT}\left[\frac{d^n}{dt^n}s_b(t)\right]=\left(j2\pi f_b\right)^n g\,A(r_b)\delta(f-f_b)\exp(j2\pi\theta), \tag{3}$$

where FT denotes Fourier transform. It should be noted in (3) that the attenuation term $A(r)$ is multiplied with $\left(j2\pi f_b\right)^n$. This means the amplitude factor is multiplied with f_b which is proportional to the target distance. This multiplication would compensate the attenuation due to path length. This technique is similar to time sensitivity control concept used in pulse radar system. The degree to the compensation rate is dependent on the number of differentiation with respect to time for the beat signal (1). This differentiation can be realized either by a simple hardware or by a software.

In addition to this simple compensation method, this technique conserves relative phase information which is a very important factor for applications to radar polarimetry and synthetic aperture processing.

2.2 Radar Polarimetry

In the FM-CW radar, if a polarimetric measurement is conducted in the HV polarization basis, the set of polarimetric data provides a scattering matrix. It is possible to synthesize a radar channel power at any polarization state if a scattering matrix given. Now, let $\mathbf{E}_t$ be the transmitted wave from the radar, and $\mathbf{E}_s$ be the scattered wave from the target. The scattered wave can be related to the transmitted wave via scattering matrix $[S]$

$$\mathbf{E}_s(\mathrm{HV}) = [S(\mathrm{HV})]\mathbf{E}_t(\mathrm{HV}), \tag{4}$$

$$[S(\mathrm{HV})] = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}, \tag{5}$$

where $[S(\mathrm{HV})]$ represents target's polarimetric scattering characteristics in the HV basis. For the Co-pol channel case (the polarization sate of the receiver is identical with that of the transmitter), the received power is obtained from

$$P = \left| \mathbf{E}_t^T(\mathrm{HV})[S(\mathrm{HV})]\mathbf{E}_t(\mathrm{HV}) \right|^2. \tag{6}$$

The problem of surface clutter is to find null polarizations which eliminate surface clutter. The null polarization states are given by

$$\rho_n = \frac{-S_{HV} \pm \sqrt{S_{HV}^2 - S_{HH}S_{VV}}}{S_{VV}}. \tag{7}$$

Therefore, the polarimetric image using (7) maximizes contrast of the desired target versus the surface clutter.

3. Experimental Result

In order to confirm the method of combined use of the radar polarimetry and the equivalent time sensitivity control technique, we carried out an experiment for target detection in underground at the Niigata University Campus. The target was a metallic plate of 15×85 cm which was buried at the depth of 38 cm in a sandy ground. The polarimetric detection was conducted in the conventional linearly polarized HV basis. The measurement situation is shown Fig.1. The target was oriented -45 degrees with respect to the scanning direction. We obtained fixed polarization radar images. Figure 2 shows fixed (HH, HV, VV) polarization radar images after a synthetic aperture processing. The surface clutter exists in all fixed polarization images and especially surpasses the target echo in the VV image which makes the target detection impossible.

For the reduction of surface clutter 1), we choose the Co-pol null state (7) of the surface for polarimetric imaging. Figure 3 shows the Co-pol null image. It is seen that the surface echo is suppressed. However, the metallic plate echo is weak. This reason is due to severe attenuation of wave in the underground. Figure 4 shows the same polarization image using the equivalent time sensitivity control technique 2). It is seen that the metallic plate echo becomes strong, and that surface echo is suppressed. The combined use of these tow techniques enhances the detection capability.

4. Conclusion

We present a method of combined use of the radar polarimetry and the equivalent time sensitivity control technique in the FM-CW radar. It is confirmed experimentally that FM-CW radar can combine the use of these two techniques. This method is effective for detection of target at far distances and enhances the FM-CW radar performance.

Acknowledgment

This work in part was supported by Grant-in-Aid for Scientific Research on Priority Areas, the Ministry of Education, Japan.

References

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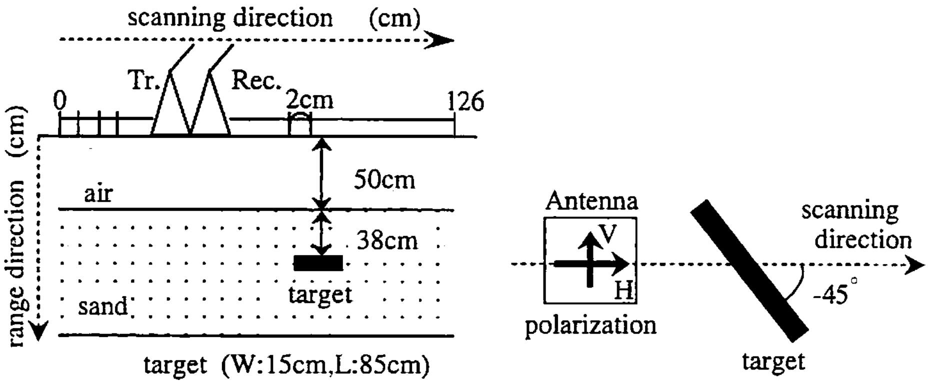
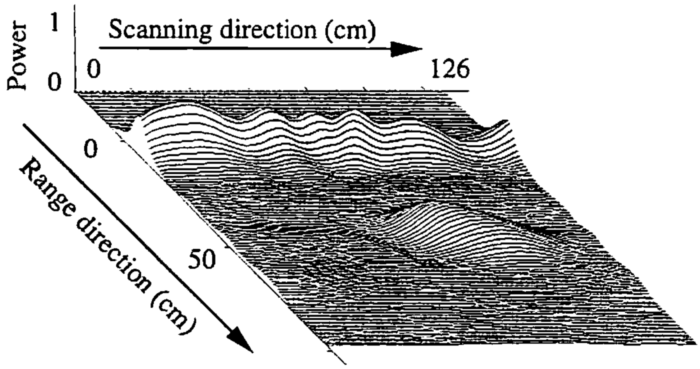
[2] H. Kasahara, Y. Yamaguchi, T. Moriyama, H. Yamada, "On the FM-CW radar for deep sounding," *Technical Report of IEICE*, SANE95-50, pp. 61-66, July 1995.

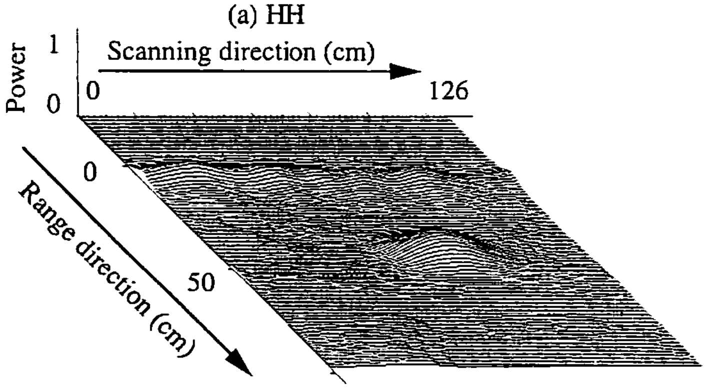


(a) Cross-sectional view (b) Top view

Fig.1 Experimental situation

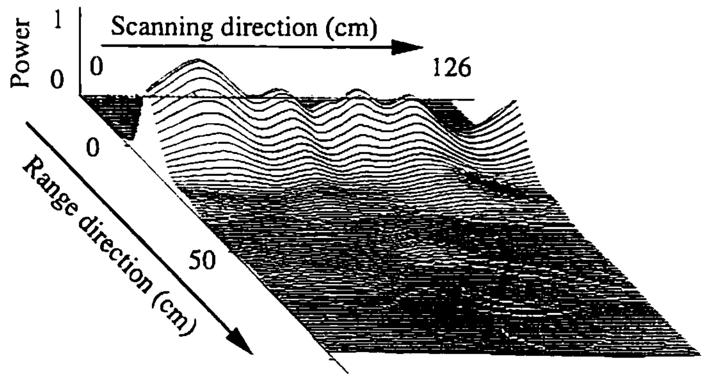


(a) HH



(b) HV

Fig.2 Fixed polarization images



(c) VV

Fig.2 Fixed polarization images

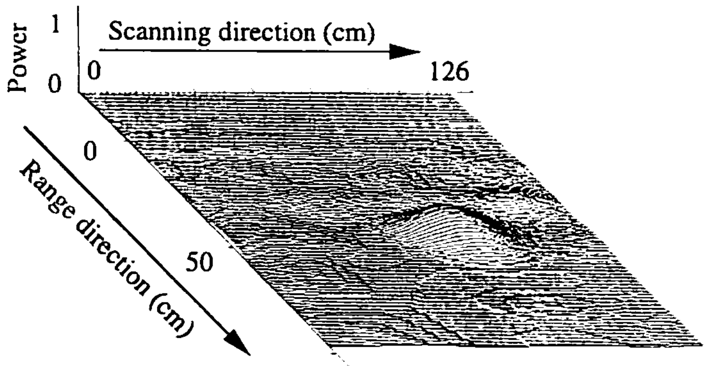


Fig.3 Co-pol null image of surface

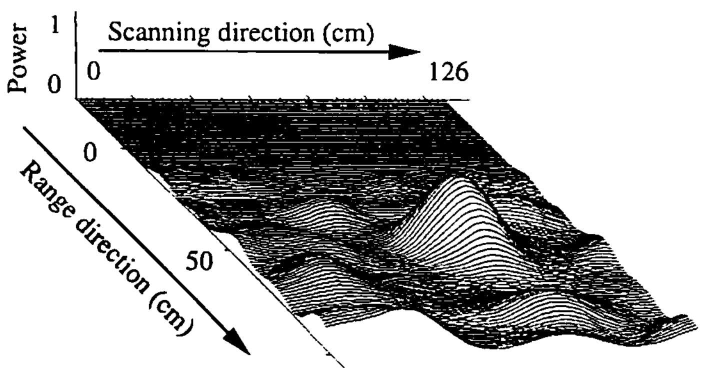


Fig.4 Co-pol null image (second order differentiation) of surface