DETECTION OF OBJECTS IN SANDY GROUND BY AN FM-CW RADAR

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Abstract- An FM-CW radar system for the detection of objects buried in sandy ground was explored and was applied to field measurement. The key factors for underground radar performance are the center frequency and the bandwidth determining the depth at which the radar can detect targets and the resolution in the range direction, respectively. To realize a practical underground radar, two ridged horn antennas are employed in the system, which are operative in the frequency range of 250-1000 MHz. The impedance matching to the ground is optimized by measuring the echo strength from a fixed target as a function of the spacing between the antenna aperture and the ground surface. It is shown that the radar with an output power of 18 dBm could detect a metallic plate (30 × 100 cm) and a pipe (10 cmϕ) buried at the depth of 1.2 m. Also the synthetic aperture technique together with an averaging and subtracting method produced fine image in shallow region up to 100 cm in the sandy ground.

1. Introduction

Ground penetrating radar has been attracting interest in recent years for the purpose of detecting pipes, broken sewers, archaeological exploration, etc[1]-[4]. Most of the ground penetrating radar are pulse-based radars. This paper describes the possibility of synthetic FM-CW radar for underground application. The FM-CW radar utilizes a wideband and continuous frequency. The flat frequency characteristics is the most important factor for the FM-CW radar. This leads to several advantages and disadvantages. The advantages are high sensitivity, low power, simple equipments, easy to build up a system, and the range accuracy can be adjusted easily by a signal processing software. The disadvantages are (1)difficulty to realize a practical radar antenna, (2)spurious beat signal may come out due to non-flatness of frequency characteristics, (3)difficulty in wideband impedance matching between antenna and ground, (4)impossible to employ STC technique.

In order to overcome these disadvantages, two ridged horn antennas operative in the 250-1000 MHz were explored in this work. The impedance matching (3) was optimized by checking the echo strength, by varying the spacing interval between the antenna aperture and the ground surface. Then an explored FM-CW radar system was applied to detect a metallic plate of 30 × 100 cm and a pipe of 10 cmϕ in a sandy ground.

Section 2 explains the principle of synthetic aperture FM-CW radar. Section 3 describes the antenna and system, followed by the experimental and signal processing results in Section 4.

2. Principle of Synthetic Aperture FM-CW Radar

The FM-CW radar basically measures the distance between a radar antenna and an object by the beat frequency of the transmitted and reflected signal from the object. The transmitting signal is usually swept linearly from $f_0 - \Delta f/2$ to $f_0 + \Delta f/2$ where f_0 is the center frequency. If a two-dimensional object whose reflection coefficient function is represented by

$$g = g(x_0, z_0), \qquad (1)$$

(x_0, z_0) : coordinate of the object

is located at a distance r in the Fresnel region within a medium of permittivity ε_r as shown in Fig.1, the reflected signal from the target arrives at the radar with a time delay by τ ($\tau = \frac{2r}{c}\sqrt{\varepsilon_r}$, $c = 3 \times 10^8$ m/s). This reflected signal and the instantaneous transmitted signal are mixed, producing a time domain beat signal. The Fourier transform of the beat signal results in[6]

$$U(x,z) = B \int_0^{\infty} \int_{-\infty}^{\infty} f(z - z_0)\, g(x_0, z_0)\, h(x - x_0, z_0)\, dx_0 dz_0 \qquad (2)$$

with B being the amplitude, and the range function in the z direction,

$$f(z - z_0) = \frac{\sin[\alpha(z - z_0)]}{\alpha(z - z_0)} = Sinc[\alpha(z - z_0)]$$
$$\alpha = \frac{2\pi\sqrt{\varepsilon_r}}{c}\Delta f \qquad (3)$$

and the phase function with respect to the propagation path

$$h(x - x_0, z_0) = exp\left[j\frac{4\pi\sqrt{\varepsilon_r}\, f_0}{c} \left\{ z_0 + \frac{(x - x_0)^2}{2 z_0} \right\} \right] \qquad (4)$$

At $z \approx z_0$, the range function $f(z-z_0)$ can be approximated as

$$f(z - z_0) \approx 1 \qquad (5)$$

which leads to

$$U(x, z_0) = B \int_{-\infty}^{\infty} g(x_0, z_0)\; h(x_0 - x, z_0)\, dx_0 \qquad (6)$$

One can see that this expression is of the convolution integral form and that it is equivalent to a Fresnel approximation to the Kirchhoff-Fresnel diffraction integral equation. Therefore, we may consider it as one kind of hologram.

The object distribution function $g(x_0, z_0)$ can be recovered by an inverse convolution integral after multiplying the complex conjugated function h* by U.

$$g(x_0, z_0) = \int_{-\frac{L}{2}}^{\frac{L}{2}} U(x, z_0)\, h^*(x_0 - x, z_0)\, dx \qquad (7)$$

L in eq(11) is the antenna-scan width in the scanning direction. This equation is the basis for the synthetic aperture FM-CW radar principle.

3. Antenna

The flat frequency characteristics is the most important for the FM-CW radar system. The radar antenna plays an important role for the system. Since low and wideband frequency antenna is required,we have chosen a ridged horn as a radar antenna because of its wideband characteristics. We have decided to it operate from 250 MHz to 1 GHz so that the antenna can be used in an actual operation. Fig.2 shows the return loss of an explored antenna placed at 30 cm above a sandy ground. Nominally, 10 dB return loss is obtained throughout the 380 - 850 MHz range. The aperture size is 60 × 48 cm.

4. Field Experiment and Signal Processing

(A) Matching

Since the FM-CW radar utilizes a wideband signal, it is extremely difficult to match the impedance between the antenna and a ground surface over the entire frequency region. In addition, the radiated field in this problem is close to so-called "near field". Therefore, we took a magnitude of spectrum due to a fixed target as a measure of matching factor and measured it by varying the spacing between the antenna aperture and the ground surface. Fig.3(a) shows the experimental scheme. Both the transmitting and the receiving radar antennas were moved at 2 cm intervals from 10 up to 50 cm above the surface. At each interval, it is possible to extract the strength due to a single target (a metallic plate of 30 cm × 100 cm). The detected strength is shown in Fig.3(b) as a function of spacing interval. It is seen that the spacing of 30 cm provides the maximum detection strength. At this spacing, the impedance matching seems to be optimized for the entire operating frequency bandwidth. The detected strength varies as much as 16 dB. Thus, the spacing between antenna and ground surface is found to be an important factor for detection operations. It should be noted that the optimum spacing interval may change at a different experimental situation.

(B) Detection result and signal processing

Using the spacing of 30 cm, a detection measurement was carried out. The target is the same metallic plate used in the matching. It was buried in a sandy ground at the depth of 30 cm. The antenna-scanned length was 128 cm with an incremental length of 2 cm which produced 64 raw data. Fig.4(a) shows the magnitude of the spectrum (real aperture detection image) of the plate by a quasi-gray scale, with black indicating strong reflection. The horizontal axis corresponds to the scanned length, while the vertical axis corresponds to the radar detection range. This radar range is calibrated by an estimated permittivity of 4.62, which is derived after the measurement taking account of free space propagation path. It is seen that the target is well detected by the radar, although there are some reflections due to medium inhomogeneities.

Synthetic aperture processing yields the target image of Fig.4(b). The resolution in the horizontal direction is improved by this technique. The improvement factor at 30 cm depth was found to be 2 by checking the detected profile according to 3-dB width evaluation. In order to suppress clutter in synthetic aperture image, we examined a method of averaging and subtracting. The algorithm of method[8] is :

1) average the value of column data at a certain depth in a synthetic aperture image,
2) transform the original data at that depth into a new one after subtracting the averaged value from the original one,
3) re-normalize the new data.

The resultant images of a metallic plate and a pipe of 10 cmϕ are shown in Fig.5(a) and (b), respectively. This method renders the target image clear, suppressing noise, although it seems to be effective only for a horizontally homogeneous medium.

5. Conclusion

Two ridged horn radar antennas operative in the frequency range of 250-1000 MHz were employed for underground FM-CW radar detection. The impedance matching to the ground was optimized by measuring the detection strength from a fixed target as a function of the spacing interval between the antenna aperture and the ground surface. The fact that the detected strength varied as much as 16 dB in the experiment indicates the importance of the spacing interval between antenna and surface. It was possible to detect a metallic plate (30 × 100 cm) and a pipe (10 cmϕ) buried at the depth of 1.2 m with an output power of 18 dBm. The synthetic aperture processing together with an averaging and subtracting method produced fine target images, suppressing noise in the sandy ground. It will be possible to detect underground targets by FM-CW radar.

Acknowledgement

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References

(1) I. Arai and T. Suzuki, "Advance on underground radars", *IEICE Trans.*, vol.E74, no.2, pp.289-294, Feb. 1985.

(2) Y. Michiguchi, K. Hiramoto, M. Nishi, T. Ootaki and M. Okada, "Advanced subsurface radar system for imaging buried pipes", *IEEE Trans. Geosci. Remote Sensing*, vol.26, 6, pp.733-740, Nov. 1988.

(3) K. Tezuka and A. Nagamune, "A highly sensitive cross bore-hole radar by M-seq. signal processing", in *Proc. of the 2nd Workshop on Subsurface Electromagnetic Measurements*, pp.117-122, Dec. 1992.

(4) I. Arai, Y. Tomizawa, and T. Suzuki, "Pulse compression subsurface radar using delay correlator", in *Proc. of the 2nd Workshop on Subsurface Electromagnetic Measurements*, pp.111-116, Dec. 1992.

(5) M. Sekine, *Radar Signal Processing Technology*, IEICE, Tokyo, 1991

(6) Y. Yamaguchi, M. Mitsumoto, A. Kawakami, M. Sengoku and T. Abe, "Detection of objects by synthetic aperture FM-CW radar", *IEICE Trans.*, vol J74-B-II, no.7, pp.413-420, July 1991.

(7) Y. Ishizuka, Y. Yamaguchi, M. Sengoku, "Field distribution in snowpack by boundary element analysis", *Technical Report of IEICE*, AP92-99, Nov. 1992.

(8) Y. Yamaguchi, Y. Maruyama, A. Kawakami, M. Sengoku, and T. Abe, "Detection of buried objects in wet snowpack by an FM-CW radar", *IEEE Trans. Geosci. Remote Sensing*, no.29, pp.201-208, Mar. 1991.

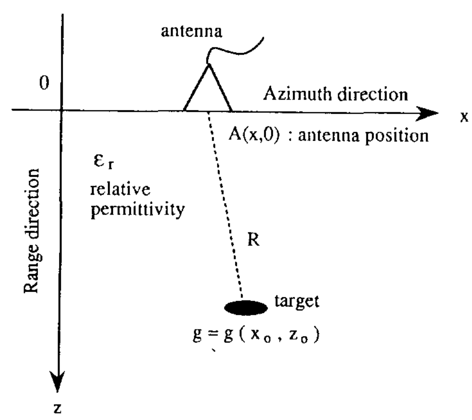


Fig.1 Location of radar and target in a medium with ε_r.

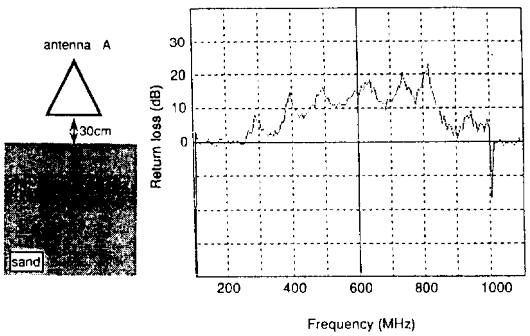
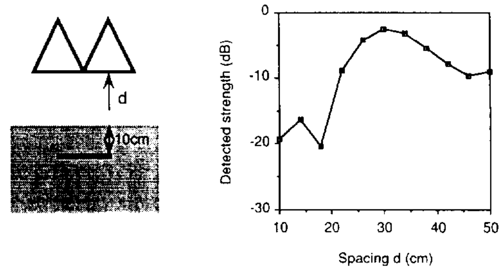
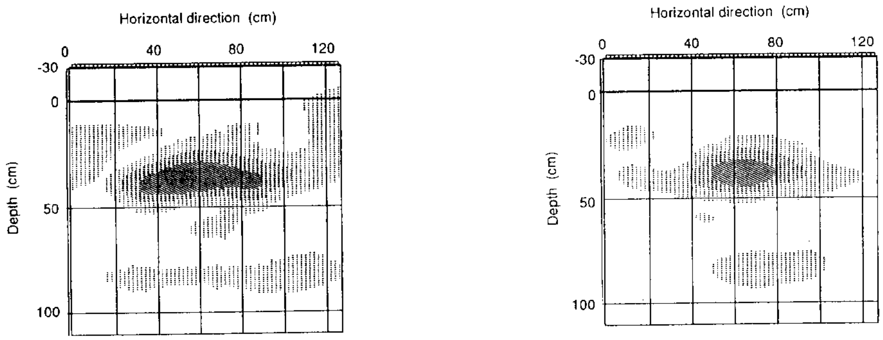


Fig.2 Return loss of a ridged horn antenna.



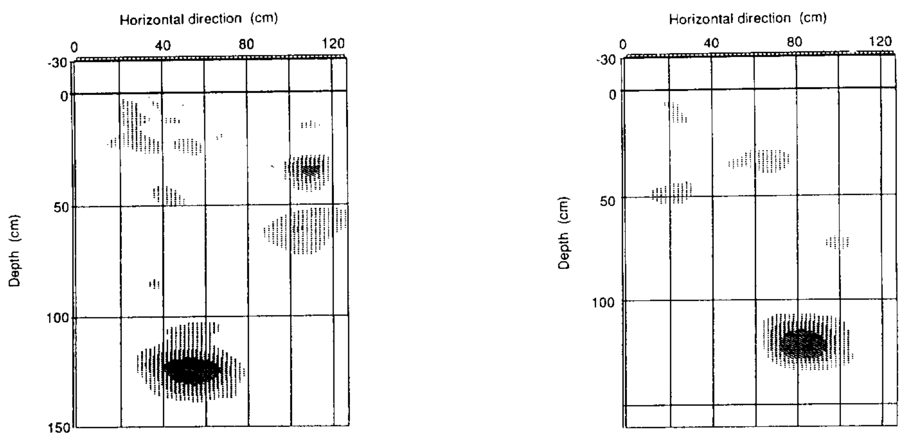
(a) Experimental scheme (b) Detected strength

Fig.3 Detection strength as a function of spacing.



(a) Real aperture image (b) Synthetic aperture image

Fig.4 Detection result of a metallic plate at 30 cm deep.



(a) a metallic plate (30 cm × 100 cm) (b) a pipe (10 cmϕ)

Fig. 5 Detection image at 120 cm deep by a method of averaging and subtracting.