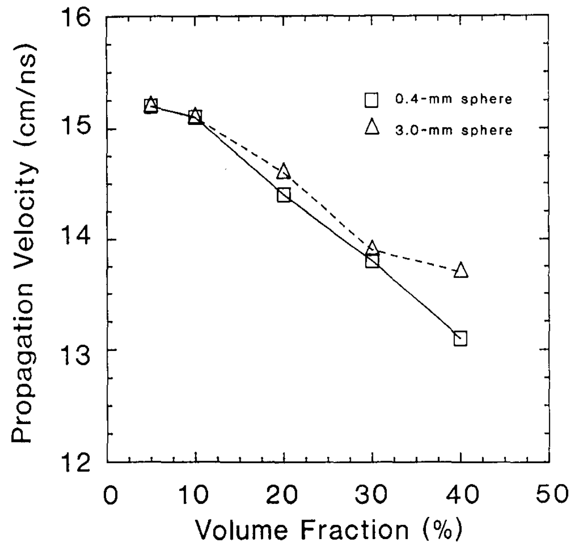

Fig. 3. Propagation velocity as a function of sphere volume fraction. Each marker represents the average velocity obtained from five different samples.

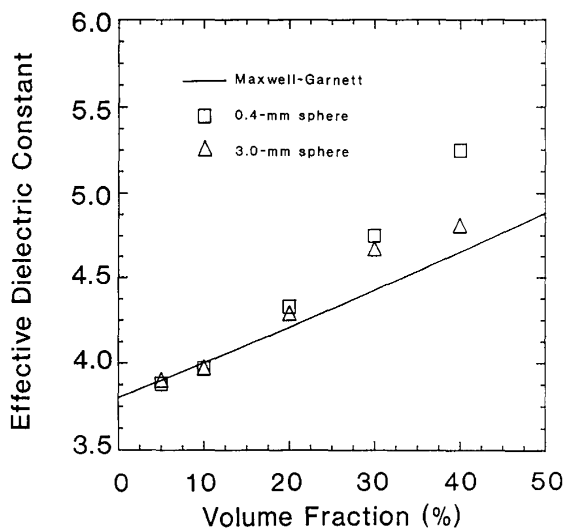

Fig. 4. Effective dielectric constants obtained from propagation velocities using (3).

becomes apparent. At volume fractions of 0.2 and 0.3, the effective dielectric constant for the 0.4 mm sample is slightly higher than that of the 3.0 mm sample. At the 0.4 volume fraction, the effective dielectric constant of the 0.4 mm mixture is significantly greater than that of the 3.0 mm mixture. It is interesting to note that for the sizes of spherical inclusions used in this report, the Maxwell-Garnett theory was able to predict more accurately the effective dielectric constant of the larger sphere mixture.

The experimental results presented in this paper suggest that the range of validity of the Maxwell-Garnett theory is limited. Additional experiments are required to provide more conclusive evidence on the limitations of the Maxwell-Garnett theory. This can be accomplished by using a wider range of particle sizes and a wider range of dielectric contrasts between the spherical inclusions and the host medium. Such experiments should also provide the necessary information to evaluate the validity of higher order approximations for predicting the effective dielectric constants of sphere mixtures in the size and volume fraction ranges where the Maxwell-Garnett theory is no longer applicable.

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Human Body Detection in Wet Snowpack by an FM-CW Radar

Yoshio Yamaguchi, Masashi Mitsumoto, Masakazu Sengoku, and Takeo Abe

***Abstract*—An FM-CW radar system was applied to detect a human body buried in a very wet snowpack. This radar uses the *L*-band microwave frequency with a maximum output power of 100 mW, and utilizes digital signal processing techniques. Field experiments were carried out to detect and map a human body embedded at a depth of 125 cm in a natural snowpack. The radar is shown to have a potential ability in detecting avalanche victims, indicating that it may become a tool for snow rescuer operations.**

I. Introduction

There is an urgent need to detect objects buried in snow in regions with heavy snowfall. The most important object is a human body that has encountered an avalanche (avalanche victim). Ordinarily, avalanche victims are buried in snowpack within, at most, a few meters. The conventional detection method relies on a man-operated

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TABLE I
SPECIFICATION OF THE FM-CW RADAR

Frequency	1.1–2.2 GHz
Antenna	Rectangular Horn
Aperture	40 × 32 cm
Maximum power of generator	100 mW
Sweep time	5.2 ms
Range resolution	5.5 cm in the air
Sensitivity at mixer input	−42 dBm
Controller	32-b personal computer
Number of sampling points in the frequency domain	512

Rammsonde-bar [1] which utilizes a force reaction to detect bodies stuck into a snowpack from the surface, or a dog nose. To improve these detection methods efficiently or to explore an alternative way is highly important and a demanding matter in snow rescuer operations. The use of microwave subsurface radar seems the most likely answer to this kind of detection problem.

This letter presents a fundamental detection result of a human body buried in a very wet snowpack by a real aperture FM-CW radar. The FM-CW radar has potential ability in measuring precise distance in shallow region [2]. In the following, the FM-CW radar system and the results of the field experiment are described, indicating that it is possible to detect an avalanche victim by the explored FM-CW radar system.

II. FM-CW RADAR

The fundamental principle of FM-CW radar system is the relation between target distance R from radar and beat frequency f_b.

$$R = \frac{c}{2\sqrt{\epsilon_r}} \frac{\Delta t}{\Delta f} f_b \tag{1}$$

where, R: distance, c : 3×10^8 m/s, f_b: beat frequency,
Δt: sweep time, Δf: sweep frequency,
ϵ_r: relative permittivity of intervening medium.

It is possible to determine R if the relative permittivity of the intervening medium (snow) and the beat frequency are known [2]. In our radar system, the beat frequency is determined by fast Fourier transformation (FFT) of the time domain beat signal. The block diagram of the FM-CW radar is shown in Fig. 1, which is a modified version of that in [2]. We added a receiving antenna in order to suppress a conversion loss at a directional coupler. A system clock triggers a saw-tooth wave generator which drives a sweep oscillator. The oscillator generates a frequency-modulated continuous wave (1.1–2.2 GHz) at a 5.2-ms interval. The microwave signal is divided into two parts by a directional coupler (nominal−10 dB coupling): One is used as a reference signal at a double balanced mixer, and the other is transmitted through a rectangular horn antenna. A backscattered wave from the target at a receiving antenna is mixed with the reference signal at the mixer, producing a beat frequency. Then the beat signal is amplified and reshaped in the preprocessing analog circuit and finally is converted to digital signals in the personal computer system where the required signal processing such as FFT operations, graphic display, and system controls is executed. This signal processing, especially 512 point FFT, is executed quite fast (less than 5 ms) in a newly equipped Digital Signal Processing Board. The total time needed for one radar display routine is approximately 100 ms. The FM-CW radar system specification is listed in Table I.

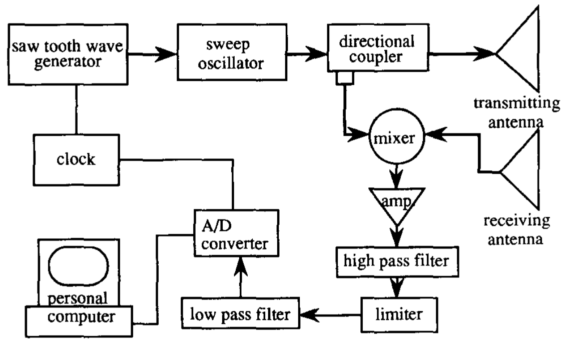


Fig. 1. Block diagram of the FM-CW radar.

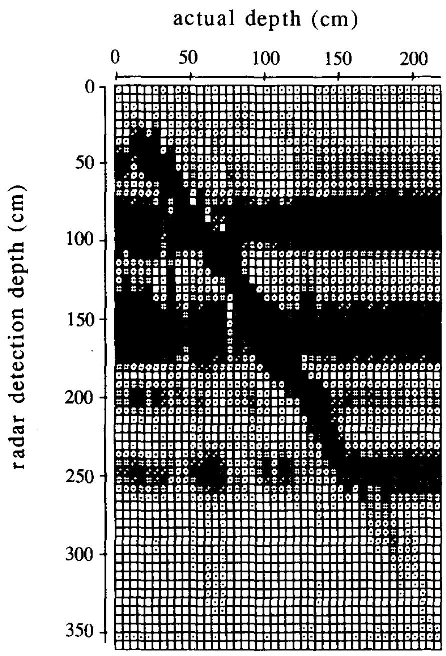


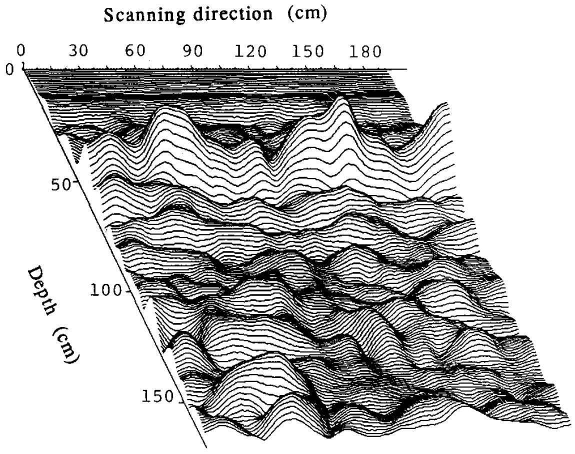
Fig. 2. Radar detectable range of a 5 × 100 cm metal plate in the snowpack.

III. FIELD EXPERIMENT

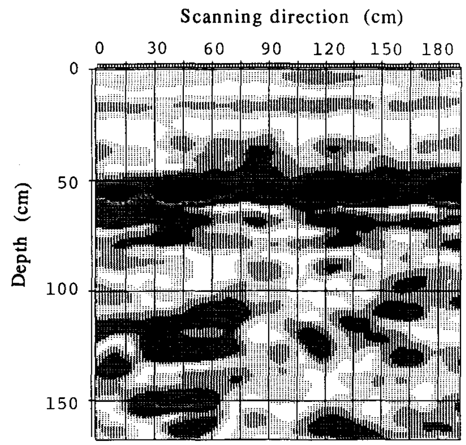
The field experiment was carried out on March 5–8, 1991 at Yamakoshi Village, Niigata Prefecture, Japan. We had a 2.3-m deep snowpack on road shoulders (see Fig. 4(c)). As mentioned in [3], the microwave attenuation in snowpack determines the maximum range at which radar can detect target. The sounding capability of the radar is dependent on the dielectric property of snow [3]–[5] and target size. Thus, in order to check the radar performance to this snowpack, we carried out two field experiments. The first one was aimed at checking range performance in snowpack, and the other, at detection of an avalanche victim.

A. Range Performance

Using a 5 × 100 cm metallic plate as a target and employing the same procedure [2], we checked the sounding capability in the snowpack. This snowpack has undergone refreezing and melting cycle repeatedly coupled with rain fall. Fig. 2 shows the detection result,

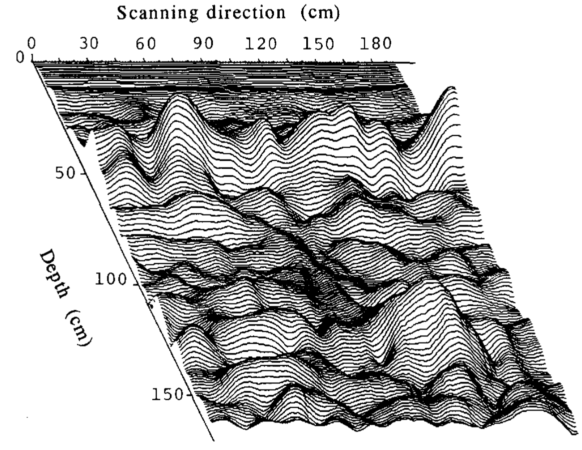


(a)

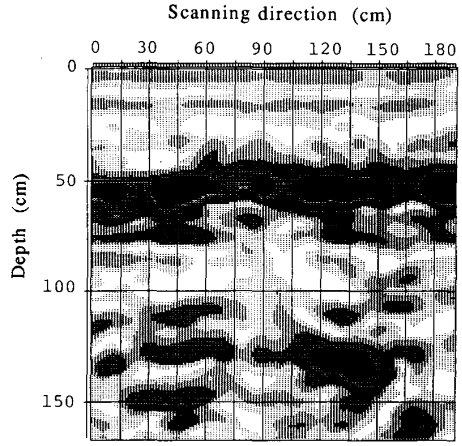


(b)

Fig. 3. Radar echo from wet natural snowpack. (a) Three-dimensional display of the beat spectrum. (b) Two-dimensional gray scale representation of (a).



(a)



(b)

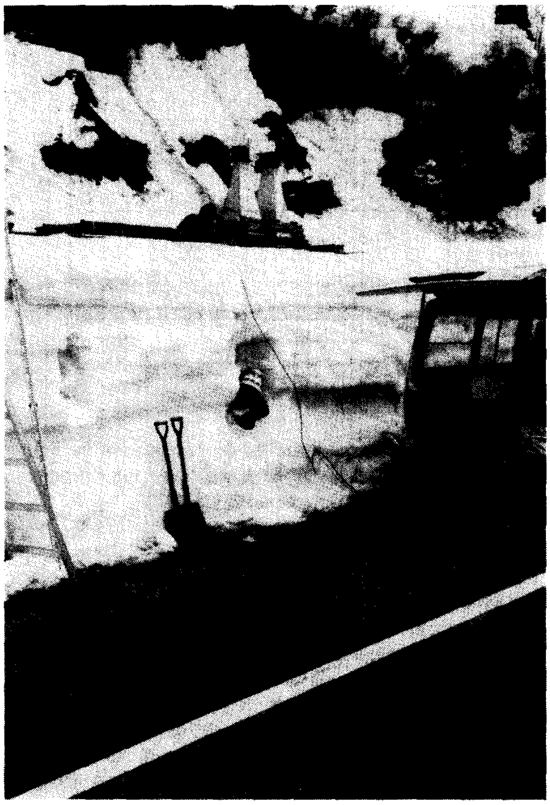
Fig. 4. Detection of human body in the snowpack. (a) Three-dimensional display of the beat spectrum. (b) Two-dimensional gray scale representation of (a).

where the horizontal axis represents the actual target depth from the surface and the vertical axis is the depth measured by the radar. Nine uniformly spaced gray-scale levels have been used to cover the entire magnitude range with black, indicating strong reflection. Once the target depth by the radar in snowpack is obtained, it is possible to determine the average permittivity of the snowpack, and to calibrate the radar range according to (1). Since the snowpack consisted of very wet snow multilayers, it was difficult to determine the permittivity of each layer. The average water inclusion in the snowpack was approximately 5–6% and snow density was 0.4–0.6 g/cm^3, which resulted in the average calculated permittivity to be 2.5–2.9 [4]. On the other hand, the permittivity obtained from this range detection measurement was found to be 2.5 for this snowpack. Therefore, we employed $\epsilon_r = 2.5$ in the range equation (1). From this figure it is expected to detect targets larger than the plate at least 1 m depth.

B. Body Detection

Both the transmitting and receiving antenna were scanned together from 0 up to 190.5 cm in the horizontal direction over the snow surface. The scanning interval was chosen to be 1.5 cm. First, a radar echo from natural snowpack (i.e., with no object inside) was obtained. The three-dimensional display of the echo by antenna scanning is illustrated in Fig. 3(a), where the height corresponds to the normalized beat signal magnitude which is proportional to the magnitude of the scattered wave, the horizontal axis corresponds to the scanned width (190.5 cm), while the oblique direction indicates the range (snow depth). It is seen there are many mountain peaks (clutter) due to dielectric discontinuities, even though the snowpack seems homogeneous at a glance. Fig. 3(b) shows two-dimensional quasi-gray scale representation of Fig. 3(a). Nine uniformly spaced gray-scale levels have been used to cover the entire level with black, indicating strong reflection. One can see that there exists a strong reflection layer around 50–60 cm depth in the snowpack, which is actually a heavily wet Depth Hoar snow layer. And one can understand that a snowpack experienced refreezing and melting cycle repeatedly is highly inhomogeneous both in the vertical and in the horizontal direction.

Next, we dug a small horizontal hole where a person could be buried. The upper rim of the hole was 125 cm deep from the surface. One of the authors became an avalanche victim model. He lay



(c)

Fig. 4 (continued) (c) Photograph of experiment scene.

horizontally with his body parallel to the polarization direction of the transmitted wave. The same scanning procedure was carried out to detect him. The result is shown in Fig. 4, where (a) is the three-dimensional display corresponding to Fig. 3(a), while (b) is the two-dimensional quasi-gray scale representation of (a). One can clearly identify the body and the location at the depth of 125 cm in the snowpack from this figure. Fig. 4(c) is the photograph of the experimental scene. Even though the body was buried below the Depth Hoar layer, it was possible to detect and map it. This is due to the transmission characteristics of L-band microwaves in snowpack, and the permittivity difference between the human body and the snow, i.e., the human body permittivity is much larger than that of any snow, there always arises strong scattered wave. If we use higher frequency above the L-band, the transmission loss in snowpack degrades the sounding capability significantly, leading to no detection.

IV. Concluding Remarks

We have demonstrated the detection results of human body in a very wet natural snowpack by using an FM-CW radar operative in the 1.1–2.2 GHz frequency band. It was possible to map body buried at least 125 cm from the snow surface. This FM-CW radar is aimed at detecting an avalanche victim within snowpack. The very first requirement is to find buried objects accurately and quickly, i.e., to check the existence of body in the snow. The total time needed for each radar display routine was 100 ms, which would be enough in real time operation. Now we are developing synthetic aperture technique and polarimetric measurement for detection. The detection result by an advanced FM-CW radar system will be reported in the near future.

Acknowledgment

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Microwave Observations of Finite-Amplitude Water Waves

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Abstract—**The brightness contrasts at 20 GHz and 37.5 GHz frequencies from mechanically generated water waves with 8–40 cm length and 0.6–3.0 amplitude are investigated. The brightness contrast depends on the wave steepness and the wave profile geometry. A surface microwave model is developed using the Kirchoff approximation with the multimode surface slope distribution. Agreement between experiment and theory is found for the nonlinear Stokes waves with steepness $Ka \leq 0.25 - 0.30$.**

I. Introduction

The surface waves have a large influence on the ocean's microwave emission. The important disturbances are finite amplitude waves—short gravity and gravity-capillary waves, which are nonlinear [1]. The profile transformation of nonlinear waves causes redistribution of geometrical and statistical properties of the surface that results in microwave emission variations. It is obvious that this effect is weak. For its measurement a highly sensitive radiometer is necessary. For this purpose the superconducting Josephson contact radiometer can be used.

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