Study on microwave remote sensing applications to snow and ice monitoring for the winter road maintenance

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Abstract

The purpose of this research program is to investigate and clarify the microwave response from snow and ice in order to apply the results to development microwave sensor for road-surface condition monitoring of winter road maintenance operation. This paper introduces the outline of this research program briefly and summarizes the dielectric measurement of snow, one of the topics of this research, which was conducted in this November.

Keywords **:** Microwave remote sensing, Winter road maintenance, Dielectric measurement of snow and ice

1. Introduction

In Japan, the road maintenance in winter is very important for the safety and the effectiveness of the traffic, because approximately half of the highways are located in the cold and snowy areas. The essential monitoring activities are namely road surface conditions monitoring, as well as the ice and snow cover monitoring.

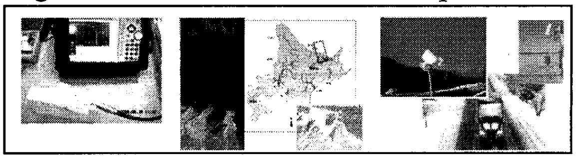
By utilizing the remote sensing technologies, the information of the road surface conditions over a wide area can be obtained without having any staffs on the road locations. Furthermore, by investigating "transmission", one of the characteristics of the electromagnetic wave, internal conditions of snow cover, volume distribution, structures of layers and snow-buried road surface conditions can be monitored. Microwave sensor, with its "transmission" properties, will complement the optical sensor in foggy or snowy situations, and the combination of both sensors will create a more powerful system.

The purpose of this research program is to investigate and clarify the microwave response from snow and ice in order to apply the results to development of microwave sensor for the road-surface condition monitoring of winter road maintenance operations.

2. Outline of research program

This research program consists of the following topics.

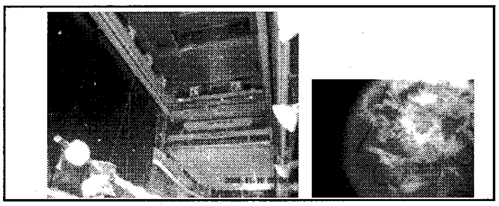
1) Fundamental research on microwave response from snow and ice. (See section 3.)
2) Development of a microwave sensor system to detect the snow and ice on road surface.
3) Development of a SAR data processing method to detect the snow and ice on road surface.
4) Designing practical applications of remote sensing to the winter road maintenance operations.



3. Topics: Dielectric measurements of snow with microwave free-space method

3.1. Introduction

To investigate the microwave response to snow, the dielectric measurements of snow by using microwave free-space method were conducted from 9th Nov. to 13th Nov. 2009 at the Snow and Ice Research Center (Shinjo, Yamagata), NIED. The measurements of artificial dry snow were made in the 4 to 6 GHz range. A linearly polarized wave obliquely incident on a surface was used. The incident angle of θ_i was 30 to 60 deg. Polarization mode were selected TE-mode and TM-mode. The temperature in the room was kept at -20C.



3.2. Methods

A permittivity value for a sample is estimated by comparing with the measured value of the reflection coefficient by network analyzer and the calculated value theoretically. The permittivity is the value which minimizes the delta calculated by following equation.

$$\Delta = \Sigma(\Gamma_{meas} - \Gamma(\varepsilon_r))^2 \qquad (1)$$

where Γ_{meas} is the measured value of reflection coefficient, Γ is the theoretical value and ε_r is the estimated value of permittivity of the snow sample.

This time, the reflection at upper surface of a sample is considered, and the theoretical value of the reflection coefficient is calculated the following equations.

The refection coefficient for TE-mode (HH) :

$$\Gamma_{TE} = \frac{cos\theta_i - \sqrt{\varepsilon_r - sin^2\theta_i}}{cos\theta_i + \sqrt{\varepsilon_r - sin^2\theta_i}}$$

The refection coefficient for TM-mode (VV) :

$$\Gamma_{TM} = \frac{\sqrt{\varepsilon_r - sin^2\theta_i} - \varepsilon_r cos\theta_i}{\sqrt{\varepsilon_r - sin^2\theta_i} + \varepsilon_r cos\theta_i}$$

where ε_r is relative permittivity of snow, θ_i is angle of incidence.

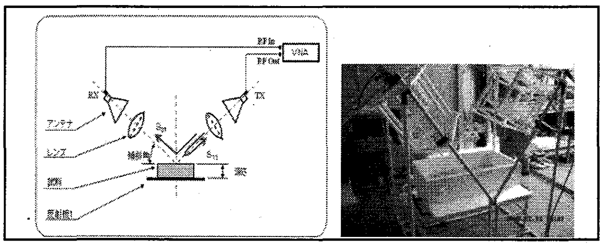
The density of sample was estimated by the following equation of an empirical model [1].

$$\varepsilon_r = \varepsilon'_r = 1.0 + 1.9\,\rho_s \qquad \text{for } \rho_s < 0.5\ [g/cm^3] \quad (4)$$

where ε_r is relative permittivity of snow, ρ_s is density of snow $[g/cm^3]$.

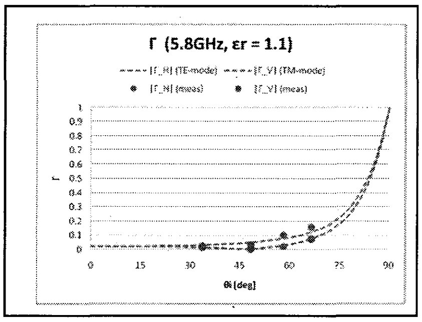
3.3. Measurement System

The measurement system consists of a network analyzer, by which reflection coefficients are measured as S11 and S11, and two antenna systems, horn antenna and dielectric lens, which emits microwave and receives. The block diagram of the system is shown in the following figure.



3.4. Example of measurement result

An example of the measurement result is shown in this section. The measured data of the reflection coefficients are shown in the following figure. Blue color means TE-mode and red means TH-mode. The dashed curves are theoretical values when the relative permittivity is 1.1 and the density of snow calculated by the empirical model is 0.053 [g/cm3]. It seems to give good estimation because that the average measured density of the sample was 0.065 $[g/cm^3]$.



4. Conclusion

This year, the following items have been conducted:

1) A number of experimental researches on the characteristics of propagation and scattering of microwave against snow and ice, e.g. measurements of reflection from snow and ice.

2) The performance evaluations of the C-band antenna designed for the sensor.

3) Examination and discussion of the method (multi-polarization SAR) applied for detecting the snow and ice.

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References

1) M.T. Hallikainen et al., "Dielectric Properties of Snow in the 3 to 37 GHz Range".