RECENT DEVELOPMENTS OF SNOW MOISTURE DIELECTRIC DEVICES [1]

A. Denoth and A. Foglar [2]

Abstract. Dielectric measuring methods of the liquid water content make use of the substantial difference between the permittivities of dry snow and water. Different types of snow moisture meters, designed to fit for practical measuring situations, have been developed and tested: A plate condenser, a cylindrical condenser and a monopole antenna are used as sensors to measure the mean water content in a comparable large snow volume; differently shaped flat condensers are used as sensors for measuring the wetness in thin layers. Snow wetness is derived from the corresponding permittivities and snow density. By the measurement of both the permittivity and the loss factor, the destructive measurement of snow density may be avoided. For this purpose, a special sensor (U-guide) with an operating frequency in the microwave regime will be tested in the next future.

INTRODUCTION

Most of the physical characteristics of a snow cover are related to the amount and the type of distribution of liquid water. Field tests on mechanical properties show an interrelation between shear-strength, density, hardness and bulk water content (Brun and Rey 1986); water content and distribution in the topmost snow layers are important for remote sensing studies in the centimeter- and millimeter-wave regime (Hallikainen 1986).

The most promising way for the determination of snow wetness is the measurement of the dielectric constant at radio or microwave frequencies (Denoth et al. 1984). In this paper new developments of volume sensitive and surface sensitive dielectric snow wetness sensors are presented.

THE DIELECTRIC SENSORS

Two types of sensors for measuring the dielectric constant of snow have been developed: volume sensitive sensors and surface sensitive sensors. Volume sensitive sensors are the plate condenser, the cylindrical condenser and the monopole antenna. The surface sensitive sensors consist of an arrangement of differently sized and shaped coplanar conducting stripes; they can be considered as the two-dimensional analogon of plate condensers. These flat dielectric sensors allow the nearly non-destructive measurement of the permittivity of a snow surface (half-space measurements) and, by inserting the sensor in snow (full-space measurement), the measurement of the mean permittivity of a small snow volume.

The Volume Sensitive Sensors

The Plate Condenser

The plate (air-gap) condenser consists of 7 parallel stainless steel plates, 10 x 13cm^2, of alternate polarity. The spacing of the plates is 2.1 cm, the thickness is 3mm, the total measuring volume is 1638 cm^3 and the effective measuring capacity in air (ε = 1) is 41 pF. This sensor is operated at a frequency of 20MHz; it can be used, however, for measuring frequencies up to 50MHz.

The Cylindrical Condenser

The cylindrical condenser consists of two coaxial cylinders with diameters of 4.0 and 9.6 cm, respectively. The length of the cylinders is 12.6 cm, the total measuring volume is 754 cm^3 and the effective measuring capacity in air (ε = 1) is 7.5 pF. This cylindrical dielectric sensor can be used for measuring frequencies up to 80 MHz.

The Monopole Antenna

To allow the measurement of a wide range of permittivities, two short monopole antennas, 4.1 mm thick, with different lengths of 9.06 cm and 17.15

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centimeter, respectively, can be mounted in the center of a large aluminium disc of 26.4 cm diamter. The resonant frequency in air is 420 MHz (long antenna) and 810 MHz (short antenna). The shift in the resonant frequency when the antenna is imbedded in snow (with the reflector plate lying on the snow surface) is a measure of snow permittivity (Aebischer 1983). This sensor allows a nearly non-destructive measurement of the mean dielectric constant in a volume of approximately 1700 cm^3 or 3000 cm^3, given by the dimensions of the reflector disc and the actual length of the antenna. A block diagram of the sensor electronics for the determination of snow permittivity with these sensors is given in figure 1.

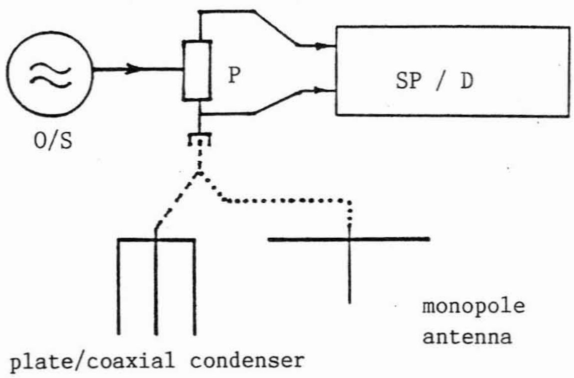

Figure 1. Block diagram of the electronics for the volume sensitive dielectric sensors. O/S oscillator or sweeper, P power splitter, SP/D signal processing and display unit.

Snow dielectric constant is calculated from the measured impedance or the reflection coefficient of the sensors. A typical response of the monopole antenna applied to air (ε = 1) and to wet Alpine snow (ε = 4.25) is shown in figure 2.

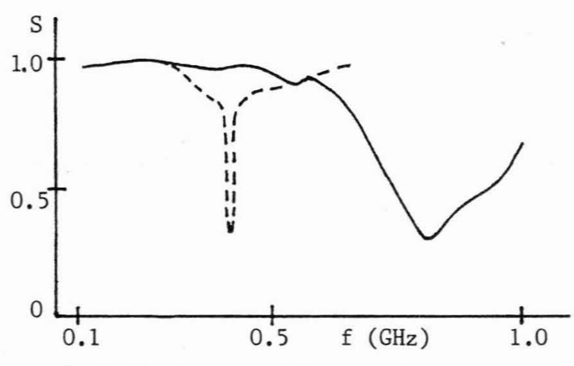

Figure 2. Reflection coefficient S of the monopole antenna in air (solid line) and in wet Alpine snow (broken line) measured in the frequency range of 100 MHz up to 1 GHz.

The Surface Sensitive Sensors

For the special case of measuring snow permittivity (water content) in thin layers, comb-shaped condensers consisting of two or more coplanar conducting stripes have been developed and tested extensively in the last years (Ambach and Denoth 1980; Denoth and Foglar 1985). The geometry and dimensions of one of these sensors is shown in figure 3. Two pairs of stripes can be operated alternatively by the switches S_1 and S_2; this allows the measurement of the dielectric properties in two different layers extending from the surface to 2cm depth, and from 2cm to 4cm depth without disturbing the snow cover. In this respect, this special sensor, which is operated at 27 MHz, is both surface and volume sensitive.

The geometries of the recently developed flat dielectric sensors, shown in the figures 4a and 4b, have been designed to allow a nearly non-destructive measurement of the dielectric profile of a snow cover with a fine spatial resolution. The spatial resolution depends only on the spacing (s) and width (d) of the strip lines; it is approximately 3 cm for the dimensions given in figure 4a. Figure 4b shows a sensor geometry given by a concentric arrangement of conducting stripes which allows an easy connection to a coaxial cable for remote operation. In addition, this geometry allows operation frequencies in the VHF / UHF frequency regime.

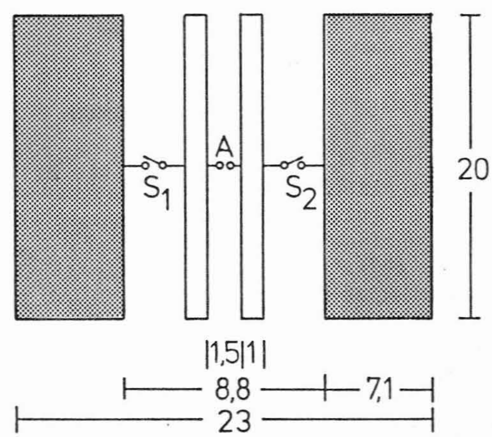

Figure 3. Geometry of the flat sensor for the non-destructive measurement of the dielectric constant of snow in two depths of 2cm and 4cm. The dimensions are given in centimeters.

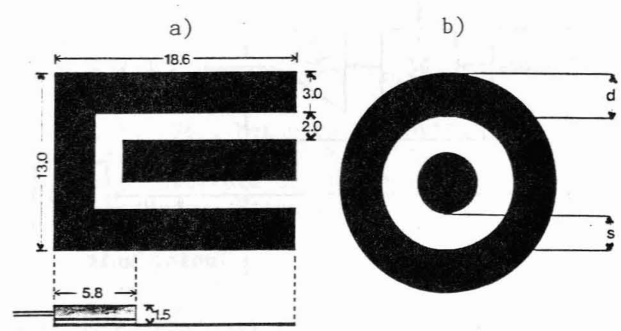

Figure 4. Comb-shaped (a) and coaxial (b) arrangement of conducting stripes for flat dielectric sensors with a fine spatial resolution. The dimensions are given in centimeters; d means the width and s the spacing of the strip lines. s and d are 2 cm for the ring-shaped sensor.

The flat construction of these sensors allows two different applications: a full-space mode (fig.5a) by inserting the sensor in a snow cover and a half-space mode (fig. 5b) by putting the sensor on a snow surface. The half-space mode gives the dielectric constant at or near the snow surface, averaged over an area of 13 x 19 cm^2; the response of the sensor in the full-space operation mode is a mean dielectric constant of a snow volume given by the effective sensor area of 13 x 14 cm^2 and a measuring depth extending 1.5cm on both sides perpendicular to the sensor plane.

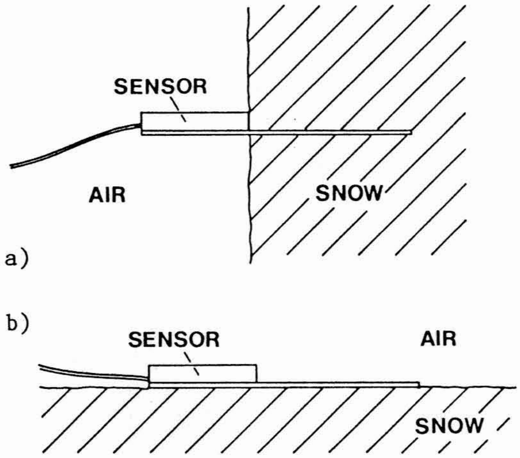

Figure 5. Application modes of the flat dielectric sensors: a) full-space measurement, b) half-space or surface measurement.

The measurement device consists of two parts: the sensor unit and the tuning and display unit. This allows an easy handling during field measurements. A block diagram of the sensor electronics is given in figure 6. The sensor electronics - twin-T-bridge, oscillator and down-converter - are mounted on the sensor plane and protected by a PVC cover. A photograph of the instrument is shown in figure 7.

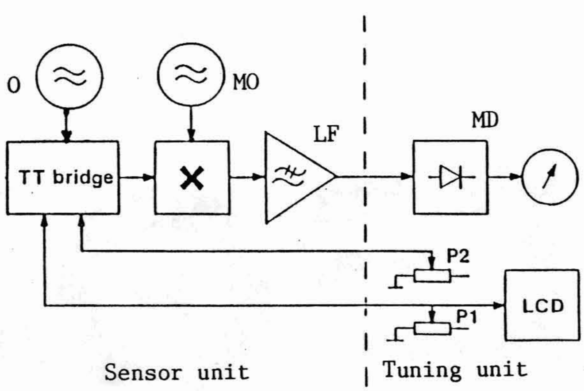

Figure 6. Block diagram of the electronics for the surface sensitive flat dielectric sensors. O oscillator, MO mixer oscillator, X mixer, LF low-pass filter, MD minimum detector, P_1, P_2 tuning potentiometers, LCD liquid crystal display.

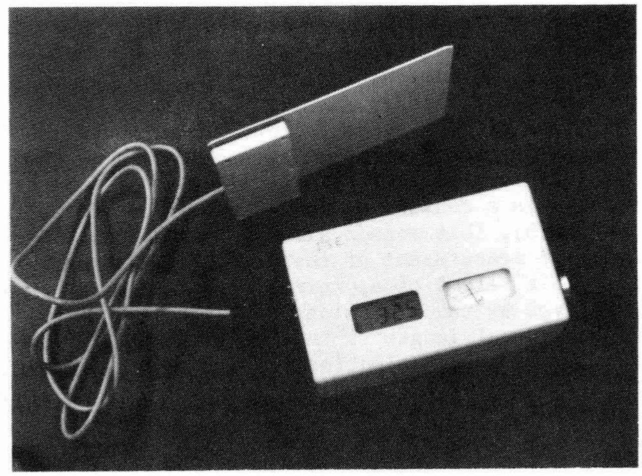

Figure 7. Photograph of the flat sensor and the tuning and display unit.

SNOW WETNESS DETERMINATION

The different sensors described above allow the measurement of the dielectric constant of snow in specific frequency ranges within 10MHz and 1GHz. Neglecting the effects of liquid water distribution on the high frequency relative permittivity (Denoth 1980) liquid water content W (in % by volume) can be calculated from ε and the density ρ of snow (Foglar and Denoth 1986):

$$\varepsilon = 1 + 1.92\rho + 0.44\rho^2 + 0.187W + 0.005W^2$$

W means the mean water content in a snow volume given by the geometric properties of the sensor used. When gradients in liquid water distribution occur in a snow cover, the different sensors may show different values of water content due to their different spatial resolution. Comparative measurements with the plate condenser, the flat condenser (cf. fig.3) and a freezing calorimeter during a field situation where large water gradients occured are shown in the figures 8a and 8b.

The Austrian snow wetness measurement set is shown in figure 9. It consists of a flat dielectric sensor connected to a tuning and display unit, a spring balance and a 500cm^3 plastic tube for snow density determination and a magnifying glass and a scaled metal plate for snow particle characterization.

CONCLUSION

Test measurements in the natural snow cover, where considerable local differences in water content and water distribution may occur, show the special properties of the different sensors: a fine spatial resolution needed for the detection of water gradients, is only given by the flat dielectric sensors; plate condenser, cylindrical condenser and the monopole antenna show a mean water content averaged over a comparable large snow volume. The measurement of the dielectric constant of snow with the plate and the cylindrical condenser is destructive; the measurements with the monopole antenna and the flat sensors are nearly non-destructive. With respect to the

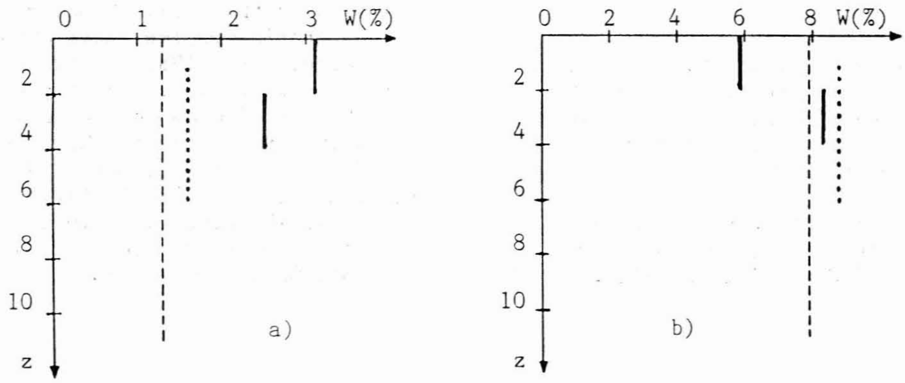

Figure 8. Comparative snow wetness measurements. Figure 8a shows the measurements during a negative wetness gradient, figure 8b shows the measurements during a positive gradient in wetness near the snow surface. Solid line: flat sensor (cf. fig.3); broken line: plate condenser, it averages over a depth of approximately 11cm; dottet line: freezing calorimeter. W is the water content in % by volume, z is the depth in centimeters.

need of a measurement of snow density, the determination of snow wetness with all these sensors is still destructive.

Measurements of the dielectric loss factor at microwave frequencies (Tiuri et al. 1984), however, indicate that the separate determination of snow density may be avoided. So, water content and density can be obtained by dielectric measurements alone: at microwave frequencies permittivity and dielectric loss increase with water content and density. For this purpose, a special dielectric sensor in the form of an u-shaped fence guide - a modification of the H-guide (Benson and Tischer 1984) - is under construction. A schematic view of this sensor is given in figure 10. This sensor will be operated in the 5 to 10 GHz frequency regime. Due to the thin and wide-spaced wire grid, the measurement of the dielectric properties of snow will be nearly non-destructive.

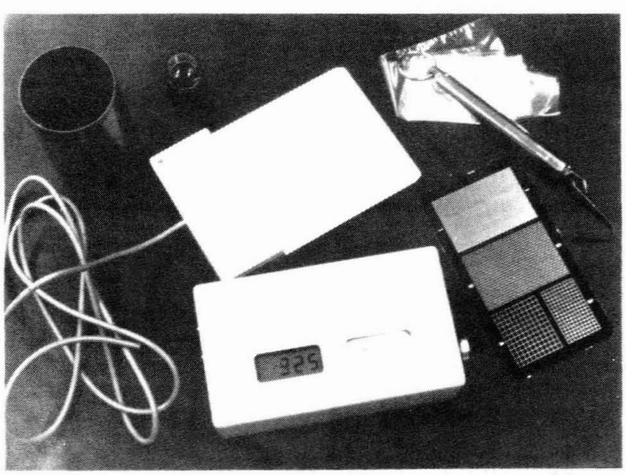

Figure 9. The Austrian snow wetness measurement set. Flat dielectric sensor, spring balance and plastic tube, magnifying glass and a scaled metal plate.

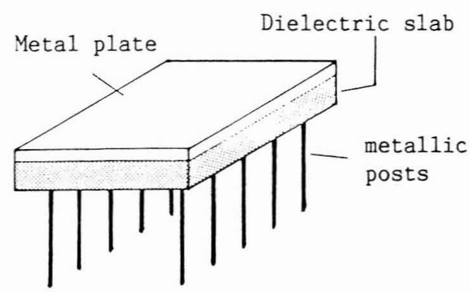

Figure 10. Schematic view of the u-shaped fence guide for the measurement of the complex permittivity of snow at microwave frequencies.

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