LIQUID WATER DISTRIBUTION AT THE SNOW-SOIL INTERFACE

Denoth A., Eller J., and A. Gschnitzer
Institute of Experimental Physics, University of Innsbruck, A-6020 Innsbruck
Phone: (#43) 512-218-6317; Fax: (#43) 512-218-2921

ABSTRACT

Hydraulic permeability changes drastically at the snow-soil interface and this affects significantely the amount and distribution of liquid water in the adjacent regions. Snow wetness has been measured using flat (plate-like) capacitive sensors with a spatial resolution of ±1.3 cm; the water content in the soil has been determined using a recently developed capacitive sensor with a fork-like geometry. This new wetness sensor can easly be inserted even in compact and hard types of soils. The spatial resolution of the soil wetness sensor is approximately ±1.5 cm; wetness is measured in a volume of ≈ 50 cm^3. In order to be more or less independent on the type of soil, a relative high frequency of 32.0 MHz for sensor operation has been selected. At this high frequency a simple relation between volumetric soil wetness and dielectric permittivity has been found experimentally, whereby soil wetness has been measured using the standard thermo-gravimetric method. The snow wetness sensors, however, are operated at a frequency of 20.0 MHz. Measurements of high-resolution vertical profiles of snow and soil wetness and wetness gradients near the snow-soil interface are reported.

INSTRUMENTATION

An intercomparison of snow or soil liquid water measurement techniques and the analysis of error surfaces shows that the smallest measurement errors under field conditions can be achieved by the dielectric method: $\Delta W < 0.6\%$ (Denoth, 1994a). The direct measurement quantity is the dielectric permittivity; it is measured using a capacitive sensor operated by a twin-T-bridge. Basically, the dielectric function of porous grainy materials depends on texture properties, on the intrinsic dielectric properties and volume fractions of the components and on the amount of liquid water present. So, measurement frequency has been selected to minimize the effects of snow or soil texture properties, to reduce the influence of snow or soil ionic conductivity and to make liquid water content the dominant parameter: 20 MHz for snow wetness measurements and 32 MHz for soil wetness detection, respectively (Denoth, 1994b; Gschnitzer and Eller, 1994). Sensor geometry has been optimized for the specific applications: a flat plate-like sensor for water detection in snow, and a fork-shaped sensor for water detection in soils. Sensor geometries with the appropriate dimensions in millimeters are given in Fig.1 (snow wetness sensor) and Fig.2 (soil wetness sensor), respectively. The fork-like shape of the soil sensor allows an easy insertion in soft and compact and hard types of soils. The spatial resolution is approximately ±1.5 cm; the measuring volume is ≈ 50 cm^3 (soil sensor) and ≈ 180 cm^3 (snow sensor), respectively. The capacitive sensors are connected to the tuning and display unit by a multi-wire cable whereby the length of the cable can be up to 5 meters. A detailed description of sensor electronics together with appropriate data for the twin-T-bridge (20 MHz version) is given in Denoth (1994b).

Calibration of the wetness sensors has been performed in the field under natural conditions using standard methods: a freezing calorimeter for snow wetness calibration and the thermo-gravimetric method for soil wetness calibration. Snow and soil wetness calibration data are given in Fig.3, whereby snow/soil incremental permittivity is plotted against liquid water content. The incremental permittivity $\Delta\varepsilon$ depends only on the volume of the liquid water component and is defined as: $\Delta\varepsilon = \varepsilon(\text{wet}) - \varepsilon(\text{dry})$, whereby $\varepsilon(\text{dry})$ is the dielectric function of dry snow or dry soil with the same porosity. The relation between snow or soil incremental permittivity $\Delta\varepsilon$ and water content W (in percent by volume) found experimentally reads as:

$$\Delta\varepsilon(\text{snow}) = 0.186\ W + 0.0045\ W^2 \qquad f = 20\ \text{MHz}$$
$$\Delta\varepsilon(\text{soil}) = 0.518\ W + 0.0054\ W^2 \qquad f = 32\ \text{MHz}$$

whereby a significant influence of the type of soil or snow (stage of metamorphism) has not been observed.

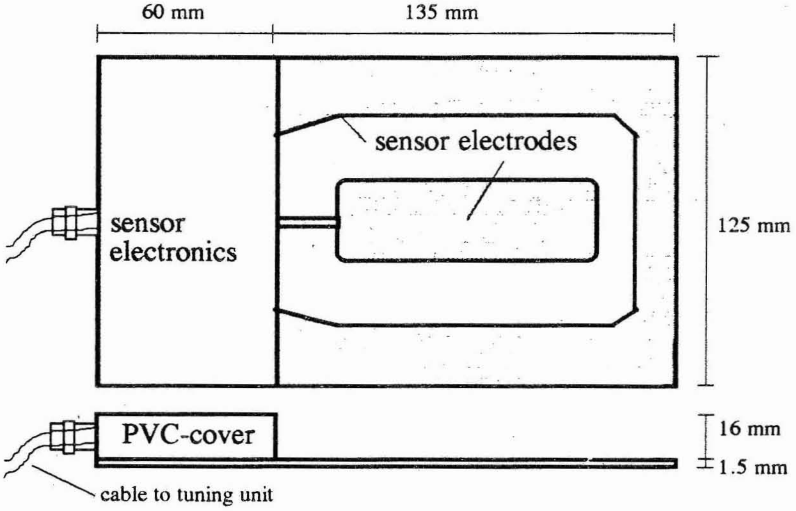

Fig. 1 Geometry and dimensions of the snow wetness sensor

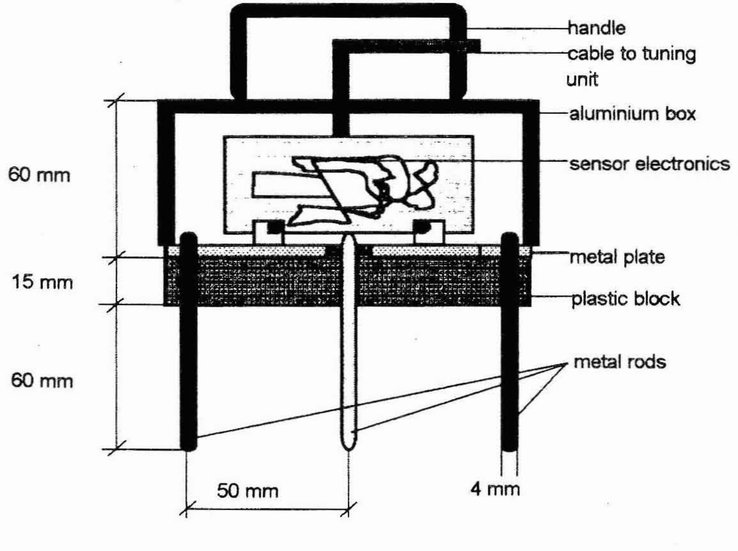

Fig. 2 Geometry and dimensions of the soil wetness sensor.

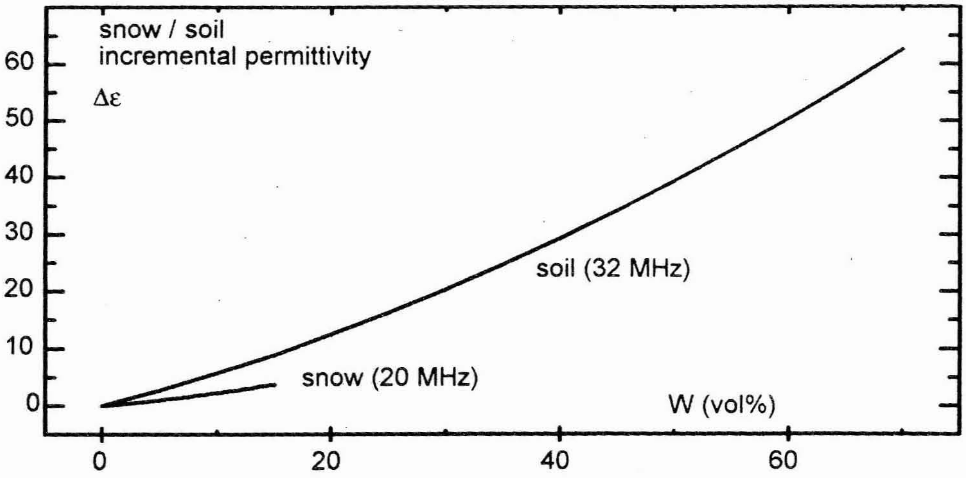

Fig. 3 Wetness calibration for snow and soils

FIELD MEASUREMENTS

As an application of these recently developed capacitive sensors high-resolution profiles of snow and soil wetness have been measured at a 5cm interval, whereby the snow - soil interface was of special interest. Soil wetness has been measured upto a depth of 25cm. Fig.4 shows a wetness profile taken in the "Stubai Alps" (Mutteberg, 1500 m a.s.l.) in March 1994 (soil under pasture covered with 95cm of moderate wet old snow, density ρ = 0.45 g/cm^3). The marked decrease in snow wetness at the 70cm and 10cm level is due to thin ice crusts at a height of ≈ 77cm and ≈ 19cm, which cause a slightly reduced hydraulic permeability. Soil wetness shows a marked maximum (W ≈ 17 Vol%) at a depth of 20cm; this can be expected for a thawing soil. Soil temperature showed a slight increase from 0°C at the snow-soil boundary to +3°C at a depth of 30cm.

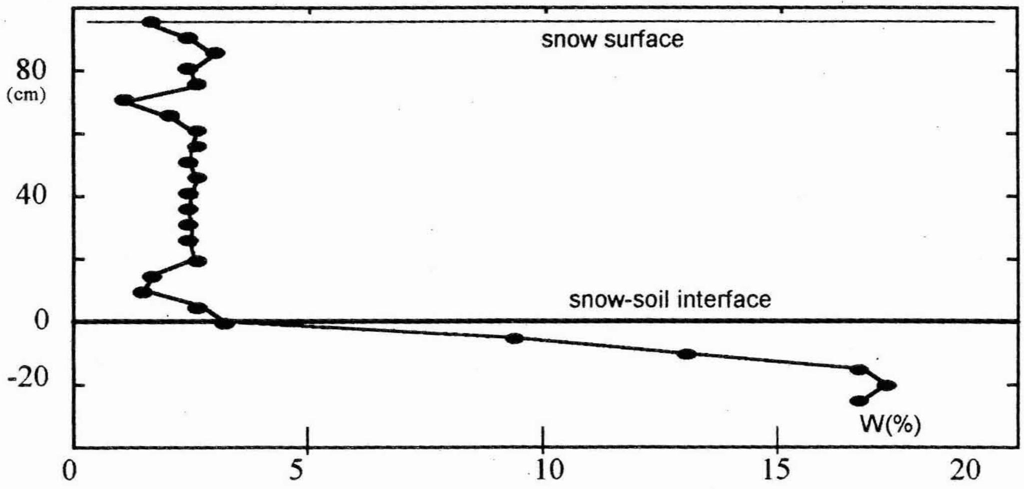

Fig.4. Wetness profile near a snow-soil interface (Stubai Alps, March 94)

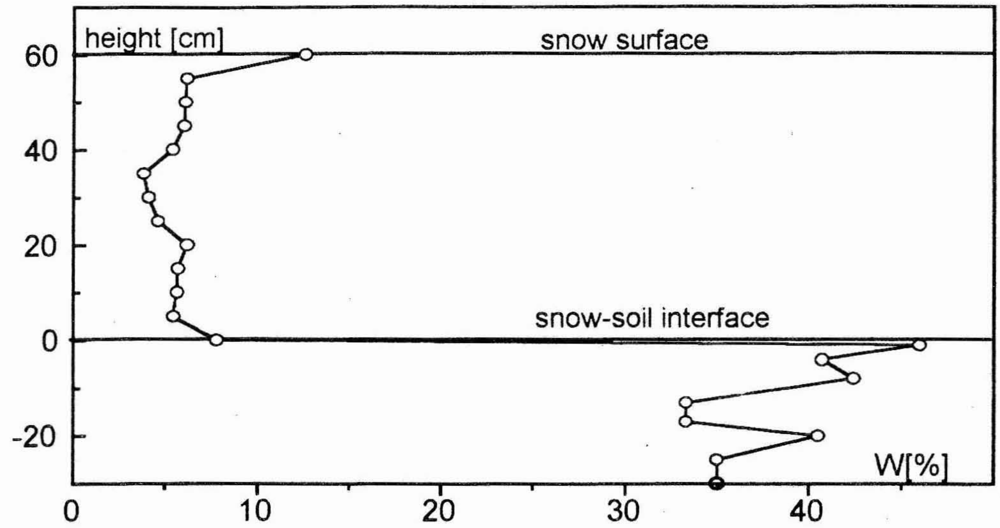

Fig.5. Wetness profile near a snow-soil interface (Kühtai, June 94)

Fig.5 represents a wetness profile measured in the "Sellrain Alps" (Kühtai, 2000 m a.s.l.) the 01. June 1994 (alpine rankers covered with 60cm of coarse grained old spring snow, density $\rho = 0.53$ g/cm^3). Compared to the wetness profile of a thawing soil (Fig.4), a significant shift in the location of maximum wetness (W $\approx$ 46 Vol%) has been observed: Maximum wetness has been detected at a depth of only 3cm.

ACKNOWLEDGEMENT

The "Wintersport Tirol AG" is thanked for supporting in part the field activities in the Stubai Alps, Austria.

REFERENCES

Denoth, A., 1994a. Snow liquid water measurements: Methods, instrumentation, results. Proc. Snowsymp'94, Manali, H.P., India; in press.

Denoth, A., 1994b. An instrument for long-term snow wetness recording. Annals of Glaciology 19, p 104 - 106.

Gschnitzer, A., and H. Eller, 1994. Entwicklung eines feldtauglichen kapazitiven Meßgerätes zur Bestimmung der Bodenfeuchte. Diploma thesis, University of Innsbruck, March 1994.

MICROWAVE X-K-BAND MEASUREMENTS ON SNOW
INSTRUMENTATION AND RESULTS

Achammer T., Giovannini A. and A. Denoth
Institute of Experimental Physics, University of Innsbruck, A-6020 Austria
Fax: (43) 512 218 2921

ABSTRACT

Dielectric measurements on dry and wet snow samples with different stages of metamorphism are reported. Measurements cover the frequency regime of microwave X- and K-band (8-16GHz). Measurement quantities are: dielectric permittivity and dielectric loss factor. All measurements have been done in a cold room in the laboratory, whereby a „free-space-technique“ has been used. This method has been preferred, because it allows measurements on large snow samples with 50*50cm^2 cross section and different thicknesses to average over possible snow inhomogeneities. From the measured magnitude and phase of the reflection and transmission coefficients for normal incidence snow permittivity has been calculated. In addition, reflection has also been measured for a set of fixed frequencies at several different incidence angles, whereby in this case the dielectric function has been calculated from both the Pseudo Brewster angle and a data fit using Fresnel's formulae. The influence of liquid water content, liquid water distribution, snow density and grain size on the dielectric response has been studied extensively. It results: snow incremental permittivity shows a strong dependence on liquid water content, whereby no significant influence of the stage of metamorphism has been observed. The loss factor, in contrast, shows a strong dependence on the content and shape of the water component, whereby indications of an increasing importance of volume scattering has been found on snow samples with relatively low water content and for frequencies exceeding 14GHz. Based on these experimental studies the concept of a field applicable microwave snow wetness sensor, designed as a monopol antenna, is given. Using this type of sensor, nearly non destructive measurements of snow wetness can be made.

MEASUREMENT TECHNIQUES AND RESULTS

The dielectric function in the microwave X- and K-band has been derived by applying the free-space measurement technique using a high frequency network analyzer (type HP8510A). All measurements have been done in a cold room in the laboratory. In order to minimize effects of a possible layering of the snow sample on wave propagation, the samples have been located horizontally between two vertical mounted horn antennas. In addition to the reflection-transmission measurements, simple reflection measurements at several preselected incidence angles (Brewster method) in the range of 20 to 80 degrees have been done. Details of the measurement setup are given in Giovannini et.al. (1994). All snow samples have been characterised by density (ρ), grain size (d) and liquid water content (W); W has been measured by a calibrated dielectric probe (Denoth, 1994). It results a strong dependence of snow incremental permittivity $\Delta\varepsilon'$ on liquid water content, whereby no significant influence of the stage of metamorphism has been observed. The incremental permittivity is given by: $\Delta\varepsilon' = \varepsilon'(\mathrm{wet}) - \varepsilon'(\mathrm{dry})$, whereby $\varepsilon'(\mathrm{dry})$ is the calculated permittivity of the dry snow sample with the same porosity as the wet snow sample. The loss factor, in contrast, shows a strong dependence on the content and shape of the water component, whereby indications of an increasing importance of volume scattering has been found on snow samples with relatively low water content and for frequencies exceeding 14GHz.

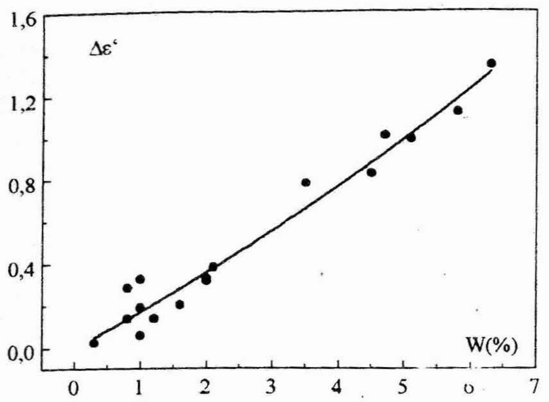

Fig.1: Incremental permittivity at 10 GHz

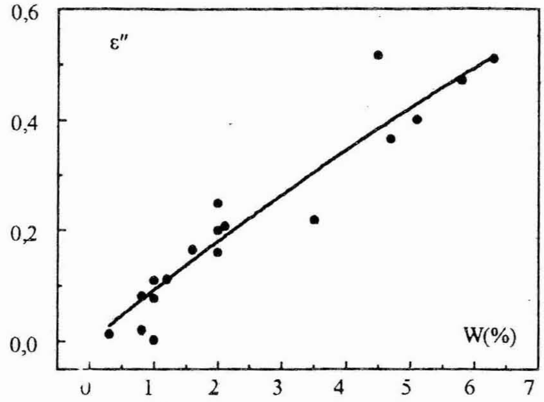

Fig.2: Total losses at 10 GHz

Fig.1 shows $\Delta\varepsilon'$ (10GHz), and Fig.2 shows the total losses ε'' (10GHz) as a function of water content W(Vol%). The following relations between liquid water content W and $\Delta\varepsilon'$, and ε'', respectively, have been found experimentally:

$$\Delta\varepsilon' = 0.164W + 0.007W^2 \text{ and } \varepsilon'' = 0.094W - 0.02W^2$$

whereby the non-linear term in ε'' seams not to be significant. At higher frequencies, especially in the microwave K-band, the sensitivity of $\Delta\varepsilon'$ on water content decreases considerably. In addition, ε'' shows no unique relation to water content W mainly because of the increased influence of liquid shape, a highly variable parameter. So, for snow wetness detection in the field it is suggested to perform such measurements at lower frequencies: $f \leq 3$GHz. As an alternative to commonly used sensors (TDR-method or coaxial resonators) a simple impedance measurement using a monopol antenna has been tested.

MEASUREMENTS WITH A MONOPOL ANTENNA

The impedance of a monopol antenna (Olson and Iskander, 1986) depends on the antenna geometry (antenna length and thickness) and on the dielectric properties of the surrounding material. So, snow dielectric function can be derived from an impedance measurement of the monopol antenna by matching (least-square fit) a calculated to the measured impedance surface. A block diagramm of the experimental setup is shown in Fig.3.

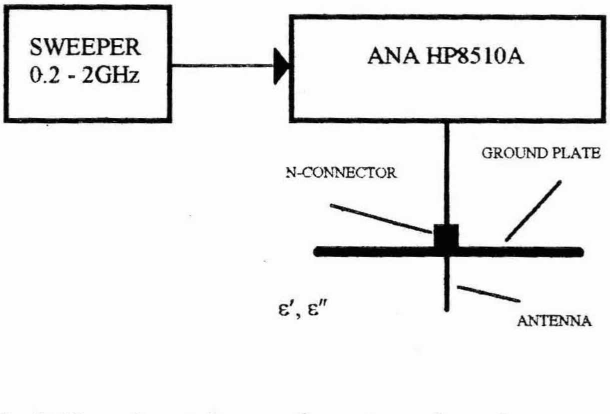

Fig.3: Experimental setup for antenna impedance measurements.

The general behaviour of the driving - point impedance of a monopol antenna in the range of 0.5 - 2GHz is given in Fig.4 and Fig.5, whereby the actual dimensions of the antenna used are: effective antenna length l = 8.8cm, effective antenna thickness d = 4mm, and the diameter of the circular aluminium ground plate is D = 26cm. The „effective“ dimensions diviate slightly from the geometrical dimensions; they have been found experimentaly by fitting the calculated antenna impedance in air ($\varepsilon' = 1$; $\varepsilon'' = 0$) to the measured one (see Fig.6). Expectation values for sensor input impedance are shown in Fig.4 and Fig.5, whereby the range of permittivities has been selected to cover the range of permittivities found in a natural snow field.

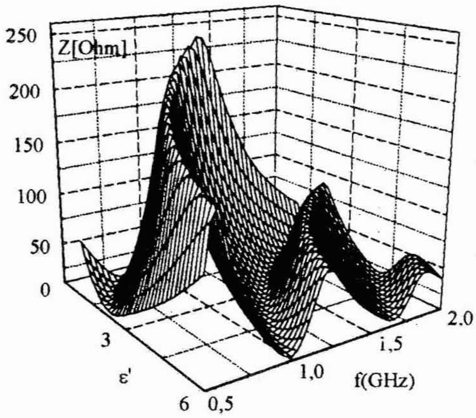

Fig.4: Impedance surface as a function of frequency and ε'; Parameter $\varepsilon'' = 0.01$

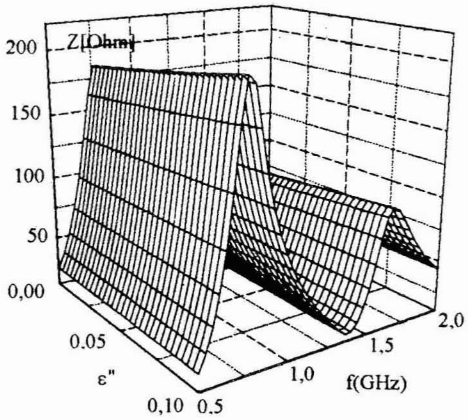

Fig.5: Impedance surface as a function of frequency and ε''; Parameter $\varepsilon' = 3$

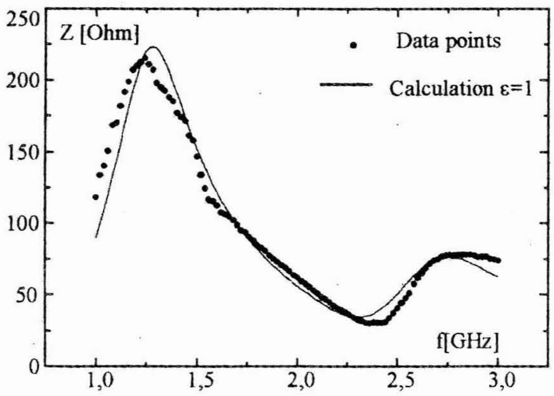

Fig.6. Calibration measurement in air

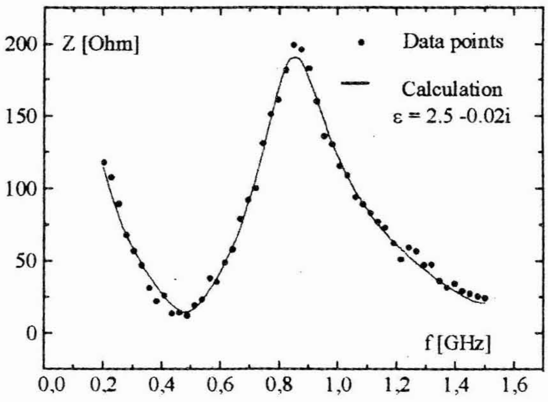

Fig.7. Measurement in wet snow: W = 2.5%, $\rho = 0.49 g/cm^3$

As shown in Fig.4, the impedance of a monopol antenna is very sensitiv to changes in ε'. In the frequency range of sensor operation snow is a low loss dielectric material; so the losses ε'' have only a minimal influence on sensor impedance and can certainly be neglected. On the other hand snow dielectric losses cannot be measured with sufficient accuracy with this type of sensor.

Fig. 7 shows a field measurement with the monopol antenna on alpine wet snow (W = 2.5% and $\rho = 0.49 g/cm^3$). The best fit to the measured impedance has been found for: $\varepsilon' = 2.5$ and $\varepsilon'' = 0.02$, which is in best agreement with the calculated permittivity $\varepsilon'(calc) = 2.54$. Liquid water content W has been measured seperately with a dielectric snow wetness probe (Denoth, 1994).

CONCLUSIONS

Microwave sensors operating at frequencies higher or equal 8GHz are less suitable for field determinations of liquid water content, because sensitivity of ε' on water content is relatively low and decreases with increasing frequency. The losses ε'' depend on water content and also on the geometry of the liquid inclusions. Unfortunately the shape of liquid inclusions is highly variable and in most cases an unknown parameter. So ε'' can not be used for snow wetness determination with sufficiant accuracy. The monopol antenna, however, is a simple dielectric sensor, which can easily be applied for field measurements on grainy materials as snow or even soils, and it allows water detection with sufficiant accuracy when operated in the frequeny regime between 200MHz and ≈ 2GHz.

ACKNOWLEDGEMENT

One of the authors, A.Denoth thanks the „Fonds zur Förderung der wissenschaftlichen Forschung“ for supporting in part these measurements through project P5907. T.Achammer thanks the „Österreichischen Forschungsgemeinschaft“ for supporting presentation through Grant number 06/3154.

REFERENCES

1. Denoth, A., 1994. An electronic device for long-term snow wetness registration. Annals of Glaciology,19, pp 104 - 106
2. Giovannini A., T. Achammer and A. Denoth, 1994. Snow dielectric measurements using active microwave techniques. Proc. Symp. on Snow and Related Manifestations, Manali, H.P, India, 26.9 - 28.9.1994 (in press).
3. Olson, S. C., and M.F. Iskander, 1986. A New In Situ Procedure for Measuring the Dielectric Properties of Low Permittivity Materials. IEEE Vol. IM - 35, No.1, pp 2 - 6.