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RADIO WAVE PROBE FOR IN SITU WATER CONTENT MEASUREMENT OF PEAT

RADIOAALTOANTURI TURPEEN VESIPITOISUUDEN MAASTOMITTAUKSEEN

1. INTRODUCTION

In surveying peat resources it is desired to determine the dry matter and the energy content of peat. These are nowadays determined by sampling the peat and analysing its in situ dry bulk density and calorific value. The practice is time consuming and the indirect predictions by means of the degree of decomposition and some other characteristics of the samples do not always give reliable results. Recent studies indicate that there is a good correlation between the in situ water content and the bulk density (e.g. Korpijaakko et al 1981, Tolonen and Ijäs 1982, Laine and Päivänen 1982). However, the volumetric peat sampling is difficult to make. Hence it was decided to study possibilities for in situ water content measurement of peat by applying radio wave methods. A radio wave sensor can be used to measure dielectric properties of peat and these can be assumed to be correlated with the water content and the bulk density.

Authors' address — *Kirjoittajien osoite:*
Helsinki University of Technology, Radio Laboratory, Otakaari 5 A, SF-02150 Espoo 15, Finland.

2. DIELECTRIC PROPERTIES OF PEAT

Dielectric properties of materials can be described by a relative dielectric constant ε_r. At high frequencies below 10 GHz the dielectric constant of water is 80 (at 20°C) and that of air is 1. For other materials the dielectric constant is usually between these limits. If the material has losses its dielectric constant is complex, $\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$, where ε_r'' is related to the losses.

Peat below the water table can be assumed to be a mixture of three substances, water, dry matter and gas. The dielectric constant of the mixture of water and other materials is approximately given by the Brown formula (Tinga et al 1973)

$$\varepsilon = k\varepsilon_w + (1 - k)\varepsilon_d \,, \qquad (1)$$

where ε is the relative dielectric constant of the mixture, k is the volume fraction of water, ε_w is the relative dielectric constant of water and ε_d is that of the mixture of dry matter and gas. The in situ gas content of peat is usually smaller than 5 percent (Laine and Päivänen 1982), and the value of ε_d is 2 . . . 3 giving $\varepsilon = 68$ when the moisture content is 85 percent, and $\varepsilon = 76$ when the moisture content is 95 percent. Equation 1 indicates that ε is directly related to the moisture by volume.

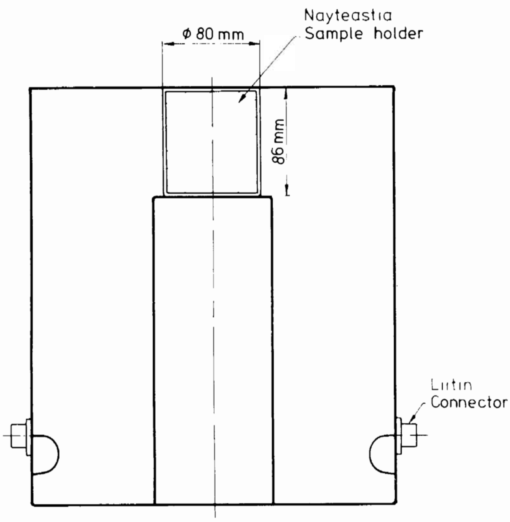

Fig. 1. A coaxial resonator with a sample holder for measuring dielectric properties of peat at frequencies around 100 MHz.

Kuva 1. Koaksiaalinen resonaattori turpeen dielektristen ominaisuuksien mittaamiseen. Mittaustaajuus on n. 100 MHz.

Table 1. Location of the mires.

Taulukko 1. Soiden sijainti.

Name	Location
Suolamminneva (abbr. Suo)	14 M, Ähtäri, Central Finland map 224109: 694651/52048
Viheräisenneva (abbr. Vih)	1 M, Ruovesi, Central Finland map 223104: 686047/51136
Lamminsuo (abbr. Lam)	3 M, Juupajoki, Central Finland map 214206: 685969/51595

The dielectric constant is also slightly dependent on the temperature of the water.

In reality the dielectric constant can be more complicated than that given by the Brown formula, for example due to the absorption (bonding) of water by the dry material, and due to the shape of particles in the dry material. More accurate equations have been derived (Taylor 1965, Tinga et al 1973) and applied for calculating the dielectric constant of peat (Jakkula 1979).

3. LABORATORY MEASUREMENTS OF NATURAL PEAT

In order to find out the dependence of the dielectric constant on the water content, natural peat samples were measured in the laboratory. A coaxial resonator with a resonant frequency around 100 MHz was used in the measurements, Figure 1. The sample was put in a thin-walled plastic cylinder. The diameter of the sample holder was the same as that of the peat sampler, and its volume was about 500 ml. The real part of the dielectric constant was determined by measuring the difference of the resonant frequency caused by the sample and the imaginary part by measuring the difference in the reflection attenuation of the resonator.

The total number of samples was 49. They were collected using the special volumetric piston sampler model (Korpijaakko et al 1981) from three different mires: Suolamminneva (19 samples), Viheräisenneva (22 samples) and Lamminsuo (8 samples). Tables 1—4 give some properties of the mires and the samples. Following

Table 2. Mire complex types and site types.

Taulukko 2. Tutkimusalueiden kompleksi- ja suotyypit.

Site	Mire complex type	Nutritional hydrology	Site type
Suo	aapa mire	slightly minerotrophic	small sedge pine bog
Vih	raised bog	ombrotrophic	*S. fuscum* pine bog
Lam	not classified	minerotrophic	ordinary spruce swamp

Table 3. Some properties of the peat samples studied.

Taulukko 3. Tutkittujen turvenäytteiden ominaisuuksia.

	range	mean	standard deviation (%)
depth (cm)	60—490	284.4	—
v. Post's grade	H_3—H_9	4.84	23.9
bulk density (field) (kgm³)	41.1—104.4	68.68	20.2
water content (field) (% weight)	89.3— 96.0	92.90	1.5
water content (field) (% volume)	89.1— 95.0	89.92	3.3

properties of the samples were measured:

— dielectric constant
— water content (percent by volume)
— water content (percent by fresh weight)
— bulk density, mass dry (105°C), volume fresh.

The peat samples were longitudinally cut into two equal parts immediately after the sampling. One of the halves, B, was used for electrical measurements and the other half, A, for weighing and drying. The bulk density was measured from both halves. These two bulk densities reveal how much the filling of the sample container in the laboratory was different compared with the conditions in the field. The correlation between the two bulk densities is shown in Figure 2 for the Vih-samples. The correlation is very good but the laboratory bulk densities (B) are higher than those in the field (A) due to the natural losses in the gas content and also in the water content (but in a less degree). Another checking was done by filling the container twice with the same sample and measuring the dielectric constant at both time. The difference in results was at highest one ε_r-unit.

The relationships between variables were analysed by means of simple correlation and regression analyses. The results are shown in Table 5. The best correlation is obtained between the dielectric constant and the water content per volume. This is as expected from theoretical considerations. The water content (percent by volume) versus dielectric constant is shown in Figure 3. The dielectric constant is smaller than obtained from equation 1 indicating that

Table 4. Distribution of the analysed peat samples in different peat types.

Taulukko 4. Näytteiden jakauma turvelajeittain.

peat type	number of samples
Sphagnum peats	8
Eriophorum-Sphagnum peats	11
Sphagnum-Carex peats	10
Carex peats	12
Woody (L) peats	2
Bryales (Hypnum) peats	6
total	49

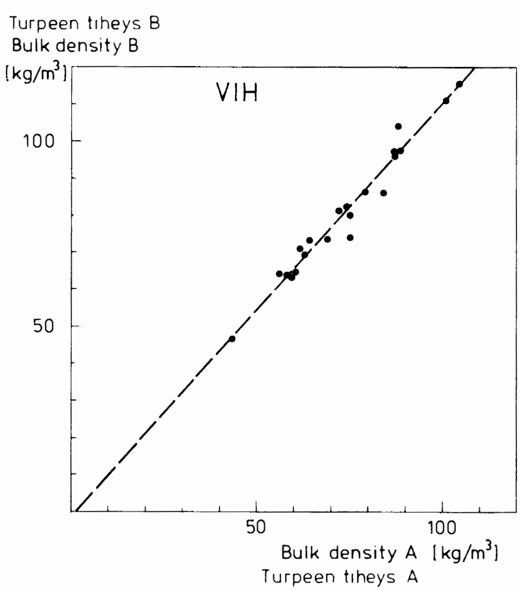

Fig. 2. Correlation between the bulk densities of the two half samples A and B made from a peat sample. Sample B was used in the sample holder for measuring its dielectric properties.

Kuva 2. Näytteen puolikkaitten A ja B tiheyksien välinen korrelaatio. Puolikasta B käytettiin dielektrisyysvakion mittaamisessa ja tiheys määrättiin kuivattamalla näyte tämän jälkeen. Puolikkaasta A määrättiin tiheys kairaamisen jälkeen.

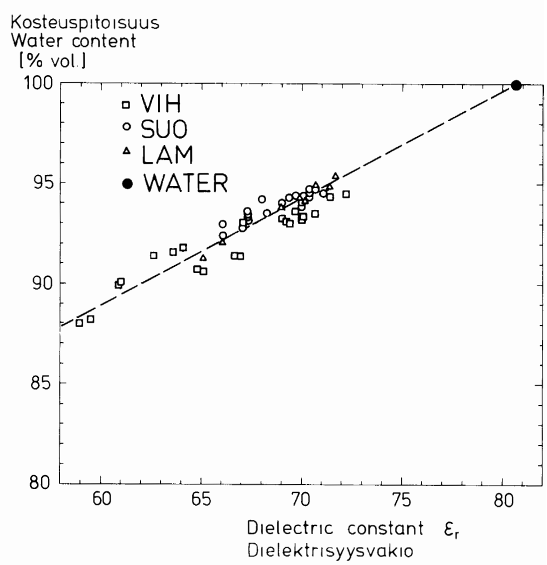

Fig. 3. Measured water contents versus dielectric constants of 49 peat samples from three different mires (sample temperature 18.5°C).

Kuva 3. Mitattujen näytteiden kosteuspitoisuuden (vesisadannes mittaustilavuudesta) ja dielektrisyysvakion välinen riippuvuus. Näytteitä on kolmelta eri suolta, kaikkiaan 49 kpl. (Näytteiden mittauslämpötila 18,5°C).

Taulukko 5. Korrelaatiokertoimet dielektrisyysvakion reaaliosan $_r$' ja eri parametrien y välillä. Riippuvuus näyttää olevan lineaarinen y = a $_r$' + b.

Table 5. Correlation coefficients between the real part of the dielectric constant $_r$' and different parameters y. The relationships seem to be linear, y = a $_r$' + b.

Mire	Number of samples	correlation coefficient r		
		water content by volume	water content by weight	bulk density
Vih	22	0.95	0.92	0.89
Suo	19	0.92	0.83	0.86
Lam	8	0.99	0.93	0.93
All samples	49	0.94	0.91	0.90

a part of the water is bonded. The dielectric losses (attenuation by reflection) of the samples were also measured. The results show, that the losses in Suolamminneva (a sedge mire) were significantly smaller than in other mires *(Sphagnum* bogs).

4. RADIO WAVE PROBE FOR IN SITU MEASUREMENTS

Several possible methods for *in situ* measurements of peat have been studied. It has been found out that a suitable sensor is a resonant slot antenna at the

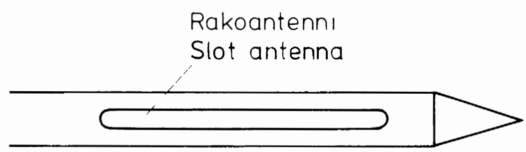

Fig. 4. The radio wave sensor for *in situ* peat measurement (Pat. pend.).

Kuva 4. Radioaaltoanturi suolla tapahtuvaan mittaamiseen (patentoitu).

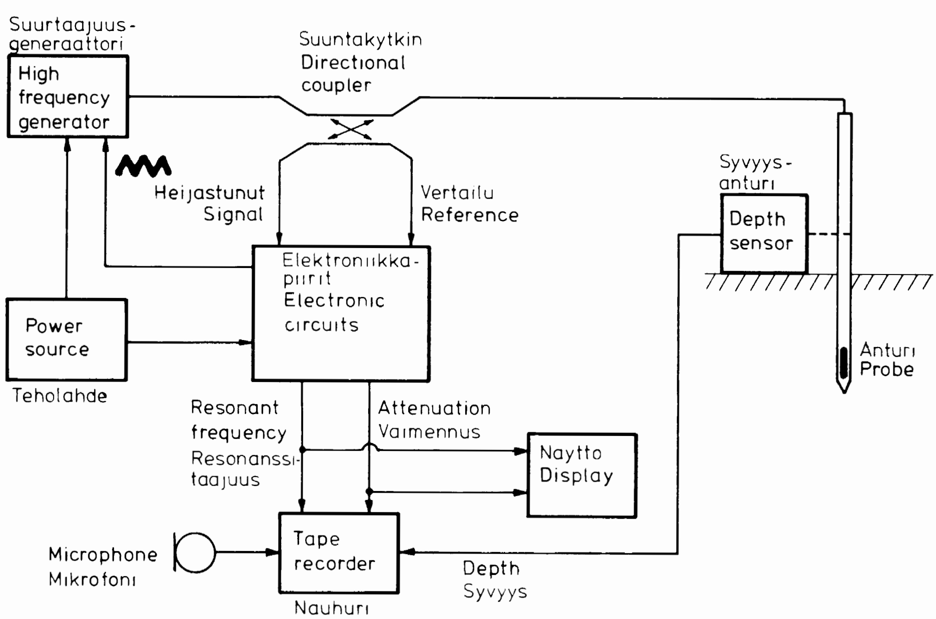

Fig. 5. The block diagram of the sensor system.

Kuva 5. Mittauslaitteiston periaatekaavio.

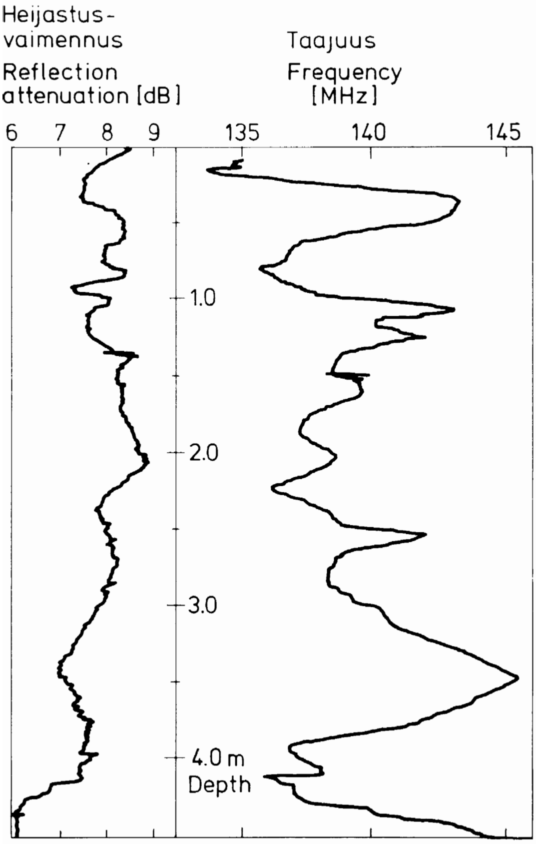

Fig. 6. A measured peat profile. Frequency corresponds to water content and reflection attenuation to losses in peat.

Kuva 6. Suolla mitattu taajuus- ja heijastusvaimennusprofiili. Taajuus on verrannollinen vesipitoisuuteen ja heijastusvaimennus on verrannollinen turpeen häviöllisyyteen. Tulostettu x-y -piirturilla.

end of a steel pipe, Figure 4. The resonant frequency of the sensor when pushed in peat varies from 130 MHz to 150 MHz and is inversely proportional to the square root of the dielectric constant of peat. The sensor area of the pipe is filled with a suitable dielectric material for preventing peat entering the pipe. The antenna is connected by a coupling loop and a coaxial line to the electronics, which measures the resonant frequency and the reflection attenuation of the resonator.

The block diagram of the sensor and the measuring system is shown in Figure 5. The frequency of the RF-generator is swept over the frequency range of the sensor. The directional coupler gives a reference signal proportional to the incident power and a reflected signal proportional to the power reflected from the sensor. The electronic circuit measures automatically the resonant frequency and the reflection attenuation of the sensor, and gives output voltages proportional to them. The voltages can be read from a numerical display. A depth sensor gives an output voltage proportional to the depth of the sensor. The three output voltages can be tape recorded with an additional spoken information. The measured profiles can later be plotted in the laboratory with an x-y recorder. An example of recorded profiles is shown in Figure 6.

REFERENCES

Jakkula, P. 1979: Soiden kaukokartoitus UHF-radiometrillä (Summary: Remote sensing of peatlands using a UHF radiometer). — Helsinki University of Technology, Radio Laboratory, Licentiate Thesis, 68 pp.

Korpijaakko, M., Häikiö, J. & Leino, J. 1981: Vesipitoisuuden ja maatuneisuuden vaikutus turpeen kuivatilavuuspainoon (Summary: Effect of water content and degree of humification on dry density of peat). — Suo 31(2): 39—43.

Laine, J. & Päivänen, J. 1982: Water content and bulk density of peat. — IPS Symposium ”Peat, its properties and perspektives of utilization”, Minsk, USSR, September 14—25, 1982, 422—430.

Taylor, L.S. 1965: Dielectric properties of mixtures. — IEEE Transactions on Antennas and Propagation, Vol. AP-13, No. 6, November 1965.

Tinga, W.R., Voss, A.G. and Blossey, D.F. 1973: Generalized approach to multiphase dielectric mixture theory. — Journal of Applied Physics, Vol. 44, No. 9, September 1973.

Tolonen, K. & Ijäs, L. 1982: Comparison of two peat samplers used in estimating of dry peat yield in field inventories. — Suo 33 (2): 33—42.

TIIVISTELMÄ:

RADIOAALTOANTURI TURPEEN VESIPITOISUUDEN MAASTOMITTAUKSEEN

Turvesaanto voidaan laskea varsin luotettavasti turpeen maastokosteuden avulla (esim. Korpijaakko ym., 1981; Tolonen ja Ijäs, 1982; Laine ja Päivänen, 1982). Tässä kirjoituksessa esitetään sähköinen menetelmä turpeen maastokosteuden nopeaan mittaamiseen.

Mittaus perustuu turpeen dielektrisyysvakion kosteusriippuvuuteen. Veden diel. vakio on n. 80, ilman 1 ja turpeessa olevan kuiva-aineen diel. vakio on noin 3. Seoksen diel. vakio riippuu sekoitettavien aineiden diel. vakioista ja sekoitussuhteista. Lisäksi sekoitettavat aineet voivat vaikuttaa toisiinsa esim. sitomalla vettä.

Turpeen dielektrisyysvakion riippuvuutta kosteudesta tutkittiin mittaamalla suosta kairattuja turvenäytteitä laboratoriossa. Sähköiset ominaisuudet mitattiin koaksiaalisessa resonaattorissa (kuva 1.). Näytteitä oli kolmelta suolta, kaikkiaan 49 kappaletta (taulukot 1—4). Näytteistä määrättiin seuraavat ominaisuudet:

— dielektrisyysvakio
— kosteus tilavuusprosentteina (vesisadannes mittaustilavuudesta)
— kosteus painoprosentteina (vesisadannes märkäpainosta)
— kuivan turpeen tiheys (105 °C)

Kairaamisen jälkeen näytteet puolitettiin. Toisesta puolikkaasta, A, määrättiin heti turpeen tiheys ja toisesta puolikkaasta, B, määrättiin turpeen tiheys sähköisten mittausten jälkeen. Vertaamalla näitä tiheyksiä saadaan käsitys siitä, miten paljon turve näyteastiassa erosi luonnontilaisesta turpeesta. Kahden tiheyden välinen riippuvuus Viheriäisennevan näytteille on kuvassa 2.

Dielektrisyysvakion ja muitten suureitten välistä riippuvuutta tutkittiin korrelaatio- ja regressioanalyysillä. Tulokset on esitetty taulukossa 5. Paras korrelaatio on dielektrisyysvakion ja tilavuusprosentteina lasketun kosteuden välillä, kuten on teorian mukaan odotettavissakin. Kuvassa 3 on esitetty vesipitoisuus tilavuusprosentteina dielektrisyysvakion funktiona.

Useita mahdollisia menetelmiä maastossa tapahtuvaan kosteuden mittaamiseen on tutkittu. Sopivaksi anturiksi on osoittautunut rakoantenniresonaattori, joka on tehty teräsputkeen (kuva 4.). Putken aukkokohta on täytetty sähköisesti sopivalla aineella, ettei turve tunkeudu putken sisään. Antenni on kytketty kytkentäsilmukalla ja koaksiaalikaapelilla elektroniikkayksikköön (kuva 5.). Elektroniikkayksikkö määrittää antennin resonanssitaajuuden ja sitä vastaavan heijastusvaimennuksen. Näistä voidaan laskea turpeen dielektrisyysvakio. Syvyysanturista saadaan mittaussyvyyteen verrannollinen signaali. Tuloksia voidaan seurata välittömästi numeronäytöltä tai ne voidaan nauhoittaa myöhempää tulostusta varten. Lisäksi voidaan samanaikaisesti nauhoittaa puhetta. Kuvassa 6. esimerkki maastossa tehdystä mittauksesta. Nauhoitus on tulostettu x-y -piirturilla.