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Development of an instrument to measure density and moisture content of snow

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This paper presents design and development of a microcontroller-based instrument to measure snow moisture and density. This instrument makes use of $\lambda/4$ RF resonator for measuring complex dielectric coefficient of snow. Snow moisture and density were computed using empirical relations.

Keywords: Microcontroller-based instrument, Snow density, Snow moisture

Introduction

Knowledge of snow parameters is important for climatology, meteorology, hydrology, flood prevention and hydropower industry. Liquid water in a snow pack shows a dominant effect on reflection, absorption and transmission of electromagnetic waves especially in microwave region. Liquid water in snow plays a major role in metamorphism, mechanics and hydrology of snow, and in soil engineering. Conventional techniques to measures snow density and moisture are very complex and time consuming[1,2]. Complex dielectric constant of snow is a measure of its response to applied electromagnetic wave[3].

This study presents design and development by CSIO Chandigarh, in association with SASE, a DRDO laboratory, of a microcontroller-based instrument to measure snow moisture and density.

Proposed Instrument

Complete system consists of (Fig. 1): i) snow moisture sensor unit; ii) microcontroller based main unit; iii) handheld keypad cum display unit; and iv) power supply unit. Technical specifications of instrument are: resonant frequency measurement range (resolution, 1 MHz), 500-950 MHz; dielectric constant $\in'$ measurement range (real part), 1-3.0; dielectric constant $\in''$ measurement range (imaginary part), 0-0.15; liquid water content measurement range (wetness), 0-15% volumetric; snow density measurement range, 0-0.6 g/cm^3; data logger storage, 4 MB NVRAM; operating temperature range, –20°C to +50°C**;** power supply (6.5 Ah sealed lead acid battery), 12 V; data transmission, RS-232; communication parameters, 115200 bps, 8 bit data, 1 stop bit, no parity, no handshaking; sensor spikes length, 75 mm; and sensor spikes separation, 20 mm.

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Snow Moisture Sensor Unit

Sensor is a fork shaped quarter wavelength microwave resonator (resonant at the frequency with length of resonant structure = ¼ of wavelength). It is open circuited at one end and short-circuited at another end. It resonates in air around 900 MHz. Prongs (made up of stainless steel) are thin enough with sharpen ends for easy and deformation less insertion into snow. Distance between two prongs is about 20 mm. Radio frequency power is fed in and out of the structure through coaxial cables and coupling loops. Handle of this unit houses RF electronics. RF Sweep generator[4-6] comprises of voltage controlled oscillator POS-1000W and RF power leveler circuitry. RF power leveler limits feeding RF signal level to 0±0.5 dBm throughout the sweeping range. It works under the control of processing card and sweeps (frequency range, 450-1000 MHz) to determine resonance frequency and other electrical parameters of sensor. Processor card under

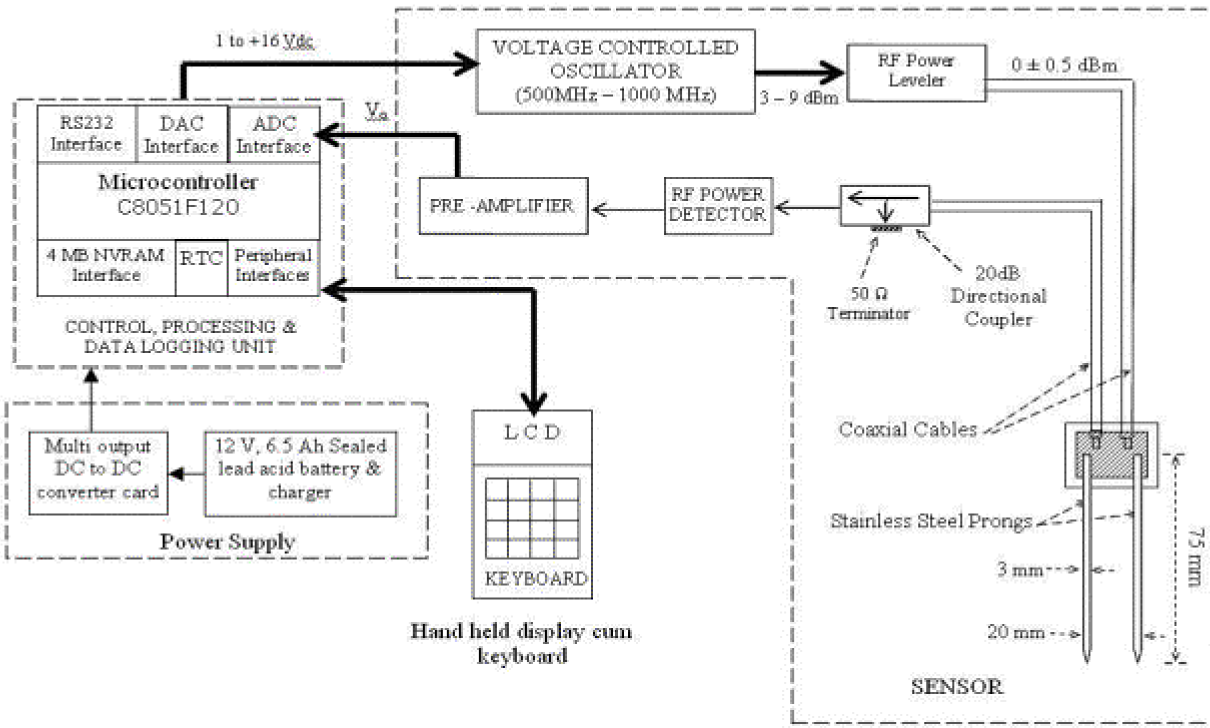

Fig. 1—Block diagram of snow moisture measurement system

software control generates a tuning voltage (0-16Vdc) signal, an input to sweep generator, which gives a RF sweep in a linear relationship with input tuning voltage signal.

RF signal is fed to resonator through coupling loops. RF power transmitted through resonator is fed to power detector ZX47-60-S+ through a directional coupler, which is used for impedance matching only, and coupled signal is terminated with 50 ohm RF terminator. Sensor works on the principle that when prongs are inserted in snow, the real part of permittivity of snow lowers resonant frequency, and imaginary part broadens resonance curve and increases signal attenuation at resonance frequency. Output of power detector is recorded by processor card at 12-bit resolution for complete sweep. Recorded data is analyzed to find out resonator's electrical parameters (resonant frequency and 3-dB bandwidth), which are fed to the empirical model for calculating snow wetness and density.

Microcontroller Based Main Unit

Controlling and processing unit (CPU) of snow moisture measurement system is designed around C8051F120 microcontroller. CPU consists of two cards, μC C8051F120 based processor card and a daughter card. Daughter card has 4 MB NVRAM with in built battery (two chips of 2MB), one real time clock (RTC), keyboard interface, and LCD interface and amplifiers to amplify DAC output with user desired gain to generate tuning voltage for VCO and other required circuitry. Microcontroller card computes algorithm to determine complex dielectric constant of snow and empirical model to derive snow moisture and density. From dielectric constant, snow moisture (*W*) and density (ρ_s) are calculated from solution of empirical relations listed by research studies[1,2,4,7,8], Helsinki University of Technology, University of Innsbruck etc, which are frequency independent in microwave region where ice is dispersion less[2,7]. Empirical relations are given as

$$\text{Real part of dielectric constant, } \varepsilon_s' = \left(\frac{900}{f_s}\right)^2 \quad \ldots(1)$$

where f_s is resonance frequency of sensor when it is inserted in snow, 900 is resonance frequency of sensor in air at snow temperature in *MHz*.

Imaginary part of dielectric constant,

$$\varepsilon_s'' = (\varepsilon_s') \left[\frac{\Delta f_s}{f_s} - \left\{ p + \left(\frac{b}{f_s} \right) \right\} \right] \quad \ldots(2)$$

where, Δf_s is 3-dB bandwidth corresponding to f_s, p and b are calibration coefficients

Moisture fraction (W) in snow,

$$\varepsilon_s'' = \frac{f_s}{10^9}\left(0.9W + 7.5W^2\right) \quad \ldots(3)$$

where $500MHz \leq f_s \leq 1000MHz$

Volumetric liquid water content in snow,

$$W[\%vol] = W \times 100 \quad \ldots(4)$$

Dry density (ρ_d) of snow relative to density of water, $\varepsilon_s' = 1 + 1.7\rho_d + 0.7\rho_d^2 + 8.7W + 70W^2$ …(5)

Density (ρ_s) of snow, $\rho_s = \rho_d + W$ …(6)

Computed values are displayed immediately on liquid crystal display and stored in NVRAM along with time stamp.

Power Supply Unit

It provides necessary voltage and current requirement of complete system, and contains a battery (12 V, 6.5 Ah) and SMPS, which gives different voltage levels (+24V, ±12V & ±5V).

Results

For calibration and validation of λ/4 resonator, different materials with known permittivity (sugar, sand and coffee powder) were used. After measurements, values of two calibration constants (p & b) were determined and used for calculating imaginary part of snow permittivity. An imported instrument, Snowfork, has been used as reference unit for validating measurements made by CSIO instrument. Developed instrument was tested in ‘Cold Lab’ at SASE, Manali, for measuring moisture and density of prepared snow samples (with known water content and density) as well as snow samples collected from field, which were preserved at subzero temperature. Results of both instruments were compared and found comparable (Fig. 2) both in laboratory testing, and in field-testing in and around Manali. In a comparison plot of wetness profile of 90 cm deep snowpack (Fig. 2), both instrument measured same density. Error was found in prepared snow samples (10%) and field snow (12%).

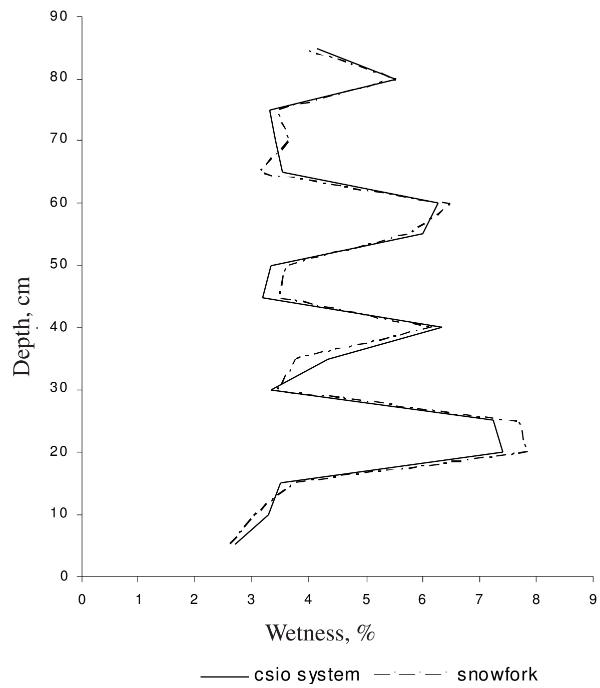

Fig. 2—Wetness plot to compare performance of CSIO instrument and Snowfork

Conclusions

CSIO in association with SASE, a DRDO laboratory, has successfully designed and developed an instrument for determination of snow moisture and density. Results of CSIO instrument and conventional instrument (Snowfork) were found comparable both in laboratory testing, and in field-testing in and around Manali. Developed instrument is still in long term testing and validation.

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