Journal of Glaciology, Vol. 27, No. 95, 1981

INSTRUMENTS AND METHODS

AN INEXPENSIVE REMOTE SNOW-DEPTH GAUGE BASED ON ULTRASONIC WAVE REFLECTION FROM THE SNOW SURFACE

By H. GUBLER

(Eidg. Institut für Schnee- und Lawinenforschung, 7260 Weissfluhjoch/Davos, Switzerland)

ABSTRACT. Total snow depth is determined by measuring the time of flight of an ultrasonic wave packet emitted from a sonic transmitter above the snow surface and reflected from the snow surface back to the receiver/transmitter system. The light-weight system is battery powered (operating time without battery change at least 8 months) and can be fixed to any post above the snow surface. The absolute precision is better than ±0.03 m. Data and commands are transmitted by a single two-wire system up to several kilometres.

RÉSUMÉ. *Un appareil bon marché pour mesurer, à distance, la hauteur de neige par ultrason.* La hauteur de neige totale est déterminée en mesurant le temps qu'il faut à un paquet d'ondes d'ultrason pour parcourir la distance d'un émitteur monté au-dessus de la couverture de neige jusqu'à la surface de manteau neigeux et retour à l'émetteur/récepteur. L'appareil de mesures, qui est léger et alimenté par une batterie (durée sans changer de batterie au moins 8 mois), peut par exemple être monté sur une barre qui fait office de jalon, au-dessus de la couverture de neige. L'exactitude est meilleure que ±0,03 m. Les données ainsi que les ordres de mesures peuvent être transmis jusqu'à plusieurs kilomètres, au moyen du même système à deux conducteurs.

ZUSAMMENFASSUNG. *Ein billiges Schneehöhenmessgerät auf Ultraschallbasis.* Durch die Messung der Laufzeit eines Ultraschall-Wellenpaketes von einem über der Schneedecke montierten Sender zur Schneeoberflähce und zurück zum Senden/Empfänger wird die Totalschneehöhe bestimmt. Das leichte, batteriegespeiste Messgerät (Betriebsdauer ohne Batteriewechsel mindestens 8 Monate) kann beispielsweise an einer Pegelstange über der Schneedecke montiert werden. Die Genauigkeit ist höher als ±0,03 m. Die Daten sowie der Messbefehl können über das gleiche Zweileitersystem bis zu mehreren km weit übertragen werden.

INTRODUCTION

Various automated systems to measure snow depth have been developed and tested during recent years. Either these systems include vulnerable mechanical parts (Good and Krüsi, 1973), are not qualified for remote application (Takahashi and Aburakawa, 1976), or are prohibitively expensive (Marbouty and Pougatch, 1978). For these reasons we decided to develop an inexpensive system, specially designed to measure snow depth, using only commercially available parts.

SYSTEM REQUIREMENTS

The desired specifications of a snow-depth measurement device are:

(1) Long-time accuracy: better than ±0.03 m.

(2) Direct measurement range of snow depth: 0–3.5 m. Recording of total snow depth greater than 3.5 m should be possible by increasing the height of the measuring device above ground during the winter.

(3) Continuous battery operation: minimum of 8 months including some 10 000 measurements.

(4) Erroneous measurements: direct indication. The system has automatically to perform additional measurements in cases when signal reflections from the snow surface are too low due to drifting snow or very soft surface layers.

(5) Data and commands: have to be transmitted by the same two-wire system. The possible transmitting distance without additional line drivers has to exceed 500 m.

(6) System configuration and costs: the system has to be simple and easy to interface to any kind of recording devices. Material costs should not exceed U.S. $300.

The system described below meets all the requirements listed above.

SYSTEM DESCRIPTION

The whole system consists of three parts: the field electronics including the sonic receiver/transmitter and the converter, the controls including the command structure, display, data storage, and binary coded decimal output, and the optional line drivers.

The field electronics are fixed to a rod 2 m long parallel to the snow surface (Fig. 1). This device, including the rod and a solar radiation reflector, has a weight of about 70 N. The field system may be fixed to any vertical post exceeding the maximum snow depth by about 0.6 m and having strength enough to withstand the extreme wind and snow forces. Installations are possible on slopes as well as on horizontal test fields.

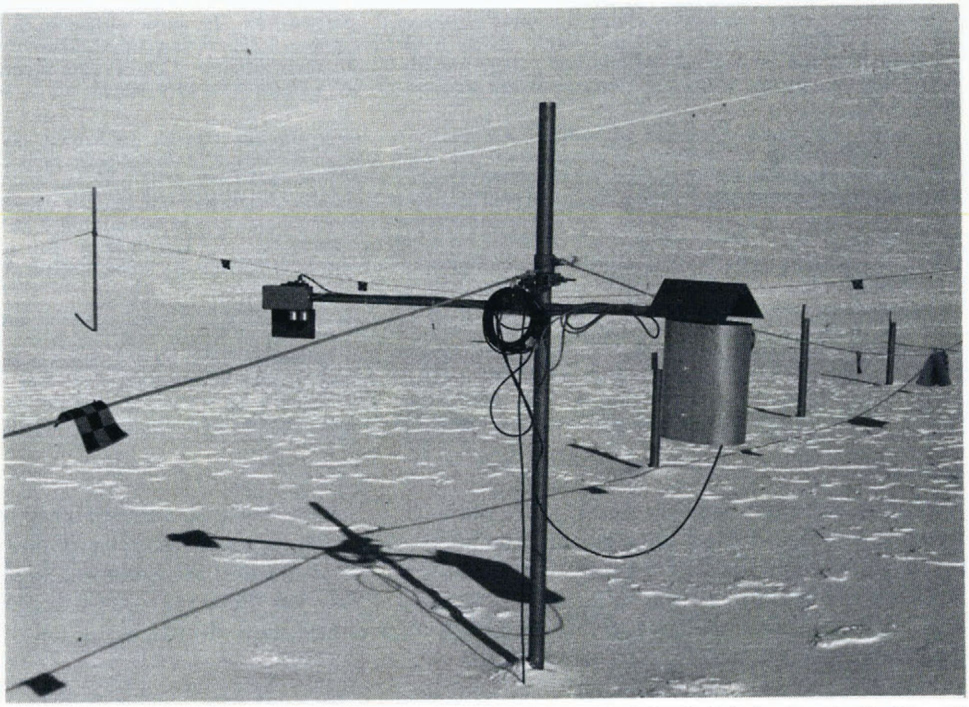

Fig. 1. Ultrasonic snow-depth gauge. The receiver/transmitter system is at the left end of the horizontal rod. The radiation-shielded converter is at the right end.

PRINCIPLE OF OPERATION

A command pulse from the control to the field device powers the converter and gives rise to the emission of a first short ultrasonic wave packet in the direction of the snow surface. Simultaneously, a temperature-controlled oscillator (compensating for the temperature dependence of the speed of sound) is turned on and transmits pulses to the control. The oscillator is turned off when the surface-reflected ultrasonic wave packet returns to the receiver/transmitter. The oscillator period is calibrated to the equivalent of 0.02 m travelling distance of a sound wave. For this reason each pulse corresponds to a distance of 0.01 m between the receiver/transmitter and the snow surface. The pulses are fed to a down-counter at the control. The down-counter is pre-set to the height of the receiver/transmitter above ground. The counter output thus corresponds to the actual snow depth in units of 0.01 m. Having an integrated controlling system reduces the possibility of erroneous measurements.

The electronic and mechanical set-up is described in the Appendix.

Tests and results

Four identical systems have been tested during spring 1978 and winter 1978/79 for a total operating time of 32 months and about 25 000 measurements. The systems operated under very different conditions: One in a flat field at Davos 1 500 m a.s.l. with automatic recording, one at Stillberg 2 000 m a.s.l. on a 25° slope with automatic recording, one in the test field of the Institut on Weissfluhjoch 2 500 m a.s.l. including a 700 m long cable to the Institut and manual recording. The fourth device is part of the automatic Gaudergrat station at 2 200 m

Table I. Results from November to March 1979

Location	*Percentage of unsuccessful measurements*		*Percentage of erroneous measurements*		*Remarks*
	November–January	February–March	November–January	February–March	
Stillberg	1·3%		2%		Slope
Davos	34%	5%	4%	3%	December and January 42% of days with surface rime or traces of new snow
Weissfluhjoch	3·7%		0·3%		Horizontal test field
Gaudergrat	25%	8%	3%	5%	Many unsuccessful measurements during November and December. West aspect with no sun and almost constant surface rime

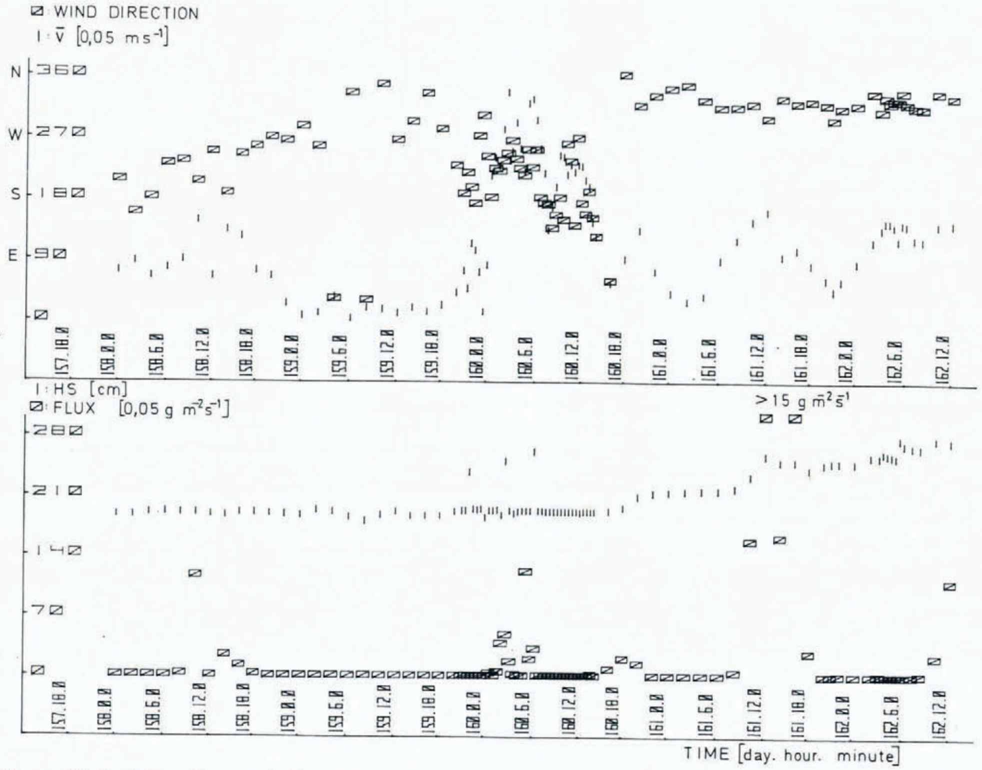

Fig. 2. Typical plot of automatically registered snow depth HS along with wind and drift data as a function of time.

a.s.l. Those data are transmitted by radio along with other weather and snow-cover parameters to the Institut on Weissfluhjoch. All systems worked well for the whole winter. All systems were in operation from the beginning of snow-fall in autumn until final melt-off. So measurements were performed with all types of snow. The maximum snow depth recorded in the field was 3.4 m. The maximum distance between snow surface and receiver/transmitter system in the field was 3.5 m. Tests with distances ranging from 0.5 m to 4 m were completely successful. The percentage of the total number of measurements which did not allow the determination of the snow depth depended strongly on the environment of the field device. Very soft surface layers as well as surface rime caused, in some cases, losses of snow-depth data for several hours, whereas strong snow-drift only caused interruptions of several minutes. Icing or riming of the receiver/transmitter microphones may prevent successful operation. All these cases were clearly indicated by the system. (Instead of the actual snow depth the pre-set height of the receiver/transmitter above the ground is shown on the display.) An erroneous interpretation of these unsuccessful measurements is impossible. Erroneous results not consistent with the actual snow depth, were received in a few cases: indication of a lower depth than the actual because of the poor directivity of the transducers in cases of critically low reflectivity of the snow surface or an indication of a larger depth than the actual in cases of strong snow-drifting. In most cases we got good results even at drift fluxes up to several 10 g m^{-2} s^{-1}. Too high a sensitivity of the ultrasonic receiving/transmitting system increases the number of erroneous results, whereas too low a sensitivity increases the percentage of unsuccessful measurements. The results are listed in Table I. The best results were received from locations where wind and radiation impeded the formation of very soft surface layers. A characteristic plot of a five-day period of snow-depth measurements from the remote Gaudergrat station is given in Figure 2. The plot shows some erroneous measurements during the periods of blowing snow.

Conclusion

It is possible to build an inexpensive snow-depth measurement device suited for remote applications. The results correspond to expectations. The device is suitable for applications where an accuracy of ±0.03 m is sufficient.

MS. received 29 May 1979 and in revised form 14 September 1979

APPENDIX

Mechanical design

Each of the electronic circuits described below is printed and wired on one board. The converter is mounted in a watertight box at one end of the 2 m long rod carrying the field electronics. This box is shielded against solar radiation (Fig. 1). The transmitter-board is mounted together with the required 45 V source in a smaller box which carries the transmitting microphones.

The receiver board together with the receiving microphone is assembled in an aluminium tube. This tube and the transmitter box are each fixed by a soft-rubber acoustic insulation to the other end of the horizontal supporting rod.

Electronic set-up

Control (*Fig. A1*)

A measurement may be initiated either manually by closing S1 or by an external trigger pulse. The internal 3.3 ms pulse from the one-shot IC8a is transmitted directly to the field device and simultaneously fires the one-shot IC9c for 1.35 s, resets the flip-flop IC10 and the BDC counter IC13 and pre-sets the down-counter IC14 to IC16 by firing the one-shot IC9b. As long as Q_3 of the counter IC13 is low and the clock input of the flip-flop IC10 does not go high, Q of IC10 remains high and enables IC13b to feed pulses from the field device to the synchronous three-digit down-counter IC14 to IC16. Each arriving pulse corresponds to a distance between ultrasonic receiver/transmitter and the snow surface of 0.01 m. The BCD pre-set switch S1 has to be set equal to the height of the receiver/transmitter system above the ground. If the down-counter IC14 to IC16 reaches zero there is either no snow, or the surface reflected pulse was too weak to stop the field oscillator IC28. If the down-counter reaches zero, a new measurement is initiated by re-pre-setting the counter through IC12b, c, IC11, IC12d, IC9b. The counter IC13 counts the number of attempts. After seven unsuccessful attempts the control is disabled by IC13, IC10, IC13b and the BCD output of the down-counter corresponds to the pre-set state.

The display frequency oscillator IC11 and the decoders IC17 to IC19 allow the results to be indicated on a three-digit liquid-crystal display. The results are also latched in the tri-state output registers IC20, IC21, from whence they can be transferred to a bus any time after the measurement cycle is terminated. In any case the measurement cycle is shorter than 1.5 s. The data are available 1.35 s after a trigger pulse has initiated the control. The control may be powered by a 5 V or 6 V power supply or by four 1.5 V monocells of 1 500 mA h.

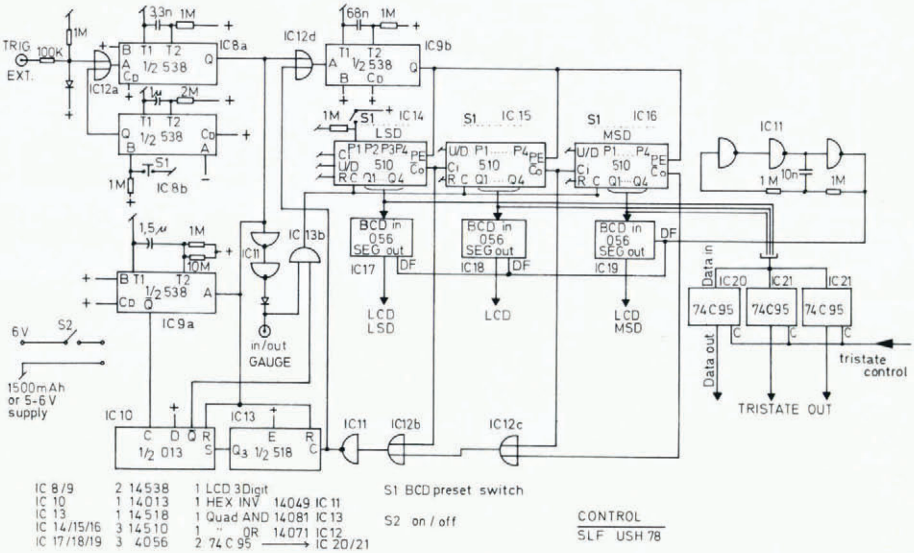

Fig. A1. Control circuit.

Field electronics, converter (Fig. A2)

A trigger pulse from the control fires the one-shot IC22a for 1.5 s. The output $\bar{Q}$ of IC22a powers the whole field electronic system (relay driver IC23, relays R1, R2). Only IC22 and IC23 are continuously connected to the batteries. The control pulse disables the field system for the first 100 ms by firing the one-shot IC22b. After the 100 ms, the sonic transmitters are turned on the first time for about 200 μs by IC24a. Simultaneously, IC24b disables the acceptance of signals from the microphone for about 4 ms corresponding to a forward and backward travelling distance of about 0.65 m. This value can be varied in the range given on Figure A2 depending on the acoustic insulation between transmitter and microphone and the sensitivity of the system. Simultaneously with the initial pulse to the transmitter, the temperature-compensated and controlled oscillator IC28 is turned on with the help of the flip-flop IC27. The NTC resistor measuring air temperature corrects for the temperature dependence of the acoustic propagation velocity to a reading error of about 0.02 m in the temperature range from −20°C to 0°C. If the NTC resistor is fixed to the converter box, the box has to be carefully shielded against solar radiation (Fig. 1). The frequency of the field oscillator IC28 is about 15 kHz and has to be adjusted to 0.01 m forward and backward travelling distance of the ultrasonic wave packet per pulse. The output of the field oscillator is fed to a three-digit asynchronous counter and by an input–output signal-separating network to the control. If the counter IC29, IC30 reaches 400, indicating that no reflected sonic pulse has reached the receiver microphone in time, Q_2 of IC30 fires the one-shot IC22b and initiates a new measurement cycle. If the level discriminator IC32 is not fired by an incoming sonic wave pack, the converter starts new measurements until the field electronics are powered down by the one-shot IC22a. IC31 is used as a 40 kHz band-pass filter–amplifier and IC32 represents an adjustable level discriminator. The receiver sensitivity has to be adjusted with this level discriminator. The converter–receiver/transmitter is powered with four 1.5 V monocells of 1 500 mA h. For normal operation one line driver (Fig. A3) is included in the converter unit and powered with the same batteries.

Transmitter (Fig. A4)

The transmitter electronics are designed to operate up to four ultrasonic ceramic transmitters. The ceramic receiving/transmitting microphones (National Matsushita, type EF12-RCB 40K2) have the advantage of good temperature and humidity stability. They have the disadvantage of poor directivity (−3 dB at about 20°).

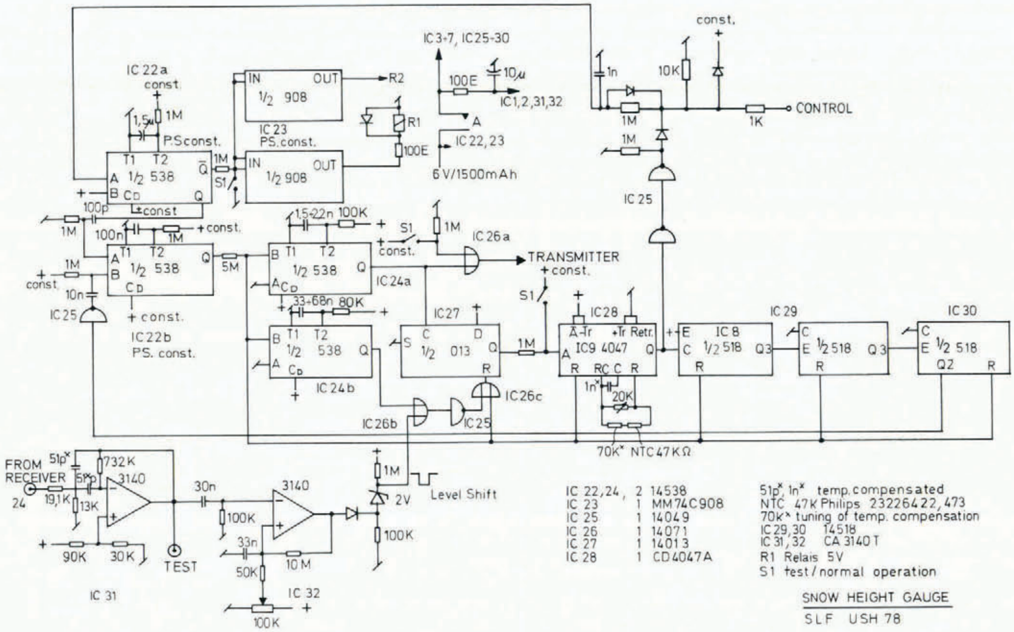

Fig. A2. Converter circuit.

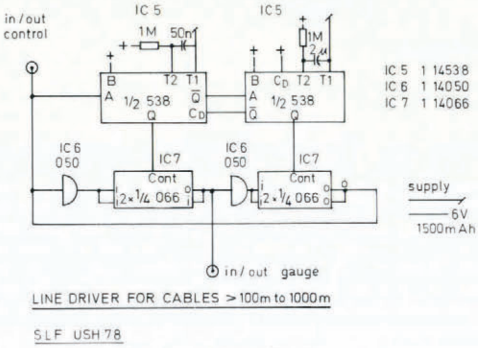

Fig. A3. Line-driver circuit.

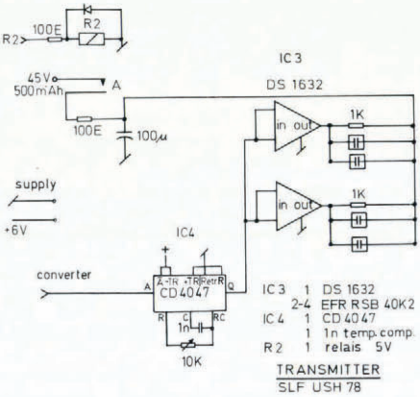

Fig. A4. Transmitter circuit.

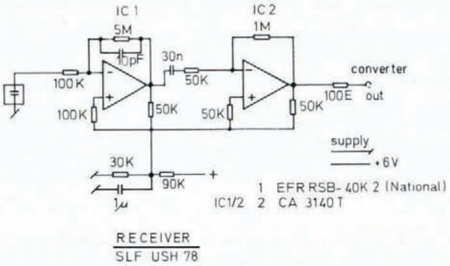

Fig. A5. Receiver circuit.

Highest sensitivity is obtained by driving the microphone near its resonance frequency of about 40 kHz. The test switch S1 on the converter board allows the tuning of the oscillator IC4 to maximum output amplitude at the test output "Test". During normal operation the oscillator is turned on by IC26a for only 150 μs. To get the highest possible output from the transmitters, they are excited with 45 V from five small 9 V batteries connected in series. The batteries are switched to a large storage capacity by relays R2.

Receiver (*Fig. A5*)

The receiver consists of a high-impedance two-stage voltage amplifier. This part of the field device has to be very carefully shielded. Besides a good electrical shield, a good acoustic shield between transmitting and receiving microphone maintains a minimum inactive range of the system of less than 0.4 m (IC24b).

REFERENCES

Good, W., *and* Krüsi, G. 1973. Ein optoelektrischer Schneehöhenmesser. *Winterbericht des Eidg. Institutes für Schnee- und Lawinenforschung*, Nr. 37, p. 150–56.

Marbouty, D., *and* Pougatch, B. 1978. Mesure de la hauteur de neige par ultrasons. (*In Comptes rendus. Deuxième rencontre internationale sur la neige et les avalanches, 12–13 et 14 avril 1978, Grenoble, France.* [Grenoble], Association Nationale pour l'Étude de la Neige et des Avalanches, p. 49–59.)

Takahashi, S., *and* Aburakawa, H. 1976. Kōgaku sen'i o riyō shita sekisetsushin kirokukei [A snow depth recorder using optical fibres]. *Teion-kagaku: Low Temperature Science*, Ser. A, [No.] 34, p. 79–86.