*Journal of Glaciology*, Vol. 17, No. 77, 1976

# INSTRUMENTS AND METHODS

## RADIO-ECHO POWER PROFILING

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Abstract. A method of continuously recording the r.f. power returned from a sub-glacial ice/rock or ice/water interface is described. Illustrations of the records produced are given and their relevance to the reconstruction of the small scale roughness of a reflecting surface is discussed.

Résumé. *Profil de puissance d'un écho-radio.* On décrit une méthode d'enregistrement continuel de la puissance d'une fréquence de radio qui revient d'une frontière sous-glaciaire entre glace et roche ou glace et eau. On présente des illustrations d'enregistrements, et on discute leur rapport avec la reconstitution de la rugosité à petite échelle d'une surface réfléchissante.

Zusammenfassung. *Profilaufzeichnung der Starke von Radar-Echos.* Eine Methode zur kontinuierlichen Aufzeichnung der Radarfrequenzstärke nach Reflexion an einer subglazialen Eis/Fels- oder Eis/Wasser-Grenzfläche wird beschrieben. Die gewonnenen Schriebe werden vorgeführt und ihre Relevanz für die Wiederherstellung der kleinräumigen Rauhigkeit einer reflektierenden Oberfläche wird diskutiert.

### Introduction

As a consequence of the successful application of radio-echo sounding to depth profiling, interest has recently been shown in the reconstruction of the small-scale statistical roughness of reflecting surfaces. This statistical roughness, whilst remaining unresolved in range, is responsible for the fading effect observed in all radio-echo records.

Since all forms of power recording necessarily result in the loss of phase information, a direct reconstruction of a reflecting surface is impossible. However, Bramely and Young (1967) and Oswald (unpublished) have shown that, in certain cases, it is possible to deduce the r.m.s. slope and auto-correlation length of the reflector from a knowledge of the variance and auto-correlation length of the peak returned power.

Oswald (unpublished), in analysing the ice/bedrock characteristics on Devon Island, Northwest Territories, obtained the power variance and auto-correlation length from a series of A-scope pictures which had been recorded sequentially at one metre intervals along a track. This sampling rate is somewhat greater than the Nyquist sampling frequency (Båth, 1974) which is computed under the valid assumption that the major contribution to the returned power comes from the first few Fresnel zones; for example, a flight altitude of 1 000 m above ice of thickness 500 m implies a Nyquist sampling distance of about 3 m.

At this optimum sampling rate, continuous A-scope recording requires up to one million frames of film per flight. It was this, together with the associated problems of data reduction, which prompted the development of a new system which would record the peak of the returned power in a quantitative form. The records were later to acquire the name echo strength measurement, abbreviated to E.S.M.

### Apparatus

The output from the 60 MHz receiver is applied to the *Y*-plates of an oscilloscope operating with the time base switched off. The signal thus appears on the screen as a vertical line, the height of which is proportional to the power in the return. 35 mm film, moving at a constant speed in front of the oscilloscope screen, is used to record the display which therefore appears on the film as a continuous band, the width of which is directly related at any instant to the peak of the returned power at that time. The horizontal scale of the recording is fixed by recording a position marker every ten seconds, whilst the temporal location of the record is established by recording an incremental LED display at intervals of twenty seconds.

Since the signal is displayed with the time base switched off, it is necessary to gate the output from the receiver in order to blank out the strong echo from the top surface which would otherwise obscure the (usually weaker) return from the bottom ice/water or ice/bedrock interface. This was accomplished by applying a gating pulse of variable width and delay, derived from the transmitter trigger pulse, to a video-band analogue switch, the output of which was displayed on a recording oscilloscope.

In the absence of an automatic tracking facility, manual tracking of the reflecting surface was required and so short voltage pulses generated at the rise and fall of the gating pulse were applied to the $Z$-input of an A-monitor scope in order to enable the operator to position the gate. Unfortunately these pulses were frequently hard to see and it was better to display the gated signal on a separate monitor scope.

A prototype E.S.M. system differed from the apparatus described here in that the output of the analogue switch was used to drive a peak voltage detector. This detector lowered the ability of the system to reject external noise and the unexpected presence aboard the aircraft of such a noise source—later traced to an electrically operated window demister—frequently masked the weak return from an ice/rock interface. A peak detector permits the blanking of power levels below the peak so that the envelope of the returned power can be recorded as a single line. However, experience has shown that the internal structure of the E.S.M. records can be of use in distinguishing between the different regimes of fading whilst recording the noise level is very useful for calibration purposes. It now seems, therefore, that the use of a peak detector is both undesirable and unnecessary.

## Results

Several examples of E.S.M. records obtained from reflectors of different roughness characteristic are shown in Figure 1. These are continuous power profiles and as such are especially useful for:

(a) Locating regions of similar bottom roughness characteristics.
(b) Following the changing nature of the ice/rock or ice/water interface along a flow line.
(c) Detecting changes in either the reflection coefficient of the ice/rock interface or the r.f. absorption properties of the ice.

Of particular interest is the record shown in Figure 1(d). This was obtained by simultaneously gating the returns from the ice/air and ice/water boundaries on the Ross Ice Shelf. A change of 25 dB in the reflection coefficient of the smooth ice/water interface indicates the presence of an r.f. absorber within the ice. The ice/air interface is smooth as expected but its r.m.s. slope is higher than that of the ice/water boundary.

In many situations it is possible to obtain the bottom roughness parameters from a detailed study of the E.S.M. record. However, as Oswald (unpublished) has pointed out, there are situations in which it is impossible to deduce the roughness characteristics from variations in peak returned power. Under these circumstances, estimates of the roughness must be made from the decay rate of the returned power, details of which are available from widely spaced A-records. (This method of analysis, proposed in detail by Berry (1973), is very sensitive to the shape of the transmitted pulse and is, in general, less accurate than the method of Oswald.) It is for this reason that the E.S.M. system must be regarded as a complement to, rather than as a replacement for, A-scope recording. To this end the E.S.M. system was supplemented by a "Leicina" super 8 cine-camera which was available to record the A-scope display, either in automatic mode or upon operator request, in bursts of up to twenty seconds duration at a sampling rate of 54 f.p.s. (frames per second). This rate corresponds to a horizontal ground spacing of roughly 2 m.

Analysis of the data is continuing and the results will be presented in a future paper.

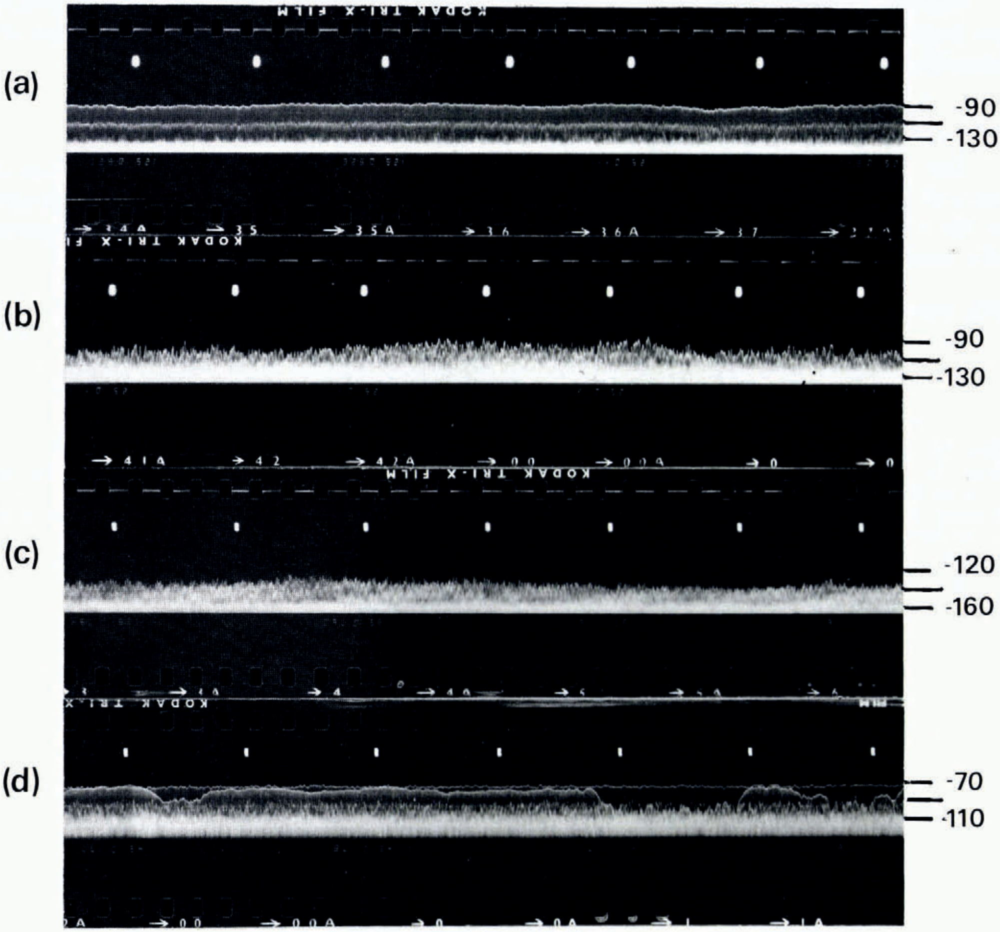


*Fig. 1. Examples of E.S.M. recording. Echo power is indicated to the right of the record in dB relative to the transmitted power. The inner structure within the records at power levels below the peak is due partly to the gate straddling returns from high angle facets of the reflecting surface, and partly to a type of ringing phenomenon which is clearly visible in (a) and which probably results from an impedance mis-match in the antenna connecting cables. Flight details are recorded at 20 s intervals from an LED display, whilst event marks occur every 10 s, this time increment being roughly equivalent to a traversed distance of one kilometre.*

(*a*) *Return from a smooth ice/water interface on the Ross Ice Shelf. Position: 80° 25′ S., 159° 00′ W. Aircraft height: 830 m. Ice thickness: 630 m.*

(*b*) *Return from an ice/water boundary of large r.m.s. slope. Position: 79° 57′ S., 177° 38′ E. Aircraft height: 740 m. Ice thickness: 310 m.*

(*c*) *Return from a rough ice/rock interface in East Antarctica. Position: 67° 40′ S., 138° 17′ E. Aircraft height: 870 m. Ice thickness: 1 730 m.*

(*d*) *Returns from both the top and bottom surfaces of the Ross Ice Shelf. Position: 79° 51′ S., 178° 30′ W. Aircraft height: 8 000 m. Ice thickness: 310 m.*

## Conclusion

The great advantage of E.S.M. records is that they allow the glaciologist to assess the qualitative nature of a reflecting surface quickly. Detailed analysis of the records can often yield values for the roughness parameters of the reflecting surface, a task for which the addition of a 300 MHz E.S.M. device to the existing 60 MHz recorder would be desirable.

Although interest has so far centred on the nature of sub-glacial reflectors, returns from the ice/air interface are seen to have regional variations suggesting that further study of this boundary could be of interest.

ACKNOWLEDGMENTS

The development of the apparatus was carried out whilst the author was in receipt of an Natural Environment Research Council research studentship. The Office of Polar Programs of the U.S. National Science Foundation supported the airborne Antarctic programme. My thanks are also due to Dr G. de Q. Robin for his continued support.

*MS. received 29 December 1975*

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