ANNALI DI GEOFISICA, VOL. 42, N. 2, April 1999

Latest improvements for the echo sounding system of the Italian radar glaciological group and measurements in Antarctica

Ignazio E. Tabacco (1), **Cesidio Bianchi** (2), **Massimo Chiappini** (2), **Andrea Passerini** (3),
Achille Zirizzotti (2) **and Enrico Zuccheretti** (2)
(1) *Sezione Geofisica, Università di Milano, Italy*
(2) *Istituto Nazionale di Geofisica, Roma, Italy*
(3) *Dipartimento di Fisica, Università di Milano, Italy*

Abstract
Radio echo sounding is an active remote-sensing method using electromagnetic wave penetration in a particular medium such as ice and permits the measurements of its thickness, the level of the bedrock and inhomogeneities *i.e.* of the internal layering of glaciers. The Italian Radar Glaciological Group has implemented technical improvements on the system operating during the 1995-1996 Antarctic expeditions, increasing the horizontal and the vertical resolution by means of a new acquisition ensemble. The new system was used during the Antarctic expedition in 1997-1998. The present paper presents the latest improvements of the radar acquisition system and radar profiles extracted from the 1995-1996 and the 1997-1998 Antarctic expeditions are presented.

Key words *radioglaciology – ground penetrating radar – ice thickness measurements*

1. Introduction

The tectonics of the Antarctic continent plays a central role in both Gondwana and Rodinia evolution but it is still the most poorly understood region of the planet.

Detailed information on the bedrock topography, in particular areas where the ice cover is nearly ubiquitous, are extremely important to supply, *e.g.*, potential field data. In the framework of the ADMAP project, a compilation of complementary data sets would be desirable. For the existing Antarctic digital ice radar measurements our objective is to enhance the geologic and tectonic utility of these data. This compilation will provide a glaciological coherent database from which a geological and geophysical synthesis may be obtained. The Italian Radar Glaciological Group will contribute to this initiative with new data and planning of future airborne surveys. An active remote sensing technique such as radar sounding provides geophysical information on ice sheets (Bogorodsky *et al.*, 1985). Its physical principles are based on the emission of a short electromagnetic pulse by means of a transmitting antenna. The pulse penetrates the glacier until it is reflected by inhomogeneities in the ice layer and by the ice-bedrock interface. The echo pulse is received and analyzed in amplitude and time to determine the physical properties of the medium.

Mailing address: Prof. Ignazio E. Tabacco, Sezione Geofisica, Università di Milano, Via Cicognara 7, 20129 Milano, Italy; e-mail: ignazio.tabacco@unimi.it

2. Hardware and software improvements

The radio echo sounding SPRI/ENEA system (Gorman, 1993) used during the 1995 expedition, operates at 60 MHz; this frequency seems to be the best compromise between the antenna size, that is about 2.5 m at this wavelength and the wave penetration in the ice, 92% of transmitted power (Bogorodsky *et al.*, 1985).

The main characteristics can be summarized as follows: the transmitted pulse width is in the range (0.3-1) μs, the maximum delay of the received signal is 51.2 μs and thus the maximum penetration depth in the ice is about 4.3 km. The received envelope signal segment is digitized and stored to be analyzed. The RF pulse has a peak power of 2 kW in order to obtain an echo signal of adequate amplitude. Figure 1 shows the arrangement of the above described system.

Hardware and software improvements on the system were performed. The most relevant changes in the new system deal with the acquisition unit, RF, control unit and the software. A new digitizing board and the related software have been developed. The sampling rate of the analog signal has been doubled to increase the accuracy of the depth determination. Data files acquired with the new system have been corrected with actual position and time according with GPS files. A new Phase Lock Loop frequency synthesizer (PLL) has been designed and manual corrections are now possible during the measurements which prevent the reflected peak power from the folded dipole antenna due to mismatching.

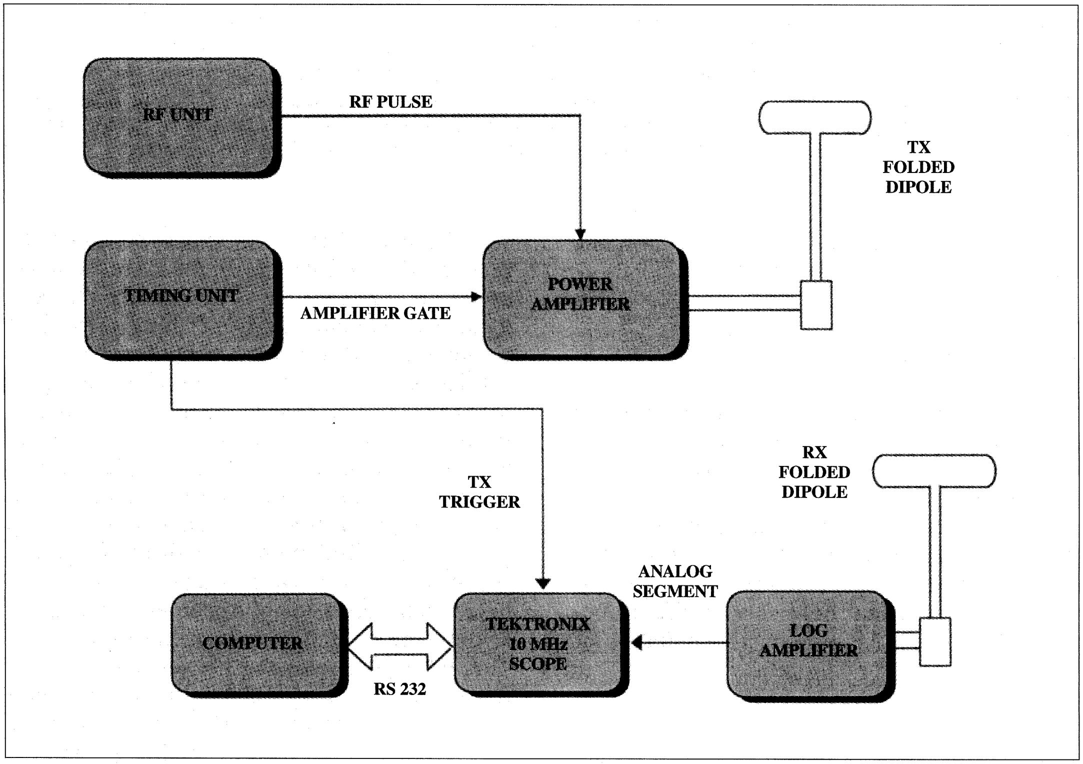

Fig. 1. Basic arrangements of the original glacioradar system used during the 1995-1996 campaign.

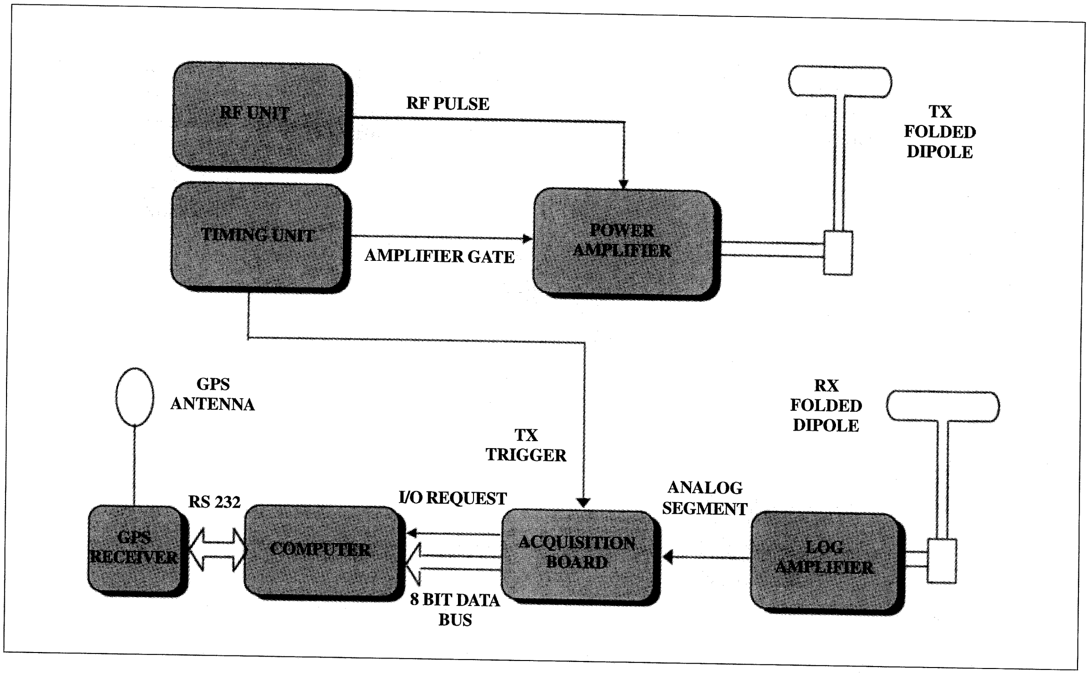

Fig. 2. Basic arrangements of the final version of the glacioradar system. With respect to fig. 1, the main improvements regarding the acquisition board and data serial link with GPS receiver are reported.

2.1. *Acquisition unit*

The original system was characterized by a signal acquisition rate of 10 MHz using a digital oscilloscope and the data were transmitted to a personal computer through a serial communication port. A maximum of a trace every three seconds was possible.

The digital oscilloscope of the old system was replaced with a PC embedded acquisition board also maintaining a channel for the scope. The arrangement for the new system is reported in fig. 2.

At the Istituto Nazionale di Geofisica (ING) laboratory, a 20 MHz sampling board (allowing depth determination, into the ice, with an accuracy of ± 4 m) based on an 8 bit A/D flash converter and Fast IC components has been designed. Figure 3 shows a block diagram of the board. The operations of the board can be divided into two phases.

Phase I is started by a trigger pulse after transmitting RF pulse; the echo envelope signal is sampled at a 20 MHz rate by an 8 bit A/D converter (ADC), to obtain 1024 digital values that are stored in a high speed local RAM. Phase I is 51.2 μs long and it is independent on the PC clock speed and a series of counters controls this operation. When 1 Kbyte of local RAM have been addressed, phase II starts with an interrupt request (IRQ7) sent to the PC. During this phase, data are transferred from local RAM to the PC RAM via the ISA bus then to the hard disk and to the monitor to be displayed. This phase has a variable time length and depends on the PC speed and on the complexity of operations after data transfer. All operations of acquisition in phase I and phase II are completed before a new TX trigger pulse occurs. At present with a 166 MHz PENTIUM based PC, a TX trigger pulse repetition rate of 50 Hz is possible with a complete display of 10 averaged traces per second.

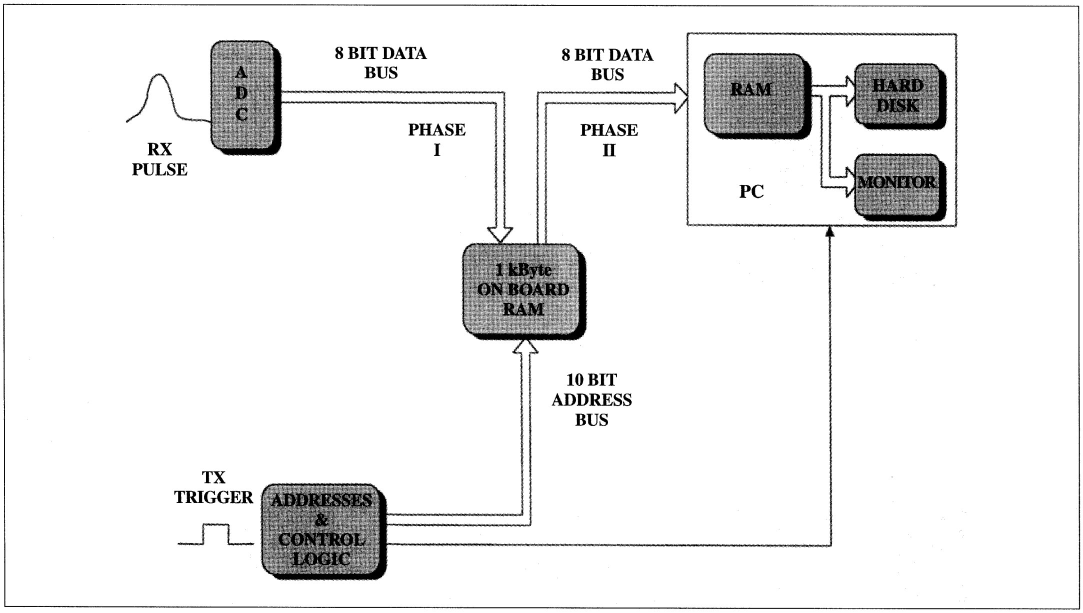

Fig. 3. Digitizing board block scheme. Phase I corresponds to the data acquisition and recording during the 51.2 μs time interval into local memory; Phase II is dedicated to the storage of data into the PC RAM, traces display, simple mathematical operations, and finally storage on disk.

2.2. *RF unit and controller board*

The RF UNIT has been substantially modified. The old oscillator has been replaced with PLL oscillator synthesizing from 40 MHz to 75 MHz with a 1 kHz step. Small adjustments in frequency can be made to avoid transmitting antenna mismatching due to its different physical characteristics in different environmental conditions.

The TIMING UNIT generates a trigger pulse for the A/D board and a gate pulse for the power amplifier. At present, the pulse repetition rate is 50 Hz coinciding with the trace acquisition rate and increases the efficiency of the system. The power amplifier is enabled 25 μs before the RF PULSE is supplied.

2.3. *Software*

A rack mounted PC with an LCD monitor and a membrane keyboard support the new A/D board and software whose code is written in C language. The software provides the acquisition of GPS data via the RS232 serial port and each data file has its own header and tail which specify the location (longitude, latitude and height) and time of survey. The interrupt signal IRQ7 defines the end of the digital acquisition, and the radar trace is stored from the memory of the acquisition board.

A maximum rate of 10 averaged traces per second is possible and they are shown on the screen and recorded. The maximum horizontal resolution is about 1 scan every 6 m for an airborne speed of 60 m/s. In the post processing operations, radar and GPS data are matched.

3. Measurements campaign

The Italian Radar Glaciological Group conducted measurements in 1993, 1995 and 1997, in support of EPICA DOME C project (Lorius

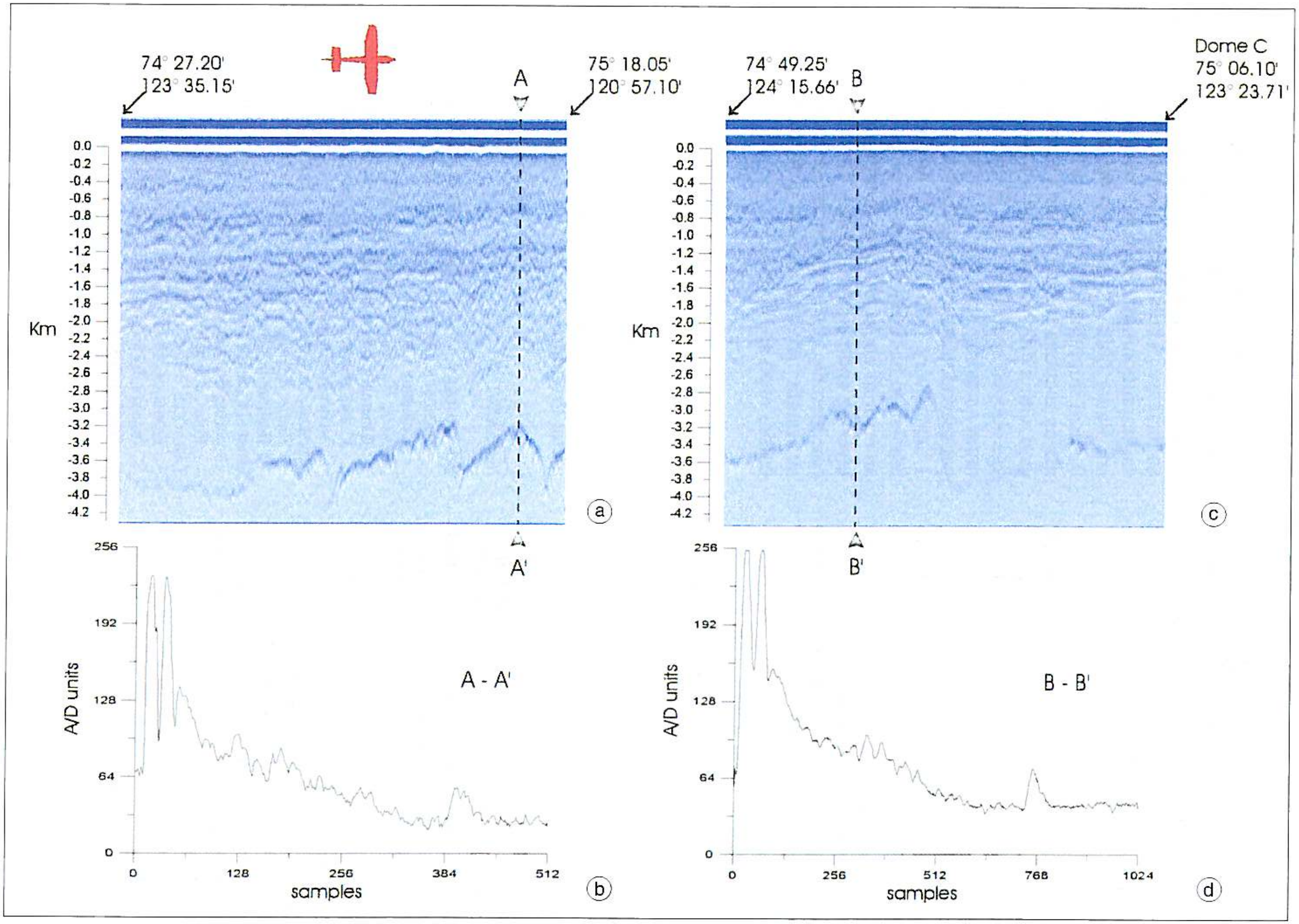

Fig. 4a-d. Examples of traces acquired during 1995 at Dome C area (a) and in 1997 during the survey flight from Terra Nova Bay towards Dome C (c). Frames (b) and (d) are the radar traces in the point where the two profiles intersect. *X* axes represent the full time range of 51.2 μs in both cases, and *Y* axes indicate the 8-bit A/D dynamics common to both systems.

et al., 1995) and Glaciology and Climatic Global Change Italian Antarctic Program in order to study the surface topography (Cefalo *et al.*, 1994), the ice thickness, the bed morphology and the internal layers geometry (Tabacco *et al.*, 1998).

During the 1995 Italian Antarctic Expedition, profiles on the Polar Plateau were surveyed, one of which provides an intersection with the Terra Nova Bay – Dome C transect performed during the 1997 campaign. Figure 4a-d shows these two examples. Frame (a) and (b) were carried out in 1995 at Dome C area while (c) and (d) were windowed from the survey flight from Terra Nova Bay towards Dome C in 1997. During this survey flight a modest scan rate of 1 scan/s was selected, an order of magnitude slower than the fastest possible rate, since we were interested in structures with minimum wavelength of about 150 m.

A typical profile is shown in fig. 4a and 4c using a sequence of radar traces. This is a convenient way to follow radar echoes along a survey flight, thus representing layering and bedrock pattern. Traces are single radar received signals whose amplitude is modulated by discontinuities and inhomogeneities of ice.

Profile (a) is 120 km long, with a spatial resolution of about 200 m (5 scan/km), while profile (c), 40 km long, was carried out with the new system at the chosen scan rate obtaining a spatial resolution of about 60 m (17 scan/km). The maximum depth from ice top is represented by the vertical scale of (a) and (c) whose maximum value is the range of our system (about 4.5 km).

Profiles (a) and (c) intersect at the point and their traces are displayed, (b) and (d), corresponding to A-A′ and B-B′ respectively. These two plots enhance the main difference between the two systems. In 1995 the sampling rate was 10 MHz while in 1997 it was 20 MHz; this corresponds to 512 samples (b) and 1024 samples (d) in the same 51.2 μs time length respectively. *Y* axes indicate the 8-bit A/D dynamics common to both systems.

4. Conclusions

In the present paper we have presented hardware and software improvements to the SPRI/ENEA radio echo sounding system that result in an increase in both the horizontal and the vertical resolution of the apparatus used by the Italian Radar Glaciological Group in Antarctica. Radical improvements were carried out in digitizing sections and controlling software associated with a PC. In particular, assuming an average aircraft speed of about 60 m/s and a maximum sounding scan rate of 10 averaged traces per second, a maximum horizontal resolution of 1 scan every 6 m has been reached. Vertical resolution has been increased as well, reaching an error of about ± 4 m in determining internal layering and bedrock depths. This represents a considerable advantage in terms of availability and quality of data, in view of regional compilations such as ADMAP.

Acknowledgements

The authors wish to thank G. Tutone for his valuable contribution. The research is supported by grants from the PNRA-ENEA National Antarctic Program.

REFERENCES

BOGORODSKY, V.V., C.R. BENTLEY and P.E. GUDMANDSEN (1985): *Radioglaciology* (Reidel Publ. Company), pp. 254.

CEFALO, R., G. MANZONI and I.E. TABACCO (1994): Kinematic processing of GPS trajectories around Dome C and between Dome C and Dumont d'Urville, *Terra Antarctica Reports,* **1**, 119-122.

GORMAN, M. (1993): *Operation Manual for SPRI/ENEA Radio Echo Sounding System*, Scott Polar Research Institute of Cambridge.

LORIUS, C. and J. JOUZEL (1995): European project for ice coring in Antarctica (EPICA), *The Ocean and the Poles,* edited by G. HEMPEL (Fischer Verlag), 263-278.

TABACCO, I.E., A. PASSERINI, F. CORBELLI and M. GORMAN (1998): Determination of the surface and bed topography at Dome C, East Antarctica, *J. Glaciol.*, **44**, (146), 185-191.