PC-DSPs-based signal processing and control system for MST radars

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Abstract - This paper describes a signal processing and control system, designed and built for the Peruvian MST radar installed in the "Machu-Picchu" Scientific Station, Antarctica (62°05'5 S, 58°28' W). System architecture, based in a single PC and two DSP boards, and design considerations are discussed. The system allows up to 4 receiver signals to be processed in parallel, with 60 range gates and 150 m maximum height resolution. System evaluation and some experimental results are reported.

INTRODUCTION

As part of the Peruvian Antarctic Research activities, with the collaboration of CIRES of the University of Colorado, a wind profiler system was designed, built and then installed at the "Machu-Picchu" Scientific Station, on King George Island, Antarctica (62°05'5 S, 58°28' W). The purpose of this paper is to present the design characteristics of the PC-based signal processing and control system of the radar. An identical system has been built for the Jicamarca Unattended Long-term Investigations of the Atmosphere (JULIA) project. This is a project designed to use the large Jicamarca antenna as a continuously operating radar at a reduced power level.

The scientific goals of the Antarctic project were twofold: 1) to measure the tropospheric and lower stratospheric winds, in an effort to better understand the role of these wind systems in the depletion of the ozone layer in the Antarctic; and, 2) given the experience of similar radars in the Arctic, where very strong echoes are received from mesospheric altitudes, known as PMSE (for Polar Mesospheric Summer Echoes [Ecklund and Balsley, 1981]), the study of their presence in the Antarctic.

The instrument was then designed as a MST radar, i.e., with capabilities to study these three regions of the middle atmosphere. The Machu-Picchu system has three antennas with three different non-coplanar beam directions. In order to determine completely the wind velocity vector: pulse transmission, data acquisition and processing are performed simultaneously for the three beams. Three independent transmitters and receivers are used. Eventhough, three receivers are sufficient for the Antarctic experiments, the system has been designed to process in parallel as many as four radar receiving coherent channels for JULIA and other potential applications. Furthermore, it is possible to use multiple altitude sampling windows, e.g., one for the troposphere, lower stratosphere and other for the mesosphere.

The system could have other applications. In fact, it has been planned to use the same radar, with a horizontally pointing antenna, as a Sea-State radar, to measure the surface currents in the surrounding bay.

SYSTEM DESCRIPTION

Objectives were to design a flexible, totally programmable processing system, while at the same time improving measurement time resolution and eliminating the need for antenna switching. The system would thus work with up to four receivers, 60 range gates (i.e., heights) and 300 m height resolution or a comparably demanding set of parameters.

The system is composed of an A/D converter unit, two DSP boards, a control computer (PC) , an optical disk drive, an HEXABYTE 8 mm tape unit and the interfaces to connect all the above. A second computer can be connected to the PC via an Ethernet link for off-line data processing and flexible, user define, graphical interface.

A block diagram of the system is drawn in Figure 1.

From a design point of view, the main features are:

- multiple ADCs for simultaneous processing of different receiver outputs;
- the use of two DSPs, each of which performs one phase of the processing;
- the use of a single PC for additional signal processing, data storing, control of the experiment and plotting of real time graphics of the data.

System outline

The system is connected to the receiver outputs and to the Radar Controller, a programmable device which generates all the timing signals of the radar. The RS-232 interface allows the Radar Controller to be programmed by the PC.

The Radar Controller was designed and built at the Jicamarca Radio Observatory. Its design and programming are not of our concern in this paper and are discussed elsewhere [Urbina, 1993].

The receiver output signals are sampled and digitized by the A/D converter unit. Sample pulses come from the Radar Controller, which synchronizes them with the transmitted RF pulses, according to the ranges to examine.

A parallel interface connects the ADC outputs to the first DSP board. The first DSP works as a coherent integrator: it reads converter data and sums the programmed number of successive samples. This is done separately for each height and for the real and imaginary component.

Time averaged data are then passed through a serial interface to the second DSP board. The second DSP, after performing range decoding, works as a frequency analyzer, computing complex FFTs and then incoherently integrated power spectra of the data.

The spectra are transferred through the PC bus to the PC RAM, then they are further integrated and finally stored in 8 mm magnetic tape and/or in optical disk. Selected data is displayed, to allow real time monitoring of the results.

A/D converter unit and parallel interface

The A/D converter unit has four input channels. Each of them employs a dual 8 bit flash converter for the in-phase and quadrature components.

The four converter outputs (2 bytes each) are multiplexed and connected to the first DSP board through a 16 bit parallel interface that conforms with DSPLink standard. The multiplexer is controlled by two bits of the DSP address bus, so each channel can be individually addressed. Time required to read one complex datum from the interface and store it into the DSP memory is 300 ns.

The system has been used with a minimum sampling interval of 2 μs (300 m resolution) with three channels, and of 1 μs (150 m resolution) with one channel.

DSP boards

The two DSP boards are installed on the PC. The DSP programs are loaded from the PC into the boards' memory via the PC BUS. At the beginning of each experiment, the parameters can be set according to the required processing.

The same type of DSP chip is used in the two boards, namely an AT&T DSP-32C working at 50 MHz (25 MFLOPS).

On the first board (coherent integrator) 160 KBytes of RAM and the DSPLink parallel interface hardware are installed. Connection to the converter outputs through the interface is memory-mapped: the DSP reads a converter output as a memory location.

The second board (frequency analyzer) has 256 KBytes of RAM and does not have a parallel interface.

The two DSPs are connected through the on-chip serial port, configured for a 2 Mbit/s throughput.

Data is taken without interruption. A double buffering scheme is implemented in both DSPs, for both: input and output stages. While one of the buffers of each pair is kept busy with the processing the other is used for data transferring.

Control PC

A 486-based PC working at 33 MHz is used as the control console. The PC processes and stores data being taken concurrent with the DSP processing.

At the beginning of each experiment, an initialization program is run, which:

- allows selection of experiment parameters;
- loads the DSP programs in the DSP boards memory and runs them;
- programs the Radar Controller with the parameters of the experiment (interpulse period, heights to sample etc.) and enables RF pulses transmission.

During each experiment, the control program continuously performs the following tasks:

- reads data (power spectra) from the frequency analyzer and stores them to the PC RAM;
- averages the power spectra according to the programmed number of incoherent integrations;
- stores processed data into the optical disk, which is a WORM (Write Once-Read Many times) device with 1 GByte capacity;

- stores copies of the processing results into 8 mm magnetic tape. This operation is redundant to recording on the optical disk. Either one of them can be selected or disabled;
- transfers all processed data, via the Ethernet link, to the second computer;
- displays a graph of total received power vs height: from this, the operator can detect system fails;
- displays graphs, in the form of contour plots or density plots, of received power versus height and frequency: thus, all spectra can be monitored in real time;
- allows the operator to stop the experiment at any time and start it again with new parameters. If no changes are required, data collection automatically continues with the same parameters. The radar station can thus work completely unattended, requiring operator intervention only for tape and/or optical disk replacement.

A double buffering scheme is also implemented at the input of the PC for data coming from the second DSP board.

Ethernet link

An Ethernet adapter is installed in one of the PC slots. A two computer network can be formed, e.g., with a UNIX Workstation.

The link can be enabled or disabled at any time during the experiment. When it is enabled, the other computer receives a copy of all processed data, for the benefit of the observer, who can look at the data with leisure using custom designed graphical programs.

The Ethernet link is not needed for the radar system to work properly but it allows further flexibility in displaying earlier data. The system has been designed to work independently of the network.

DESIGN CONSIDERATIONS

The design of the processing system is influenced by the following considerations:

1) sampling is not uniform over time: instead, sampling instants form short bursts, repeated with constant delay after each transmitted pulse. This is due to the fact that a small height range is usually observed, while echoes are received from a much larger height interval, e.g., if a wind profiler is sounding heights between 3 and 12 km and the unambiguous height limit is 150 km, sampling window only spans 60 μs of the 1 ms pulse repetition period.

2) furthermore, the operator can define multiple sampling windows: e.g., heights between 3 and 12 km and between 85 and 95 km can be sampled at the same time.

3) pulse transmission and sampling instants are triggered by the radar controller. This device has its own clock, independent of the processing system, so that sampling is not synchronized with the DSP nor the PC clock.

These first considerations suggest the use of interrupts for coherent integrator input. Each sample pulse generates an interrupt signal to the first DSP, which then reads data from the parallel interface. As converters are individually addressed, the DSP can be programmed to read one, two, three, or all of them.

A further consideration is of concern for system performance:

4) height resolution depends on time interval between successive samples: to achieve a good height resolution, input speed has to be as high as possible.

Consequently, interrupt execution time has to be kept to a minimum. Hence, the interrupt routine reads converter data and stores them in a buffer, leaving the task of updating the running sums to the main program.

As stated above, time required to read and store a datum is 300 ns. Thus, 1200 ns are required for four channels. Interrupt overhead (320 ns maximum) must be taken into account: total input time (i.e., minimum sampling interval) is 1.52 μs. Corresponding limit for height resolution is 230 m. Higher resolution can be obtained with a reduced number of channels, e.g., 95 m with one channel.

On the other hand, overall processing speed of the first DSP is not as critical as input speed. In fact:

a) the main program only performs a small number of operations (as many retrieve, sum and store operations as sampled heights);

b) a large fraction of time is available, as the sampling window only covers a small fraction of the interpulse period.

Actually, the first DSP processing speed would allow more functions to be implemented (phase decoding before coherent integration, windowing, etc.), which will be part of future enhancements of the system.

If we now consider the second DSP board, the two design parameters of importance are processing speed and on-board memory.

Processing speed forces a trade-off between minimum number of coherent integration and maximum number of heights. In fact, the DSP must calculate all power spectra of a data set before the next one is ready. If less integrations are performed, less time is available, so a smaller number of heights can be processed.

However, time required to compute a 256-point FFT is around 1 ms: thus, processing speed is not a limit, except when a low number of coherent integration is used.

On the other hand, on-board memory can limit number of heights, because all data are kept in memory while computing FFTs. Also, double buffering is used for data transfer, so the required RAM size is doubled. Nevertheless, with the actual configuration, 60 heights with four beam directions can be processed.

PERFORMANCE SUMMARY

Measurement characteristics of the described system can be summarized by the following parameters:

1) four beams are processed at the same time, thus eliminating the need for antenna switching. In wind profiling, where three beams are used, time required to obtain a profile is reduced to one third of what would be required in a multiplexed system for a comparably accuracy. With typical parameters, a wind profile can be measured in 2 minutes.

2) multiple sampling windows can be used.

3) with typical wind profiling parameters, 60 heights can be processed at the same time on four beam directions (or 80 with three directions). Such a number of heights fits the current requirements for MST radars.

4) Height resolution is 300 m with four beam directions and 150 m when only one is used. Height resolution (i.e., data acquisition speed) could be improved with further development of the interface between A/D converter unit and coherent integrator. However, the sampling interval should match the duration of the pulse transmitted by the radar, which is limited by RF hardware. Pulse durations currently used in VHF MST radars are of the order of our system sampling interval.

Some further features of the system are the following:

5) programming flexibility allows the operator to set all the parameters of the experiment using a single program on a PC. Processing parameters (e.g., number of integrations), radar parameters (e.g., transmitted pulse duration) and other system parameters (e.g., number of heights to observe) can all be controlled and set on a single software "control panel", by editing the values displayed on the monitor.

6) the system could be applied with slight or no modifications to other remote sensing devices that require Doppler processing, e.g., boundary layer radars, RASS, etc.

7) radar control and data collection are fully automatic, allowing unattended operation.

8) finally, the system was realized at minimum cost.

EXPERIMENTAL RESULTS

After being tested at Jicamarca Radio Observatory, in January 1994 the described system was installed at the "Machu-Picchu" Scientific Station in Antarctica, where the 50 MHz MST radar had been installed in 1993 [Balsley, ***et. al***, 1993]. The system replaced a previous, single-DSP system.

Wind profiling between 3.5 and 12 km as well as mesospheric sounding from 70 to 95 km were performed simultaneously.

Power and spectral profiles obtained in a mesospheric sounding experiment using the vertical beam are shown in Figure 2. Contours represent levels of received power. Plots of this kind are shown in real time on the control console. In a typical wind profiling experiment, three plots of this kind are obtained every 2 minutes.

ACKNOWLEDGEMENTS

Installation of the MST radar in the Antarctica is a Peruvian-USA collaborative project funded by the Comision Nacional de Asuntos Antarticos and the Consejo Nacional de Ciencia y Tecnologia on the Peruvian side, and by National Science Foundation of the USA. We would like to thank Dr. Ben B. Balsley, of CIRES, University of Colorado at Boulder, Principal Co-investigator of the project, for his technical, scientific, financial and logistic support. We would also like to thank Vice-Almirante Jorge Broussett and Comandante Hector Soldi, of the Direccion de Hidrografia y Navegacion de la Marina Peruana, for their support in the construction and operation of the radar in Antarctic.

REFERENCES

Balsley, B.B., R.F. Woodman, M. Sarango, J. Urbina, R. Rodriguez, E. Ragaini and J. Carey, (1993). Wind Profiler installed in Antarctica. *EOS Trans.*, 74 (35), pp.395-396

Ecklund, W.L. and B.B. Balsley, (1981). Long-term observations of the Arctic mesosphere with the MST radar at Poker Flat, Alaska. *J. Geophys. Res.*, 86, pp.1775-1780

Urbina, J., (1993). *Diseño e implementacion de un Controlador de Radar MST para la Base Antartica Peruana "Macchu Picchu"*. E.E. dissertation, Universidad Nacional de Ingenieria, Lima, Peru

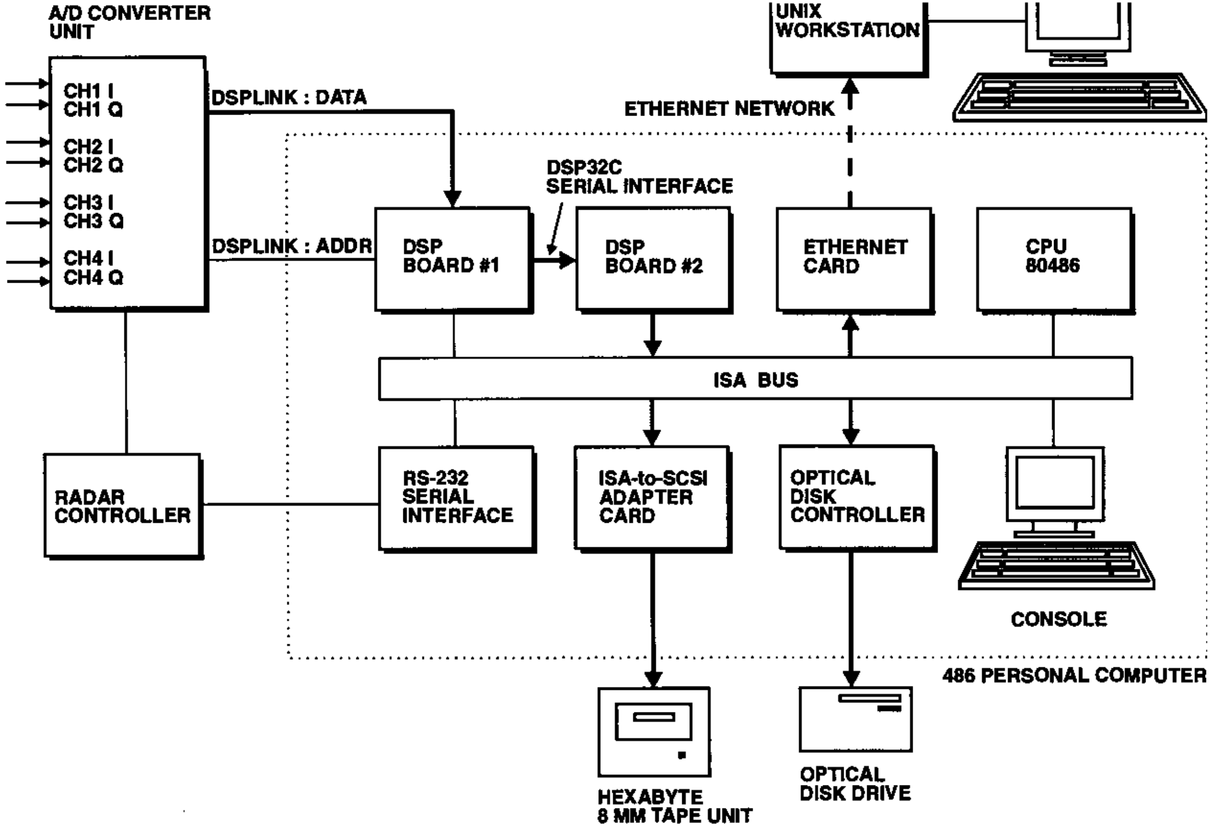

Figure 1: Signal Processing and Control System Architecture.

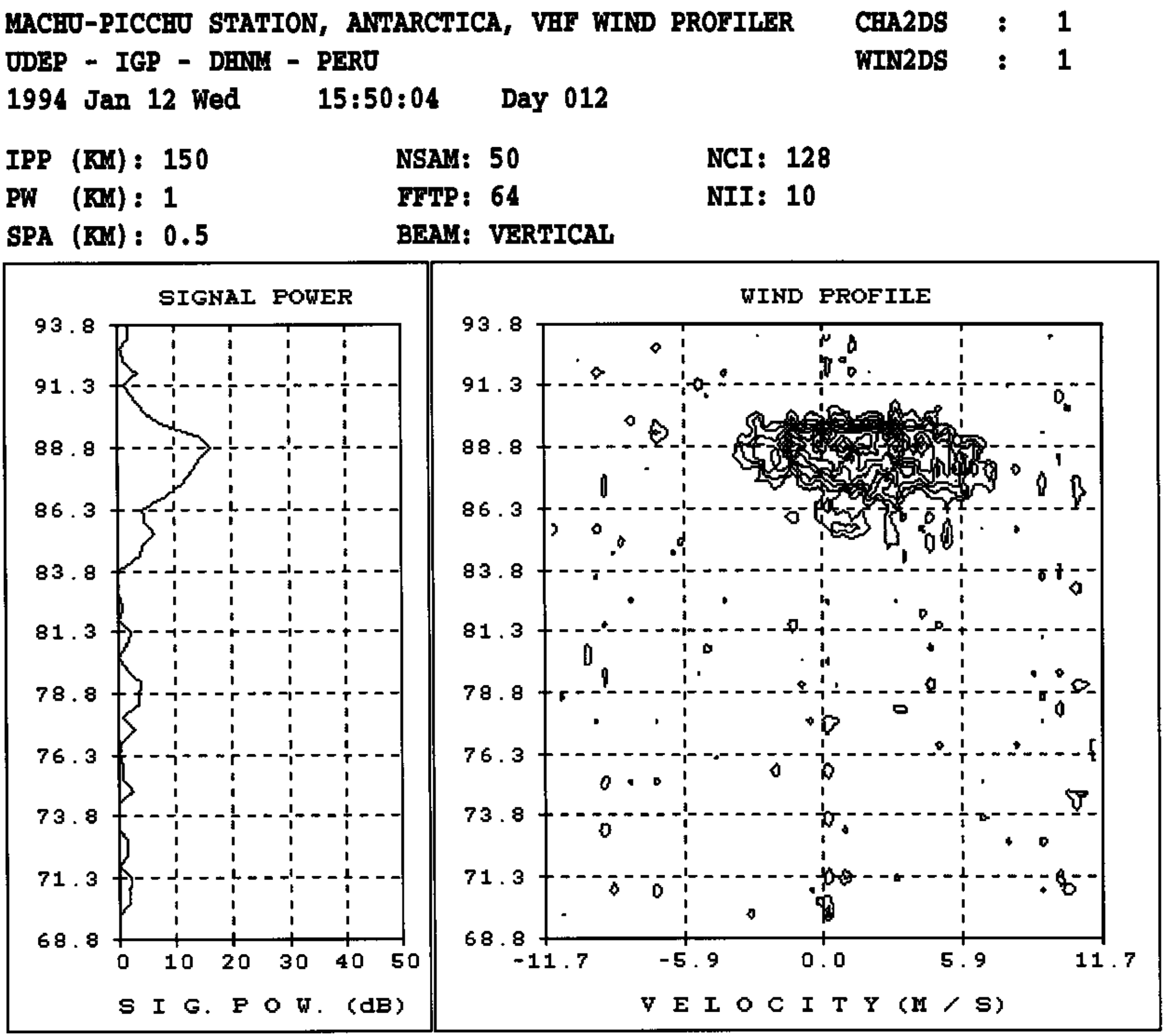

Figure 2: Mesospheric sounding data measured at "Machu-Picchu" Station, Antarctica. These graphs are displayed in real-time by the system during data collection.