SIGNAL PROCESSING AND CONTROL SYSTEM FOR THE ANTARCTIC PERUVIAN MST RADAR

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This paper describes a signal processing and control system, designed and built in collaboration between Jicamarca Radar Observatory and University of Piura, Peru, for the peruvian MST radar installed in the "Machu-Picchu" Scientific Station, Antarctica (62 05'5 S, 58 28' W). An identical system has been built for the Jicamarca Unattended Long-term Investigations of the Atmosphere (JULIA) project.
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 receivers are used. Eventhough, three receivers are sufficient for the Antarctic project, the system has been designed to process as many as four coherent receivers in parallel, for JULIA and other potential applications.
System architecture and algorithm implementation are discussed.
The incoming data, digitized with fast A/D converters, are sent to a first DSP board (PC mounted) for time-domain averaging (coherent integration). The speed of the DSP is the decisive factor, as the peak data sampling rate can reach 1 MSPS with a corresponding maximum data rate of 8 MBytes/s. An AT&T DSP32C chip working at 50 MHz is used. The averaged data is then transmitted to a second DSP board (DSP32C based) mounted on the same machine.
The two DSP boards are connected via the DSP32C's serial interface. The second board performs decoding, Fourier transform calculations and statistical data processing. The processed data is transmitted to the PC bus, to be stored in video tapes and/or in optical disks. The PC is used as the control console. At the same time, the PC stores data being taken and display real time graphics of the experiment results. A UNIX workstation, networked to the PC, performs additional analysis calculations and graphics, according to the needs of the observer using IDL, Spyglass or other high level graphical and/or processing languages. The use of the network is optional.
Finally, system evaluation and some experimental results are reported. The system allows up to 4 receiver signals to be processed at the same time, with 60 range gates and 150 m maximum height resolution.

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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). This paper describes a PC-based signal processing and control system developed for 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 continuosly operating radar at a reduced power level.

The scientific goals of the antarctic project were: 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 an 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. 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. Futhermore, it is possible to use multiple altitude sampling windows, e.g., one for the troposphere, lower stratosphere and other for the mesosphere.

SYSTEM DESCRIPTION

Objectives were to design a flexible, totally programmable signal processing and control 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.

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.

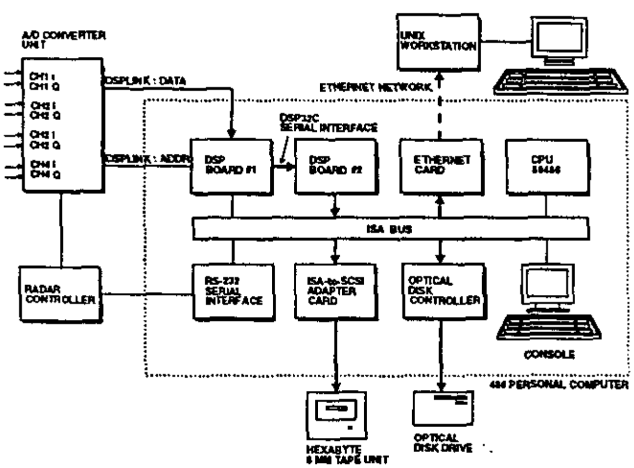

Fig. 1: Signal Processing and Control System Architecture.

System outline

The system is connected to the receiver outputs and to the Radar Controller. 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. It is described elsewhere [Urbina, 1993].

The receiver output signals are sampled and digitized by the A/D Converter Unit. The incoming data are sent, via a parallel interface, to a first DSP board for time-domain averaging (coherent integration). Time averaged data are then passed through a serial interface to a second DSP board. The second DSP, after performing range decoding, works as a frequency analyzer, computing complex FFTs and then power spectra of the data. The spectra are transferred via the PC bus to the PC RAM, then incoherently integrated and stored in 8 mm magnetic tape and/or in optical disk. Sample data are displayed to allow 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.

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. The same type of DSP chip is used in the two boards, namely an AT&T DSP-32C (25 MFLOPS). On the first board (coherent integrator), parallel interface hardware is 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) does not have a parallel interface. The two DSP boards are connected through the on-chip serial port configured for a 2 Mbit/s throughput.

Control PC

A 486-based PC is used as the control console. At the same time, the PC processes and stores data being taken.

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 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 results into 8 mm magnetic tape and/or optical disk (WORM with 1 GByte capacity);
- transfers all processed data, via the ethernet link, to the second computer;
- displays spectral profiles (contour or density plots) and power profiles in real time: from these, the operator can detect system problems;
- allows the radar station to work completely unattended, requiring operator intervention only for unfrequent tape and optical disk replacement.

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. Still, the Ethernet link is not needed for the radar system to work properly. 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.
2) furthermore, the operator can define multiple sampling windows: e.g., heights between 3 and 12 km and between 80 and 95 km can be sampled at the same time.
3) sampling is not synchronized with the DSP nor the PC clock.

These first considerations suggest the use nf interrupts for coherent integrator input. Each sample pulse generates an interrupt signal to the first DSP. 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) 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. The 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 nf 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-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.

System Evaluation

Measurement characteristics nf 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. With typical parameters, a total 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 (nr 80 with three directions).
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 ADC Unit and coherent integrator.

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 nther system parameters (e.g., number of heights to nbserve) can all be controlled and set on a single software "control panel".

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 with off the shelf components at minimum cost.

EXPERIMENTAL RESULTS AND FINAL REMARKS

After being tested at Jicamarca Radio Observatory, in January 1994 the described system was installed at the "Macchu 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. 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.

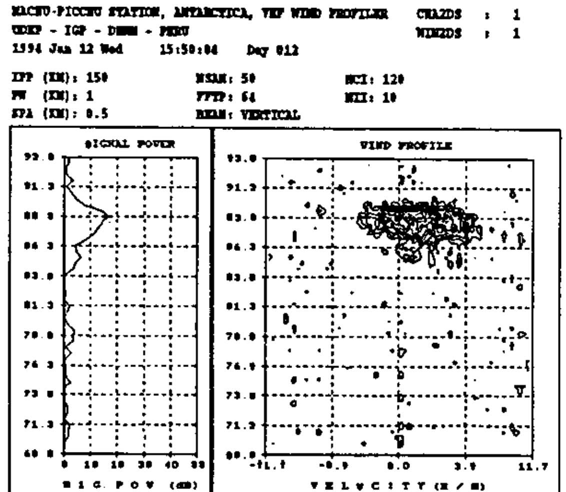

Fig. 2: Mesospheric sounding data measured at "Machu-Picchu" Station, Antarctica. These graphs are displayed in real-time by the system during data collection.

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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*, 74 (35), pp395-396

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, pp1775-1780

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

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