1.5A THE ECONOMICS OF DATA ACQUISITION COMPUTERS FOR ST AND MST RADARS

B. J. Watkins

Geophysical Institute
University of Alaska
Fairbanks, AK 99701

INTRODUCTION

The goal of this paper is to present some low cost options for data acquisition computers for ST (stratosphere, troposphere) and MST (mesosphere, stratosphere, troposphere) radars. The particular equipment discussed will reflect choices made by the University of Alaska group but of course many other options exist. We believe the low cost microprocessor and array processor approach presented here has several advantages because of its modularity. An inexpensive system may be configured for a minimum performance ST radar, whereas a multiprocessor and/or a multiarray processor system may be used for a higher performance MST radar. This modularity is important for a network of radars because the initial cost can be minimized while future upgrades will still be possible at minimal expense.

This modularity also aids in lowering the cost of software development because system expansions should require little software changes.

It is assumed in this paper that the functions of the radar computer will be to obtain Doppler spectra in near real-time with some minor analysis such as vector wind determination.

SYSTEM REQUIREMENTS

The costs for computer and signal processing components depend greatly on the desired radar performance. The height coverage, height resolution, time resolution, Doppler resolution, and number of antenna beam positions all affect the quantity of data to be processed and hence the equipment cost. An ST radar with coarse height resolution (e.g., 1-2 km resolution with about 16 range gates) and poor time resolution (data every few minutes or more) can be purchased for a low cost. A higher spatial and temporal resolution with the capability of height coverage into the mesosphere will require a greater capacity CPU and/or an array processor and have a higher cost.

To simplify the cost comparison, Figure 1 shows possible radar performance specifications and we will estimate the cost for each configuration. For simplicity it is assumed that Doppler spectra will be derived from 64 point FFTs (Fast Fourier Transforms), and that the radar antennas will be directed in three directions for vector wind measurements.

If these radars are to be used only for average wind measurements, then time resolution is likely to be of little significance. Measurements every 2-10 minutes may be adequate. On the other hand, if wave motions are to be distinguished, the sample rate must be fast enough to prevent aliasing. Observed wave periods can be as low as 4-5 minutes in the lower atmosphere. Therefore to make vector measurements of wave motions, a total sampling and analysis time for three antenna directions should be less than about 2 1/2 minutes.

Doppler data are generally obtained in three directions by changing the antenna position if it is physically steerable. or phasing an array. The sequence of data taking and real-time analysis is assumed as follows:

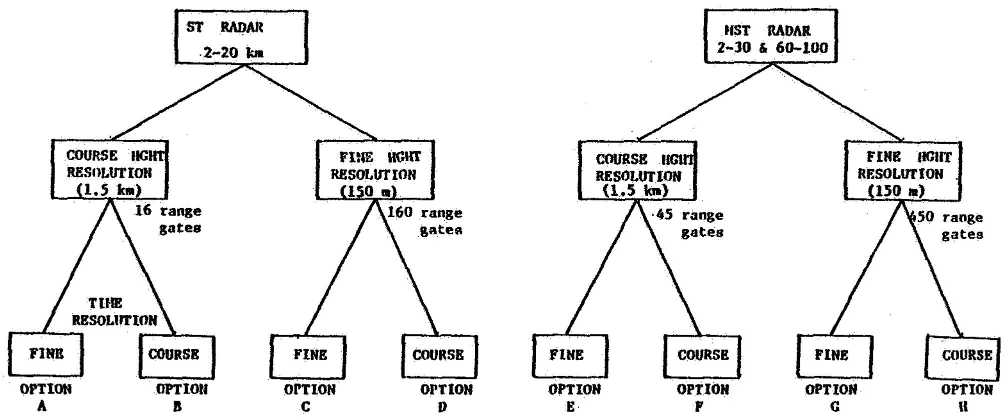


Figure 1. Eight possible radar performance specifications (A--H). For the purposes of this paper, coarse and fine height resolutions are defined as 1.5 km and 150 m, respectively. The time resolution is defined as the total time to determine a vector wind measurement (data from 3 antenna directions); fine resolution is considered $\leq$2.5 minutes and coarse resolution is 2.5--10 minutes.

(1) Select first antenna direction
(2) Transmit $N_p = N_f \cdot N_c$ pulses
where N_f = number of FFT points
N_c = number of coherent integrations.
(3) Sample and store a complex receiver sample at each range, for all N_p pulses.
(4) At the completion of transmitting N_p pulses, the coherent integration process is performed.
(5) At each range a power spectrum of the returned signals is computed using an FFT.
(6) If multiple spectra are to be averaged, steps (2) to (5) above are repeated N_{AV} times. (N_{AV} = number of averaged spectra).
(7) The N_{AV} spectral from each range gate are averaged and finally stored on tape.
(8) A new antenna direction is selected and steps (2) to (7) are repeated.

If phase-coded pulses are used then an additional decoding step is necessary after the coherent integration is performed. This is a minimal task timewise by comparison with other computations so we have neglected it in our timing estimates.

CHOICE OF COMPUTER

The computer should ideally be the lowest cost unit that will perform the required tasks. However, the exact needs are difficult to define because researchers rarely agree on the mode of operation for radar experiments and frequently place more demands on equipment as time progresses. For example, it is now recognized that high resolution and hence more range gates are desirable for studying turbulence structures. Several ST and MST radars are now upgrading for this higher resolution. Thus, an important specification is expandability.

We have considered many hardware options that would provide the absolute lowest cost system suitable for a simple ST radar that may be used in a network and yet be expandable to a high performance MST radar.

The University of Alaska group has chosen a microcomputer that uses a Motorola 68000 microprocessor in conjunction with two low cost array processors (APs). While there are many other hardware options available that other researchers may choose, our choice illustrates the modularity concept and the substantially lower cost by comparison with the computers at established radar sites.

The 68000 microprocessor has the advantage of 32-bit internal architecture, and coupled with an array processor provides fast arithmetic capabilities. Each AP ($6,000) can perform one million 32-bit floating-point operations per second; they are made by Sky Computer Corporation. The APs have no memory of their own but share a common memory with the main CPU. This has the advantage of low cost memory, the ability for the AP to access a very large amount of memory (up to 16 M bytes in our case), and minimizing data transfer times.

The microcomputer cost depends greatly on the amount of memory required but should be in the range $5,000 to $15,000. A more detailed costing is given later.

By comparison, presently established radars have computer costs about a factor of ten larger. For example at Millstone Hill and Arecibo, the Harris Computers and Floating-Point System APs have costs far in excess of $100,000. These APs do indeed provide a speed advantage, but as well as their initial high cost, the addition of extra memory is very costly. Even other relatively low price APs that are now available become very costly when any substantial amount of memory is added to them. For example Computer Design and Applications, Inc., sells an AP for about $24,000 with minimum memory, but costs $85,000 with 2 M bytes of memory.

Although many radar experiments, particularly a simple ST radar network, may initially have no need for an AP, it is worthwhile planning for their use so that upgrade costs will be minimized.

MODULAR APPROACH

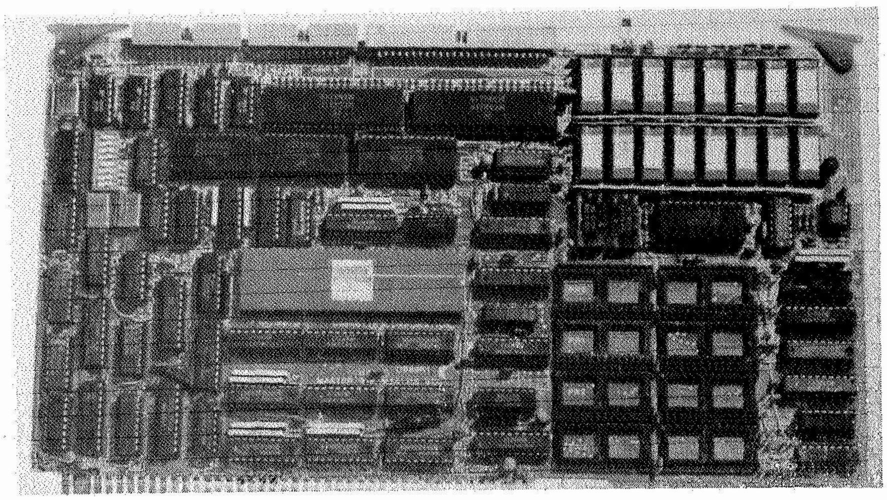
To illustrate how a modular approach can be used to assemble computers of different processing capabilities, we present some possible examples including the system now being constructed by the University of Alaska group.

Figure 2 shows the single board computer (made by Omnibyte Corporation) and array processor used. The boards are 7" x 12" and conform to the IEEE Multibus specifications (SNIGIER, 1982; WILSON, 1982). These boards, together with a card cage, power supply and case form the basis of a computer system. Providing there are enough spare slots in the card cage, the system may be expanded by plugging in more memory (up to 15 M bytes), multiple CPUs and multiple APs.

Some examples of various computer configurations are shown in Figure 3. No construction costs are necessary because these boards are commercially available and simply plug together. The University of Alaska system has one CPU, 640 K of memory and two APs operating in parallel.

DETERMINATION OF REQUIRED PROCESSING POWER

With a given radar specification it is necessary to determine both the time duration to gather the data and the processing time. This total time duration should not be excessive; for example 3 measurements must be made in less than about 2 1/2 minutes to determine waves in the stratosphere. Further, the time



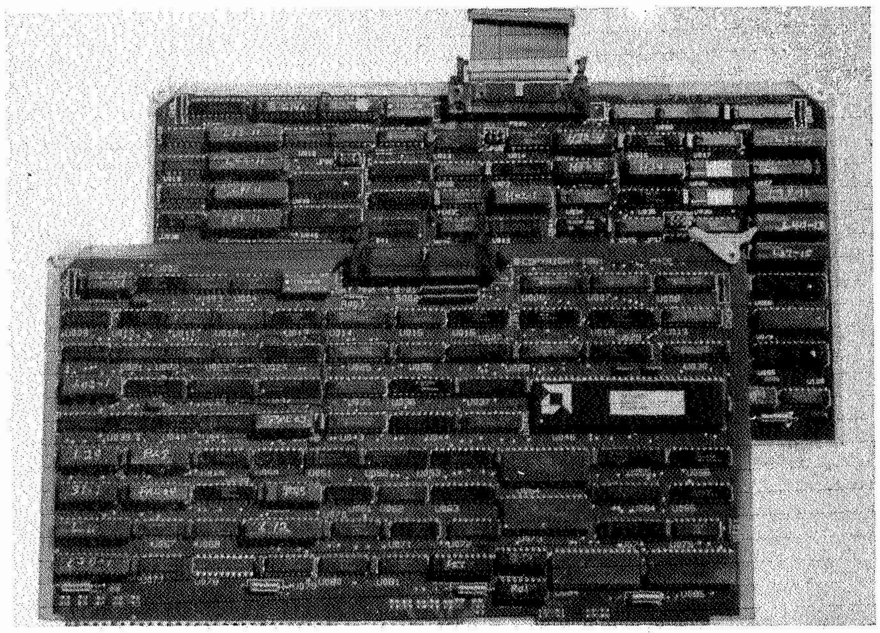


Figure 2. TOP: Single board computer with 128 k of memory, two I/O ports, and two 16-bit parallel I/O ports (cost $2000). BOTTOM: Array processor (two board set, cost $6000).

to process the data should not be large compared to the time required to gather the data. Ideally this processing time should not exceed about 5 - 10% of the time required to take the data. When too much time is wasted processing data instead of sampling, fewer spectra may be integrated in a given time, and hence signal detectability suffers at the upper heights.

The time required to collect samples for three antenna directions, and averaging N_{AV} spectra at each range gate after N_c coherent integrations is given by

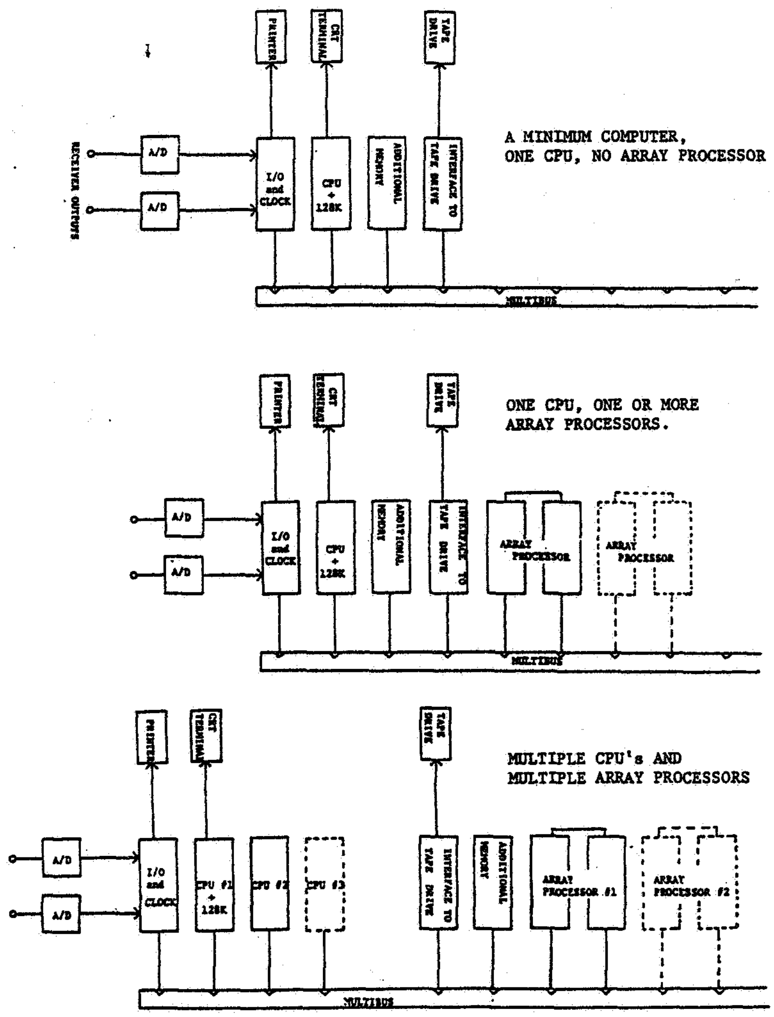


Figure 3. Some possible computer configurations utilizing one or more CPUs and up to four array processors. The University of Alaska has implemented the middle configuration above with two array processors.

$$T_{DATA} = \frac{3 \cdot N_f \cdot N_c \cdot N_{AV}}{PRF} \qquad (1)$$

where PRF = transmitter pulse repetition frequency.

For example if $N_f = 64$, $N_c = 64$, $N_{AV} = 10$, PRF = 1250 Hz then $T_{DATA} = 98$ sec. This value for the PRF is about the maximum possible for an MST radar without range aliasing; it gives a maximum unambiguous range of 120 km. A higher PRF is possible for an ST radar that receives no data from the mesosphere. The values for N_f and N_c are somewhat arbitrary, but together with the PRF and radar wavelength λ, determine the Doppler resolution δv where

$$\delta v = \frac{PRF \cdot \lambda}{2 \cdot N_f \cdot N_c} \text{ m/s} \qquad (2)$$

For a 50 MHz radar (λ = 6 m), using the above values yields δv = 0/9 m/sec. This should be a usable value as the Poker Flat MST radar has operated with δv = 1.3 m/s with excellent results.

The method we have adopted for determining the required computer processing power is to first determine the required radar parameters (e.g., PRF, N_c, N_{AV}, N_f, $\delta\nu$) required to obtain the data with sufficient resolution and signal/noise ratio. The parameters are best estimated from experience and extrapolation from established radars. The values quoted above are typical for the 50 MHz Poker Flat radar although higher values of N_{AV} have been used at Poker Flat.

Next T_{DATA} is calculated; this sets an upper limit to the data processing time. A computer is then selected so that the processing time plus the data-acquisition time is not too large. For example, to detect waves, this total time should be less than ~ 2 1/2 minutes (data in three directions).

The time $T_{PROCESS}$ required to process the data (from 3 antenna directions) is the total time required to perform coherent integration plus the FFTs

$$T_{PROCESS} \approx 3 \cdot N_c \cdot N_{AV} \ (T_{FLOAT} + T_{SUM}) + 3 \cdot N_g \cdot N_{AV} \cdot T_{FFT}$$

where N_g = number of range gates

T_{FLOAT} = Time for AP to change complex integer array of N_g samples to floating point.

T_{SUM} = Time for AP to sum a complex vector.

T_{FFT} = Time for AP to perform FFT on array of N_f samples.

The minimum amount of memory required by given by:

$$M = 4 \cdot N_f \cdot N_c \cdot N_g \text{ bytes} \qquad (3)$$

The factor 4 comes from the use of 16-bit complex samples.

We have adopted the technique of first acquiring all data before performing any coherent integration. By contrast it is possible to use far less memory by performing the coherent integration pulse by pulse. However, this places constraints on the minimum interpulse period of the transmitter because without a very powerful, and hence costly, computing system it is difficult to perform this integration as well as other required tasks during the interpulse period. It is far more cost effective to use a lesser capacity computer and AP in conjunction with a fairly large memory. In the case where memory requirements become excessive (e.g., Case G on Figure 1 and Table 1) it is then desirable to use a dedicated preprocessor for performing the coherent integration. Such a preprocessor is hard-wired to perform fast additions and may be constructed for about \$6,000 (JOHNSTON, 1983).

It should be noted that there are many possible compromises available in establishing a radar's operating parameters. For example, both the data-acquisition time, T_{DATA}, and the processing time are affected by the number of averaged spectra N_{AV}. If this parameter value is decreased it may be possible to use a computer of lesser capability and cost. However, a lower N_{AV} will

Table 1. Costs for radar options A--H in Figure 1.

	A	B	C	D	E	F	G	H
Approx. time to acquire and process data	103 secs	600	117	600	108	330	127	380
Costs: CPU board	$2000	$2000	$2000	$2000	$2000	$2000	$2000	$2000
Memory	$1550	$1550	$7750/$1550	$1550	$3100	$1550	$1550/$21,700	$1550
Parallel I/O board with clock	$550	$550	$550	$550	$550	$550	$550	$550
Case, power supply and Multibus rack	$1000	$1000	$1000	$1000	$1000	$1000	$1000	$1000
Array Processor(s)	$6000	--	$12000	$6000	$6000	$6000	$24,000	$6000
A/D's and sample-holds	$700	$700	$700	$700	$700	$700	$700	$700
Hardware Preprocessor	--	--	-/$6000	--	--	--	$6000/-	--
Tape drive + Interface	$5800	$5800	$5800	$5800	$5800	$5800	$5800	$5800
Printer	$700	$700	$700	$700	$700	$700	$700	$700
TOTAL COSTS	$18,300	$12,250	$30,500/$30,300	$18,300	$19,850	$18,300	$42,300/$56,450	$18,300

Notes

(1) Radar options C and G have been calculated with and without a hardware preprocessor. Without the preprocessor the memory costs are higher.

(2) For radar option D it has been assumed that data will be acquired and processor by range stepping, i.e. processing 32 range gates at a time. This saves memory but greatly lengthens the total processing time.

(3) The time quoted are for determination of a vector wind measurement, i.e. acquisition and processing times for 3 sequential antenna directions.

decrease the signal detectability and it is likely that data from some upper heights may be lost. Such compromises should be carefully evaluated before deciding on the radar operating parameters.

COST SUMMARY

Using the method outlined in the previous section, we have evaluated the costs for different radar specifications A - G in Figure 1. A summary is given in Table 1. In addition, the approximate times required to acquire and process data from three antenna directions are given. These times are worst-case values because it has been assumed that during data acquisition the computer is only required to perform the sampling. This reserves some time during the interpulse periods for other tasks such as graphics display, calculation of vector winds, signal/noise ratios, etc.

For the computer configuration B in Table 1 that has no AP, the data-processing time is relatively slow. We estimated the time for floating-point FFTs using the University of Alaska's microcomputer (8 MHz clock). It could be speeded up either by using an integer FFT instead of floating point, or use of an additional simple hardware arithmetic unit, or a CPU with higher clock frequency. The 68000 microprocessor is now available for operation with a 12-MHz clock and a 16-MHz version should be available in future.

It is assumed that some type of hard copy printer (with graphics), and a 9-track tape drive are common to all configurations. In addition, the approximate cost of analog-to-digital converters is included and the Appendix briefly discusses some cost options.

All the costs listed in Table 1 are for a quantity of one. Discounts (15 - 30%) are available for larger quantities that would be purchased for a network of radars.

It should be emphasized that the costs in Table 1 are for hardware only. There may be substantial initial costs for software. A competent programmer may take several months to develop the data-aquisition program. The use of an AP will reduce the software costs because much signal processing software is provided by the AP manufacturer. It is most efficient to develop software using a high-level language, an operating system and disk drives and at the University of Alaska we are doing this with a real-time operating system, a 20 Mb disk drive and the C programming language. The costs for this extra hardware, software and labor should be considered, but for a large network the cost per radar would not be large.

APPENDIX: ANALOG AND DIGITAL CONVERTERS

The choice of analog-to-digital (A/D) converter resolution may affect the cost of the radar computer. If an 8-bit A/D is chosen the computer will require only half the memory (for storing samples) compared to a 10- or 12-bit data word that is commonly used since data are stored in 8-bit increments. However, the overall dynamic range of the radar will generally be limited by the A/D converter not by the receiver. Unless the radar is sited to substantially reduce ground clutter (e.g., placed in a valley with nearby shielding hills), the dc offset at the receiver output from clutter echoes will be large compared to the noise and signal fluctuations. In practice, a 10- or 12-bit converter is preferred and the calculations in Table 1 have assumed this.

The cost of A/D converters is relatively small. As a cost example in Table 1 we have used a 12-bit 2 μsec A/D converter made by ILC Data Device Corporation ($150 each) and a Sample/Hold made by Analog Devices ADSHM-SK ($199).

A faster but lower resolution A/D is approximately the same cost, e.g., Analog Devices 10 bits, 1 μsec, MAH-1001 ($219).

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