A Proposal to Allow High Time Resolution Observing with the VLA

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I. Introduction

When operated as a phased array, the VLA offers many of the advantages of a single-dish while continuing to function as a synthesis telescope. The high angular resolution and low confusion level of the arcsecond synthesized beam are maintained while the analog sum output of the array offers the versatility of a single-dish IF output. This could be useful for high time resolution observing of point sources (pulsars and flare stars) or time variable sources such as the sun which have very small-scale angular features. Additionally, the VLA correlator can be "gated" in synchronism with a periodic signal, such as that from a pulsar, in order to increase the signal-to-noise ratio of the correlation or to study the properties of the unpulsed emission from the vicinity of the pulsar. This can only be done, however, if the signals controlling the blanking are properly phased with respect to the pulsar profile, a task that requires processing of the analog sum outputs to form the profile.

These observations are not frequently attempted at the VLA because there is no general-purpose capability to record data from the analog sum output and, if required, gate the correlator in synchronism with the accumulated signal.

This proposal describes a super-microcomputer based system that could perform data acquisition and correlator control in a manner requiring very little modification to the current synchronous control system, in either hardware or software. Since this would be a stand-alone system, software development could proceed in an unpressured environment, and the system would be available for other applications or tests when it was not required at the telescope. The development costs for this system would be small since extensive data acquisition, control, and display capabilities are already built into the computer, and the software development required is very similar to that needed for the Green Bank spectral processor project.

For ease of identification I will refer to this system as the "analog sum processor" in what follows.

II. Scientific Considerations

A. High time resolution observing

Observations of three kinds of sources -- flare stars, the sun, and pulsars -- would immediately benefit from the analog sum processor. Flare star observations at the VLA are currently hampered by the 3 second time resolution and the need to make a map in order to obtain the flux level at each time sample. Recent observations at Arecibo (Lang, Bookbinder, Golub, and Davis 1983) show burst-like emission from the M dwarf AD Leo with rise times less than their resolution of 200 milliseconds (Figure 1). Determrining the time scale of these bursts is important since it leads to upper limits on the size of the emitting source and allows an estimation of the fraction of the stellar surface involved in the burst. Similar observations could be made at the VLA with the analog sum processor, taking advantage of the lower confusion limit, 3.4 times more sky coverage, better frequency coverage, and wider useable bandwidth. For nearby stars the resolution of the VLA would make it possible to determine which star in a binary system is flaring. Simultaneous, multi-frequency observations could also be made with the VLA to test theories of the coherent emission from these stars. These could be made using subarrays or, for those sources within the Arecibo declination range, by coordinating between the observatories.

High angular resolution observations of solar radio bursts made with the VLA (e.g., Willson 1983; Lang, Wilson, and Felli 1981) show structure on the order of 6" - 10", a highly variable degree of circular polarization, and time variations apparently unresolved on 10 second time scales (Figure 2). As in the flare star case, the peak brightness temperature is used to estimate the electron temperature and, indirectly, the magnetic field strength. If the shortest time-scale features observed are unresolved, peak brightness temperatures are underestimated as well as the energy densities and magnetic field strengths. The ability to probe fluctuations on millisecond time scales, while maintaining the small beam size of the VLA would aid in the understanding of these radio bursts. Simultaneous, multi-frequency observing of these bursts, particularly the polarization changes, may lead to a better understanding of physical conditions along the propagation path. Note that the distributed character of the VLA collecting area, with the resulting incoherent summation of individual system noise, results in a much better sensitivity in the solar case than does a single-dish with comparable collecting area.

Pulsar observing would benefit greatly from the capabilities of the analog sum processor. Besides forming average waveforms for the correlator gating described below, it would be possible to study individual pulse behavior, including multi-frequency observations of the total intensity and polarization behavior. Although dual-frequency observations will be most interesting when the array is operable at 327 MHz, there are many pulsars whose individual pulse properties can be studied at L band and above with the sensitivity of the VLA. In addition, very high signal-to-noise ratio interpulse searches could be performed with the VLA, taking advantage of its sky coverage, sensitivity, large bandwidth, and relative interference immunity. The sensitivity advantage of an array in the presence of strong background emission can be used to good advantage in one important case: high signal-to-noise measurements of the Crab pulsar waveform, an observation that is extremely difficult with a single dish. All of these observations could be performed concurrently with gated synthesis mapping observations.

B. Gated Correlator Observations

The main use of the correlator gating capability arises in pulsar observing, although there may be some application, particularly at low frequencies, to interference suppression by means of correlator gating. In the pulsar case the gating signal would be synchronized with the pulsar period. Observations divide into two classes depending on whether the correlator is gated on or off during the pulse.

Observations that would benefit from "on-pulse" gating are pulsar-based astrometry and the investigation of interstellar scintillation through spectral observations. Since each IF output can be independently gated, attempts to infer pulse emission radii from differential scintillation observations (Cordes, Weisberg, and Boriakoff, 1983) could also be made. The exclusion of the approximately 90% duty cycle of uncorrelated receiver noise would improve system sensitivity by a factor of 3 - 4. This would substantially increase the number of pulsars for which astrometry can be done and improve the accuracy of individual measurements. Similar improvements would occur for scintillation observations.

The second class of observations are those for which "off-pulse" gating is appropriate. These include the search for nebulosity around the pulsar position as well as the search for an unpulsed component of the pulsar emission. Both of these observations are currently hampered by the inclusion of strong pulsed emission, which cannot be reliably cleaned since pulse-to-pulse fluctuations of the total intensity are non-gaussian in character. This severely limits the dynamic range of nebulosity searches and makes it impossible to separate possible unpulsed emission from the pulsed component. Both of these observations are particularly well suited to the VLA's capabilities since high angular resolution is essential to the nebulosity search and the ability to measure absolute flux levels is required for the unpulsed emission search.

There are other good projects that could be undertaken with the VLA if analog sum processing capabilities existed, for example, the high-resolution study of planetary emission.

There is ample scientific justification for adding high time resolution and correlator gating control to the VLA; the question is how best to do it. In the next section I will describe a system that provides these capabilities without requiring any substantial change to the synchronous computer system or any major hardware or software development manpower.

III. Analog Sum Processor

A. Possible System Designs

The main task of the proposed system is to sample (as rapidly as every 10 microseconds) up to 4 analog inputs, record and/or synchronously average these data, and store them on magnetic tape for further processing. Monitoring of the incoming time series should be possible in order to check for equipment malfunction and setup errors. The system must be able to produce up to 4 correlator control signals that are variable in duration and phase with respect to the periodic input signal. A phase-continuous frequency synthesizer must also be updated periodically (typically once every 10 seconds) to account for the changing period during pulsar observations. Finally, enough information must be obtained from the synchronous computer to record the data in a self-documented fashion.

Three options were considered for the design of this system: a software/hardware extension of the synchronous computer system, a signal averager/microcomputer based system, and a super-microcomputer based system with its own peripherals. The super-micro based processor is recommended on the basis of system modularity, flexibility, and minimal demand on hardware and software development manpower.

Although the synchronous computers could perform the tasks required of the analog sum processor, they could not do so without extensive modification to the current data-taking system. It might not prove possible, even with an expanded system, to perform the analog sum data acquisition concurrently with the standard synthesis data-taking. Furthermore, the reprogramming effort needed to add these capabilities would fall on a few people, would have to be squeezed into very limited system development time, and would be very prone to unwanted interaction with the current data-taking system.

An alternative approach would be to perform the data acquisition with a multi-channel signal averager and provide processor control with a relatively simple microcomputer. Data storage could be provided by a tape unit connected directly to the signal averager or, with some of the disadvantages mentioned above, by the synchronous computer system. The main advantages of such a system were thought to be ease of development and relatively low cost. The ease of development this approach has to offer, however, is directly offset by its inflexibility. A signal averager is designed to perform a few tasks well, but it is not easily adapted to handle the complexities of a particular situation (such as those introduced by the waveguide cycle dropout -- see the Appendix). Signal averagers are also more expensive than was originally thought, costing from $20K - $40K, with the higher price range occupied by 4-channel designs. This system design also has the hidden cost of connecting many independent units into a working system.

The system that is recommended here is made possible by the advent of fully packaged super-microcomputer systems, based on 32-bit microprocessors such as the Motorola 68000. These systems offer a large address space, advanced architectural features, standardized software and bus choices, and speed at a moderate cost ($20K - $100K). They allow the data acquisition and control functions of the processor to be combined into one unit with enough processing power left over to monitor and display the data as they are acquired.

There are many super-micro systems to choose from, but of these only a few offer data-acquisition capabilities, an industry standard bus (Multibus or Versabus), and a standard operating system (Unix). The selection of the Green Bank spectral processor computer, which has very similar system requirements, narrowed the field down to two companies: Charles River Data Systems and Masscomp. A detailed comparison of these systems indicated that Masscomp provides much more data acquisition and graphics engineering, both hardware and software than does Charles River or any other current vendor. A number of NRAO people have visited Masscomp recently (R. Burns, M. Damashek, E. Greisen, J. Marymoor, D. Stinebring, and D. Wells) and have been impressed with the engineering expertise and financial health of the company.

The recommended computer (Masscomp MC-560) is a Multibus sytem based on two M68000 chips running at a clock rate of 12.5 MHz. Table 1 provides a cost breakdown of the system components, shown in Figure 3. The computer comes with a 27 Mbyte Winchester disk, 1 Mbyte floppy disk, data acquisition and control processor, and a monochrome graphics processor. The data acquisition and control processor is an independent, programmable processing unit that can handle continuous data rates up to 2 Mbytes/sec. The A/D convertor board plugs into this unit, as well as the control boards for the frequency synthesizer and the correlator gating signals (all available from Masscomp). The graphics processor has many advanced features, including multi-windowing, switchable graphics frames, and a separate M68000 chip to speed up processing. The floating point processor (expandable to an array processor for an additional $8K) will speed computation times.

The only item that needs to be purchased in addition to the computer is a programmable frequency synthesizer. A phase-continuous model manufactured by the Rockland Corporation has been used by J. H. Taylor for many years in his timing of the binary pulsar.

An analog polarimeter to convert the orthogonally polarized IF's into full Stokes parameter form is included in the price list, although it is not needed for the initial operation of the processor. Either an adding or a multiplying polarimeter design would be suitable. A very rough estimate of the cost for this (presumably) NRAO-built unit is listed.

B. Communication with the Synchronous Computer

The analog sum processor is envisioned to be relatively independent of the synchronous control computer. It seems adequate to pass scan update information and the current header information from the synchronous computer to the analog sum processor by means of a serial communication line. There may be no need for communication back in the other direction, although simple processor status information may be useful. In general, interaction between the two systems should and could be kept to a minimum. It is worth noting in this regard that the analog sum processor would probably be used less than 5% of the VLA observing time, at least initially, and that a user of the system could be expected to be more responsible for control of the experiment than a typical VLA user.

C. Software Development

Much of the software development needed for the analog sum processor parallels that needed for the Green Bank spectral processor. Although a final computer choice has not been made for the spectral processor, there is strong sentiment in favor of a Masscomp system. It is hoped that much of the timekeeping, ephemeris, and synthesizer control software needed for that project can be obtained from current pulsar data-taking programs. This would leave the higer-level programming effort of observer interfacing and data monitoring and display to be done, as well as the generation and monitoring of the correlator gating signals. The advanced system software available under the Masscomp Unix system, enhanced by their user-alterable menu system, should greatly facilitate program development. Assuming some help from the spectral processor software develpment, 2 man-months of work should yield a usable (but limited) system, with about 6 man-months of effort needed to complete the development.

D. Expansion

A strong advantage of the proposed system is its flexibility and growth potential. Modifications to the basic data-taking programs should be straightforward and can proceed independently of the main VLA software system. The software should be written in Fortran and C and should be modular enough that interested observers can make alterations and extensions.

It is possible that a spectrometer could be useful at the VLA analog sum output for spectral-line observations of point sources and pulsar observing. Possible observations could include HI absorption studies against background continuum sources and the study of time-variability from masing regions. The analog sum processor, as proposed here, would be capable of supporting such observing with only minor modifications. In fact, if a copy of the Green Bank spectral processor hardware were produced, the analog sum processor could be upgraded to a spectral processor system with little additional effort.

IV. Summary

High time resolution coupled with control of correlator gating would enhance the scientific capabilities of the VLA. Observations of flare stars, the sun, pulsars, and planetary emission would immediately benefit. Unexpected benefits might result from combining high angular resolution and high time resolution into one telescope. A simple and relatively inexpensive system, based on a super-microcomputer, could be built to provide these capabilities. Manpower requirements would be small because of the data acquisition and control features of the computer and the stand-alone nature of the system. The possibility of future expansion, particularly with an eye toward point-source spectroscopy, would be left open.

Appendix

Waveguide Cycle Dropout

The basic waveguide cycle of 52 milliseconds consists of 51 milliseconds of data transmission followed by 1 millisecond of control information transmission. Data is not available during this 1 millisecond interval and the analog sum outputs drop to zero. Although the waveguide dropout only represents a 2% data loss, properly accounting for it in a time series or a synchronous average can be difficult. Two solutions to the problem exist.

In the first, currently implemented, a sample-and-hold circuit is placed after the square-law detector in the analog sum data path. This circuit is turned on during the 1 millisecond dropout and maintains the analog output at its pre-dropout level across the 1 millisecond interval. This has the disadvantage of introducing spurious time structure into the signal being sampled, a problem that is more severe when the signal is being synchronously averaged.

The second approach, which could be followed here, is to not add data to the accumulated average during the dropout interval. This is easy to accomplish in a general-purpose computer (although not in a signal averager) since the timing of the dropout can be both sensed and predicted.

References

Cordes, J. M., Weisberg, J. M., and Boriakoff, V. 1983, Ap. J., in press.

Lang, K. R., Bookbinder, J., Golub, L., and Davis, M. M. 1983, preprint.

Lang, K. R., Willson, R. F., and Felli, M. 1981, Ap. J., 247, 338.

Willson, R. F. 1983, Solar Physics, 83, 285.

Figure Captions

Figure 1: Rapid, highly polarized spikes observed during a 1400 MHz radio burst from the dwarf M star AD Leo (Lang, et. al. , 1983). Both the right and left hand circularly polarized components are shown. Notice that the sequence of spikes are all 100% left hand circularly polarized.

Figure 2: The time profiles of a multiple spike solar burst detected at 20 cm wavelength with the VLA (Willson, 1983). The total intensity (top panel) and the percentage circular polarization (bottom panel) are shown for two interferometer pairs. Note the rapid changes in the circular polarization during the bursts.

Figure 3: A block diagram of the proposed analog sum processor. The computer is a Masscomp MCS-560. The detector and integrator circuitry currently exists for two IF's. All components are commercial except the baseband analog polarizer network.

Masscomp MCS-560	$36,800
1 Mbyte ECC memory	2,700
floating point processor	5,000
1/2" tape drive/controller	5,700
1 MHz A/D convertor	3,000
32 line TTL interface	700
real-time clock board	600
printer	1,200
computer subtotal	$55,700
Rockland synthesizer	4,000
analog polarizer network	4,000
system total	$63,700

<u>Table 1</u>: Cost estimate for proposed analog sum processor.

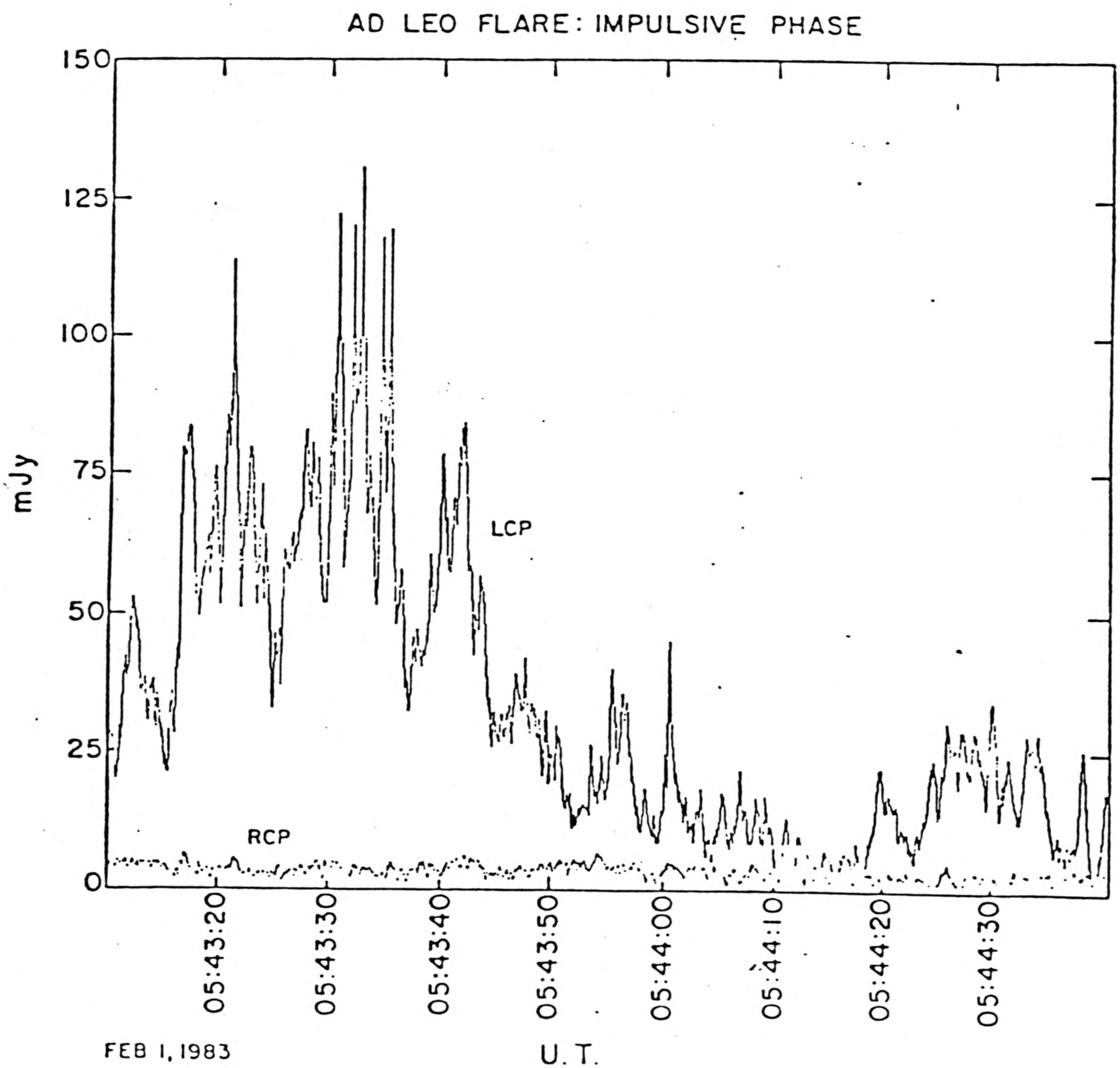

Figure 1 (Lang, et. al., 1983)

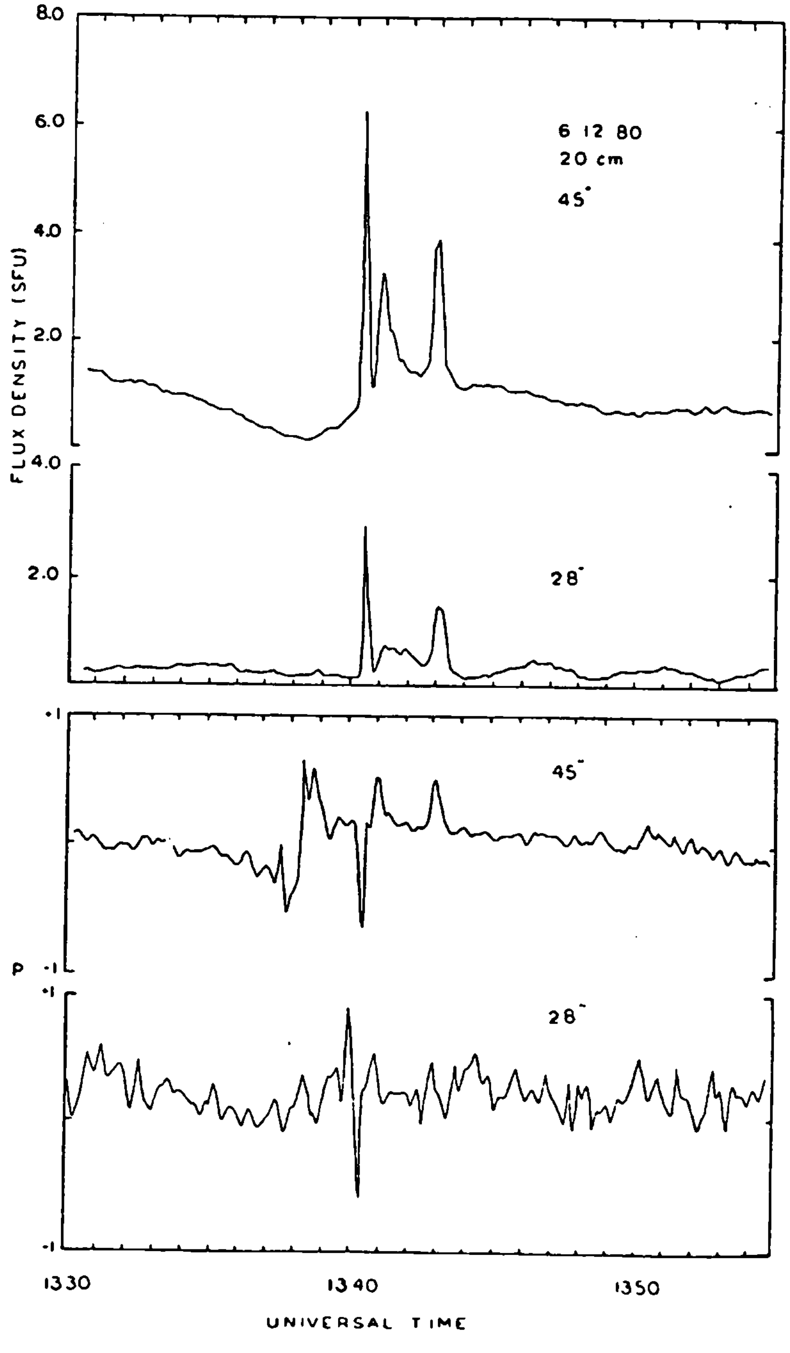

Figure 2 (Willson, 1983)

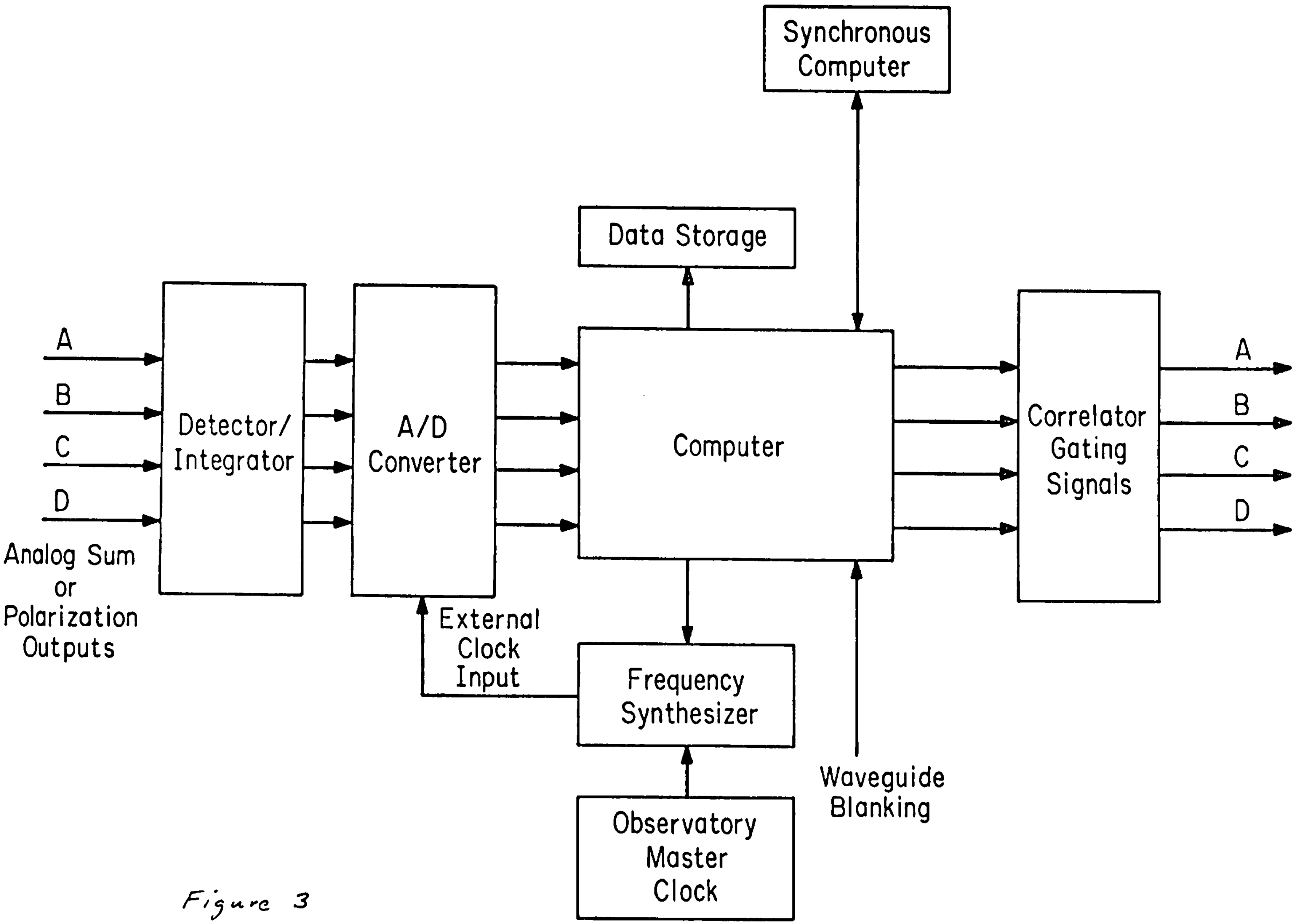
Synchronous Computer
Data Storage
A
B
C
D
Detector/ Integrator
A/D Converter
Computer
Correlator Gating Signals
A
B
C
D
Analog Sum or Polarization Outputs
External Clock Input
Frequency Synthesizer
Waveguide Blanking
Observatory Master Clock

Figure 3