GBT Memo No. 51

NATIONAL RADIO ASTRONOMY OBSERVATORY
Green Bank, West Virginia

GBT Control and Monitor System
Update and Commentary

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1. Introduction

On May 1-2, 1990, a workshop was held in Green Bank to discuss the control and monitor system for the GBT. The goal was to attempt to obtain some consensus on guiding principles and to identify key issues that must be resolved in order to engineer the system. Since, at that time, no one had been assigned responsibility for the design, any final resolution of issues or design tradeoffs was not possible. In this memorandum, identified issues have been resolved tentatively for purposes of discussion. The meeting and associated conversations with NRAO personnel provide the input to this memorandum. In attendance were: B. Burns, E. Childers, M. Clark, J. Coe, D. Emerson, F. Ghigo, G. Hunt, R. Lacasse, J. Lockman, R. Maddalena, R. Norrod, D. Schiebel, G. Seielstad, B. Vance, and D. Wells.

The workshop and memorandum take as its initial approach Chapter V of the Final Proposal for the GBT. In that vein, we have attempted to follow the format of that document. Only extensions and modifications to Chapter V are described here.

2. Overview

The first source for guidelines and problem areas in building monitor and control systems for single-dish telescopes is past efforts. The 92 and 12 meter NRAO telescopes have recently upgraded their systems. Though these efforts were built onto existing antennas thus retaining much of their older equipment, they still provide valuable experience. There were several key or common lessons that came out of these efforts.

The key design principle identified in both projects was the use of modular design in both hardware and software. This greatly reduced development time, raised reliability, and increased flexibility. Development time and effort were reduced because of reduced complexity and the ability to develop pieces of the project independently and concurrently. Of course, for modular design to succeed, one must have sufficient intelligence built into the modules and, when possible, standard buses connecting them. In a system containing real-time subsystems, modularity provides an opportunity to isolate the real-time functionality. Reliability and robustness are enhanced through reducing complexity by careful selection of interfaces between modules and by more thorough testing, since independent modules may be tested individually. Flexibility is an important quality for single-dish telescopes because the instruments often need to be configured to perform novel tasks, even to the point of users bringing their own backends or analysis computers. Well-defined modules with standard interfaces greatly increase the ability of the staff to satisfy the needs of these more creative observers.

Implementation on portable, non-proprietary systems was seen as a positive decision in both projects. Therefore UNIX platforms, C compilers, and industry standard buses are the systems of choice.

The final lesson that the experience of both projects stresses, is that the user interface should be developed concurrently and completed with the hardware and other software in the monitor and control system.

Issue - Modular Real-Time Systems: The desire for modularity -- for the reasons expressed above -- and the demands for synchroneity created by real-time aspects of a control system are inherently inconsistent goals. The former attempts to create loose coupling between modules, and the latter demands tight coupling. At least two participants with real-time experience expressed concerns with the modular approach. Nonetheless, because of past lessons and the need for flexibility, our working assumption is that the initial design will be modular. If real-time constraints force a closer coupling between modules, then that coupling will be made, but the need must be proven. All design efforts will be toward preserving modularity whenever possible. The SAM bus is a good example of a real-time feature that preserved modularity in the 12-meter monitor and control system.

3. Programming Environment

The goals for the programming environment as described in Chapter V have not changed, and given past experience and current projects, it is apparent that Green Bank will continue to be a "UNIX shop." The experience of using Wind Rivers VxWorks on the new 12-meter control system, the VLBA correlator, and the new VLBA monitor and control systems have all been positive. VxWorks communication support meshes perfectly with our goal of modularity. Unless someone can make a very strong case for an alternative system, VxWorks will be the real-time/development system for the GBT.

4. User Interface

The discussion of the user interface to the monitor and control system was kept to a minimum at the meeting (so will it be in this document) because no topic suffers more from the ills of "design by committee." Chapter V described a process by which this software should be developed, but a number of needs were expressed at the meeting which follow:

- Tracking (source, planets, satellites, ...) and maps of all types can be handled by the user.
- All settings should be accessible by the control computer and the user dynamically.
- Full monitoring capabilities should be available to the user through his or her computer.
- The user should have programmable dynamic control of the telescope with monitoring information available, without compromising the safety of the telescope or personnel.
- The interface should be "easy" to use.
- The user should be able to choose between interactive and batch mode.
- A physical or virtual control panel should be available to the operator.
- System should be documented by on-line aids and a short tutorial.
- Feedback to the user should be designed such that various modes (type of offsets, epochs used, front end

activity, ...) are obvious to the user.

- Both command-line and GUI (graphical user interface) control are desirable.

5. Remote Observing

Security of the system from the Internet is a concern, but must not be construed to be any more serious or more likely than physical security of the telescope and system from on-site or internal threats. Remote observers should have full monitoring capability, but not control of the telescope. Integrity must be provided by the operator. The guiding concern for security should be safety for personnel equipment and the user's data.

More bandwidth than the current 9600 baud link to the Internet will certainly be required if remote observing is to be successful.

6. Software Standards

The system should be based on the UNIX operating system and C programming language though these are not hard and fast requirements. For example, if certain FORTRAN analysis routines can be obtained, then such software should be taken advantage of.

A word about software effort at this point -- we obtained ten independent estimates of the staff-years for implementing the system described in Chapter V. These were all educated guesses, but all were experienced in similar software efforts. These estimates did not include the implementation of new backends, and the lower estimates seemed to exclude a sophisticated user interface. It is interesting that all the estimates ran fifteen staff-years plus or minus five years.

7. Structure of the Control System Hardware

The purpose of the following design is to act as a "straw man" to allow the discussion of issues and principles to be more concrete. The basic design is very much like that in Chapter V, except many modules and buses have been given more descriptive names and the current design is a little less sketchy. In the following discussion on motor servos, a slow rate means approximately every one or two seconds, and fast rate means at an approximate 10 to 50 msec rate.

Also a module means an independent unit with algorithmic capabilities and defined input/output channels, i.e., a single-board computer or a process on a multi-tasking machine.

7.1 Antenna Control Bus

In order to control the movement of the beam on the sky, the monitor and control system must provide a fast rate command to over a dozen drive cabinets which control the motions of azimuth and elevation of the antenna, focus for the prime and gregorian receivers, translation and tilt for both subreflectors and the prime focus, and polarization rotation of the prime focus and some of the secondary focuses. These rates will be generated by 32-bit single-board computers which will accept encoder signals continuously, angle position commands at a slow rate from the antenna controller, precision corrections at a fast rate, and binary status bits from the drive cabinets (see Figure 1 for JPL's implementation). They will also generate angle position information at a fast rate and, in some cases, correction signals at a fast rate. The programs will be responsible for interpolating the position commands into rate commands while including precision corrections and providing actual position information. The programs will attempt to compensate for as much error as possible in the mechanics of the system as well as handling the problems of damping and other typical servo duties. It is the hope that by having these servo controllers deal in angles that the same program can be used in all of the controllers with only minimum differences. The use of general-purpose computers for controllers will enable the system to provide a wider range of monitoring capabilities at all levels of the system.

Issue - Precision Pointing: At this point it is not clear how the two precision pointing systems will interact with the monitor and control system. It would be ideal if it entered only as a precision correction or error signal over a serial line directly to and between the controllers. Currently, one system is being initially designed so that this would be possible. If, however, the antenna controller must get involved in the inclusion of these fine corrections at a fast rate, then the loose coupling between these modules will be lost; then rather than the antenna simply sending position commands at a slow rate to an "ideal" telescope, it then will become necessary to synchronize all the controller modules.

In addition to the servo controllers, the antenna controller must initialize, monitor, and command the gregorian and prime focus selector, the surface controller, and the receiver table selector. All of these controls, of course, can take place at commanded intervals because of the static nature of the tasks.

All of the commands and resulting monitoring will take place over the antenna control "bus" (Figure 2) which, in actuality, may be a combination of shared memory, a VME backplane, or an ethernet, depending on how synchronous the activities need to be.

7.2 Observation Control Bus

Controlling the pointing of the telescope is just one activity that the monitor and control system must perform. In addition, it must direct the activity of the receivers, the Local Oscillator, the data collator, and the backends, as well as accept commands from users. The responsibility for managing and monitoring observations is given to the observation controller which accepts specifications from the users and, in turn, commands and monitors the receiver controller, the backend controllers, the LO controller, the data collator, and antenna controller over an internal ethernet called the observation control bus (Figure 2). All of these controllers will probably be single-board computers in order to have enough processing power to handle all of their own moment-to-moment responsibilities. The more independently these units can act, the less activity required on the observation control bus.

7.3 Data

The criteria for selecting a bus for data (Figure 3), which will pass information from the backends to the data collator, are simple. It should be the fastest standard bus available because some users will want to interface with this bus, and astronomers will always desire faster sampling rates and greater amounts of data thoroughput. Hopefully, this decision can be made at a later date to take advantage of what technology has to offer. Today, the likely choices are ethernet or FDDI.

The task of the data collator is to combine astronomical data and telescope data (position and time) and to package them into a format suitable for the demands of analysis, archival, and access (data base system). It is likely that this machine will be a high-powered workstation to allow high bandwidth monitoring of astronomical data and telescope status, as well as keeping up with the highest possible input from the data bus.

7.4 Synchronous Buses

There are three types of information that have strict timing constraints across the described modules: binary status, time, and position. Because of the specific nature of these information types, the need for synchroneity, the unidirectional flow of information, and the large number of modules requiring access, it makes sense to place these information types on their own buses.

It turns out that most of the time critical information in the system can be summarized by a single bit, e.g., cals' on-off, sig/ref, or on/off source signals. Therefore, much of the modularity of the system can be preserved by the use of a binary status bus (Figure 4) like the 12 meter's SAM bus.

Issue - The SAM Bus: The SAM bus is an invention of the NRAO Tucson staff to couple intelligent modules in real time. It is implemented with 16 differential wire pairs. Industry standard connectors and line drivers are used; however the protocol is Tucson specific. The SAM bus may be viewed as a distributed 16 bit register where each bit can be written by only one driver but any number of receivers may look at any bits at almost any time. There is a short period of time after the station 100 msec time tic during which bits may be changing and should not be considered valid. The concept of the SAM bus was endorsed by the group. However, the implementation on a large telescope is not straightforward. This is because the bus must span 350 meters or more from the receiver room at the focus to the control room. Cable characteristics will result in at least a 2us delay in the bus. The possibility of high common mode voltages on the pairs due to lightning and ground potential differences seem high; the fact that these pairs interconnect most of the sensitive, high speed computers controlling the telescope and data acquisition electronics seems like a recipe for disaster! It seem like some sort of isolation is called for, say fiber optics, but the implementation is not obvious. The time resolution of the SAM bus was discussed to some extent. The bottom line was that the time resolution of the signals on this bus ought to be less than integration times of backends. For the Spectral Processor, for example, the integration time is 12.8us or greater. Therefore the time resolution of flags on the SAM bus ought to be considerably less than 12us. An additional complexity is the possible requirement for varying modules to drive a specific bit in different operational modes.

Many subsystems require time to an accuracy of approximately 10 milliseconds. The present plan is to provide time to at least this accuracy in some sort of standard format or bus (Figure 5). Two options were discussed by the participants. The first is IRIG, an industry standard serial bus, for which off-the-shelf hardware and software is available. In their monitor and control upgrade, the Tucson staff exercised this option. Their only reservation in whole-heartedly recommending this system is the cost; however, they still feel it is the best available option. Other participants noted that a common real-time programming practice is for each processor to keep time by first being initialized and then counting interrupts from a timing source. There are other industry standard timing buses available, about which the participants knew little. Also JPL is purported to have developed a similar bus for their timing applications (per B. Parvin).

The monitor and control system must handle apparent position (Figure 6) as well as commanded position in real-time for monitoring and data tagging. This requirement is made more difficult because, unlike time and binary status information, position has high precision quantities associated with it as well as strict timing requirements. Because the servo controllers know only angles, the beam position on the sky must be computed from the azimuth and elevation angles, all of the subreflector (or prime focus) angles, the time, and the pointing corrections. Much of this information is generated continuously, and the results are needed by the antenna controller, the observation controller, the surface controller, and/or the data collator. Thus the resolution of this problem greatly determines the architecture of the system.

The commanded position must be combined with the local corrections (from a user-selected calibrator) and telescope corrections (those which are azimuth/elevation interdependent). Traditionally, the translation of the angles returned by the servos and all corrections to apparent position in right ascension and declination is performed in -- in the nomenclature of our model -- the antenna controller, since it is the next highest module in the hierarchy. Also, all the information necessary to calculate the error from commanded position would be available in this module. Modules requiring position information synchronously include controllers (e.g., surface controllers), the antenna controller, and the data collator. The observation controller will require position at least asynchronously.

Issue - Position Bus: As an alternative to basing all position activity in the antenna controller, one might separate the role of commanded and apparent position into separate modules. The position as passed to the servo controllers could still be commanded by the antenna controller at a slow rate. A position monitor module would accept angles from the servo controllers at a fast rate over a position bus and commanded positions and associated corrections from the antenna controller at a slow rate over the antenna control bus. It would then be available to provide information at a fast or slow rate to any module either continuously or on-demand in specified units. So, for example, it could provide position to the data collator for position-tagging of data points over the data bus, provide on-off signals over the binary status bus by monitoring error limits, or provide the position at a specified time to the observation controller over the observation control bus.

7.5 Physical Placement of Modules

The discussion of physical placement of these modules was in general terms because of the lack of specific definitions of the various modules, but some general principles were noted. There are two lines representing physical separation that can be drawn through the design. The first is between the modules placed on the antenna in equipment rooms and those in a local control building. The second is between a local control building and a remote control center. The key factor, as far as monitor and control is concerned, is which information streams need to be physically extended given the placement of specific modules on either side of these two lines. For example, if one wishes the servo controllers to be in a local control room, which would leave the drive cabinets on the antenna, then the rate commands lines would have to run a long distance. This could possibly cause problems even if a digital optic link were used. On the other end, the specification stations can be placed almost anywhere since their communication needs can be satisfied by an Internet link. Control buses that do not handle fast rates, such as the observation control bus, are easily extended, whereas the issues associated with more time critical signals, such as the binary status bus have already been described. If some modules must be tightly coupled because of timing needs, such as the antenna controller and servo controllers, then it would be difficult to separate them physically.

Issue - IF Distribution: Although not strictly a part of the monitor and control system, the IF distribution system has a direct bearing on the location of the backends, relative to the telescope. There is very little experience anywhere currently with doing spectral line astronomy using fiber optic cables. In coax cables, reflections are attenuated by the high loss in the cable. Fiber optic cables have considerably less damping. Hence it is anticipated that reflections due to splices and connectors in the system may introduce standing waves in the cables and baseline ripple in radio spectra. NRAO is currently preparing a test to see if such ripple can be detected, using existing cable and the Spectral Processor. The distance of the control room from the receiver room may have some effect on the number of cycles of ripple in the spectra. However the point must be made that baseline ripple is due to changes in reflections due to cable flexure; the flexure will occur only on the telescope and not on the run from the base of the telescope to the control room.

Other factors mentioned in the physical architecture and placement of equipment handling monitor and control follow:

- What equipment cannot be placed on the alidade because of its movement or vibration?
- Can the alidade support personnel and at what cost?
- What monitoring equipment is needed that is now handled first hand, e.g., visual, auditory, and inspection?
- What are cost tradeoffs of a new building vs. additional cabling to plus renovation of current facilities?
- What are the problems of RF noise of equipment near the telescope?
- What will the additional maintenance costs and effort be for distributing equipment between structures?
- How will the physical placement of equipment affect flexibility in accommodating users' more intrusive requests, e.g., bringing their own "non-remote" equipment that may have to be close to the antenna and monitored by humans?

7.6 General Requirements

A number of desirable general requirements were mentioned.

- Optical fiber should be used for long interconnections.
- The same single-board computers should be used throughout the monitor and control system to simplify development and aid spares.
- For those portions of the system linking computers and controllers only standard buses or, if not available, very simple in-house buses should be used.
- Monitoring is no less important than control and should be built into all aspects of the system. This will allow the users the capability to monitor in detail specific parts of the system, as well as provide a full range of internal checks.
- Local manual control of the telescope should be available in all key work areas on the antenna.
- The observer's needs are primary. Some observers desire separation from the telescope and/or operator while other's work requires close interaction with either or both. The satisfaction of both of these needs must be engineered into the system.

8. Conclusion

The workshop provided many guidelines, ideas, and issues to be resolved for the designers of the monitor and control system of the GBT. However, all the detailed design lies ahead. What hardware is available to implement the concepts outlined here and in the proposal? What development tools (hardware and software) are required to get the job done. What are the costs of various options? What is the cost of a minimal monitor and control system? There are also mundane issues that need to be settled, like the reliability of various fiber optic connectors. Details of the interfaces to other other telescope subsystems need to be worked out in fairly short order so as not to impede their development. This list of tasks is formidable and woefully incomplete. To have any hope of doing a creditable job, the design effort must start soon.

9. Acknowledgements

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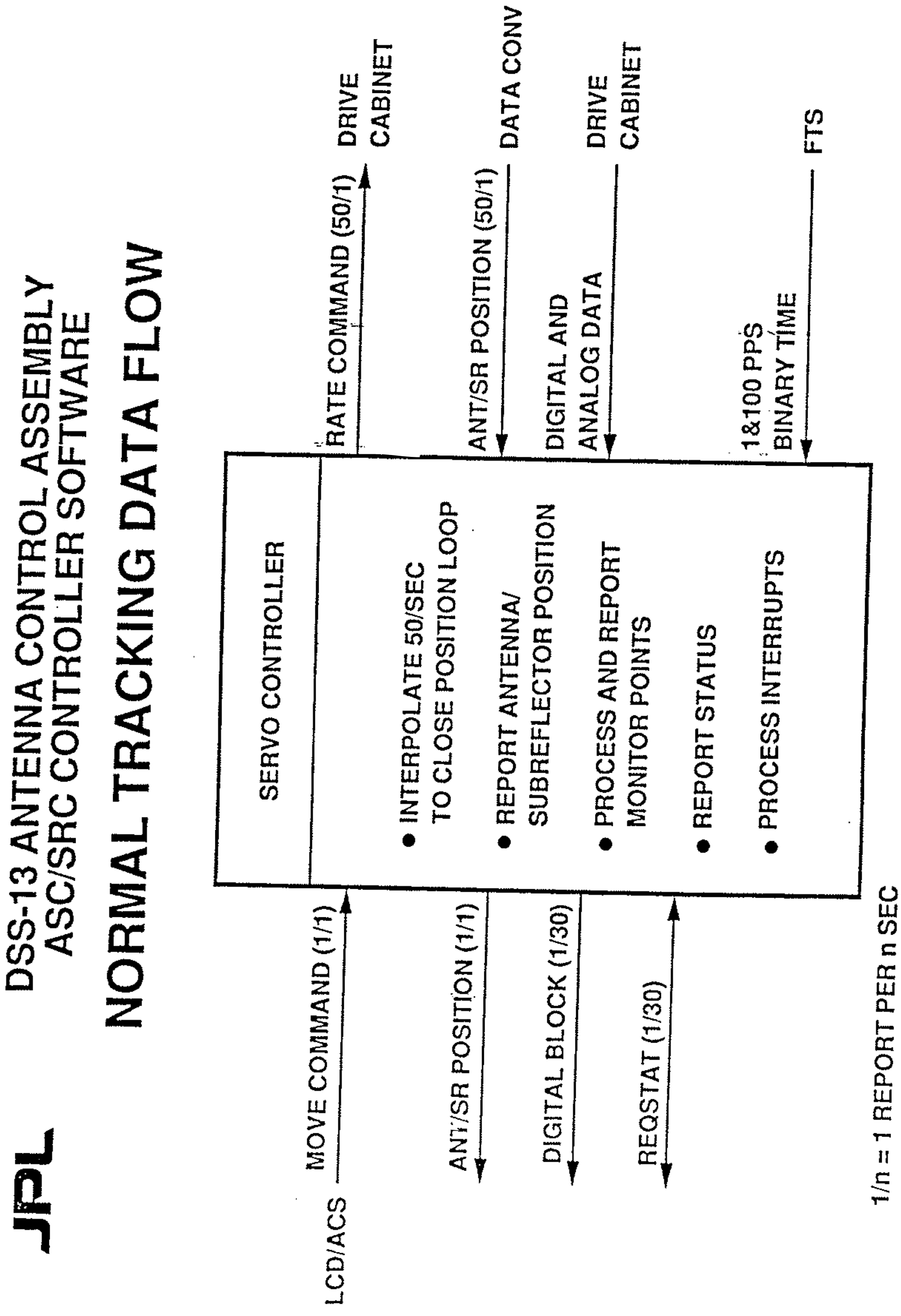

Figure 1 - Servo Controller

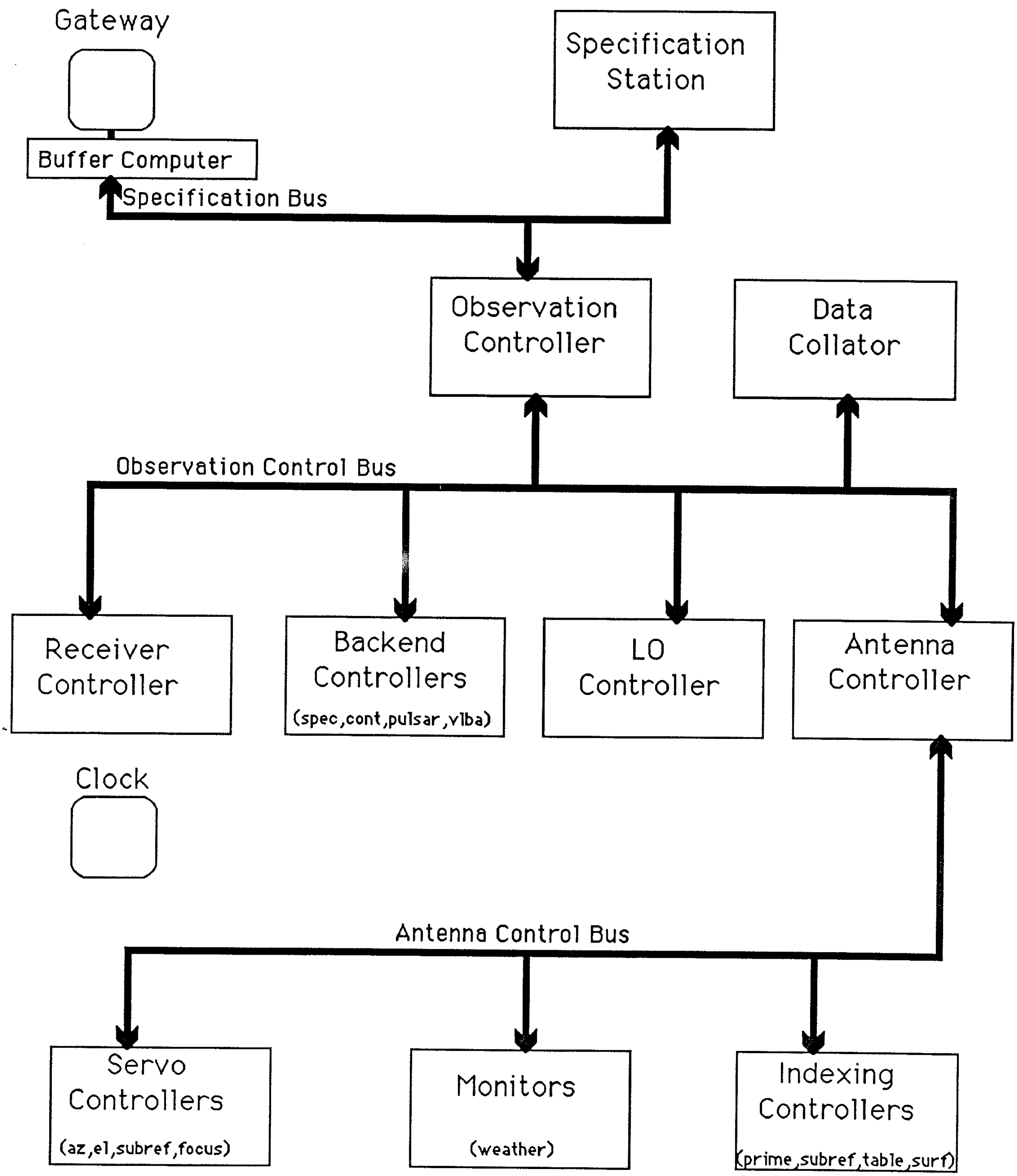

Figure 2 - Monitor and Control

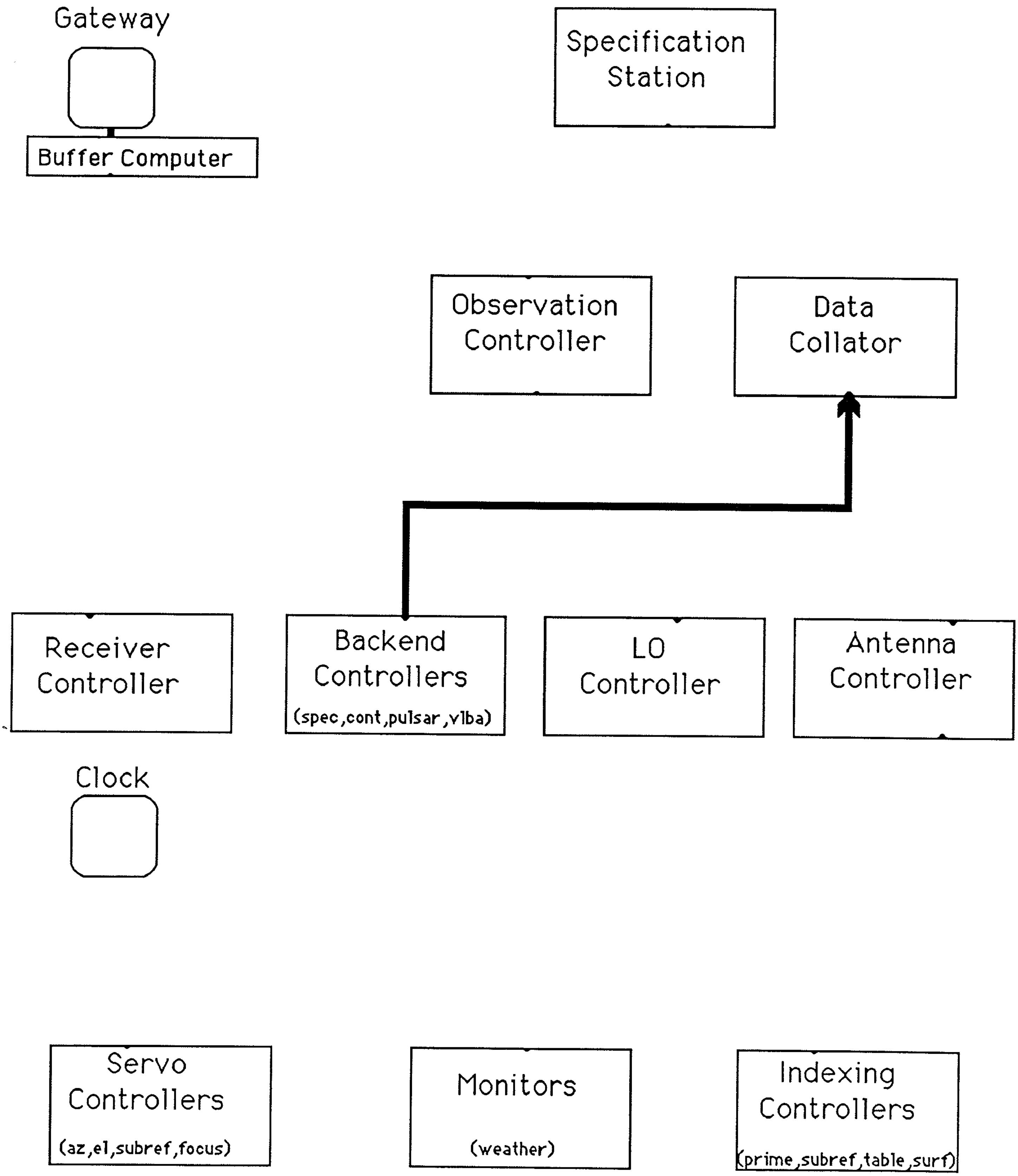

Figure 3 - Data

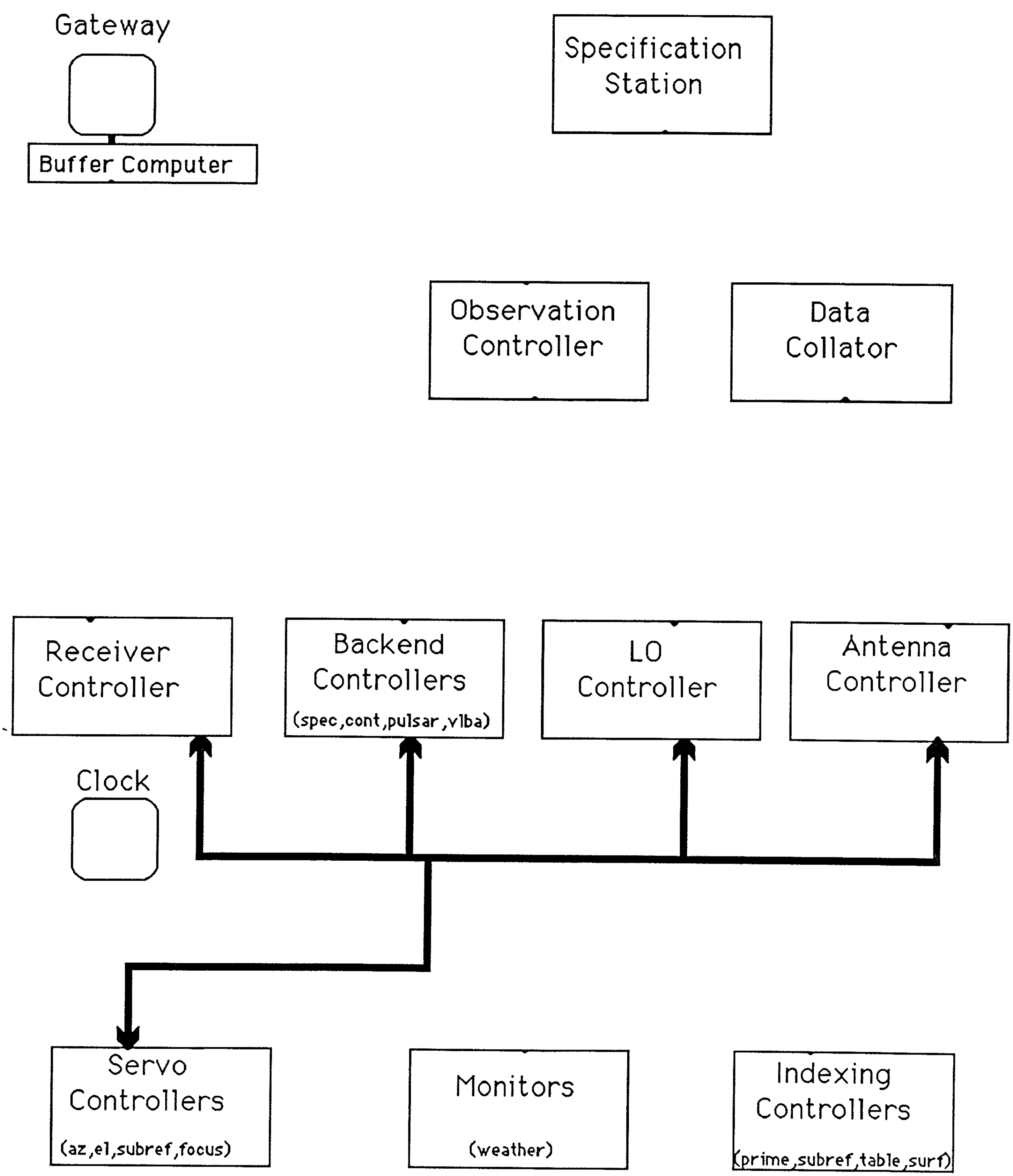

Figure 4 - Binary Status

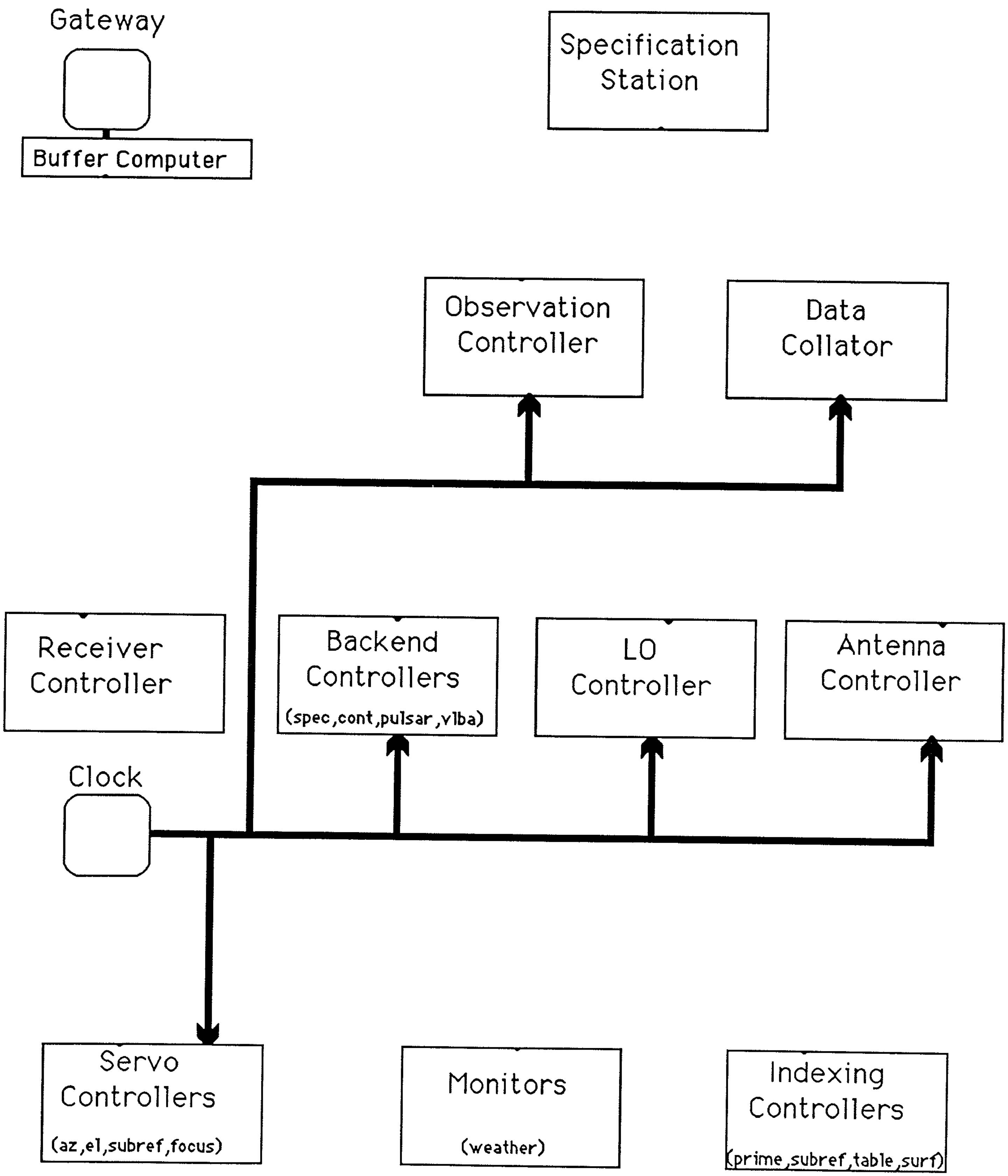

Figure 5 - Time

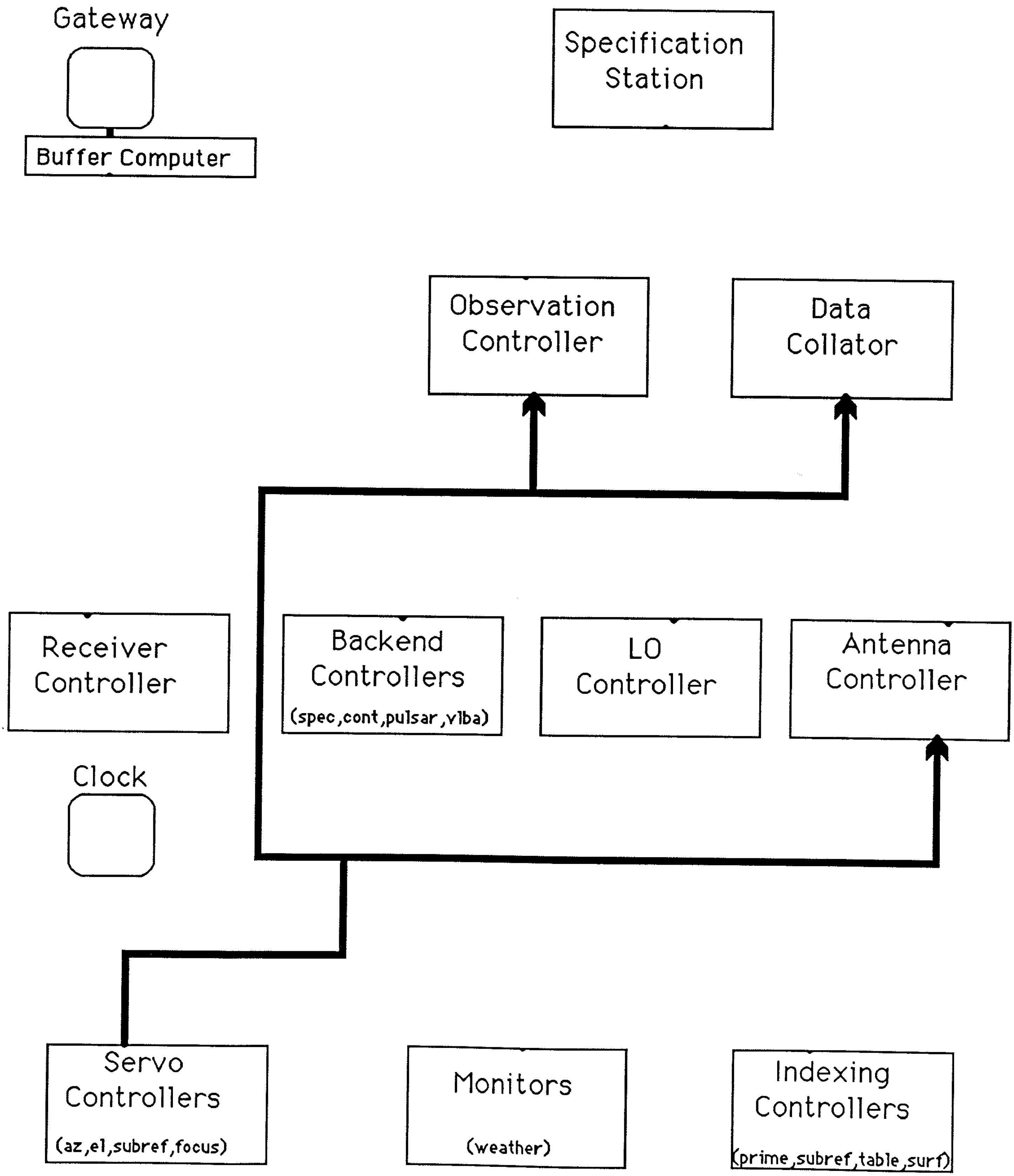

Figure 6 - Apparent Position