Precision Telescope Control System

PTCS/SN/5: The High Frequency Observing System

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Contents

Abstract

This document describes the current GBT observing system, and the additional functionality which will be required to allow the observing system to be used for high-frequency operation with the Precision Telescope Control System (PTCS).

1 Introduction

The goal of the PTCS project is to enable effective observations at wavelengths down to 3mm. The key development required to achieve this is a significantly improved ability to measure and control the positions of the GBT optical elements; this is therefore the primary focus of our current technical work. Precision measurement and control of the GBT will be performed by the core Precision Telescope Control System proper — this will replace the “conventional” control currently implemented in the Antenna Control Unit.

As for most other telescopes, above the specific antenna control software the GBT has higher level “observation” control software, which provides the user interface, co-ordination between the antenna, receivers and backends, and so on. The ability to accurately measure and position the GBT will not be particularly useful unless we can integrate these capabilities into this higher level software in an intuitive and effective way. We intend to build on the existing facilities currently in use at the GBT. However, these will need some modifications to accomodate the PTCS, as well as some additional functionality not currently available. The intent is to develop a single overall observing system which will be used for all GBT observations; we use the term “High Frequency Observing System” (HFOS) here simply to distinguish between the current system and what will ultimately be required.

The remainder of this document is divided into two parts. Section Two provides a rather brief conceptual outline of the current GBT observing system. We anticipate that at least the core architecture of this system (if not the current implementation) will be carried forward into the HFOS. This section also describes the way in which the PTCS will be interfaced to the observing system. Section Three briefly enumerates the additional functionality which will be required for high frequency operation, and for each component indicates whether we consider this to be the responsibility of the PTCS project, entirely out of scope for the PTCS project, or a collaboration between groups.

2 The existing GBT observing system

This section briefly describes the existing GBT Control System, with an emphasis on describing how observations are executed. In GBT terminology an **observation** (for example a raster map of a source) is composed as a sequence of one or more **scans** (for example, a single raster row of a map). Both of these concepts are elaborated in more detail below.

The GBT observing system employs a highly modular, distributed architecture. From an observing (as opposed to engineering) viewpoint, the system is divided into four major components: Configuration, Observation Control, Scan and Device Control, and Data Monitoring and Analysis (see Figure 1).

Scan and device control is provided by **Ygor -** the generic portion of the GBT monitor and control software. This provides the facilities for the four basic functions of control, monitoring, message/alarm handling and data production. Ygor is described in considerable detail by Clark (1998). Ygor is a

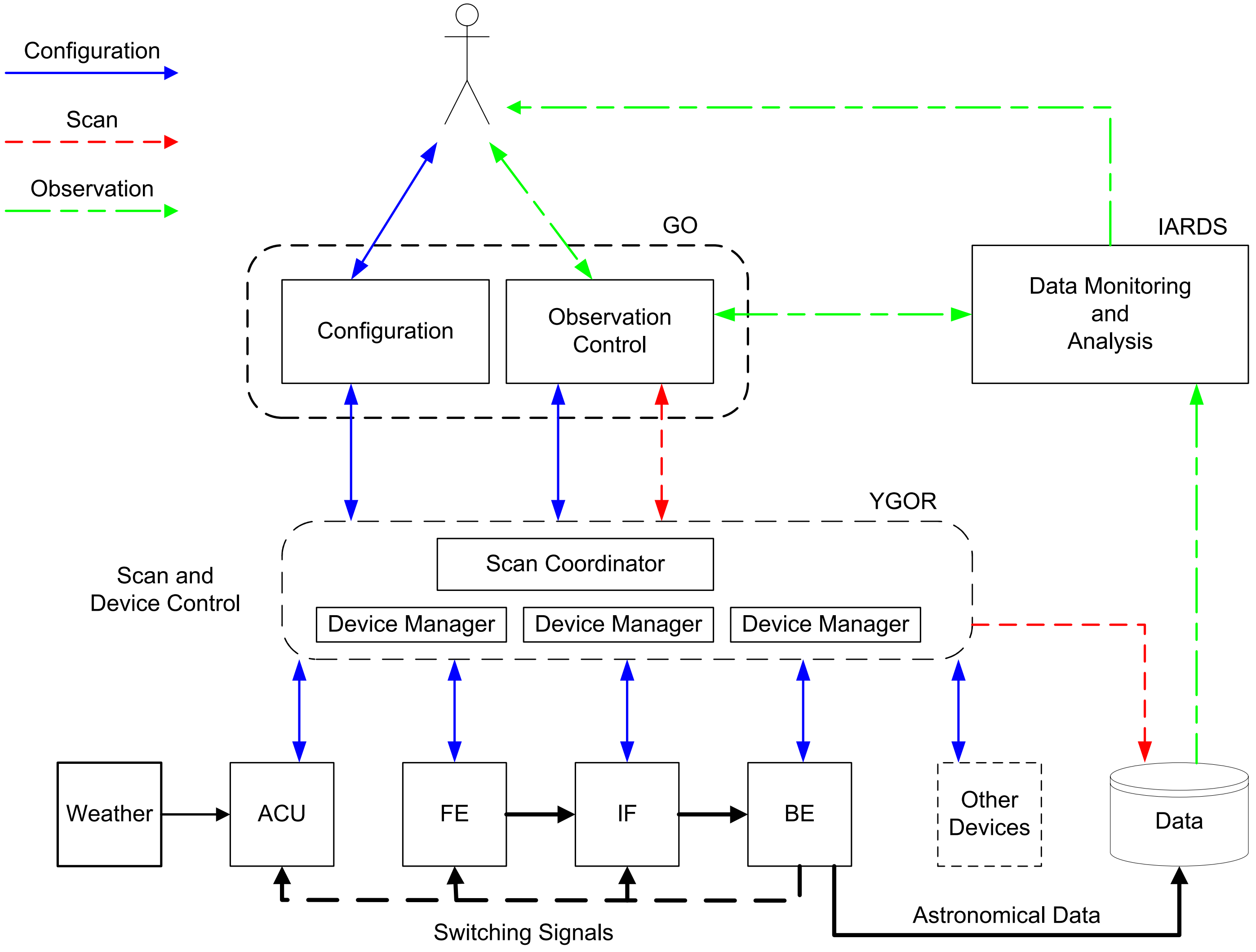

Figure 1: The GBT observing system

telescope-independent, fully distributed, object-oriented system. Control functionality is provided by a base class, the **manager**, which provides a common control interface and which implements a core set of functionality required by all devices. A derived class, a **Device Manager** is used to add the functionality required for a specific device (e.g. a receiver, a backend or the antenna). The Manager has the ability to coordinate other Managers using the control interface, so for complex devices, control may be implemented using a hierachy of Managers. More details of the Ygor monitor, message/alarm handling and data production facilities are provided in Clark (1998).

The core (and only!) observing primitive provided by Ygor is the **scan**. A scan is a contigous period of data collection defined by a finite set of variables. In advance of a scan, all participating devices (Managers) are configured by setting their control parameters as required. Managers are state machines: the state sequence for a successful scan is Ready, Activating, Committed, Running (collecting data), Stopping, Ready. A co-ordinating Manager is able to synchronize the start of a scan across its “children” by requesting from each of them their Earliest Guaranteed Start Time (EGST). The co-ordinating Manager initiates the scan by using the EGST as the commanded start time for its children [1].

At the root of the Manager control hierarchy is the Scan Coordinator. As it’s name suggests, the Scan Coordinator is a co-ordinating manager specifically intended to co-ordinate scans within the context of a GBT Observation. It may be configured to include or remove specific Device Managers as appropriate into the scan execution; thus for example to change receivers, a new receiver Manager is included in the Scan Coordinator sub-system selection, and the previous one removed. The Scan Coordinator also has a number of key parameters (e.g. observing frequency, position); once set in the Scan Coordinator, these are automatically passed down to all its selected children.

The intention of the Ygor layer is to expose the full functionality of the underlying hardware to the higher level software, in a complete and consistent manner. At the Ygor layer, the system knows very little about astronomy, or indeed about performing observations. This additional knowledge is provided in the GBT observing system by the Configuration and Observation Control capabilities currently implemented in the “GO” (GBT Observe) package.

GO is a package implemented in glish/tk which combines a User Interface, device configuration capability and observing procedures (scripts) to define and execute observations.[2] At the Ygor layer, device parameters are typically expressed in engineering terms. At the GO level, the user is presented with astronomically meaningful parameters. As the user configures the system, GO translates between the astronomical parameters and Ygor device parameters (this may be a one-to-many mapping) and configures the Scan Coordinator and Device Managers appropriately.

An observation at the GBT is defined as a sequence of one or more scans executed through a GO observing procedure. All the usual types of observation (point source observations with various switching schemes, grid and raster maps, calibration observations, etc) are supported. An example of performing a “peak” observation is illustrated in Figure 2. The purpose of this observation is to update the antenna local pointing corrections (LPCs) by performing a cross scan about a pointing calibrator source position, and fitting the offset between the expected and observed position of peak signal. The cross scan consists of a raster row in positive azimuth across the source position, a row in the negative direction, and two corresponding rows in the elevations direction. Each of these comprises a single scan.

The observation is executed as follows. First, the user configures the overall system as required through GO. This includes selecting the appropriate receiver and the continuum backend, setting the observing

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[1] Time is synchronized across devices by an IRIG timing signal and a 1 PPS hardware signal

[2] Currently, the ability to completely configure all devices is not fully implemented in GO, and so in many cases this is actually performed through the Engineering User Interface, CLEO. That detail is ignored in the following discussion.

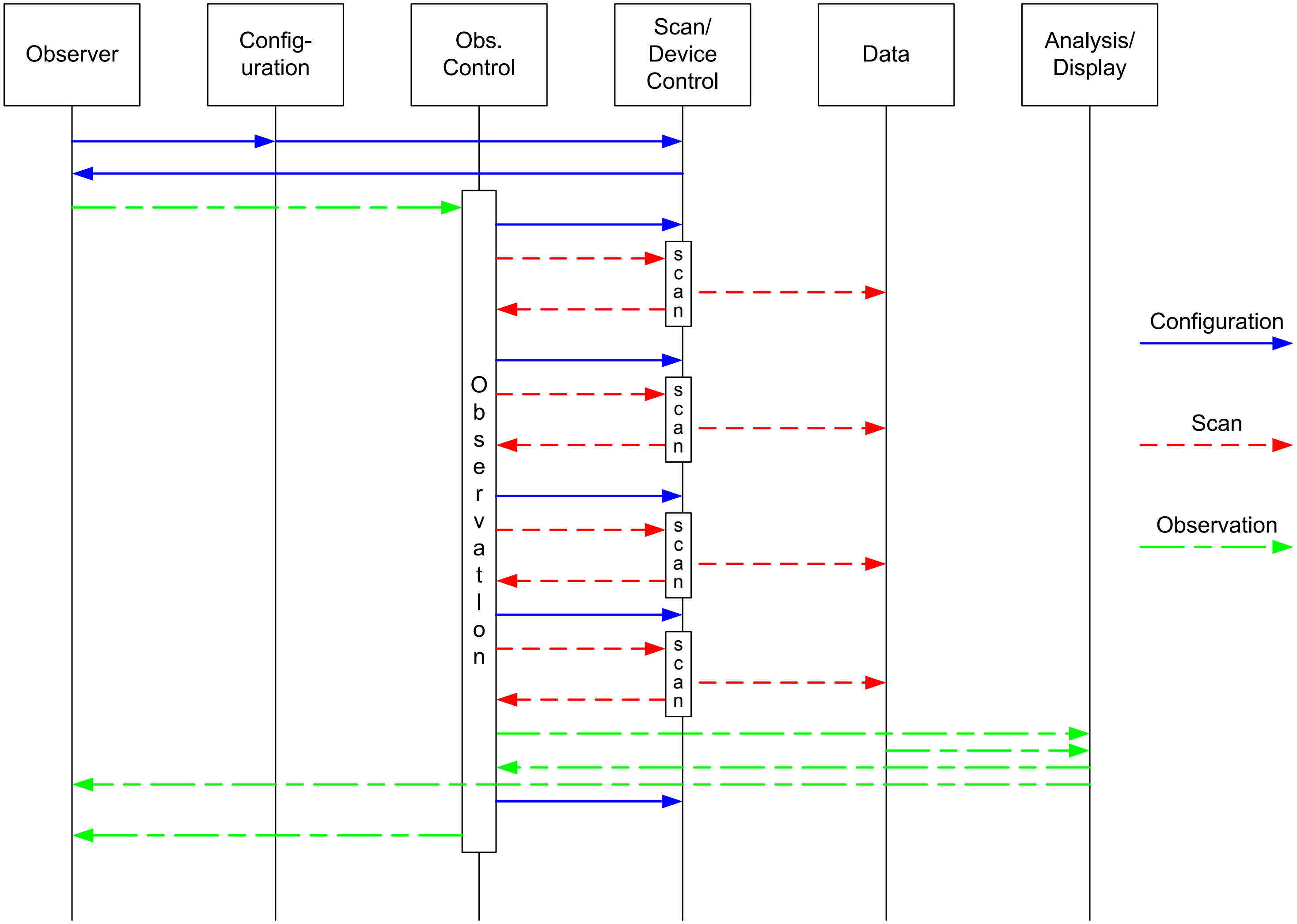

Figure 2: GBT Observation Control

frequency and bandwidth, and so on. The user also selects the parameters of the "peak" observing procedure; in this case the source co-ordinates, and the size of the cross and speed in each of azimuth and elevation.

Once the user presses the "start" button for the observation, the GO observing procedure takes control. The procedure sends additional configuration informationto the selected devices as required (in this case, the antenna position scan segment which defines the first scan), and commands the Scan Coordinator to start the scan. The Scan Coordinator negotiates the earliest guaranteed start time between its children (in this case, almost certainly determined by the antenna, which needs to slew to position), and instructs all selected Managers to start the scan at that time. From this point until the end of the scan, each Manager executes independently, synchronized by absolute time and the hardware switching signals. During this time, the backend Manager collects data, and writes it to disk. Although not shown on this diagram, "data associated parameters" from other selected Managers may also be written to disk; in the case of the antenna this includes the actual pointing direction, and other information describing the scan.

Once the first scan is complete, the observing procedure configures the selected devices for the second scan, and the process repeats itself. At the end of the fourth scan, the observing procedure sends a glish message to the interim analysis and real-time display system (IARDS). This package retrieves the data from disk, performs gaussian fits to the various scans, and determines the local pointing offsets, which are returned to the observing procedure. The data and resulting fits are also displayed for the user for review. Assuming that automatic acceptence of results is enabled, the observing procedure then instructs the antenna manager to update its LPC values as appropriate, and the procedure then completes.

The scan concept, and co-ordination through the Scan Coordinator is appropriate for timescales of tens of seconds or longer. Changes in the state of the system at faster rates are co-ordinated through hardware using the GBT switching signals system. These consist of a set of TTL levels which are distributed to all devices which require them, and include signals which define "Sig/Ref", "Cal On/Off" and 'blank". The definitions of signal and reference depend upon the device and application. In general, the backend is the switching signal master, and all other devices slaves. A typical application might be double-beamswitched observations using electronic feed-horn switching combined with nodding the antenna. The Spectrometer backend would generate the Sig/Ref signal, modulated at, say 10Hz. The selected receiver would then switch the feed-horn transfer switch at this rate. Above this, the beamswitch observing procedure would command a series of scans of, say, 30 seconds duration. In the first scan, the antenna would be configured so that the first beam was on-source, and the second on sky. At the end of this scan, the antenna configuration would be updated to switch the beams on the sky, a second 30 second scan would be executed, and so on.

In summary, the key points of the system are as follows. The system is extremely modular. A new device is added by providing a Device Manager; the common control interface ensures that all devices present a uniform interface to the higher level system. The core building block for any type of observation is a scan; co-ordination of the devices selected to participate in a scan is performed by the Scan Co-ordinator. Precise timing synchronization is acheived by distributing IRIG and a 1 PPS signal to each device. Observations are performed via GO observing procedures, which alternately (re)-configure devices and execute scans as required. Switching at rates higher than $\sim$ 10 seconds is achieved via a hardware switching signal distribution system.

2.1 Antenna Control

The current control of the antenna is described in detail in Brandt (2000); some brief details are given here.

The complete control system for the antenna is collectively referred to as the Antenna Control Unit (ACU), this is responsible for control of the primary, subreflector and prime focus axes.

Trajectory specification from the higher levels takes the form of a list of piecewise parabolic curves, each valid over a specified interval of time. These curved line segments are referred to as **track segments**; the complete list of track segments is referred to as the **commanded track**, or simply the **track**. When the ACU is requested to execute a scan by the higher level system, it attempts to drive each axis (azimuth, elevation and the subreflector axes) along the trajectory described by the relevant track.[3]

Tracks are used to specify motions for each of the GBT axes. The primary axes also include an additional term **offset**, also specified as a function of time. The ACU accepts track segments in a variety of co-ordinate systems, including equatorial, Galactic, (az,el) and so on. In many cases, track(t) will be constant for the scan - for example to perform simple frequency-switched observations of a point source with the track specified in J2000 co-ordinates. In other cases, both track and offset may be functions of time; for example mapping the moon, using track(t) to follow the center of the Moon, and offset(t) to perform the raster rows.

In normal operation, the construction of track segments is performed by GO, and entirely hidden from the user. For the above example, at the GO level, the user would specify SOURCE MOON, and provide the required (az,el) scan lengths and rates. GO would then construct the track and offset segments as required.

During normal operation, the ACU calculates the required position for the subreflector to maintain the image of the primary on the feed horn of the receiver as both the primary and subreflector feed-arm move due to gravity. This is referred to as **focus-tracking**. With focus-tracking enabled, subreflector track segments are relative to the nominal position; with focus-tracking disabled, track segments are relative to the subreflector home position.

The ACU performs standard co-ordinate transformations to (az,el), applies a refraction correction and a traditional pointing model. Weather parameters for the refraction correction are obtained from the site weather stations via http requests.

At the hardware level, the ACU interfaces to contractor-provided servo systems for the primary and subreflector controls. The ACU provides demand positions, velocities and accelerations at a fixed 100ms loop rate. The servo loops are closed at a 20ms loop rate. The servo system uses the accelerations provided to interpolate between 100ms intervals. The ACU receives the actual encoder values back from the hardware, and in the case of the primary axes, performs the reverse pointing transformations to determine the actual antenna position in the demand co-ordinate system.

Currently the active surface is controlled independently of the ACU via the the decidated Active Surface Manager (ASM), which may be selected with the Scan Coordinator for high-frequency operation. The interface to the ASM accepts the same track segments as the ACU. Internally, the ASM calculates the elevation at the mid-point of the scan - actuator demands are then generated from the FE model of the antenna for that elevation, and passed to the lower-level active surface control system

2.2 Upgrading the current observing system to the HFOS

For the specific observation control system described above, the main change required to achieve 3mm operation will be to replace the ACU with the PTCS. In fact, we expect this will be an evolutionary

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[3] Note that for the subreflector, the trajectory specification may be supplied as (x,y,z) positions and tilts, co-ordinates of the two foci, or link actuator values.

upgrade - some components of the existing ACU will be reused in the PTCS, and we expect to phase in the PTCS functionality as it becomes available. The very broad changes are shown schematically in Figure 3.

At the top level, we expect the PTCS interface to be a superset of the current ACU interface. We intend to maintain the concept of the track and offset scan segments, and the higher level software will continue to construct these as before. The main change will come internally after topocentric (az,el) demands have been calculated; rather than simply run these through a traditional pointing model, they will be passed to the Precision Control System, which will construct encoder demands based both on the command input, and knowledge of the actual alignment of the GBT optical elements provided by the Precision Measurement System. At the bottom level, the interface to the contractor-supplied servo systems will remain unmodified.

Clearly, the PTCS will have a rather richer command and user interface than the current ACU. For example, there may be a number of different control strategies for the various optical elements which may be selected by the user for different purposes, as opposed to being hardwired as is currently the case. The PTCS will also provide a considerably richer set of feedback parameters. This is indicated in figure 3 by showing a separate PTCS GUI/API. This is simply intended to illustrate that considerably more functionality will be available; the GUI and interface to the PTCS for observing will be implemented using the standard Ygor facilities as for any other manager.

Figure 2 showed the Weather station as existing outside the ACU. For HFOS operation, we expect that many additional sensors (including for example an anomalous refraction monitor) will be required. These are subsumed in Figure 3 into the PTCS sub-system.

3 Additional New Components Required for High-Frequency Operation

This section briefly reviews the additional components required for the HFOS. A summary is provided in Table 1. This summarizes the particular component, who is responsible for delivering that component (PTCS project staff, staff external to the PTCS project, or a collaboration), and whether delivery of the component is a requirement of the PTCS project, or only a goal.

Component	Responsibility	Req./Goal
Dynamic Scheduling	External	Goal
Observation Control (spiral scans, etc)	Collaboration	Requirement
Real-time monitoring of generic atmospheric conditions	External	Goal
Real-time telescope performance monitoring	PTCS Project	Goal
Antenna trend monitoring (pointing models, etc)	PTCS Project	Requirement
Calibration tools (pointing scans, focus scans)	Collaboration	Requirement
Antenna Calibration	PTCS Project	Requirement
Pointing and flux calibrators	PTCS Project	Requirement
Anomalous refraction correction (line of sight radiometers)	Collaboration	Goal

3.1 Dynamic Scheduling, Queue-based and Remote Observing

Excellent 3mm observing weather is a comparatively rare event at the Green Bank site; it will be vital to maximize the effective use of those periods when conditions are suitable. This implies that at least some

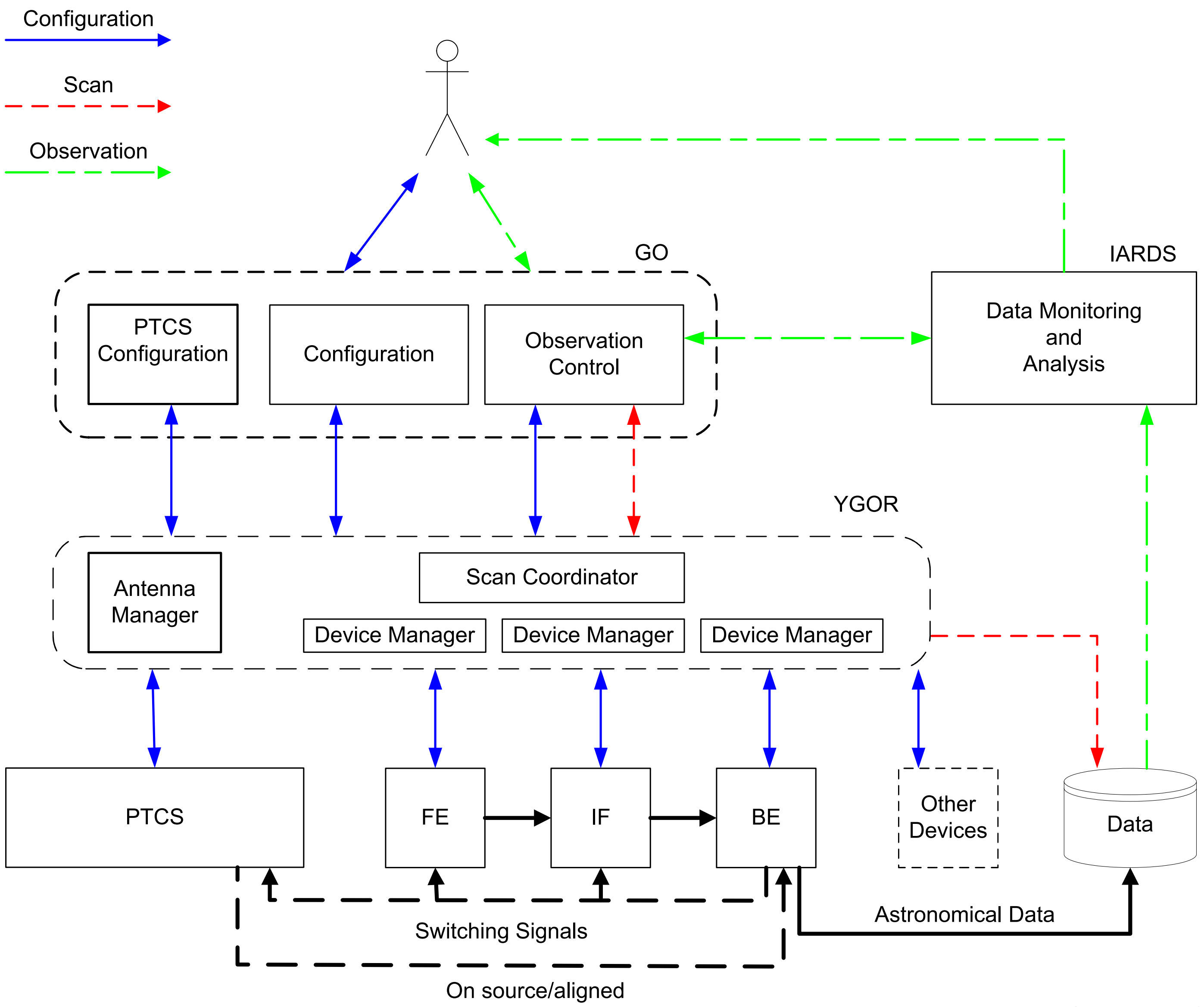

Figure 3: Upgraded Observing System

fraction of the observing time will have to be dynamically scheduled. The potential ability to perform 3mm observations is likely to depend upon rather a large number of variables. In addition to the obvious atmospheric parameters (i.e. opacity and phase stability), these might for example include wind speed, presence of ground fog, rapid temperature fluctuations and so on.

The NRAO Data Management Division intends to address dynamic scheduling as part of the ”e2e” (end-to-end) project; example operational models (and potentially actual implementations) are available from a number of existing observatories. The PTCS should deliver relevant information (e.g. PMS determinations of currently achieved pointing stability and surface accuracy) to the higher level control system for use in real-time scheduling. The PTCS Project should eventually provide models that predict future performance on the basis of current and predicted environmental conditions. However, all other aspects of developing dynamic scheduling and remote observing capability should be out of scope for the PTCS project.

3.2 Observation Control (spiral scans, etc)

As discussed in Section Two, the core unit of GBT control is the scan. Higher level observation control software will generate the required set of scan segments required to perform an observation, and pass these to the PTCS for execution. Currently, a fairly rich, but rather standard set of observations have been defined. For example maps may be performed as a series of discrete grid points, a series of separate raster scans, one per row, or with multiple scan segments (one per row) being commanded as a single scan. To perform optimal 3mm observations, more sophisticated obervation definitions might be required. For example, a spiral pattern could be used to cover a region of sky with minimal antenna accelerations. Other examples include more sophisticated chopping/nodding schemes than are currently possible.

We assume that the PTCS project will assist in the development and prototyping of additional new observing procedures which might be required to take full advantage of new capabilities; once developed these should supported as a standard part of the GBT observing system.

3.3 Real-time monitoring of generic atmospheric conditions (phase, opacity)

Two quantities important for dynamic scheduling, and observation planning during classically scheduled observing, are the bulk atmospheric opacity and phase stability. The GBT has currently available on site a number of weather stations, an atmospheric phase monitor (based on the ALMA site test interferometer) and an 86GHz water vapor radiometer. We assume that these will continue to be supported outside of the auspices of the PTCS project.

3.4 Real-time telescope performance monitoring

Again, both for dynamic scheduling purposes and for actual observing, it will be important that at all times the PTCS can report how well it is doing. Thus the PTCS will have to provide not only measurement information for the control system, but general ”figures of merit” - primarily achieved pointing stability and achieved surface accuracy. For dynamic scheduling, it will be important to obtain these even while low-frequency observations are underway (and so, for example, the active surface might be turned off). Therefore, the system will either have to be capable of monitoring performance even while the control side is not in use, or be simple to enable/disable so that spot checks can quickly be made.

All of these capabilities will be the responsibility of the PTCS Project.

3.5 Antenna trend monitoring (pointing models, etc)

Even when the PTCS is working well, we will need to keep track of astronomically measured performance, both through dedicated measurements (e.g. pointing runs) and by logging measurements such as pointing and focus checks performed by visiting observers. We will also need to perform trend analysis on the information provided by the PTCS itself (for example, the PMS might reveal an unexpected change or drift in one of the traditional pointing model terms).

The PTCS project will be responsible for generating, archiving and reviewing all of this information.

3.6 Calibration tools (pointing scans, focus scans)

Although the core functionality is already available, in certain cases (e.g. performing collimation checks) both the execution of observations and analysis of the data is rather cumbersome. In addition, as we seek to approach subarcsecond performance, we will need to critically review current implementations to ensure that these are rigourously correct, and that for example the algorithms used in the data analysis correctly match those used to command the antenna.

We anticipate that the PTCS will prototype the required control procedures and data analysis scripts; these will then be handed over to other Green Bank software developers and the aips++ group for production support.

3.7 Antenna Calibration

The PTCS Project will provide estimates of the required calibration quantities (aperture and main beam efficiencies, beam profiles, etc) sufficient to satisfy a ”typical” observer. Observers with unusual requirements will be expected to perform additional calibration.

3.8 Pointing and flux calibrators

Expanded pointing source and flux calibrator lists will be required for 3mm operation. We assume it will be the responsibility of the PTCS Project to provide and maintain these.

3.9 Anomalous refraction correction (line of sight radiometers)

It is possible that anomalous refraction will become the limiting factor in performing 3mm observations under certain conditions. (The alternative is that when, for example the wind speed and opacity conditions are suitable for 3mm operation, anomalous refraction is not a problem). In principle, it might be possible to correct for the effects of anomalous refraction on pointing by using line-of-site water vapor radiometer(s), as discussed by Lamb and Woody in ALMA Memo 224.

Investigation of the likely magnitude and effects of anomalous refraction should be performed as part of the PTCS Project. If we decide that real-time corrections are possible and desirable, PTCS project members should specify requirements, and liaise with the GBT electronics and software divisions (or external groups) to develop the required instrumentation, but not be directly responsible for delivering them.

4 Acknowledgements

Thanks to Joe Brandt and Mark Clark for helping produce the figures, and discussions on how the GBT control system works.

5 References

Brandt, J. J. “Controlling the Green Bank Telescope”. In *Advanced Telescope and Instrumentation Control Software*, Hilton Lewis, Editor, Proceedings of SPIE Vol. 4009 (2000).

Clark, M.H. “The Control Software Architecture for the Green Bank Telescope”. In *Telescope Control Systems III*, Hilton Lewis, Editor, Proceedings of SPIE Vol. 3351 (1998). Also available as GBT Memo 180.

Lamb, J.W. & Woody, D. “Radiometric Correction of Anomalous Refraction”, ALMA Memo 224 (1998).