Charisma: Trimble's Modernized
Differential GPS Reference Station and Integrity Monitor Software

*Dr. Benjamin W. Remondi

Trimble Navigation, Ltd., Sunnyvale, California

Abstract

Around 2002, the United States Coast Guard (USCG) identified a need to re-capitalize their Reference Station (RS) and Integrity Monitor (IM) equipment used in the Nationwide Differential Global Position System (NDGPS). Commercially available off-the-shelf differential RS and IM equipment lacked the open architecture required to support long-term goals that include future system improvements such as use of new civil frequencies on L2 and L5 and realization of a higher rate NDGPS beacon data channel intended to support RTK. The first step in preparing for this future NDGPS was to port current RTCM SC-104 compatible RS and IM functionality onto an open architecture PC-based platform. Trimble's product Charisma is a PC-based RS and IM software designed to meet these USCG goals. In fact USCG engineers provided key designs and design insights throughout the development. We cannot overstate the contribution of the USCG engineers. Fundamental requirements for this effort were that it be sufficiently flexible in hardware and software design to support fluid growth and exploitation of new signals and technologies as they become available, yet remain backward compatible with legacy user receivers and existing site hardware and system architecture. These fundamental goals placed an implicit adaptability requirement on the design of the replacement RS and IM. Additionally, project engineers were to remain focused on sustaining the high level of differential GPS service that 1.5 million legacy users have come to depend on.

This paper will present new hardware and software (i.e., Trimble's Charisma software) architecture for the next generation NDGPS RS and IM. This innovative approach to engineering on an open architecture PC-based platform allows the system to continue to fulfill legacy NDGPS system requirements and allows the USCG and others to pursue a scalable hardware re-capitalization strategy. We will use the USCG's recapitalization project to explain the essential role of the Charisma software.

1.0 Biography

Dr. Benjamin W. Remondi worked for NASA and NOAA, completing his government career at NOAA's National Geodetic Survey. He received engineering degrees from The University of Delaware, The Johns Hopkins University, and The University of Texas at Austin. Dr. Remondi has worked as a GPS research scientist since 1981.

2.0 Introduction

The U. S. Coast Guard Differential GPS (USCG DGPS) concept was originally developed to overcome an intentional degradation of the GPS by the U.S. Department of Defense known as Selective Availability (SA) – now ended. This DGPS technique places a GPS receiver at a known location to determine errors in the received GPS signals and then transmits those errors, in the form of correctors, to remote users. Users apply those correctors to their received GPS signals. This had the effect of removing the SA effects (SA could induce 100 meters of error in the users' computed positions). A secondary benefit to this technique is the removal of other common-mode errors, such as atmospheric and orbit errors, which tend to be much smaller error contributors. The differential GPS technique provides remote GPS users with accuracies that tend to exceed that of autonomous GPS users by a factor of 10 or more.

The USCG DGPS System is a collection of broadcast sites that are networked with two Control Station components. The Control Stations provide system experts with status and remote operational control over each broadcast site. Each site contains a redundant suite of RS GPS receivers, IM GPS receivers, and transmitter components. Each site computes GPS data correctors, combines integrity information, and transmits the resulting correctors using its Medium Frequency (MF) transmitter. The system provides accuracy performance of about 1 meter. [1].

The USCG DGPS concept was originally targeted at coastal navigation. The United States Army Corps of Engineering (USACOE) contributed funding to add inland waterway navigation. Under the leadership of a multi-agency Policy and Implementation Team (PIT), the USCG and other Federal agencies (such as the Federal Railroad Administration) have combined resources to further expand the DGPS system to include coverage over the interior region of the United States. This expanded system, called the Nationwide Differential GPS system (NDGPS), consists of 84 operational sites and may expand to some 130 stations intended to provide redundant coverage of C/A-Code correctors throughout the United States.

The Initial Operation Capability (IOC) of the USCG's maritime DPGS system was declared in January 1997; the Full Operational Capability (FOC) was declared in 1999 [1]. The GPS receiver models used at the DGPS IOC were first manufactured in the early 90's. Those GPS equipments have never been replaced and are quickly reaching the end of their lives.

The USCG and partner agencies needed to modernize NDGPS. The modernization potentials included not only GPS receiver technology, but also networking technologies, new GPS signals, possible data compression techniques and signal generation techniques, all of which were aimed at providing the end-user with improved capabilities (accuracy, integrity, and availability). A system architecture was developed that would meet the following major objectives:

- Allow for a well planned, methodical replacement of existing RS and IM Components.
- Maintain backward compatibility with existing NDGPS system components.
- Provide flexible component interconnectivity to support a wide variety of potential system architectures (i.e., open architecture).
- Provide a platform supporting Rapid Prototyping (RP) to leverage development and testing of new signals and technologies as they become available.
- Provide a flexible and cost-effective platform on which new NDGPS equipment and technologies can rapidly be deployed.

This paper seeks to provide a description of the next generation NDGPS RS and IM and how Trimble's new Charisma software enables it. Herein, we will present various NDGPS station architecture and various RS and IM software architectures, all aimed at revealing the immediate and potential capabilities of Trimble's Charisma while still meeting the needs of legacy NDGPS users.

3.0 Existing RS and IM Architectures

There are three major functional components in USCG NDGPS system:

1. Control Station (CS);
2. Reference Station (RS); and
3. Integrity Monitor (IM)

The USCG has two Nationwide Control Stations (NCS). They are located in Alexandria, VA and Petaluma, CA. Either NCS site can control all or part of the NDGPS system. Using the NCS software, watch-standers can observe the status of, and control the operations of, each broadcast site throughout the nation. At each NDGPS broadcast site there are two RS's and two IM's. These consist of mutually exclusive components controlled by the NCS (see Figure 1). Each broadcast site consists of a "Side A" and a "Side B", and for each "Side" there is an RS component, an IM component, and broadcast components. Should one "Side" experience a failure condition, the NCS can switch over to the "Standby Side".

Thus far, we have presented the RS and IM as software functional components. However, in the legacy NDGPS system, the RS software component is contained in the firmware of an Ashtech Z12R GPS receiver and the IM software component is contained in the firmware of a Trimble 4000IM GPS Receiver. The rack-mounted Z12R GPS receiver also has an integrated Minimum-Shift-Key (MSK) modulator board. The Z12R GPS receiver, acting as a reference station, generates RTCM messages (Version 2.3 [2]), predominantly in the form of L1 code correctors, and then modulates them onto a medium frequency carrier which is then output to an RF Linear Amplifier for subsequent transmission. The RS is also directly tied to the IM component through an RS-422 interface. The integrity data

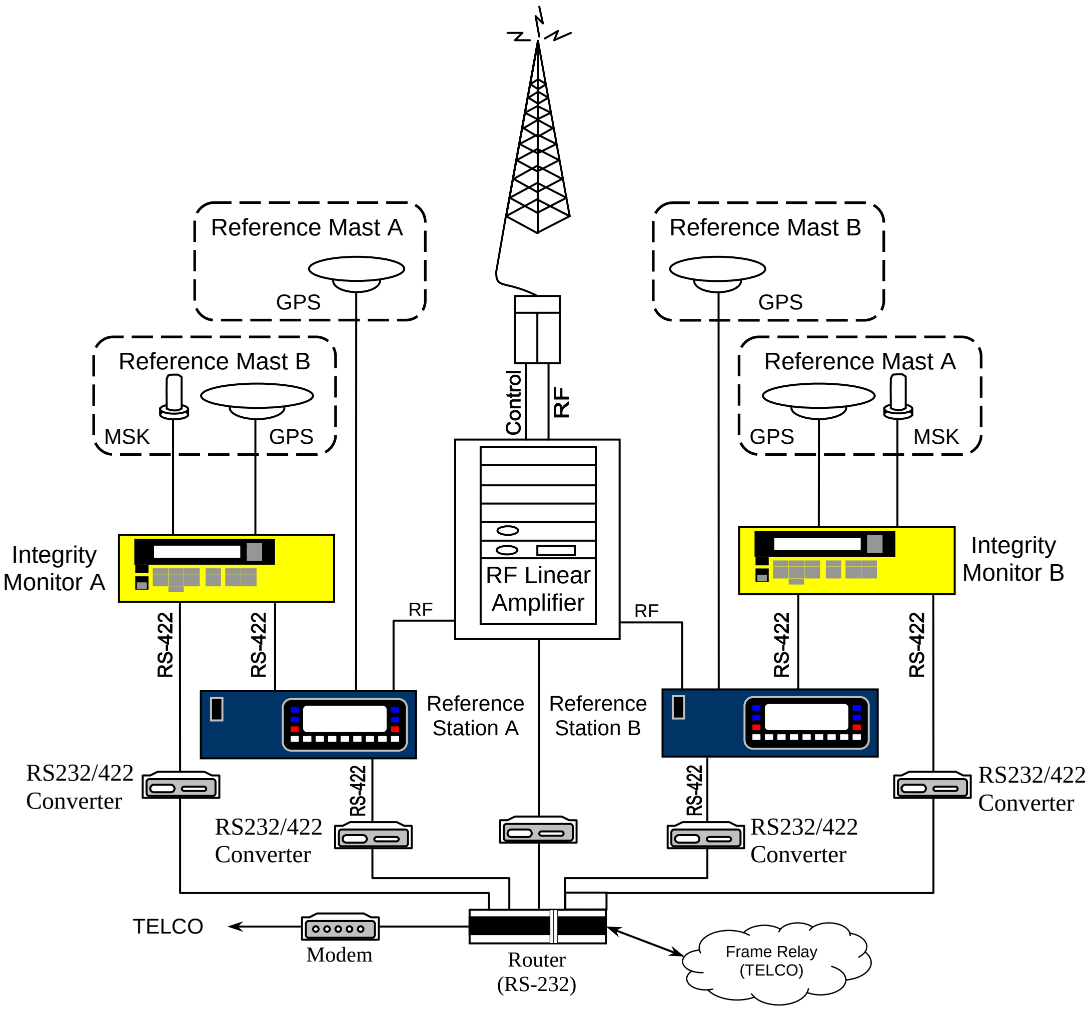

Figure 1: Legacy USCG DGPS Broadcast Site

provided to the RS by the IM is included in the RTCM messages broadcast by the RS (i.e., the RTCM messages contain integrity and health bits). The RS is connected through a router, via a frame relay connection, to the NCS and provides station status and health information. An operator at the NCS can determine the health of and control parameters of the RS. The NCS status and control are communicated using a messaging standard known as RSIM Version 1.1 [3].

The legacy IM, a rack-mounted Trimble 4000IM receiver, incorporates a GPS receiver, an MSK demodulating receiver, and an integrity monitoring algorithm. The RTCM messages broadcast by the RS are received by the MSK demodulating receiver and decoded. The IM collects Reference Station independent GPS data using the integrated GPS receiver. Within the unit, the IM collected GPS data and the reference station RTCM data (i.e., the corrector data) are combined and analyzed by the integrity monitoring algorithm. Any unsafe conditions detected by the IM are immediately reported to the RS and to the NCS in the form of RSIM messages [3]. These IM alert conditions are provided directly to the locally connected RS via a local RS-422 interface. Like that of the RS, the IM is connected with the NCS through the router. Similarly, the IM provides the NCS component with station status and health information. An operator at the NCS can control the parameters of and the operations of the IM.

4.0 Next Generation RS/IM Architecture

The current USCG NDGPS system employs equipment that will soon be obsolete. While the current design has been time tested and has performed superbly, it lacks adaptability to accommodate equipment changes, new signals, new functionality, and new services. As a result, a new RS/IM system architecture was defined by engineers at the USCG Command and Control Center (C2CEN) to allow for the inclusion of these possibilities.

The next generation RS and IM software components will reside on a PC-based platform. For the USCG NDGPS Broadcast sites, this platform is a rack-mount industrial computer with an Intel motherboard, a Pentium 4 processor, 512 MB RAM, 40 GB Hard Drive, an onboard 100/10baseT Ethernet connection, and an onboard RS-232 port. For architectures requiring such, additional RS-232/422 can be added using available PCI slots. Contained in each RS/IM computer is a specialized board suite, known as a **D**igital **S**ignal **P**rocessor / **P**CI card format **M**odulator **A**nalog **F**ront-**E**nd (DSP/PMAFE) I/O card.

The DSP/PMAFE board interfaces with software using Application Programmers Interfaces (APIs) supplied by the board manufacturer. Through software API calls, programs can configure the various options of the board and provide that board with data to be modulated. One of the key features of the board design is its independence from the Operating System (OS) and Central Processing Unit (CPU) of the computer in which it is housed. Through API calls, programs provide the board with commands and data through Direct Memory Access functions. Once the buffers of the board are loaded, the board is then free to perform its functions independently of the CPU and OS of the PC. In this way, the DSP/PMAFE board is not slaved to the potential non-deterministic nature of the Operating System that may be driving the PC. Furthermore, one can continue to load the DSP/PMAFE buffers even while it is handling data and commands from previous similar load operations. The result is a continuous and independent operation that allows PC program developers to design software that exploits the board, with little concern about the non-deterministic nature of the Operating System on which their software resides. Stated yet another way, the board provides a continuous and uninterrupted modulation stream even when the resource demands on the PC's CPU become extreme.

At this point we need to emphasize that while an entire PC configuration has been specified, it does not restrict the potential for use of another computer system: i.e., it should be treated as a minimum. GPS receiver vendors have begun adding Ethernet connections along with serial port connections to their equipment. This eliminates the need for a GPS receiver to be directly tied to an RS or IM component. Likewise, other devices, such as MSK demodulators, can be attached to the network using RS-232 to Ethernet converters. Network connections permit more interconnectivity options: i.e., an increase in the number of reconfiguration possibilities in response to device failure, thus increasing overall system availability.

The USCG decided that the PC-based hardware configuration for the RS and the IM would be the same. The onboard NDGPS software, Charisma, can take on the role of either RS or IM. So each NDGPS PC has the entire suite of RS and IM software. When the technician installs the device at the target site he configures it to act either as an RS or an IM. This approach reduces the number of configurations maintained at the depot level and reduces overall maintenance costs.

The software architecture is also open. Thus it supports development and testing, while meeting the current needs of the system. Figures 2 and 3 depict the software architectures of the RS and IM, respectively. The software components in each drawing are shown in navy blue. Specifically, Charisma as an RS comprises programs GRIM, DGPS_Eng, XYZ_MM, and optionally DGPS_Mon. Charisma as an IM comprises programs GRIM, DGPS_Eng, DRIM, and optionally DGPS_Mon. Notice that there are common components between these two configurations.

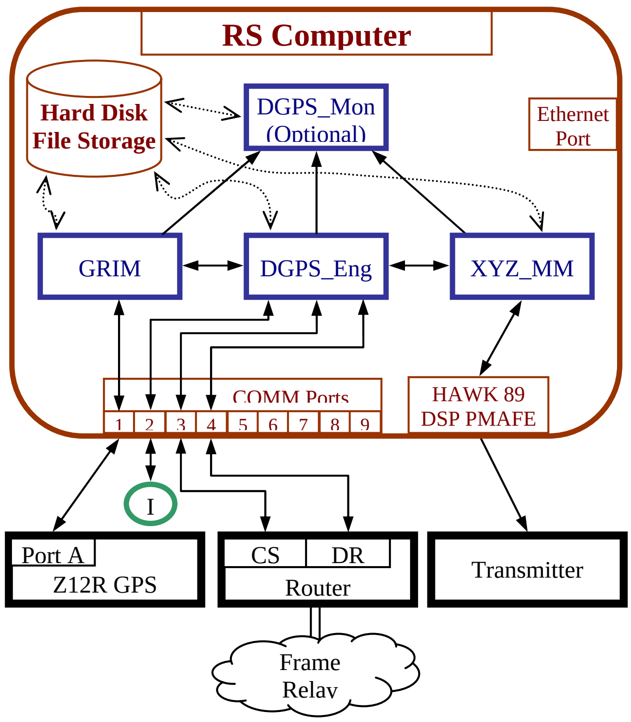

Figure 2: Charisma RS Architecture (Phase I)

The GPS Receiver Interface Module (GRIM) is used in both the RS and IM roles and was specifically designed to interface with various GPS receivers. Its primary purpose is to provide real-time processing programs with consistent, almost RINEX-like, GPS receiver data interface. The primary motivation is that each GPS manufacturer, as well as the various receiver generations from a GPS manufacturer, implements a different messaging protocol. These protocols are often significantly different, and the semantics of the message elements can vary widely. This makes it difficult and impractical to put the GPS receiver interfacing mechanism within various real-time programs. Thus, Charisma implements a concept whereby real-time processing applications can interact with software that standardizes the GPS data interface. This notion goes further in that GRIM removes the burden of establishing and maintaining the GPS receiver connection and thus hiding the details of interfacing with GPS receivers. As new GPS receivers become available, or firmware changes to existing receivers require changes in message handling, GRIMs can be created and/or modified to handle the specifics of each receiver/protocol while leaving the interface with other real-time processing programs intact.

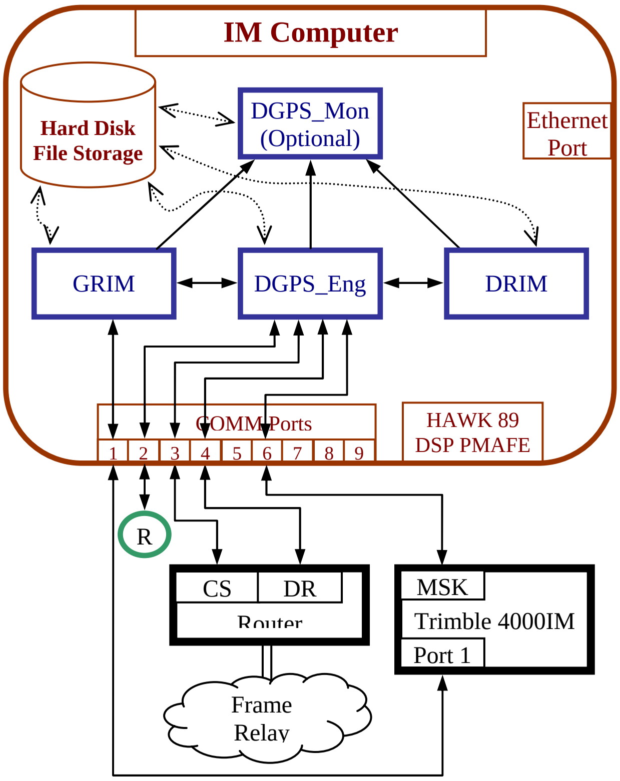

Figure 3: Charisma IM Architecture (Phase I)

At the heart of Charisma's RS and IM components is a DGPS Engine (i.e., DGPS_Eng). This software program can take on the role of either RS or IM.

When configured as the RS, DGPS_Eng interfaces with GRIM to obtain raw GPS observation data from the reference GPS receiver. DGPS_Eng interfaces with the IM to obtain integrity information for the RS. The program uses this information to generate RTCM SC104 messages (i.e., these messages contain GPS corrector data, along with integrity information). These messages are then handed over to a modulation program (i.e., they are passed to XYZ_MM) for subsequent modulation and ultimately amplified and broadcast by the RF Linear Amplifier.

When configured as the IM, DGPS_Eng interfaces with GRIM to obtain raw GPS observation data from the GPS receiver collecting data for integrity purposes. DGPS_Eng interfaces with DRIM (Demodulation Receiver Interface Module) to obtain received and decoded RS transmitted RTCM104 messages. A demodulation receiver receives the same signals that are broadcast to DGPS users, it decodes these signals, and then DRIM provides that data to DGPS_Eng for integrity purposes. Relevant integrity data generated by the IM is then fed back to the RS for inclusion in its broadcast RTCM SC104 messages. Integrity data and other status data are also fed back to the NCS as well.

Please note that this paper was not intended to discuss the particular functional requirements of the RS and IM components. These requirements and capabilities are detailed in the documents referenced at the end of this paper (i.e., [2], [3], and [5]).

The XYZ_MM program is used when the software is configured in its RS role and is basically responsible for modulating the RTCM SC104 message created by DGPS_Eng. The modulator comprises a Momentum Data Systems Hawk 89 ADSP board with custom designed and built daughter board [4]. RTCM SC104 messages are modulated onto a medium frequency (MF) signal and fed to a radio frequency linear power amplifier (RFLPA). Thus, the XYZ_MM sub-component accepts modulation link configuration data (for example, modulation frequency and bit rate parameters) and RTCM SC104 messages from the DGPS_Eng, it queues those messages, and then interfaces with the DSP/PMAFE board to modulate those queued messages.

When in the IM role, the XYZ_MM sub-component is replaced by a DRIM sub-component. The primary purpose of DRIM is to provide real-time processing programs with consistent, almost RINEX-like, demodulated RTCM data and demodulator status data. The primary motivation is that each MSK Beacon Receiver manufacturer, as well as the various receiver generations from that manufacturer, implements a different messaging protocol. These protocols are often significantly different, and the semantics of the message elements can vary. This makes it exceedingly difficult to put the demodulating receiver interfacing mechanism within various real-time programs. XYZs has used the same concept for DRIM as for GRIM whereby real-time processing applications can interact with software that standardizes the interface for demodulator data. As new MSK demodulating receivers come onto the market or firmware changes to existing demodulators requires changes in message handling, DRIMs can be created and/or modified to handle the specifics of each new protocol while leaving the real-time processing program intact.

In both the RS and IM roles, one can employ an optional DGPS_Mon program. This software sub-component is a monitoring program that provides NDGPS technicians with front-end status and support information. This is optional in that it is not required for the operation of the Charisma RS/IM software in the NDPGS system. For example, when DGPS_Mon is installed and operating, on-site technicians view basic operational go/no-go displays which contain high-level/summary status information. Using the display features of this program, technicians can more readily determine simple system problems. More complex problems will likely need to be diagnosed using the displays of the other sub-components of the RS/IM software conglomerate. The monitoring features of the DGPS_Mon include an optional 'watchdog' feature which requires each of the participating sub-system components to provide DGPS_Mon with timely status report information (which resets the watchdog timers). If a timer expires, DGPS_Mon will take corrective actions (including, but not limited to, rebooting the computer in an effort to perform a fresh start of the entire software suite).

There is an inherent modularity in the Charisma software architecture. Each component can be replaced by a component performing a similar function. For example, there are currently DRIMs for Trimble ProBeacon receivers and Raven beacon receivers. As it is desired to incorporate other demodulators or other demodulator features, DRIM capabilities can be added. These DRIM additions can occur without affecting the other components of the system. This modularity opens up the architecture such that other hardware components can be utilized and quickly incorporated. For example, GRIM can be modified to handle new GPS receivers and new receiver capabilities. Likewise, DRIM can be modified to handle new demodulation receivers and their capabilities. XYZ_MM and the DSP/PMFAE board could be replaced should new modulation requirements come about. That is, the hardware, and features of the software that support that hardware, can be augmented and modified without necessarily affecting the other software of the system, thereby reducing upgrade and maintenance costs.

It is important to note that in both Figures 2 and 3 there are nine communications ports and an unused Ethernet port. We stated earlier that the architecture was designed to meet the current needs and facilitate future growth. Along these lines, the Phase II system nearly eliminates the need of the RS-232/422 PC ports. These ports have been replaced by using network device connectivity. The PC is connected as a network node using its Ethernet port. Likewise, the other devices are connected to the network either by the direct network support by the device or by using an additional device that converts RS-232/422 to Ethernet. The software design of the Next Generation RS/IM facilitates this approach in that it can employ a variety of communication connects for each existing connection. For example, the connection between the RS and IM hardware components is currently an RS-422 interface. The Phase I and Phase II architectures directly support that approach (i.e., the RS to IM interface can be configured as an RS-232/422 interface just as readily as it can be configured to employ a TCP/IP Socket connection). Figure 4 depicts the current Phase II concept.

With the network component interconnectivity and the configuration options inherent in the software, the possible system configurations are numerous. For example, GRIM currently supports interfaces with GPS receivers that are on a network. Furthermore, a GPS receiver can provide data to either an RS or an IM component. This is because GRIM provides a consistent GPS receiver interface to DGPS_Eng (which is configured as either an RS or IM), but GRIM is not RS or IM role aware (i.e., its features are independent of the RS/IM roles). Thus, any GPS receiver visible on the local sub-network (i.e., any GPS receiver at a broadcast site) could provide data to either an RS or IM. A receiver does not need to be tied to a particular RS or IM computer (such a tie exists in the legacy deployed system). Thus, a GPS receiver failure would not invalidate an entire "Side" of a NDGPS broadcast site because another receiver could be easily incorporated in its place.

There are other potential advantages and features that have yet to be explored and implemented. These include remote network login, remote software and receiver firmware updates, remote data archival and retrieval, incorporation of new civil GPS L2 and L5 signals, and RTCM Version 3.0+ and its incorporation of

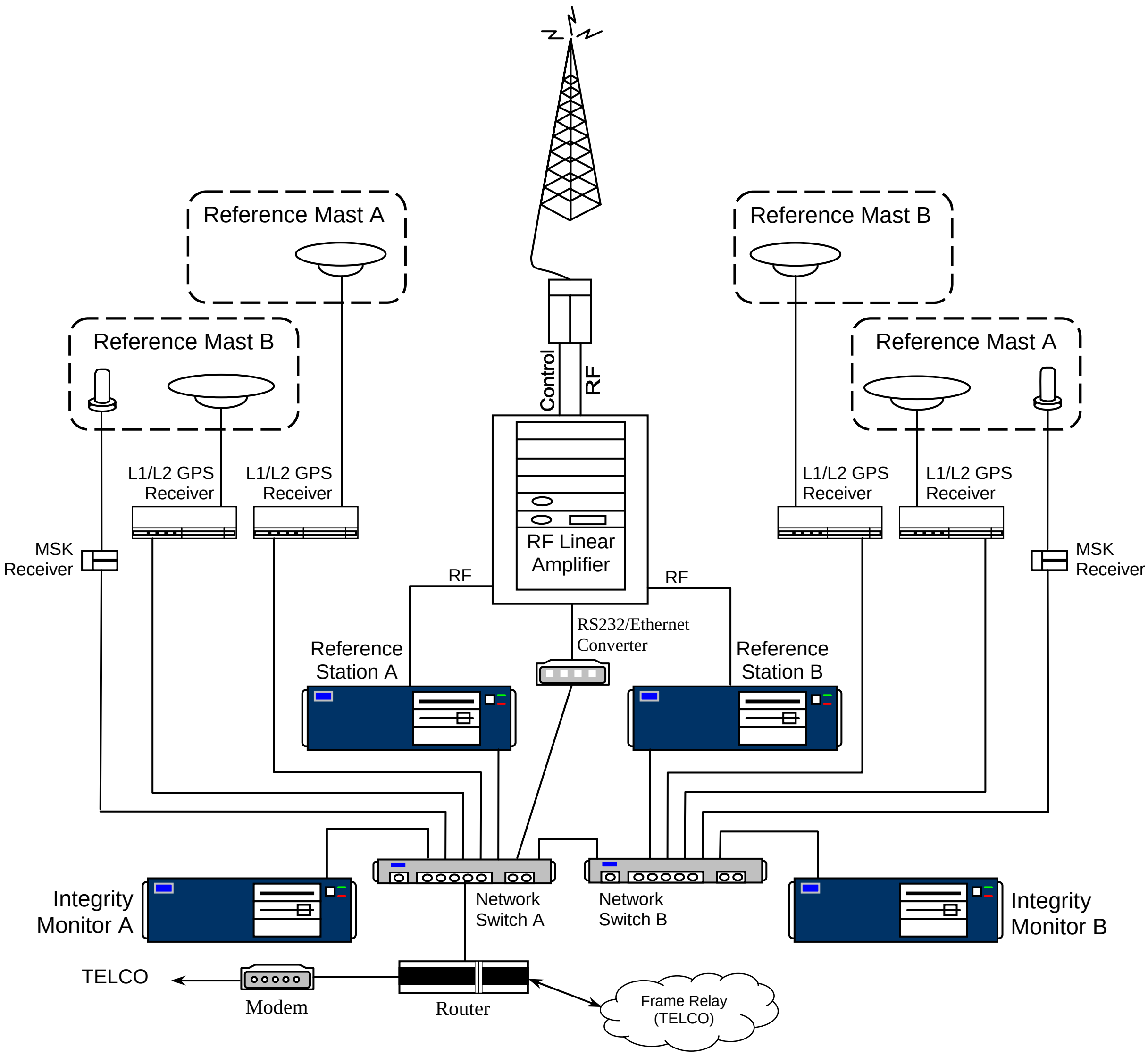

Figure 4: Phase II USCG DGPS Broadcast Site

carrier observations. Charisma also supports the modern RSIM 1.2 Standard approach to integrity monitoring of both pre- and post-broadcast integrity monitoring of correctors. However the pre-broadcast feature has yet to be exploited by the USCG NDGPS system.

The Next Generation RS/IM has already been implemented and has undergone many levels of testing. It has been installed at the USCG Portsmouth, VA engineering/test facility (C2CEN). Accuracies achieved thus far are at least compatible with those of the legacy system. Trimble testing thus far has yielded results that are well within those specified by the Coast Guard.

5.0 USCG Deployment Schedule

The U. S. Coast Guard NDGPS recapitalization deployment is two-phased, which should not be confused with the aforementioned two-phased integration effort. Under recapitalization deployment, Phase I begins by replacing the "Side B" of 5 selected broadcast sites, using existing GPS receiver and beacon receiver hardware but Charisma RS and IM software and Trimble Zephyr antennas. After an initial testing period, Phase I becomes a nationwide dual-sided (i.e., Sides A and B) deployment, using existing GPS receiver and beacon receiver hardware but Charisma RS and IM software and Trimble Zephyr antennas nationwide. The Phase I 5-station deployment and testing is scheduled to be completed by the end of 2006, at which point Phase I system-wide will begin. The Phase I system-wide deployment is scheduled to be completed July 2008. The Phase II deployment will replace all beacon receiver hardware, all GPS receivers, all GPS antennas, and fully deploy the Charisma RS and IM software (Figure 4 provides a hardware architectural drawing of the Phase II USCG system). Phase II deployment begins at the completion of Phase I (i.e., July 2008) and is scheduled to complete by the end of 2009.

As a note of interest, because of the early teamwork efforts between the USCG and Charisma development engineers, there have been very few issues reported thus far. Of those that have been reported, all have been considered by both teams to be minor in nature and all have been resolved.

6.0 Summary and Conclusions

This paper has presented the next generation architecture of the RS and IM components of the U.S. Coast Guard's Nationwide Differential GPS system. We have described how the next generation RS and IM hardware and combined with the various Charisma supported software architectures meet the NDGPS needs and provide a fluid adaptation in support of numerous potential future needs.

The combined software and hardware architectural designs described in this paper will serve the public well in the years to come. This includes not only its ability to meet the production level needs of the USCG NDGPS system, but also in its ability to act as an engineering test-bed backbone in the investigation and research of potential new NDGPS capabilities, as well as its abilities to support numerous other NDGPS-like deployments. With the designed-in flexibility of Charisma, numerous architectures and configurations can be supported.

References

1. Joe Chop, David Wolfe, Connie Judy, and Amy Kritz, *Local Corrections, Disparate Uses, Cooperation Spawns National Differential GPS,* GPS World Magazine, Vol. 13, No. 4, April 2002, pp. 38-41.
2. Radio Technical Commission for Maritime Services, Special Committee No. 104, *RTCM Recommended Standards for Differential GNSS (Global Navigation Satellite Systems) Service*, Version 2.3, August 20, 2001.
3. Radio Technical Commission for Maritime Services, Special Committee No. 104, *RTCM Recommended Standards for Differential NAVSTAR GPS Reference Stations and Integrity Monitors (RSIM)*, Version 1.1, August 20, 2001.
4. Marty Poppe, Cambridge Engineering, Inc., *SMSK Signal Modulator* (Developed under delivery order DTCG23-02-F-DNJ309), P.O. Box 3099 Burlington, VT 05401-3099.
5. U.S. Department of Transportation, United States Coast Guard, *Broadcast Standard for the USCG DGPS Navigation Service (COMDTINST M16577.1)*, April 1993, 2100 Second Street S.W, Washington, D.C., 20593-0001.