Sapphire *DART*
Digital Active Real-Time Tracking

(Model H651 Indoor/Outdoor)

User's Guide

Revision 2.0

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1 General Hardware Description

The Sapphire *DART* Ultra Wideband *Digital Active Real Time Tracking* system is designed for the tracking of personnel and/or equipment. A system is defined as one (1) processing hub, four (4) or more receivers, one (1) or more reference tags, and multiple tags for individual assets.

1.1 Concept of Operation

Sapphire DART uses short pulse, or ultra wideband (UWB), technology to determine the precise location of a UWB radio frequency identification (RFID) tag and operates as follows:
Each *Sapphire DART* tag repeatedly sends out a packet burst consisting of a short train of UWB pulses, each pulse having an instantaneous bandwidth of over 1 GHz. Since individual tags are not synchronous, and the packet bursts are of extremely short duration, the probability of tag packet collision is very small allowing for the simultaneous processing of hundreds to thousands of tags in a local area.

These transmitted UWB pulse trains are received by one or more *Sapphire DART* UWB receivers which are typically located about the periphery of the area of coverage. Reception by three or more receivers permits accurate 2-D localization, while reception by four or more receivers allows for precise 3-D localization. If only one or two receivers can receive a tag transmission, proximity detection can also be readily accomplished.

Each *Sapphire DART* UWB receiver uses a highly sensitive, very high speed, short pulse detector to measure the precise time at which a tag packet arrives at its antenna. The extremely wide bandwidth of the UWB pulses permits the receivers to measure these times-of-arrival to sub nanosecond precision. To determine the actual tag position from these measurements, the *Sapphire DART* Hub/Processor, using calibration data from the *Sapphire DART* UWB reference tag, determines the differential times-of-arrival between receiver pairs from these individual receiver measurements and implements an optimization algorithm to determine the location using a multilateration technique. Since the speed of light is approximately 0.98 feet per nanosecond, these differential times-of-arrival are readily converted into the appropriate measurement distances.

The *Sapphire DART* Hub/Processor performs several other functions as well – it provides a source of DC power to the individual receivers, it provides a stable clock reference to each receiver allowing individual receivers to be frequency-locked for high measurement stability (US Patent 6,882,315), and also incorporates a graphical user interface (GUI) and communications ports for client access. THE *Sapphire DART*, using Multispectral Solutions' patented ultra wideband technology, provides unprecedented performance for high accuracy (sub-foot) localization in severe operational environments.

1.2 Processing Hub (Model H651)

The Model H651 processing hub houses a single board CPU which interprets the data sent from the receivers, and generates the identity and location of each tag within a designated area. The results are made available via the hub LAN interface to client computers for further processing and display. A simple JAVA™ client applet is provided for initial system check-out.

Figure 1: *Sapphire DART* (Model H651) Processing Hub

The hub software included in the *Sapphire DART* system runs a version of the Linux Operating System. The Model H651 accepts input power of 100-240 Volts AC, and provides power to the receivers over CAT 5E cable. A clock source is sent to the receivers over the same CAT 5E cable which also carries serial communication data to the receivers. Provision has been made for powering receivers from an external AC adapter, but should only be necessary in cases requiring extremely long cable runs.

Caution

CAT5E *shielded* cables with shielded RJ-45 connectors must be used for connection between the Model H651 hub and receivers. The use of unshielded cables may result in significant electrical damage to the hub and receivers. It is also strongly recommended to turn a receiver's power switch OFF while connecting cables, and to turn the corresponding port power switch on the hub OFF when swapping or connecting cables.

Figure 2: Model H651 Processing Hub (rear view)

The hub chassis is enclosed in a metal enclosure with optional rack mount brackets. The rear panel of the hub has both an Ethernet interface (accessible through an IP network) and a serial interface (console) for configuring the hub and passing output information over the LAN.

The front panel of the hub has a series of eight RJ-45 connectors that are used for connecting receivers to the hub. Each RJ-45 connector has a corresponding port power switch that is used for turning on power to receivers connected to that port. These RJ-45 connections are paired into four groups of high-speed connections, with a maximum throughput per pair of 1Mbps of receiver data. In general, it is recommended to distribute the connections among the groups. For example, in applications where four or fewer RJ-45 connections are used, use port connections #1, #3, #5, and #7, if cabling permits, in order to balance the communication load.

Caution

Use care to only connect receivers to the hub port connectors on the front panel and to only connect LAN cables to the Ethernet port connector on the rear panel. Improper connections may result in damage to receivers, hub or external LAN equipment.

Caution

Receivers should only be added to a receiver port on the hub when power to that port is switched OFF.

1.3 *Sapphire DART* Receiver (Model R651)

The *Sapphire DART* Model R651 consists of a UWB receiver with a nominal center frequency of 6.35GHz. The receiver contains an antenna and circuitry that detect pulses from the UWB tags and generates packets of information which are in turn sent to the hub over shielded CAT5E cable. Receivers can be connected directly to a hub port connection or connected in a daisy chain to other receivers. Each receiver receives 48VDC from the previous receiver (or from the hub if it is the first receiver in the line) and passes the 48VDC on to the next receiver in line via the CAT 5E cable. Similarly, each receiver receives a clock and bi-directional data from the previous receiver (or from the hub if it is the first receiver in the line) and passes these on the next receiver in line.

Figure 3: *Sapphire DART* Receiver

RJ45 Connectors: There are two RJ45 connectors on the back of each receiver, one to connect to the previous receiver or hub in the line (labeled ***IN***) and one to connect to the subsequent receiver in the line (labeled ***OUT***). There are two green LEDs that are always on when the receiver is getting power and a yellow LED that flashes on when data is being read from the receiver (note the flashing may be too short to be noticed when data traffic is heavy). Each receiver takes approximately 25ma at 48VDC which is supplied by the power supply in the hub.

Figure 4: *Sapphire DART* Receiver (rear view)

Receiver power switch: Each receiver has a power switch used to control power to the receiver. The power switch is used when installing receivers to an existing receiver chain to ensure that power to the receiver is off when cable connection is made. Note that when multiple receivers are connected in a chain, a receiver's power switch will also control power to its "OUT" port and, hence, to receivers farther down the chain.

AC adapter connection: Each receiver has an auxiliary AC adapter connection that is used to supply additional power to the receiver when hub power is not adequate. This should only be necessary in cases requiring extremely long cable runs. Note: When a Sapphire DART Receiver is powered from an external 48VDC Power Supply it shall be a listed "Limited Power Source" power supply.

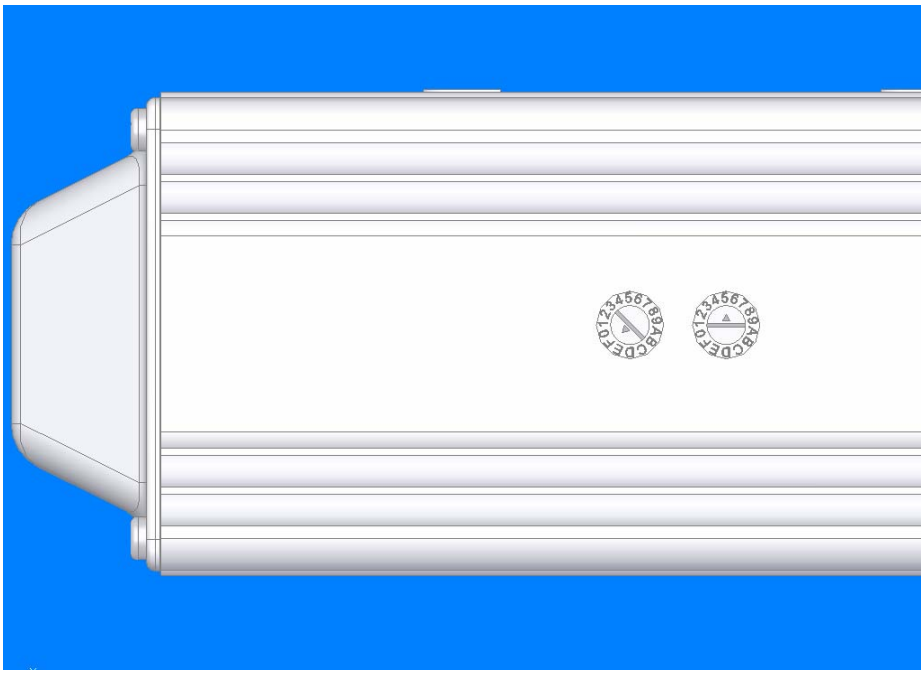


Figure 5: *Sapphire DART* Receiver Rotary Switches (RX ID = F5)

Rotary ID Switches: Each receiver has an unique ID (01 -FF) which is set using two rotary switches on the side of the receiver. Each rotary switch can be set to 0 – F using a small flat-head screwdriver. This unique ID will be used to identify the receiver in the *Sapphire DART* software configuration (see Section 6.3).

1.4 *Sapphire DART* Tags

The *Sapphire DART* Tags are UWB transmit only devices that communicate to the receivers wirelessly. *Sapphire DART* tags have a nominal center frequency of 6.35 GHz with a peak and average power compliant with FCC Part 15 regulations. Tags are powered with a 3V battery with a life expectancy proportional to the size of the battery. Two form factors are currently available for tags, the T651-1x1 (for mounting on assets) and the T651-BDG (for personnel tracking). Asset tags can be mounted to any object via two screws. The default tag update rate is one UWB transmission per second.

> **CAUTION:** *There is a risk of explosion if battery is replaced by incorrect type. Make sure to insert new batteries correctly, following the symbols for positioning the positive (+) and negative (-) ends of each battery. Use only batteries with the size and type specified in this manual. Please dispose of batteries according to the local laws and regulations of your region. If you are not able to identify the applicable rules in your area, please check the instructions of the battery manufacturer.*

Figure 6: *Sapphire DART* T651-1x1 UWB Tag

1.5 *Sapphire DART* Reference Tag

Every *Sapphire DART* system will require at least one reference tag. Any tag can be designated as a reference tag. Each reference tag must be placed in a permanent, stationary position such that at

least two receivers connected to a given hub have an unobstructed path to it. It is recommended that reference tags are carefully positioned to maximize the visibility of the reference tag to as many receivers as possible; this will minimize the number of reference tags required in the system. The reference tag is required in order to synchronize the counting functions inside the receivers.

2 Unpacking the *Sapphire DART* System

Follow these steps to unpack the *Sapphire DART system:*

Step 1	Open the shipping container and carefully remove the contents.
Step 2	Return all packing materials to the shipping container and save it.
Step 3	Ensure that all items listed in the "Package Contents" section are included in the shipment. Check each item for damage.

2.1 Package Contents

A typical *Sapphire DART* system is shipped with the following items:

- Processing Hub (H651-PC4-8HS) (Quantity 1)
- Power Cable (for H651-PC4-8HS) (Quantity 1)
- Receiver (R651-HS) with antenna (Quantity 4 or more)
- T651-1x1 (UWB Tag) (Quantity 11)
- User's Guide (Quantity 1)
- **Shielded** CAT 5E Cable (optional) (Quantity 4)

Note If any item is damaged or missing, notify your authorized MSSI sales representative.

2.2 Additional Equipment Required for Installation

The following equipment may be needed for installation:

- 10BaseT Ethernet Hub for Ethernet Network connectivity.
- Computer
- Tape measurement reel (for laying out an accurate X-Y grid)
- (Optional) Receiver Mounting Brackets and associated hardware for affixing Receivers to the wall or ceiling.
- (Optional) H651 Processing Hub Rack Mount Kit

3 Installing the *Sapphire DART* Hardware

The *Sapphire DART* system is a precision tracking system and requires a degree of precision in installation. Specifically, the receiver and reference tag locations are critical to insure optimum performance. The accuracy of these positions will directly influence the accuracy of the results.

3.1 Placing the H651 Processing Hub

The H651 Processing hub must be placed within 1000 feet of the first receiver in the receiver chain. The Hub must also be placed in a location where either LAN or computer connection is available.

3.2 Placing the Receivers

Identify the physical area desired to be covered; the system can be configured with a single receiver if tag detection (presence) only is required. A minimum of 3 receivers are needed to identify the x-y positions of one or more assets.

The ideal installation is a rectangular box with receivers in each of the four corners, installed as high as possible (near the ceiling) with the antenna of each receiver pointing towards the center of the box.

3.3 Placing the cables

Cable lengths, which limit the distance between the receivers, should not exceed 300 feet between each receiver. The cable can be laid in the open, or installed professionally; it is recommended that cable connections are tested with a cable tester prior to installing the system. Cable end breakage during installation is a common trouble-shooting problem. Cables must be shielded CAT 5E, 26AWG (or higher gauge) is recommended for best results.

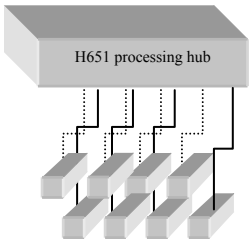
3.4 Positioning the Reference Tag

The reference tag must be positioned in the area to be monitored in a position that is easily seen by each of the receivers. The optimal location for the reference tag is in the center of the box formed

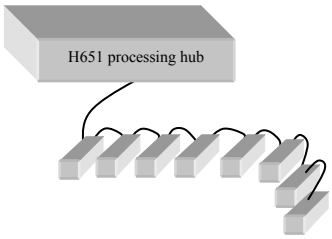
by the receivers. Each of the receivers must have a direct line of sight with the reference tag. The reference tag must be a position where it cannot easily be moved or obstructed during operation.

4 Connecting the Receiver Power/Data Cables

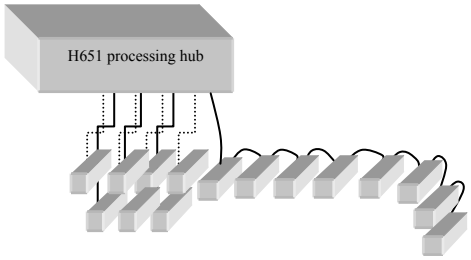
Receivers can be connected directly to a hub port connection or connected in a daisy chain to other receivers. Each receiver receives 48VDC from the previous receiver (or from the hub if it is the first receiver in the line) and passes the 48VDC on the next receiver in line via the CAT 5E cable. Section 4.1describes the star configuration with direct connections to the hub; Section 4.1 describes steps used to connect receivers in a daisy chain configuration and Section 4.3 describes the setup for receivers that are connected as a combination of the daisy chain and star configuration.



Star Configuration
H651 with 8 receivers directly connected to the hub



Daisy-chain Configuration
H651 with 8 receivers connected to one hub port connection



Combination Daisy-chain and Star Configuration
H651 with 8 receivers directly connected to the hub and a daisy chain of 7 receivers connected to receiver #8

4.1 Connecting Receivers Directly to the Hub (Star Configuration)

Follow these steps to connect the CAT5E power/data cables between the H651 processing hub and the receivers in a star configuration:

Step 1. Make sure the hub port connector switch on the front panel hub is in the OFF position prior to connecting cables to connector.

CAUTION: *Plugging a receiver into a powered ON receiver port on the processing hub may result in electrical damage to the hub and receiver. It is recommended that power to the receiver is turned OFF when swapping or connecting cables.*

Step 2. Plug the RJ-45 Ethernet connector of the first CAT 5E cable into one of the eight hub connector ports marked RECEIVER on the front of the processing hub.

Step 3. Repeat Step 2 (above) for all remaining receivers to connect to the hub.

NOTE: The H651 supports direct connection of 8 individual receivers (labeled 1 – 8). These connections are grouped in pairs (labeled as "A", "B", "C" and "D") on the front of the H651 hub. These pairs are grouped together for a data throughput. In order to maximize throughput, when all 8 hub ports are not required, it is recommended that only one of each receiver group pair is used.

4.2 Connecting Receivers to the Hub in a Daisy Chain Configuration

Follow these steps to connect the CAT5E power/data cables between the *Sapphire DART* processing hub and the receivers in a daisy chain:

Step 1. Make sure the hub port connector switch on the front panel hub is in the OFF position prior to connecting cables to connector.

CAUTION: *Plugging a receiver into a powered ON receiver port on the processing hub may result in electrical damage to the hub and receiver. It is recommended that power to the receiver is turned OFF when swapping or connecting cables.*

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Step 2. Plug the RJ-45 Ethernet connector of the first CAT 5E cable into one of the eight hub connector ports marked RECEIVER on the front of the processing hub.

Step 3. Connect the other end of the CAT 5E cable in to the RJ-45 connector marked "IN" of receiver #1.

Step 4. Connect a second CAT 5E cable to the RJ-45 connector marked "OUT" of receiver #1.

Step 5. Connect the remaining end of the second CAT 5E cable in to the RJ-45 connector marked "IN" of receiver #2.

Step 6. Connect a third CAT 5E cable to the RJ-45 connector marked "OUT" of receiver #2.

Step 7. Connect the remaining end of the third CAT 5E cable in to the RJ-45 connector marked "IN" of receiver #3.

Step 8. Connect the last (fourth) CAT 5E cable to the RJ-45 connector marked "OUT" of receiver #3.

Step 9. Connect the remaining end of the fourth CAT 5E cable in to the RJ-45 connector marked "IN" of receiver #4.

Step 10. Continue to connect additional receivers as required to the chain in series.

Step 11. Turn the hub port connector switches on the front of the processing hub to the ON position.

4.3 Connecting Receivers in Series and Parallel to the Hub (Combined Daisy chain and Star Configuration)

The H651 hub supports a combination of daisy chain and star receiver connections. This can be accomplished by using the appropriate steps from Sections 4.1 and 4.1, respectively.

5 Connecting the Processing Hub to the Computer

Configuring and retrieving data requires a computer connection to the processing hub. The connection from the computer to the hub can either be through a direct connection or through a LAN. The default IP settings for the hub are as follows:

IP address	192.168.1.202
Subnet mask	255.255.255.0
Default gateway address	192.168.1.1

5.1 Connecting the Processing Hub Directly to a Computer

If the 192.168.1 subnet is not accessible through your LAN then you must connect the hub directly to the computer. Follow these steps to connect the *Sapphire DART* processing hub directly to the computer:

Step 1. Plug the RJ-45 ***cross-over*** Ethernet cable into the **Ethernet** port on the **back** of the H651 processing hub.

Step 2. Connect the other end of the ***cross-over*** Ethernet cable to the computer.

Step 3. Plug the power cable in and turn the power on.

Step 4. Configure the IP address of the computer to be on the 192.168.1. subnet.

Section 6.1 will describe the steps for changing the IP address for the hub.

5.2 Connecting the Processing Hub to a PC through a LAN

If the 192.168.1 subnet is accessible through your LAN then you may connect the hub directly to your LAN using the following steps:

Step 1. Plug the RJ-45 Ethernet cable into the **Ethernet** port on the back of the H651-PC4-8HS processing hub.

Step 2. Connect the other end of the Ethernet cable to the LAN.

Step 3. Plug the power cable in and turn the power on.

Section 6.1 will describe the steps for changing the IP address for the hub.

6 Configuring the *Sapphire DART* for Location Tracking

Now that your computer is connected to the hub (see section 5); the *Sapphire DART* can be configured for tracking one or more reference tags. It is recommended that the user become familiar with single reference tag setup and then add additional reference tags as required.

This section describes the following setup steps for configuring a single reference system.

Step 1. Configure the hub network parameters

Step 2. Establish a user-defined coordinate system

Step 3. Configure receiver and reference tag positions

Step 4. Configure boundary parameters.

Step 5. Select computation options.

6.1 Configuring the Hub Network Parameters

Use the following steps to configure network parameters:

Step 1. Access the configuration menu by opening a web browser (e.g. Internet Explorer 6.0 or Netscape 7.1) to http://192.168.1.202. This address will load a web page to enable you to modify the IP address and *Sapphire DART* setup parameters.

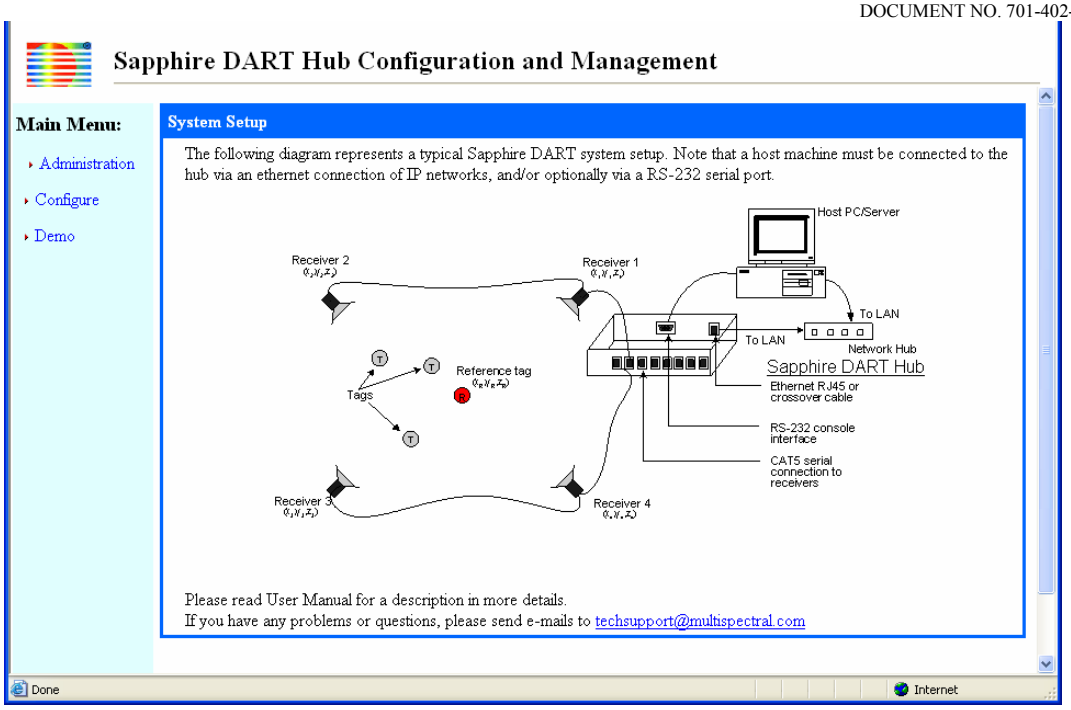

Figure 7: *Sapphire* Hub Configuration and Management Main Menu

Note: The hub configuration utility requires a JAVA™ Plug-in installed with the web browser. If JAVA has never been installed, the web page will prompt you to install the Java2 Runtime Environment (JRE version 1.4.2 or later). This JRE version can be found at the Sun Microsystems web-site (i.e., http://java.sun.com/j2se/1.4.2/download.html).

Step 2. From the **Hub Configuration and Management** main menu, select **Administration**; next select the **Network** tab within the **Administration** menu. (

Figure 8)

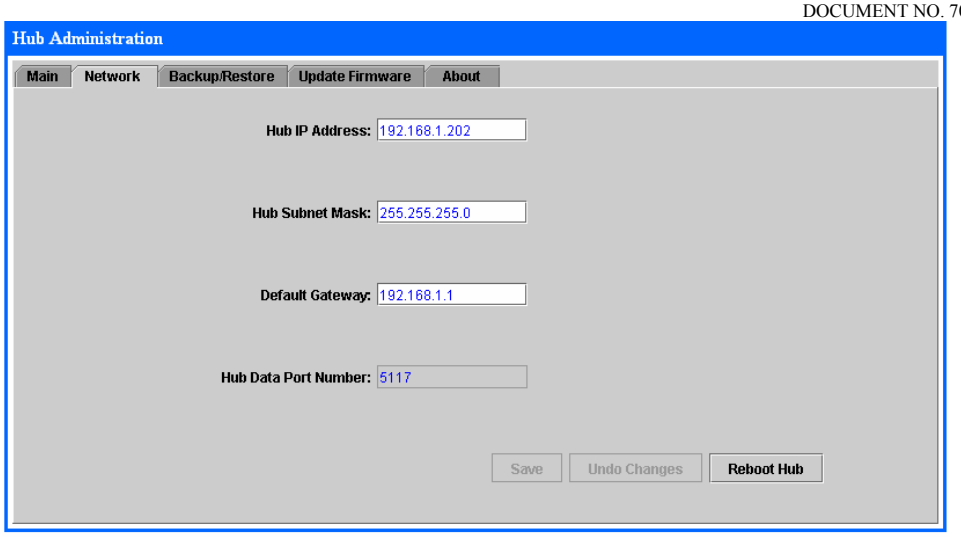

Figure 8: *Sapphire* Hub Configuration and Management Main Menu

Step 3. Modify the IP settings as needed. In order for the new IP settings to become active, you must click on **Save** to save settings and click on **Reboot Hub** to reboot the hub.

6.2 Establishing a User-defined Coordinate System

For tag localization, the positions of the receivers and reference tag must be established for the system to operate properly. The user must define an origin and measure the x, y, and z positions of each receiver and reference (in feet or meters) with respect to that origin.

Choose an origin (0, 0, 0) point, next measure the (x, y, z) coordinates of each receiver from the (0, 0, 0) point. Measurements should be made to the front of the antenna. Measure the (x, y, z) position of the reference tag from the (0, 0, 0) point.

6.3 Configuring Receiver Positions

Use the following steps to define the location of each active receiver within the system:

Step 1. Access the configuration menu by opening a web browser (e.g. Internet Explorer 6.0 or Netscape 7.1) to the IP address of the PAL650 hub.

Step 2. From the **Hub Configuration and Management** main menu, select **Configure**; next select the **Hub Setup** tab within the **Configure** menu. (See Figure 9.)

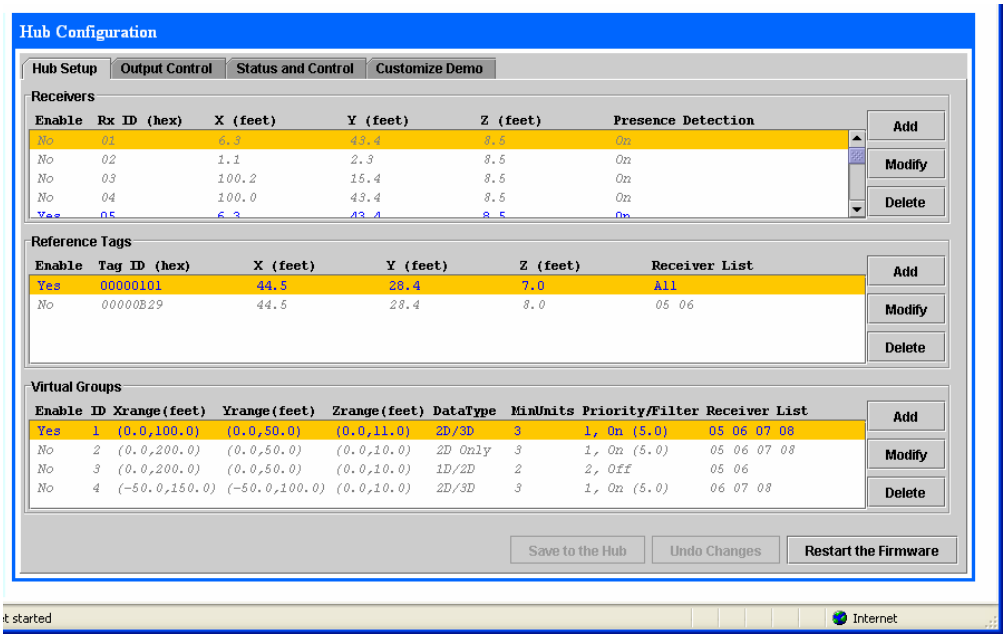

Figure 9: *Sapphire* Hub Setup Menu

Step 3. Enable and enter location data (x, y, and z) for each active receiver. To add a new receiver, select **Add** and enter data as shown in Figure 10. Setting the **Enable** flag activates this receiver for data collection. Setting the **Presence Detection** flag directs the software to output a string indicating that a tag is visible at the receiver when position information is not available.

Step 4. Once changes are entered, select **Accept**.

Step 5. Follow Steps 3 and 4 for all receivers that are connected to this hub.

Step 6. In order for the new receiver positions to become active, you must click **Save to the Hub** on the **Hub Setup** menu.

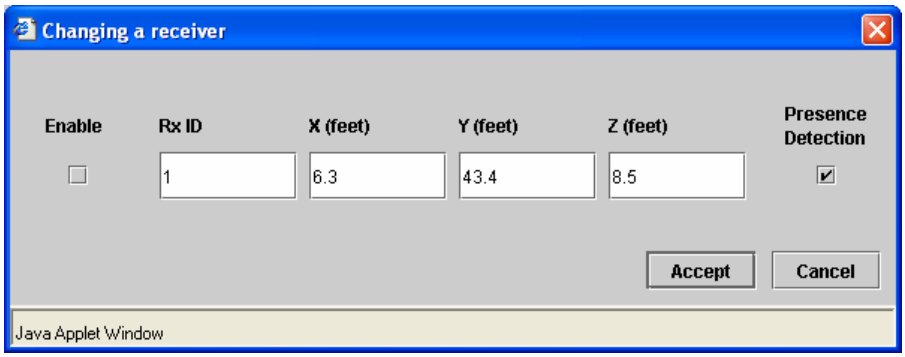

Figure 10: *Sapphire* Receiver Configuration Menu

6.4 Configuring Reference Tag Position

A *Sapphire DART* system requires the use of one or more reference tags. These are necessary in order to establish a common time base among the receivers. For a reference tag to be useful, it is necessary for it to be in a location that is unobstructed from at least two receivers. Preferably, a position is chosen such that many receivers have such an unobstructed path. Many reference tags may be used, but it is generally a good idea to use as few as necessary. However, it is necessary that each receiver must be associated with at least one reference tag, and that each reference tag has more than one receiver associated with it.

Use the following steps to define the location of the reference tag.

Step 1. From the **Hub Configuration and Management** main menu, select **Configure**; next select the **Hub Setup** tab within the **Configure** menu. (See Figure 9.)

Step 2. Enable and enter location data (x, y, and z) for each reference tag. To add a new reference tag or to modify the parameters of an existing reference tag, select **Add** or **Modify**, respectively, and enter data as shown in Figure 11. The following fields are required for each reference tag definition:

- **Enable** flag: Check box to enable; the Enable flag is used to indicate that a reference tag is active and should be used in calculations;
- **Reference Tag ID:** Tag ID number (shown on the factory label).
- **Receiver List:** Receiver ID number of each receiver that has direct line of sight to the reference tag. Receiver ID is found on the rotary switches on the left side of the R651 receiver (values range from 01 to FF).
- **All RX:** When set, all enabled receivers will be associated to this reference tag.
- **Tag Position:** Measured (x, y, z) position of the reference tag with respect to the origin (0, 0, 0) of the user-defined coordinate system.

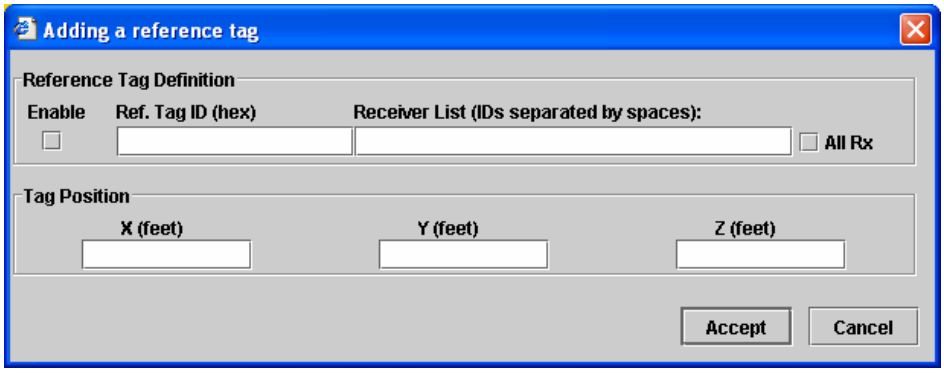

Figure 11: Menu for configuring a reference tag

Step 3. Once changes are entered, select **Accept**.

Step 4. Follow Steps 2 and 3 for all reference tags that are used by this hub.

Step 5. In order for all new reference tag configuration information to become active, you must click **Save to the Hub** on the **Hub Setup** menu.

6.5 Configuring Virtual Groups

In order to enhance the performance and accuracy of the *Sapphire DART* system, it is useful to form virtual groups among the receivers. In many cases, where unobstructed view of the entire coverage area is available to all receivers, all receivers will belong to a single virtual group. However, in cases where obstructions (walls, large machinery, etc.) make complete coverage undependable, installation of extra receivers will help, especially when properly configured into additional virtual groups.

Essentially, a virtual group is a pre-defined group of receivers for which position calculations will be done and reported. Any extra tag receptions from receivers outside that group will not influence the position determination from that group. Virtual groups can overlap, and a receiver can belong to several virtual groups. However, position calculations are only performed with data received from receivers within a common group. This keeps unreliable receptions, typically which have arrived as a result of reflected signals, from having a harmful influence on a position calculation.

Note that the establishment of virtual groups is unrelated to the association of receivers with reference tags.

Use the following steps to define the Virtual Groups.

Step 1. From the **Hub Configuration and Management** main menu, select **Configure**; next select the **Hub Setup** tab within the **Configure** menu. (See Figure 9)

Step 2. To add a new Virtual Group or to modify the parameters of an existing Virtual Group, select **Add** or **Modify**, respectively, and enter data as shown in Figure 12.

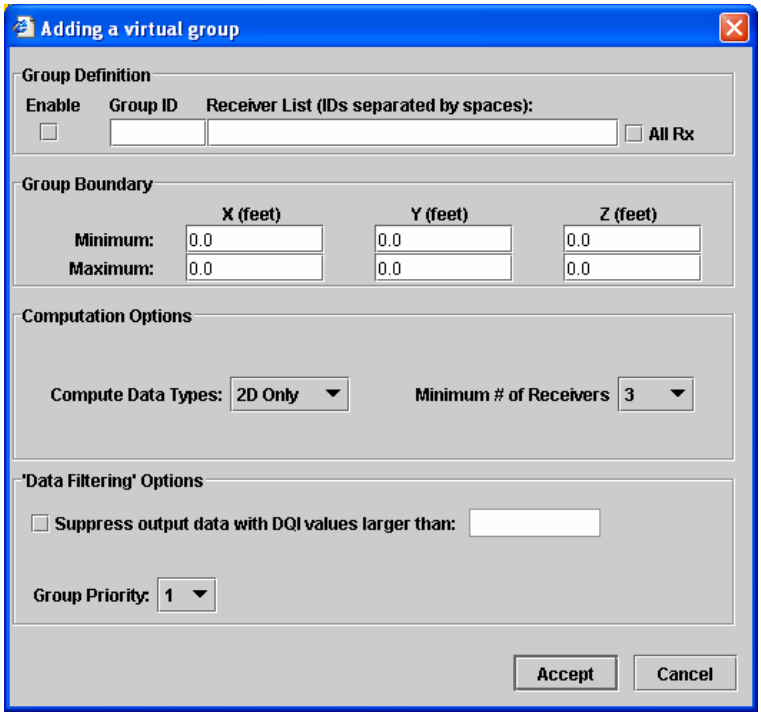

Figure 12: Menu for configuring a virtual group

The following fields are required for each virtual group definition:

- **Enable** flag: Check box to enable; the Enable flag is used to indicate that a virtual group is active and should be used to generate tag position output;
- **Group ID:** User assigned ID number to be associated with a particular receiver group.
- **Receiver List:** Receiver ID number of each receiver to be associated with the virtual group. Receiver ID is set using the rotary switches on the side of the R651 receiver (values range from 01 to FF).
- **All RX:** When set, all enabled receivers will be associated with this virtual group.
- **Group Boundary:** The Tag Location Boundary defines the area where the virtual group is defined. The *Sapphire DART* system will discard any tag data (as determined by this virtual group) outside of this space boundary. Minimum and maximum coordinate values must be specified for <x>, <y>, and <z>. Typically the minimum x value will be the smallest x-coordinate value set for the receiver positions and the maximum x will be the largest x-coordinate value set for the receiver positions.
- **Computation Options/Data Type:** Defines the types of computational data that is to be generated by the processing hub. Selections and descriptions are shown below:
    - 2D data only: 2-D calculations are carried out when 3 or more receivers detect the tag transmission;
    - 3D data only: 3-D calculations are to be performed whenever 4 or more receivers detect the tag transmission.

- 1D and 2D data: 2-D calculations are to be performed whenever 3 or more receivers detect the tag transmission, alternatively 1D position data is provided whenever 2 receivers detect the tag transmission ;
- 2D and 3D data: 3-D calculations are to be performed whenever 4 or more receivers detect the tag transmission, alternatively 2-D position data is provided whenever 3 receivers detect the tag transmission;
- 1D, 2D, and 3D data: 3-D calculations are to be performed whenever 4 or more receivers detect the tag transmission, 2-D position data is provided whenever 3 receivers detect the tag transmission; and 1D position data is provided whenever 2 receivers detect the tag transmission;

- **Computation Options/Minimum Number of Receivers:** Defines the minimum number of receivers that must detect a specific tag transmission for location computation. Sometimes accuracy can be enhanced by requiring more receivers within a given virtual group to have received a tag transmission before computing the tag position. This option allows the user to increase the minimum number of receivers required for computation. If Data type is set to 1D/2D/3D, 1D/2D, or 2D/3D then the minimum number of receivers is set by the hub software.

Data Type	Minimum # of Receivers
1D, 2D, and 3D data	2
1D and 2D data	2
2D and 3D data	3
2D data only	3 or more
3D data only	4 or more

- **Data Filtering Options:** Data filtering options are only applicable for successful data computations. A successful data computation is defined as a computed position based on tag event that satisfies the group boundary constraints and computation options described above. The Sapphire DART provides two types of data filtering; data suppression based on DQI and/or by virtual group priority.

  - **Data Filtering Options /Suppress output data using DQI:** Defines DQI values that are considered too high by the user. Larger DQI values generally indicate a larger data error, or poorer accuracy in the position measurement. In an ideal case where there are no measurement errors, the DQI value would be zero. Enabling this feature will cause position data with DQIs greater than the specified value to be suppressed from the data stream.

    Note: Filtering output based on DQI values is considered an advanced feature requiring experimentation; initial and possibly most installations should avoid using this feature.

  - **Data Filtering Options/Group Priority:** Defines the priority of this virtual group for arbitrating between tag data positions that are calculated by two or more virtual groups. In general, the group, or groups, with the highest

priority for a given successful data computation will generate output. The following examples illustrate this priority filtering:

Example 1: All groups set with equal priority. By setting all virtual groups to the same priority, all successful data computations will be output from all enabled virtual groups.
Example 2: Groups having unique priorities. By setting different priority values for each virtual group, the highest priority group (lowest numerical number) with a successful data computation will output position data.
Example 3: Groups having a mixture of equal and unique priorities.
Consider the following example:

Virtual Group	Priority	Successful Data Computation
1	1	No
2	2	Yes
3	2	Yes
4	3	Yes

In this example, virtual groups 2 and 3 have equal priority and are have higher priority than other groups having successful computations. In this case, the data output will be generated from virtual groups 2 and 3.

Note: Filtering output based virtual group priorities is considered an advanced feature requiring experimentation.

Step 3. Once changes are entered, select **Accept**.

Step 4. Follow Steps 2 and 3 for all virtual groups that are to be used by this hub.

Step 5. In order for virtual group information to become active, you must click **Save to the Hub** on the **Hub Setup** menu.

7 Configuring Output Control

The default data output stream provided from the processing hub to the client program is shown below:

<Data Header>, <tag #>, <X>, <Y>, <Z>, <battery>, <timestamp>, <unit><LF>

Details of each parameter in the data stream are found in Section 11. The data output from the hub can be modified to provide increased resolution in the timestamp field. The user can enable output of diagnostic messages (D-packets) from the hub. An additional data field may also be programmed to indicate the quality of data provided from the hub. The following sections describe the optional data outputs that are available from the hub:

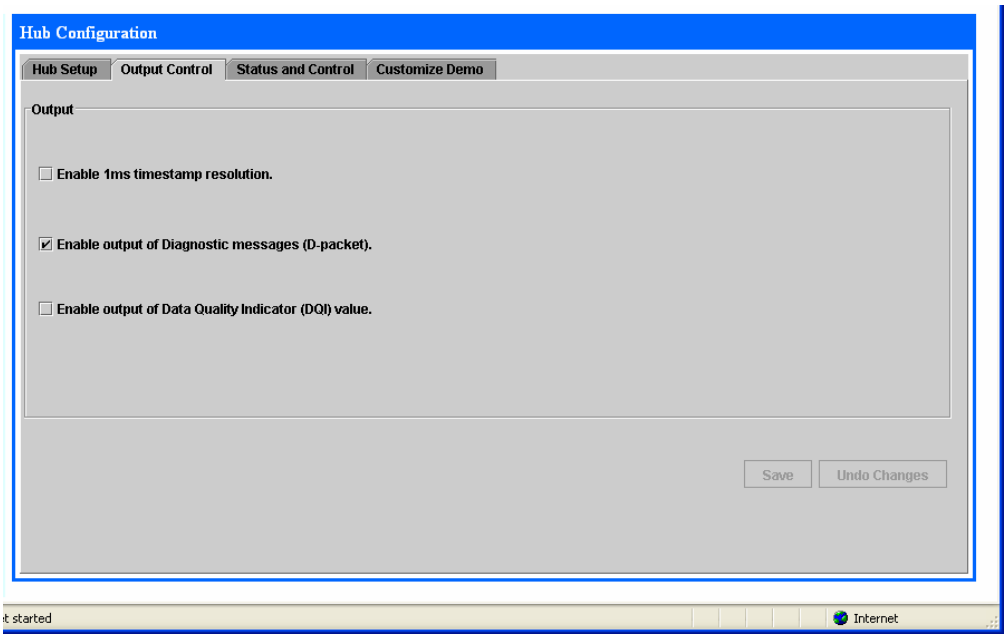

Figure 13: Output Control Menu

7.1 Adding Higher Resolution Timestamps

The default timestamp for the data stream is 1-second resolution. This time resolution can be modified to 1-millisecond by selecting the appropriate check-box option.

7.2 Enabling D-packets as Output

D-packets are optional diagnostic packets which are useful for diagnosing problems encountered during both installation and normal operation. When set to "on", these packets are sent as part of the data output stream.

During system initialization, D-packets are sent during the initialization period after firmware restart. For non-critical errors or events, the corresponding D-packet will be sent only once each time there is an event/error condition. For critical system errors, the corresponding D-packets will be continuously sent until the error condition has been cleared.

Data output format with D-packets is as follows:

D, <ID>, <X>, <Y>, <Z>, <battery>, <timestamp>, < DpacketID>, 'readable info' <LF>

7.3 Adding Data Quality Indicators

The DQI value provides a metric for quantifying the quality of the position data calculated by the hub. The DQI result is calculated through a minimization process of an error function. The DQI data is only meaningful for 2D or 3D data computations. When the DQI result is not meaningful (i.e., for "P" data, "O" data) this field will contain an asterisk.

Data output format with DQIs:

<Data Header>, <tag #>, <X>, <Y>, <Z>, <battery>, <timestamp>, <unit>, <DQI><LF>

Note: If DQI is not available this field contains an asterisk "".*

8 Viewing Status and Control

The Status and Control menu provides the current status of the system, and a simple way to verify proper operation of reference tags and receivers. The Status and Control menu lists the IDs of receivers which are detected or enabled in the system. It also displays the active tag IDs currently detected by the system, the status of reference tags, and message reports from active receivers. The status information is updated each time the **Refresh** button is clicked.

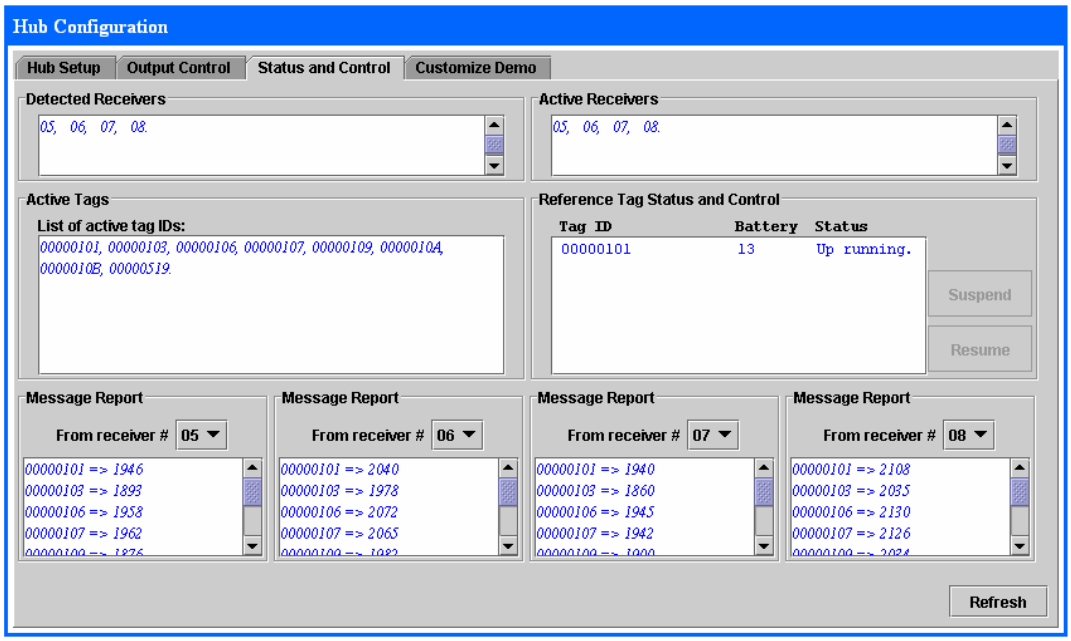

Figure 14: Status and Control Menu

8.1 Detected Receivers

Each number (in hex), separated by commas, represents a receiver ID detected by the system. The list allows user to know which receivers are currently connected and communicating to the hub.

A receiver that is connected, but does not appear in the list, may indicate lack of power to the receiver or failure of the communication cables between the hub and receiver.

8.2 Active Receivers

Each number (in hex) and separated by commas represents an active receiver ID. The list allows user to know which receivers are currently enabled to report tag data back to the processing hub. A receiver becomes active only if the receiver is detected and also enabled in the software configuration. (See section 6.3).

8.3 Active Tags

This active tag list shows the tags which are currently detected by any receiver in the system. An active tag will drop out of the tag list if the tag transmission has not been detected by any receiver for 5 seconds.

8.4 Reference Tag Status and Control

The reference tag status displays current status information for the reference tag(s). It includes the battery power level and operation state. You may temporarily suspend the operation of a selected reference tag, by first selecting the tag and then clicking the **Suspend** button. When a reference tag is suspended it may be removed or moved (e.g., for a battery change). To begin getting reference tag updates, click the **Resume** button once after the reference tag is returned to the original position.

8.5 Message Report

Four message report windows are available to display the counts of tag messages received by four selected receivers. The list will display data from any active receiver using the pull-down menu for receiver ID list. In the message report, each line starts with a tag ID (e.g. 00000001), followed by a decimal number. The decimal number represents a count of the tag transmissions detected by the receiver since the last display update (**Refresh**). Message reports are updated each time the **Refresh** button is selected. The message report provides an inside view to the operation status of individual receivers and the associated tags. This information can be very useful for initial system setup, and for debugging an existing system setup. For example, if the message report shows no tag transmission reports from a particular receiver, it may indicate that there is a complete blockage of UWB signal from the tags to that receiver.

9 Hub Administration

This section describes the following administrative features provided with the Model H651 processing hub:

- Access protection
- System shutdown
- Backup/Restore
- Software updates

9.1 Setting Access Protection to the Hub

The user has the ability to limit access to the *Sapphire DART* **Administration** and **Configure** menus by setting password protection. Figure 15 shows the **Main** page tab within the **Administration** menu; selecting the "**Change Access Level**" setting will prompt the user to set access control to one of the following (see Figure 16):

- No access restrictions: The setting allows all users to view and modify all hub processor functions.
- Restricted access to the Administration functions: The setting requires users to enter a password to modify or view the **Administration** functions of the hub processor. The **Configure** and **Demo** functions are available without use of a password.
- Restricted access to the Administration and Configure functions: The setting requires users to enter a password to modify or view the **Administration** and **Configure** functions of the hub processor. The **Demo** functions are available without use of a password.

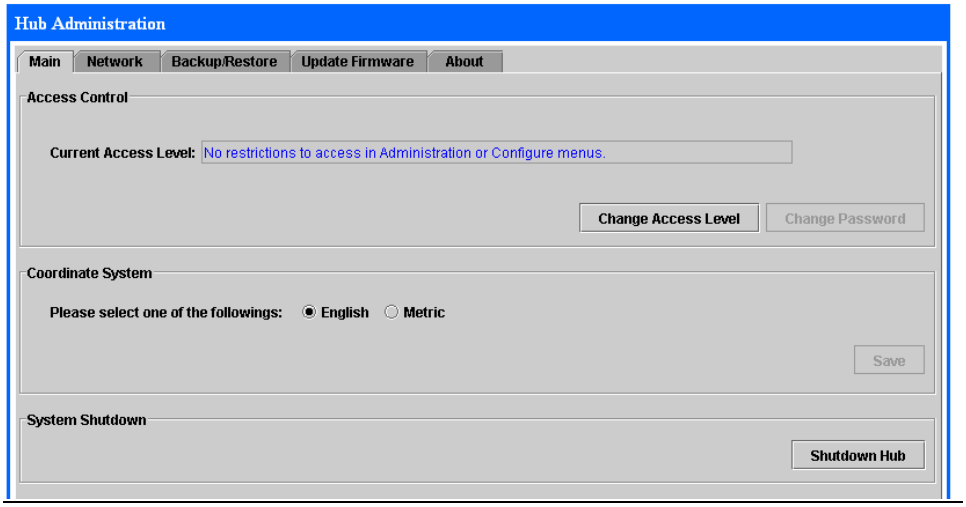

Figure 15: Administration menu for access protection and system shutdown

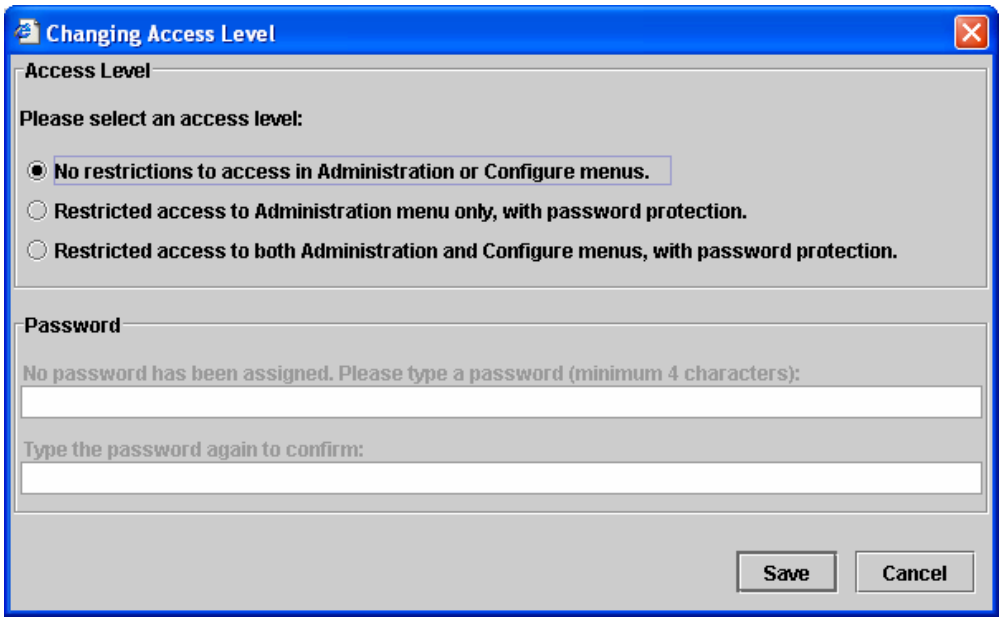

Figure 16: Access control menu

9.2 Shutting Down the Hub Processor

It is recommended that the hub processing software is shutdown prior to turning off power to the processing hub. This is done by using the **Shutdown Hub** feature found on the **Main** page tab within the **Administration** menu.

Once the Shutdown has started, a pop-up menu will indicate progress. It is necessary to wait until the shutdown process is complete (see Figure 17) prior to switching the power off to the hub.

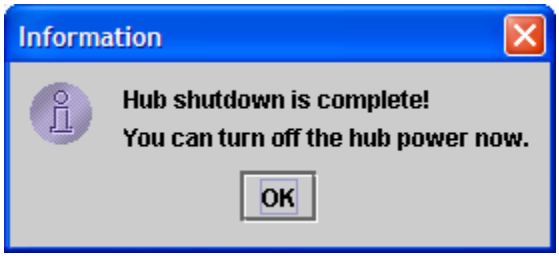

Figure 17: Hub Shutdown Complete Message

9.3 Backing Up and Restoring Hub Configuration Data

This feature is provided to allow data backup of current hub configuration settings. This will preserve all configuration settings including receiver and reference tag locations, virtual group settings, and user maps. The backup/restore feature is useful for preserving data, for moving configuration settings from one hub to another, and for backing up data on the hub while experimenting with additional settings.

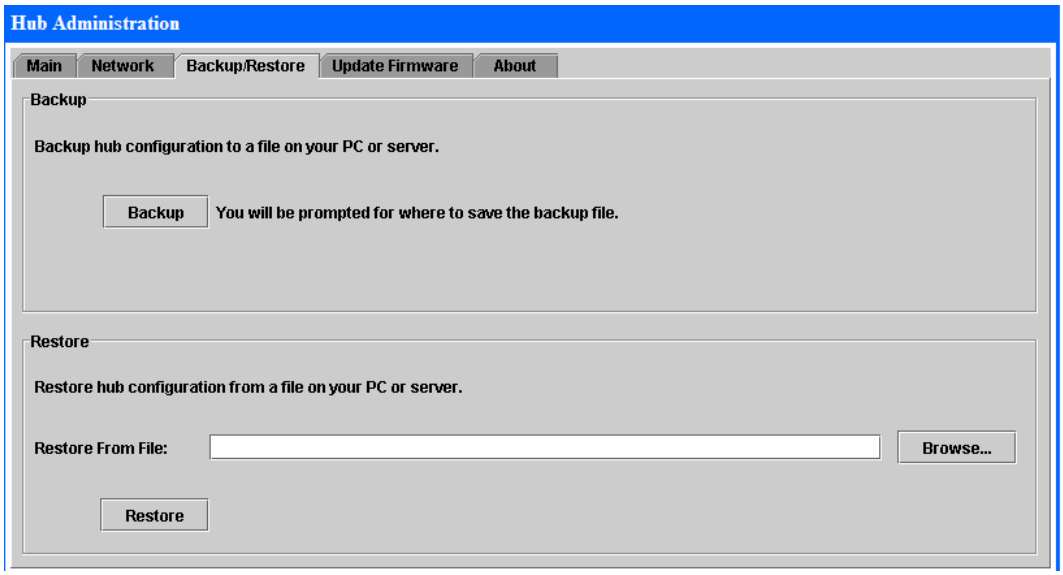

Figure 18: Backup/Restore menu

9.4 Updating the Hub Firmware Revision

This feature is provided to allow upgrades of newer versions of the hub software. Follow these steps to upgrade the *Sapphire DART* firmware:

Step 1. Make sure the firmware is accessible to the client machine (either through CD, hard drive or on a local network).

CAUTION: *Updating firmware is a non-reversible step; use care to ensure that the proper firmware is being upgraded to the hub.*

Step 2. Select the **Update Firmware** tab within **Hub Administration**.

Step 3. Select the check box shown in Figure 19 **t**o preserve current hub configuration settings (recommended). This will preserve all configuration settings including receiver and reference tag locations, virtual group settings, user maps, etc.

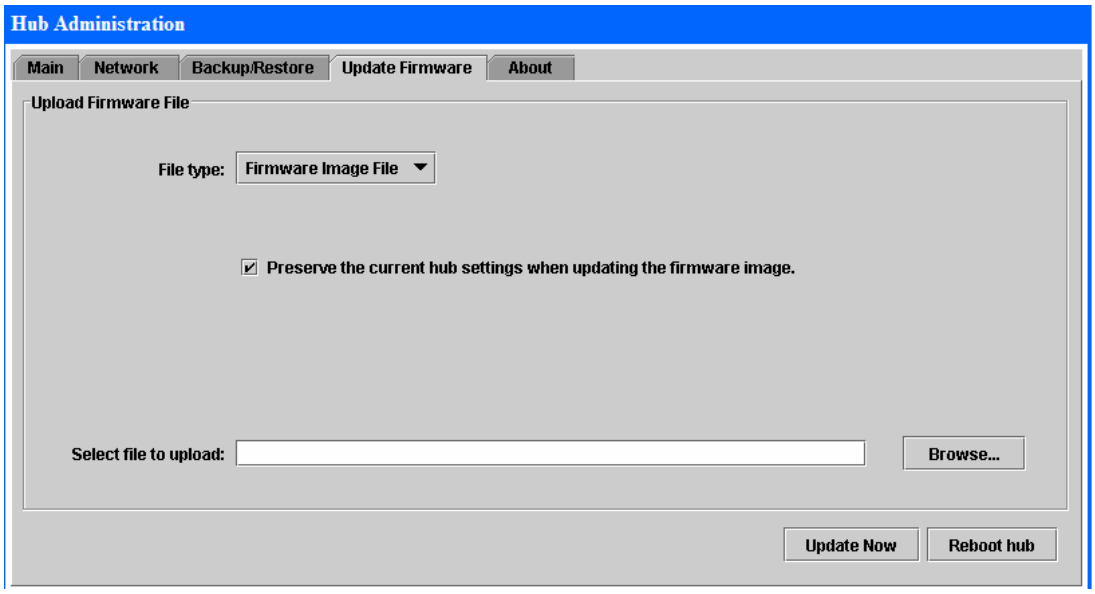

Figure 19: Update Firmware Menu

Step 4. Browse and select the file to be uploaded.

Step 5. Once the file has been selected, click **Update Now**.

Step 6. Select **Reboot hub** to restart the software with the uploaded firmware.

Step 7. Close and re-open the Explorer window to begin using the new firmware.

10 Demo Software

A simple JAVA™ client applet is provided as a reference for initial system check-out and results display. It is expected that most users will find it necessary to obtain client software that is tailored to a more specific application. This reference software provides a user-defined two-dimensional results display for displaying location of tags and receivers.

This user-definable reference demo can be controlled using the following features:

- Editing the real-time demo graphics
- Viewing and filtering the raw data stream from the hub
- Changing the display background
- Adding user graphics to the display background

10.1 Editing the real-time demo graphics

The **GUI** tab shown in Figure 20 of the **Demo** menu provides the user the ability to modify the graphics displayed on the two-dimensional results display using the following:

- Location Averaging Weight: (range of 0.1 – 1) Used to reduce jitter in tag locations; the lower the averaging weight, the higher the averaging. To turn averaging off, set the averaging weight to 1. For smallest amounts of jitter to be visible on the display, an averaging weight of 0.1 to 0.3 is recommended.
- Data Type Filter: Allows optional display of 3D, 2D and/or 1D data. Data type must be checked to be displayed. Note that "P" data is not available for display on this results display grid.
- Display Options: Allows customizing of background grid spacing, display of receivers, reference tag, corner coordinates, and tag IDs.
- Zoom In/Out: This setting allows zoom in/out of a particular area of the display grid.

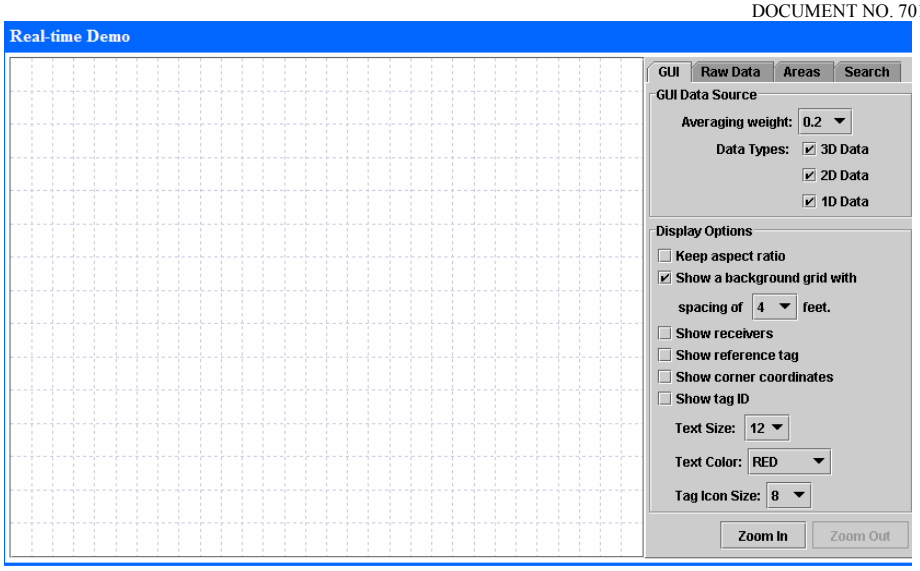

Figure 20: GUI editing tab (shown on left)

10.2 Viewing and filtering the raw data stream from the hub

The **RAW DATA** tab shown in Figure 21of the **Demo** menu provides the user the ability to view, record, and filter the raw data stream of location data from the hub. The following selections available for viewing and filtering the raw data stream:

- Filtering by Data Type: The user has the option to filter data types selections are All data, 3D, 2D, 1D, P data or 1Dand 2D data
- Filtering by Tag ID: Provides the option to filter tag data by a single ID number. User can select a tag ID from the pull down menu.
- Recording Raw Data: This feature enables the user to record the data stream to a text file. When recording is selected, the user will be prompted to enter a file name for the logging data; the **Record Data** LED will flash while data is being recorded. Recording is ended using the **STOP** command.
- Suspending/Resuming Raw Data Streaming: Stops/starts output flow of hub data to this display and/or recording.

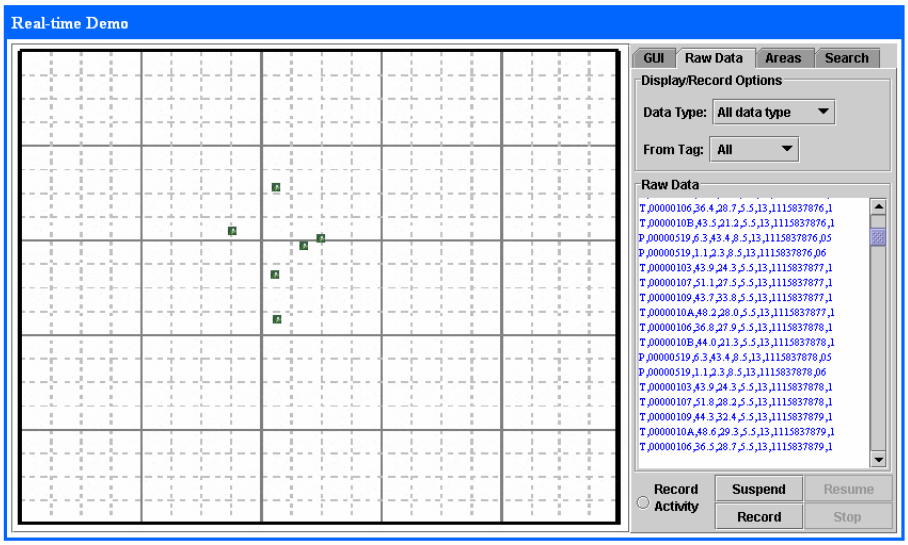

Figure 21: Real-time Demo GUI Display

10.3 Changing the display background

The **Area** tab shown in Figure 22of the **Demo** menu provides the user the ability to change the background of the 2-D grid used for graphical results display. Section 10.4 describes how the user can input their own graphics area for display.

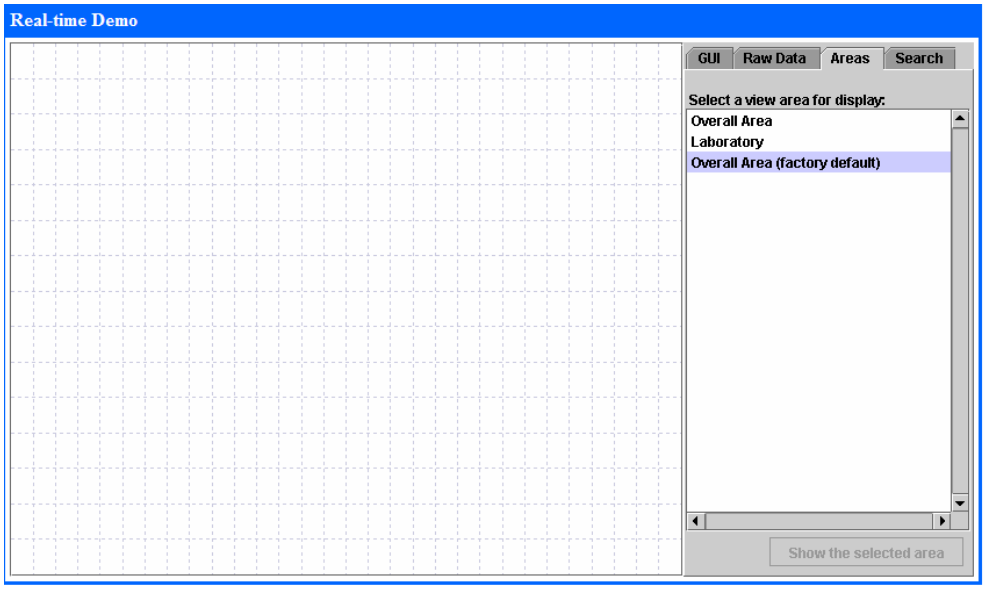

Figure 22: Real-time Demo (Area Selection)

10.4 Adding user-defined graphics to the hub

A *Sapphire DART* Demo pages can be modified to allow user-defined backgrounds. Background files must be in the form of a .jpg or .gif and accessible to the client.

Use the following steps to add customized graphics to the hub:

Step 1. From the **Hub Configuration and Management** main menu, select **Configure**; next select the **Customize Demo** tab within the **Configure** menu. (Figure 23).

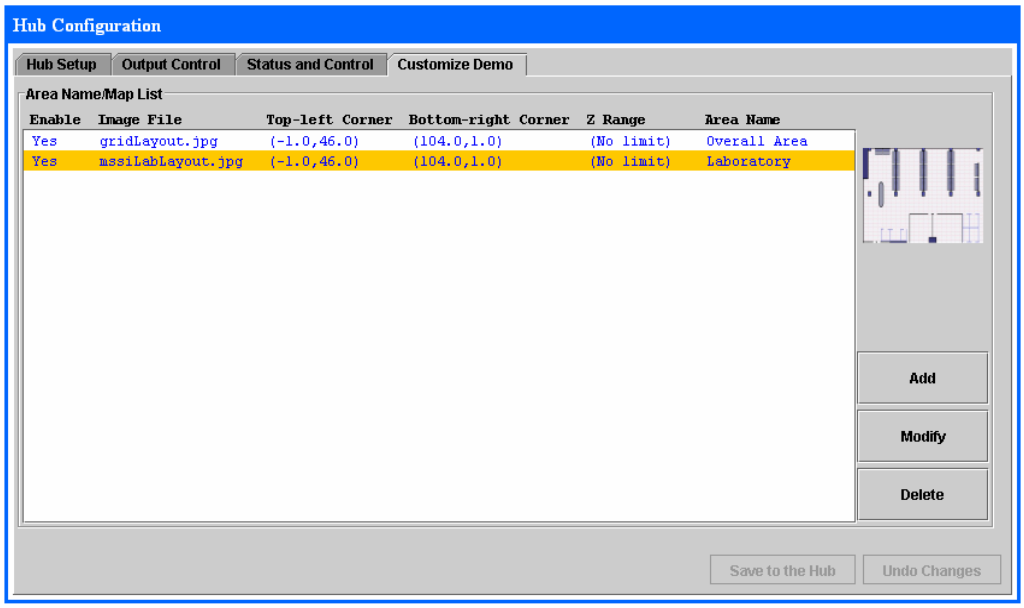

Figure 23: Customize Demo Configuration Page

Step 2. To add a user map or to modify an existing map, select **Add** or **Modify**, respectively, and enter data as shown in Figure 24. The following fields are required for each user-defined image:

- **Enable** flag: Check box to enable; the Enable flag is used to indicate that area name and map are available for use.
- **Area Name:** User defined area name (used for storing this image to the hub).
- **Map File:** Allows user to browse and show location of map to be stored on hub.
- **X, Y:** Defines X and Y coordinates for corners of the map.

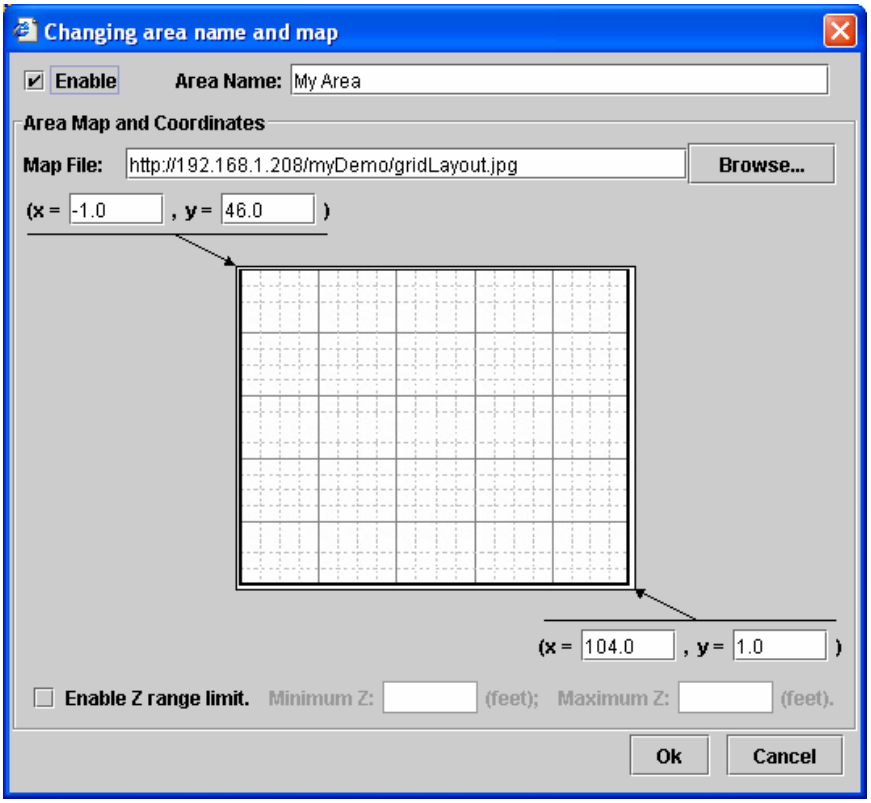

Figure 24: Adding New Maps to the Demo GUI

Step 3. Once changes are entered, select **OK**.

Step 4. Follow Steps 2 and 3 for all user maps that are to be used by the hub.

Step 5. In order for user-defined maps to be available, you must click **Save to the Hub** on the **Customize Demo** menu.

11 System Output

A client program using stream communication protocol is required to retrieve data from the hub. Any client program connecting to the hub must use port id 5117. All data and error messages will be sent over the LAN interface as ASCII strings. Tag location data may be identified by the 'R,', 'T,', 'O,' or 'P,' sequence in the first 2 characters.

Tag location output format is as follows:

<Data Header>, <tag #>, <X>, <Y>, <Z>, <battery>, <timestamp>, <unit><LF>

<Data Header> represents the tag dimensional information. Expected values for <Data Header> are as follows:

R: 3-D calculation valid for X, Y, and Z. 3-D calculations require 4 or more non-coplanar receivers to detect an event and for software computations to complete successfully.

T: 2-D calculation valid for X and Y. 2-D calculations occur when 3 receivers respond and the software is able to compute the X and Y locations. (Z value is estimated to be the average heights of associated receivers)

O: 2-D estimated calculation for X and Y. This can occur in the event of only 2 receivers responding such that software estimates the tag position to be at an intermediate point along the line connecting the receivers.

P: Presence indicator. It indicates that a tag was detected by a receiver. Presence indicator data may be sent only when the "Presence Detection" flag is set for the receiver, and when less than "Min_unit" number of receivers are heard (i.e. not enough information to calculate position), or 1-,2-, or 3-D calculations are unsuccessful.

D: Diagnostic packet (D-packet). D packets are optional error and/or warning messages that are useful both during initial installation and for continuous monitoring of the *Sapphire* system. For a complete description of D-packets, see APPENDIX III.

<tag#> is the tag ID.

<X>, <Y>, <Z>, except for "P" type data, are the calculated tag coordinates in feet or meters with respect to a user supplied origin, for "R", "T", "O" type of data. In the case of "P" type of data, <X>, <Y>, <Z> represents the coordinates of the receiver which detects this tag message transmission.

<battery> is the tag's low battery indicator. The value is a number between 0 and 15, where 15 represents a fully charged battery.

<timestamp> represents the hub system time. The format for timestamp is UTC time, day, and year the data was computed. The value represents the number of elapsed seconds since January 1, 1970. There are two different output formats: one is in an integer format with 1-second resolution (default setting). The second output format is in decimal format with a higher resolution (i.e.

1/1000th second). Output format is selectable through a checkbox of "Enable 1ms timestamp resolution" in the **Output Control** page (see section 7.1).

<unit>, except for "P" type data, is a Virtual Group ID (in decimal). The tag location data is computed from the time of flight measurements of the receivers within the virtual group. In the case of "P" type data <unit> is the ID of the receiver that detected the transmission.

<LF> is a Line Feed character (with ASCII code = 0x0A), to terminate a location data string.

If the checkbox for "***Enable output of Data Quality Indicator (DQI) value***" is checked or enabled in the Output Control page (see section 7), the output data will also appear in the following format with an additional field <DQI>:

<Data Header>, <tag #>, <X>, <Y>, <Z>, <battery>, <timestamp>, <unit>, <DQI> <LF>

Where <DQI> is the Data Quality Indicator value for the location data. In the case of "P" data, "O" data,

The following is an example of system output from a *Sapphire* hub.

```
T,00000107,40.2,29.7,5.5,13,1113406967,1
O,00000001,3.3,19.6,8.5,12,1113406967,1
P,00000009,6.3,43.4,8.5,13,1113406967,05
R,00000106,35.9,28.9,7.6,13,1113406967,1
P,00000007,1.1,2.3,8.5,13,1113406968,06
R,0000010B,44.8,19.5,8.2,13,1113406968,1
T,00000005,13.5,15.5,5.5,13,1113406968,1
T,00000002,13.8,18.9,5.5,13,1113406968,1
O,0000000C,3.3,20.1,8.5,13,1113406968,1
O,00000006,3.3,20.1,8.5,13,1113406968,1
O,00000004,3.3,19.6,8.5,13,1113406968,1
O,0000000B,3.2,18.6,8.5,13,1113406968,1
P,00000103,1.1,2.3,8.5,13,1113406968,06
P,00000109,99.8,43.4,8.5,13,1113406968,08
O,0000000A,3.3,19.6,8.5,10,1113406968,1
T,00000003,14.1,18.3,5.5,13,1113406968,1
T,00000499,30.4,42.8,5.5,12,1113406968,1
R,0000010A,48.7,26.9,8.3,12,1113406968,1
R,00000107,52.4,28.0,8.3,13,1113406969,1
O,00000009,3.3,19.6,8.5,13,1113406969,1
O,00000001,3.3,20.1,8.5,12,1113406969,1
P,00000106,6.3,43.4,8.5,13,1113406969,05
P,00000106,1.1,2.3,8.5,13,1113406969,06
P,00000106,100.2,15.4,8.5,13,1113406969,07
P,00000106,99.8,43.4,8.5,13,1113406969,08
O,00000007,3.4,20.5,8.5,13,1113406969,1
T,00000002,13.8,18.9,5.5,13,1113406969,1
O,0000000C,3.3,19.6,8.5,13,1113406969,1
R,0000010B,44.5,21.6,8.2,13,1113406969,1
```

12 APPENDIX I: Safety and Regulatory Information

This section contains required safety information that is not included elsewhere in the manual.

1. Warning Definition

Warning denotes a hazard. It calls attention to procedure(s) which, if not correctly performed or adhered to, could result in injury or loss of life. Do not proceed beyond a warning note until the indicated conditions are fully understood and met.

Warnings applicable to this instrument are:

Warning	No operator serviceable parts inside. Refer servicing to qualified personnel. To prevent electrical shock, do not remove covers.
Warning	For continued protection against fire hazard, replace line fuse only with same type rating (2.5A, 250V). The use of other fuses or materials is prohibited.

2. Caution Definition

Caution denotes a hazard. It calls attention to a procedure that, if not correctly performed or adhered to, would result in damage or destruction to the instrument. Do not proceed beyond a caution sign until the indicated conditions are fully understood and met.

Cautions applicable to this instrument are:

Caution	Always use the three-prong AC power cord supplied with this instrument. Failure to ensure adequate earth grounding by not using this cord may cause product damage.
Caution	Plugging a receiver into a powered ON receiver port on the *Sapphire DART* hub may result in electrical damage to the hub and receiver. Always turn power to the receiver OFF when swapping or connecting cables.

3. Regulatory Information

Certifications for the Sapphire DART system are as follows:

Intended Emissions:	**FCC ID: QCJPAL650, QCJPALBDG** This device complies with Part 15 of FCC rules. Operation is subject to the following two conditions: This device may not cause harmful interference; This device must accept any interference received, including interference that may cause undesired operation; and this device is for indoor use only.
	FCC ID: QCJPAL6511X1 This device complies with Part 15 of FCC rules. Operation is subject to the following two conditions: This device may not cause harmful interference; and This device must accept any interference received, including interference that may cause undesired operations.

13 APPENDIX II: Release Notes

The following is the release history for the hub firmware versions:

The current release is version 3.4. The change history between different versions is summarized below.

Version 3.4: (October 2005)

1) Added support for D-packet output.
2) Improved connection speed problems and fixed 'ghost' imaging problems seen when running newer versions (1.5.0) of Java Run-time Engine.
3) Changed Data Quality Indicator (DQI) filtering support from a global filter to virtual group level. Added additional configuration parameters to each virtual group: priority number, output filtering based on threshold. Removed the DQI filtering at global level.
4) Added DQI output (instead of "*") in the case of T data with 3 receivers, or R data with 4 receivers. DQI values are now normalized with number of receivers used in the computation.
5) Added an English/Metric selection option. User can select either "feet" or "meter" units for the position data.
6) Fixed a problem related to space(s) in user map file names. A space in the image file names will be automatically replaced with an underscore ('_') character, when the configuration is saved into hub.
7) In the Demo GUI under the "Raw Data" tab, added two additional filtering options, "3D/2D/1D Data only" and "Diagnostic Data only".
8) Fixed a partial message output problem caused by slow processing of data clients. When a data client is too slow to read out the incoming data from the TCP/IP socket, a buffer overflow could occur at the transmit side of the socket, resulting in a partial message being transferred to the data client. A work-around has been implemented in this version to prevent partial messages in the output stream.
9) Fixed an intermittent issue which may cause the firmware to crash or hang when a data client connection is shut down or when the user switches from the configuration connection (e.g. Administration and Configure menus) to a data connection (e.g. Demo menu).
10) Fixed a bug which occasionally would stop the data output from all clients when one of data clients no longer was accepting incoming data from the hub. For example, if a laptop, which was connected to hub data port, entered "sleep" or "standby" mode, the laptop would stop processing the data from the hub connection, and consequently block the hub from sending data to other connected clients. This version fixes this side-effect, so that a slow or hang client would not impact the hub service to other clients.

Version 3.02, July 2005

(1) Fixed a bug related to multiple Virtual Group (VG) computations on the same tag transmission. When one (and only one) VG computation was successful but it was not the last VG in the computations, the optimization process was incorrectly determined as unsuccessful. As a result, P-type data, instead of position data (R, T, O type), would be outputted. In this version, position data will be reported.

Version 3.01, April, 2005
Initial release.

14 APPENDIX III: D-Packets

This section contains description for all D-packets that may be output by the *Sapphire DART* Ultra Wideband *Precision Asset Location System*™.

D-packets are sent to the output stream only when enabled in the OUTPUT CONTROL CONFIGURATION Menu. These messages are either error or warning messages that are useful both during initial installation and for continuous monitoring of the *Sapphire* system. For critical system errors, the corresponding D-packets will be continuously sent until the error condition has been cleared. For non-critical error or events, the corresponding D-packets will be sent only once each time there is an event/error condition.

The basic D packet basic format is as follows:

D, <ID>, <X>, <Y>, <Z>, <battery>, <timestamp>, < DpacketID>, 'event text string' <LF>

D-packets will be sent during firmware initialization after a firmware restart and during normal operation. During normal operation, D-packet outputs are event driven, and sent each time there is a state change in the status of either a reference tag or receiver. Errors sent during initialization will typically indicate either hardware or software setup errors.

The following D-packets are possible during initialization/installation:

1. **No receiver enabled**

   Description: Configuration setup is missing; no receivers have been defined in the hub.
   Recommended action: The user needs to enable one or more receivers using the HUB CONFIGURATION menu.
   Message Type: This error packet will be sent continuously until the error condition is cleared.
   Message Format:

   D, 0, 0, 0, 0, 0, timestamp, DpacketID, 'Error: no receiver enabled'

2. **No reference tag enabled**

   Description: Configuration setup is missing; no reference tags have been defined in the hub.
   Recommended action: User needs to enable one or more reference tags using the HUB CONFIGURATION menu.
   Message Type: This error packet will be sent continuously until the error condition is cleared.
   Message Format:

   D, 0, 0, 0, 0, 0, timestamp, DpacketID, 'Error: no reference tag enabled'

3. **No virtual group enabled**

   Description: Configuration setup is missing; no virtual groups have been enabled in the hub.
   Recommended action: User needs to enable one or more virtual groups using the HUB CONFIGURATION menu.
   Message Type: This error packet will be sent continuously until the error condition is cleared.

Message Format:

D, 0, 0, 0, 0, 0, timestamp, DpacketID, 'Error: no virtual group enabled'

4. No receiver detected

Description: No receivers have been detected by the hub.
Recommended action: User should verify connections and power from the hub to the receiver(s).
Message Type: This error packet will be sent continuously until the error condition is cleared.
Message Format:

D, 0, 0, 0, 0, 0, timestamp, DpacketID, 'Error: no receiver detected'

5. No receiver activated

Description: A receiver or receivers have been detected, but none are enabled to send messages to the hub.
Recommended action: A receiver may be detected, but not enabled. User must activate the receiver through the HUB CONFIGURATION menu.
Message Type: This error packet will be sent continuously until the error condition is cleared.
Message Format:

D, 0, 0, 0, 0, 0, timestamp, DpacketID, 'Error: no receiver activated'

6. Enabled receiver detected/not detected

a. **Enabled receiver not detected**

Description: An individual receiver with receiver ID <rxID>, which is configured and enabled at location (x, y, z), has not been detected or has never communicated with the hub since firmware restart.
Recommended action: User should verify connections and power from the hub to the receiver(s).
Message Type: The warning packet will be sent only once after the hub firmware restart.
Message Format:

D, rxID, x, y, z, 0, timestamp, DpacketID, 'Warning: Enabled receiver not detected'

b. **Enabled receiver detected**

Description: A receiver with a receiver ID <rxID>, which is configured and enabled at location (x,y,z), has been detected for the first time since a hub firmware restart.
Recommended action: None.
Message Type: This D packet will be sent once for each active receiver after a hub firmware restart.
Message Format:

D, rxID, x, y, z, 0, timestamp, DpacketID, 'Enabled receiver detected'

7. Unknown receiver detected

Description: A receiver with receiver ID <rxID>, which is not enabled and/or configured in the HUB CONFIGURATION menu, has been detected after the hub firmware restart.
Recommended action: Verify that all expected receivers configured in the HUB CONFIGURATION menu are detected in the STATUS and CONTROL menu. It is possible that the user will either need to activate the unknown receiver through the HUB

CONFIGURATION menu or change the rotary settings for the RX ID to the expected hexadecimal value.
Message Type: This warning packet will be sent only once upon the detection after a hub firmware restart.
Message Format:
D, 0, 0, 0, 0, 0, timestamp, DpacketID, ''Warning: unknown receiver detected'

8. Receiver "00" detected

Description: Receiver 00 (which is an invalid RX ID) is communicating with the hub.
Recommended action: Verify that all expected receivers configured in the HUB CONFIGURATION menu are detected in the STATUS and CONTROL menu. User will need to determine which receiver is set to '00' and change the rotary settings for the RX ID to a valid hexadecimal value.
Message Type: This error packet will be sent only once upon the detection after a hub firmware restart.
Message Format:
D, 0, 0, 0, 0, 0, timestamp, DpacketID, '' Warning: Receiver 00 detected'

9. Virtual group has no valid reference

Description: A virtual group with group ID <groupID> has no valid reference between all receivers within the virtual group.
Recommended action: Verify that all expected receivers configured in the virtual group <groupID> are within range of the reference tags associated with that group.
Message Type: The error packet is sent continuously until resolved.
Message Format:
D, groupID, 0, 0, 0, 0, timestamp, DpacketID, 'Error: no valid reference'

10. Receiver has never seen a valid reference tag / has detected a reference tag

a. **Receiver has never seen a valid reference tag**

Description: An active receiver with receiver ID <rxID>, which is configured at location (x, y, z), has never seen one of its associated reference tags after a hub firmware restart.
Recommended action: Verify that receiver with receiver ID <rxID> has power and is within range of the reference tag.
Message Type: If other receivers detect the reference then the error packet is sent continuously until resolved; if no other receivers detect the reference then the error packet is sent only once.
Message Format:
D, rxID,x, y, z, <refTagID>, timestamp, DpacketID, 'Warning: receiver has never seen reference tag <refTagID>'

b. **Receiver has detected a reference tag**

Description: An active receiver with receiver ID <rxID>, which is configured at location (x, y, z), has seen one of its associated reference tags after a hub firmware restart.
Recommended action: None required.
Message Type: This information packet is sent once.
Message Format:
D, rxID,x, y, z, <refTagID>, timestamp, DpacketID, 'Receiver detect reference tag <refTagID> '

The following D-packets are possible during operation:

1. **Reference Tag Lost/Detected**
   a. **Reference tag lost**
   Description: A reference tag with tag ID <refTagID>, configured to be at location (x,y,z), has lost signal for more than 5 seconds. The <battery> represents the tag battery level at the last detection time, and <timestamp> is the UTC time (i.e. the number of elapsed seconds since January 1, 1970), at which the reference tag signal was last detected.
   Recommended action: Verify the reference tag is present and not damaged.
   Message Type: This event packet will be sent only once when the reference tag has not been detected for 5 seconds
   Message Format:
   D, refTagID, x, y, z,battery, timestamp,DpacketID, 'Warning: reference tag not detected'

   b. Reference tag detected
   Description: A reference tag with tag ID <refTagID>, configured to be at location(x,y,z), is detected with a tag battery level of <battery> at UTC time of <timestamp>.
   Recommended action: No action required.
   Message Type: This event packet will be sent only once when the reference tag is detected for the first time.
   Message Format:
   D, refTagID, x, y, z, battery, timestamp, DpacketID, 'Reference tag detected'

2. **Active Receiver Communication Lost/Detected**
   a. **Active receiver communication lost**
   Description: A receiver with a receiver ID <rxID>, which is in the active receiver list and configured to be at location (x, y, z), has lost normal communication to the hub. The <battery> field is always 0, and <timestamp> represents the last time (in UTC format) when the hub is still able to communicate with the receiver.
   Recommended action: Verify the receiver is present, powered on and not damaged.
   Message Type: The event packet will be sent only once after the hub lost the communication with the receiver.
   Message Format:
   D, rxID, x, y, z, 0, timestamp, DpacketID, 'Warning: active receiver communication lost'

   b. **Active receiver communication detected**
   Description: A receiver with a receiver ID <rxID>, which is in the active receiver list and configured to be at location(x,y,z), has re-established a normal communication to the hub after previous loss-of-communication. The <battery> field is always 0, and <timestamp> represents the UTC time that the hub starts to communicate with the receiver again.
   Recommended action: No action required.
   Message Type: The event packet will be sent only once when the hub re-gains communication with the receiver.
   Message Format:
   D, rxID, x, y, z, 0, timestamp, DpacketID, 'Active receiver communication OK'

Table 1: D-packet Event Messages

D-Packet	DpacketID	Message Type	Continuous Message?
No receiver enabled	**-10**	Error	√
No reference tag enabled	**-20**	Error	√
No virtual group enabled	**-30**	Error	√
No receiver detected	**-11**	Error	√
No receiver activated	**-12**	Error	√
Enabled receiver detected Enabled receiver not detected	**13** **-13**	Status Warning	
Unknown receiver detected	**-14**	Warning	
Receiver 00 detected	**-15**	Warning	
Virtual group has no valid reference	**-31**	Error	√
Receiver has never seen reference tag Receiver has detected reference tag	**-16** **16**	Warning Status	√Note 1
Reference tag detected Reference tag lost	**21** **-21**	Status Warning	
Active receiver communication lost Active receiver communication OK	**-17** **17**	Warning Status	

Note 1 If other receivers detect the reference then the error packet is sent continuously until resolved; if no other receivers detect the reference then the error packet is sent only once.

15 APPENDIX IV: Specifications

This section contains specifications for the *Sapphire DART* Ultra Wideband *Precision Asset Location System*™:

***Sapphire DART* Processing Hub Specifications (*Sapphire*-PC4-8HS)**	
Dimensions	12" x 9" x 4"
Weight	6.5 lbs
Maximum number of receiver ports per hub	8
Data throughput per receiver high-speed pair	1 Mb/s
Maximum number of tag events processed per second	500
Maximum distance between RX#1 and hub	1000 feet**

Receiver Specifications (R651- HS)	
Dimensions	6.5" x 2.5" x 2.5"
Weight	15 ounces
Maximum distance between RX#1 and hub	1000 feet**
Maximum number of receivers in one daisy chain	8 receivers (assuming each with 300 feet of cable separation)
Number of receivers supported by one hub	64
Receiver ID range	01 - FF

***using 26AWG CAT 5E shielded cable*

UWB Tag Physical Specifications (T651- family)			
TAG	**Size**	**Weight**	**FCC ID**
T651-BDG	1.5" x .25" x 2.5"	.6 ounces	QCJPAL6511X1
T651-1x1	1" x 1.75" x 1"	.6 ounces	QCJPAL6511X1

UWB Tag Battery Specifications (T651-family)		
TAG	**Battery Type**	**Battery Life (1 transmission/second)**
T651-BDG	CR2032	4.3 years
T651-1x1	CR2032	4.3 years