Some further GPS notes of possible interest for the Auger Observatory

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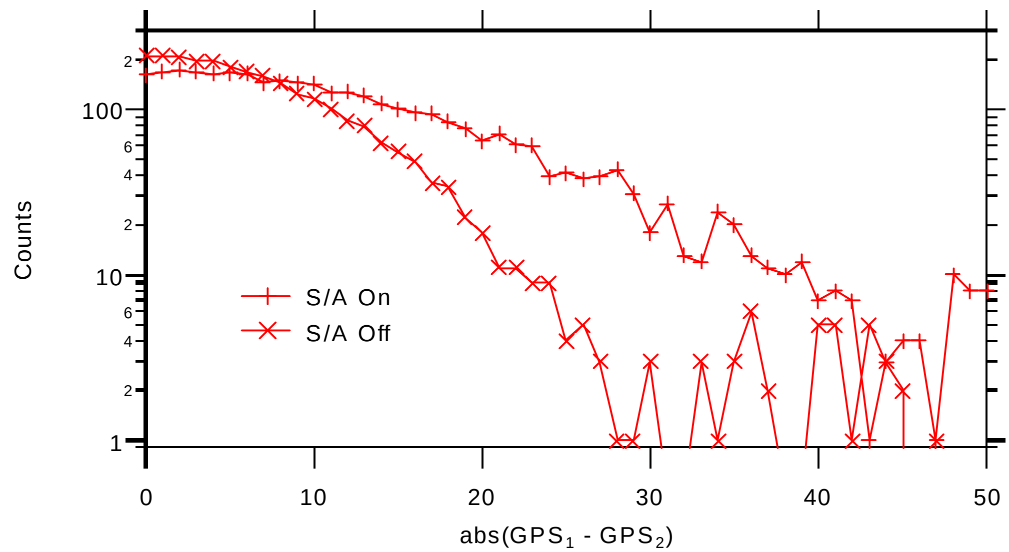
In this short note, I'd like to update my comments from GAP-98-007 and add some new information on GPS re-broadcasting, time and phase transfer experiments, a few notes on recommended test procedures, and some references that have been useful to me. Basically this is a download of my GPS knowledge in a form which might be useful to some collaboration members.

GPS re-broadcasting

A simple way of providing GPS signals to an entire lab without multiple cables and multiple external antennas (especially useful for basement labs) is commercially available in the form of a GPS rebroadcasting kit. This consists of an amplified GPS antenna, either a high-gain timing antenna or a lower-gain general-purpose antenna, connected to a small amplifier and broadcast antenna at the other end of up to about 100 meters of cable. For semi-permanent installations, another advantage of this setup is the considerable reduction in the complexity of the lightning protection scheme. The total cost of the system (including amplified antenna, 100m of cable, and rebroadcast antenna) is approximately US$400-1000. Such kits are available from GPS Source (http://www.gpssource.com/), Dallas Avionics (http://www.dallasavionics.com/), and NavTech (http://www.navtechgps.com/).

Time and phase transfer

Experiments using a pair of inexpensive, commercial Garmin GPS units, Garmin differential correction (DGPS) receivers, and the St. Paul, Minnesota DGPS beacon were performed to look at errors in DGPS timing between two receivers. Over two months, I was able to keep the time signals (the 1 PPS outputs) to within 50ns in all measurements, and with a FWHM error of about 10ns (compared to about 20ns with S/A on). One of the receivers was moved extensively throughout this time period (it was kept in my car between measurements). The Motorola unit being used in the surface array is a similar receiver, and they are likely to operate with about the same level of precision. The elimination of S/A has, most notably in the area of timing, truncated the timing error distributions significantly. See the figure for an S/A-on versus S/A-off comparison of timing error distributions. S/A-on here is a software implemented interpretation of S/A and not exactly the real thing (since it's off at the moment, no true test of S/A-on is possible, but the algorithms for it are relatively well known).



NB: The two sets of measurements are not normalized to each other.

Phase transfer experiments to connect the U.S. coast-to-coast through DGPS timing with a few ns resolution have been largely successful. Mean timing errors from Atlanta to Seattle and New York to Los Angeles have been less than 10ns. Real-time kinematic (RTK) surveying systems are now quoting millimeter resolutions over 10s of kilometers. (RTK surveying of the actual physical tank placements, perhaps either during phototube or electronics installation would allow the station controller GPS to be operated in fixed position mode.)

Mask Angle

Kaplan's book and several papers in the Navigation selected papers discuss the tradeoffs between satellite availability, RAIM, and mask angle. Essentially satellites below about 15 degrees will likely drop out the time-position solution due to RAIM algorithms even without a mask angle set. However, the mask angle is a faster correction to the time-position solution. That is, the suspect data never enters into the solution rather than entering into the solution and later being deprecated by RAIM. Another however is that mask angle cut can reduce satellite numbers below tolerable minimums while RAIM cuts disappear as the number of visible satellites decrease. It seems worthwhile to run a simulation of the site's GPS coverage for various mask angles and RAIM strategies with an eye towards minimizing timing errors both for the moment (with floating position solutions requiring three satellites minimum) and the desired setup (with fixed positions and only one satellite required).

Recommended test procedures

The Institute of Navigation (ION) publishes a set of recommended tests for certification and evaluation of GPS receivers. Although the tests in the official GPS Receiver Test

Procedure Manual are quite simplistic for the Auger application, they might be useful in specifying commercial quality control standards. All manufacturers of GPS hardware that I've looked into follow these recommended test procedures and make product specification based on these test results.

Annotated Bibliography

Understanding GPS: Principals and Applications, ed. Elliot Kaplan, Artech House, 1996 (ISBN: 0890067937)
This is a great general introduction to the GPS system (indeed GNSS in general). The book is dated only when it comes to system hardware in the last chapter.

Global Positioning System: Publications of the Institute of Navigation (ION)/Journal Navigation, Volumes 1-6, Institute of Navigation, 1980-1999 (ISBN: 0936406 - 00,01,02,03,05,06 - 3,1,1,8,4,2 for volumes 1-6 respectively)
These are a treasure trove of analysis techniques, applications, and source papers on what have become standard GPS techniques. There is more on the timing applications in these volumes than in most other sources. They are available from NavTech and in most research libraries.

ION STD 101: Recommended Test Procedures for GPS Receivers, Revision C, Institute of Navigation, 1997 (ISBN: 0936406046)
This is the official standard for testing user-level GPS devices. Probably it is most useful for making specifications to the device manufacturer. For example, the warm-start reacquisition time that varies so much between the Motorola units for the EA is a specified test value that should be in the product specification of the board.