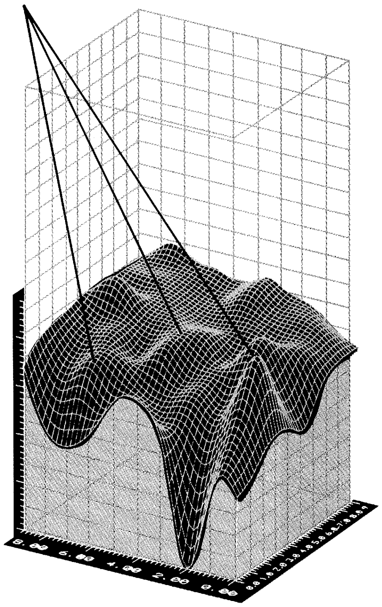
The Issue of Selective Availability

Yola Georgiadou
Kenneth D. Doucet

Reprinted from GPS WORLD September/October 1990



"Innovation" is a regular column in GPS World *commenting on GPS technology, product development, and other issues and needs of the GPS community. This time we look at selective availability and assess its effect on GPS measurements.*
This column is coordinated by Richard Langley and Alfred Kleusberg of the Department of Surveying Engineering at the University of New Brunswick. We welcome your comments and suggestions for future columns.

The Issue of Selective Availability

Yola Georgiadou
Kenneth D. Doucet

Geodetic Research Laboratory,
University of New Brunswick

Selective availability (SA) is a method of denying unauthorized GPS users high position accuracy. Although it stands for "accuracy denial," the term was probably introduced because it sounds more positive and less ominous. The United States Department of Defense (DoD) formally implemented SA on March 25, 1990 and put an end to "a long period of uncertainty, apprehension and heated debate," as the May/June 1990 issue of *GPS World* put it. Nominal three-dimensional point position accuracy of the Standard Positioning Service (SPS) with SA switched on is 120 meters, assuming that the complete satellite constellation is in place. A more than threefold decrease in accuracy for SPS (the accuracy of SPS without SA is in the 20- to 40-meter range) is a serious concern.

In this column we shall review the reasons that led to withholding the full system accuracy from most civilian users, discuss the implementation of SA, and examine its effect on our measurements and positions. Finally, we shall discuss a technique known as differential GPS, which appears capable of reducing the effect of SA errors for a large variety of users.

HISTORY

The issue of selective availability is closely tied to the history of GPS development. After the NAVSTAR GPS concept was born in 1973, a Joint Program Office established by the DoD was assigned the task of developing and deploying a single system that could serve defense positioning and navigation needs. Personnel from the Army, Navy, Marine Corps, Air Force and Defense Mapping Agency were to cooperate towards this goal.

Extensive testing of user equipment took place at this early stage. Ground-based transmitters and later, Block I prototype satellites, provided the necessary navigation signals for these initial tests. The idea was that sophisticated high-precision equipment, utilizing the precision or P-code, would be later reserved for military use. Low-cost units operating with the less precise coarse/acquisition or C/A-code were intended to be generally available to everyone. This is roughly how the full system accuracy was to be reserved for authorized (military) users.

The test results were both encouraging and surprising. System accuracies at the 10- to 20-meter level achieved with P-code receivers lent necessary momentum to the program as it entered the full-scale engineering development phase. And there was a big surprise! The low cost C/A-code unit proved to be much better than expected. Although it was predicted to provide position accuracies of no better than 100 meters, its actual performance was at the 20- to 30-meter level!

This turn of events marked the beginning of a remarkable era. The emergence of the C/A-code unit as a precise navigational tool was quickly followed by a rethinking of the strategy for high-accuracy availability. The DoD invited the Office of the Joint Chiefs of Staff, the Office of the Secretary of Defense, and the National Security Council to establish a national policy regarding availability of GPS to the general public. At this time the positive sounding term *selective availability* was coined. Initially, a decision was reached to intentionally degrade the accuracy available to unauthorized users to 500 meters by implementing SA on Block II satellites. That figure was later revised to 100 meters. The DoD also stated that this policy of intentional degradation would be reviewed annually in an effort to increase the accuracy available as conditions warranted.

As soon as Block II satellites were available for tracking, some research groups started performing tests to assess the degree of error introduced in measurements and position due to SA. Guesses as to the SA effect on position became quite fashionable. Now that SA has been switched on officially, this period of uncertainty and speculation is over. All Block II satellites launched in the future will have SA enabled as soon as each is declared operational. Currently no plans exist for implementing SA on Block I satellites, but the DoD has reserved the right to do so.

According to the current DoD "SA policy," the nominal position accuracy for horizontal coordinates (latitude and longitude) is 100 meters at a probability level of 95 percent. This means that position errors should be less than 100 meters at least 95 percent of the time. However, DoD has not indicated how large these errors may become during the remaining five percent of the time. An interagency U.S. working group that includes DoD representation has proposed a guarantee of position accuracy of less than 300 meters for 99.9 percent of the remaining five percent. That proposal is contained in the current draft of the 1990 Federal Radionavigation Plan. (See Washington View column elsewhere in this issue.)

The corresponding accuracy level for heights is 150 meters. If we consider horizontal and vertical coordinates together as a three-dimensional position, it is 120 meters. In velocity determination, errors of the order of 0.3 meter/second are anticipated. And for the time-transfer error in GPS time dissemination, we may find it is about 300–400 nanoseconds, considering that a position error of one meter translates to a time error of about three nanoseconds.

It should be kept in mind that these nominal values will be relevant when the full satellite constellation is operational with a dilution of precision (DOP) factor of three to five (see the Innovation column in the *GPS World* March/April 1990 issue for a discussion of DOP). During the buildup to the full constellation, accuracy at times could be worse.

Most GPS users will have to live with these levels of accuracy in position, velocity, and time determination. Only authorized users may recover the undegraded data and exploit the full system potential. To do so, they must possess a key that allows them to decrypt correction data transmitted in the navigation message.

In addition to denial of accuracy through SA, the DoD can restrict the use of signals from the operational Block II satellites through the encryption of the P-code. Termed anti-spoofing (A-S), this technique is a method of protecting military operations against hostile imitation of the P-code. It is widely believed that A-S will only be turned on in times of national emergency and for testing purposes.

IMPLEMENTATION

The way the DoD has implemented selective availability reflects the nature of positioning with GPS through the fundamental relation:

Pseudorange Measurement + *Satellite Position* = *User Position*

The *pseudorange measurement* is derived from a comparison between satellite and receiver clocks. SA introduces errors that have both rapidly and slowly varying components into the pseudoranges by manipulating (dithering) the satellite clock, the so-called δ-process. Pseudorange errors multiplied by the DOP factor are mapped directly into user position errors.

The *satellite position* is extracted from orbit information in the broadcast message. Deliberate introduction of errors into the broadcast orbital parameters, known as the ε-process, leads to a degradation of accuracy of the orbital information broadcast by a satellite. These orbital errors are expected to exhibit only slow variations to conform with the parametric representation of the orbit in the broadcast message. These orbit errors transform to user position errors with the same slowly varying nature. In most applications, the user cannot distinguish between the two SA constituents because both have slowly varying components.

SA EFFECTS

Basically, a GPS receiver can make two kinds of measurements: pseudoranges on one of the two codes, and carrier phase measurements. Both types of measurement reflect the distance between satellite and receiver.

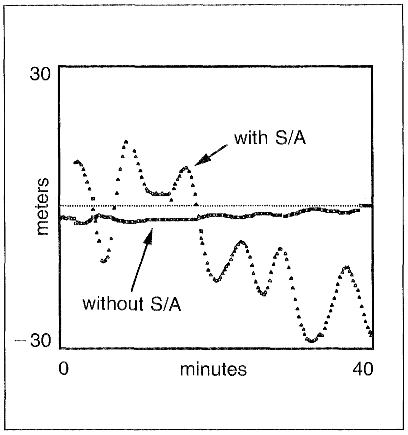


Figure 1: C/A-code range measurement errors with and without SA

Both are affected by SA in the same fashion because the same atomic clock on board the satellite controls the timing and frequency for the carriers and the two codes.

Now let's take a closer look at measurements obtained with a C/A-code receiver in an "SA environment." We shall compare these with simultaneous measurements on a satellite free of SA errors. And, most importantly, we shall look at the resulting position accuracy with and without SA.

Figure 1 illustrates the potential magnitude of SA-induced errors on pseudorange measurements from GPS satellite PRN 14 (with SA enabled). The 40-minute data set was collected on May 16, 1990, at a known location. The measurement error was computed by differencing the observed and theoretical ranges. For PRN 14, the differences were of the order of ±30 meters. This error level in the pseudoranges is consistent with the behavior expected of SA-affected measurements. On the other hand, measurements made simultaneously to satellite PRN 9 (SA not enabled) have errors of the order of four meters, a level of accuracy conforming to potential C/A-code measurement accuracy.

Figure 2 illustrates the magnitude of GPS position errors from C/A-code measurements collected at a known location. The top portion of the plot shows horizontal position errors for a total of 690 individual position fixes. The data was collected on February 22, 1990, with SA inactive. Position errors were at the ±15 meter level, as anticipated from undegraded C/A-code measurements. The lower plot shows horizontal position errors for a total of 160 individual fixes for the same location about two months later (May 3, 1990) after the official implementation of

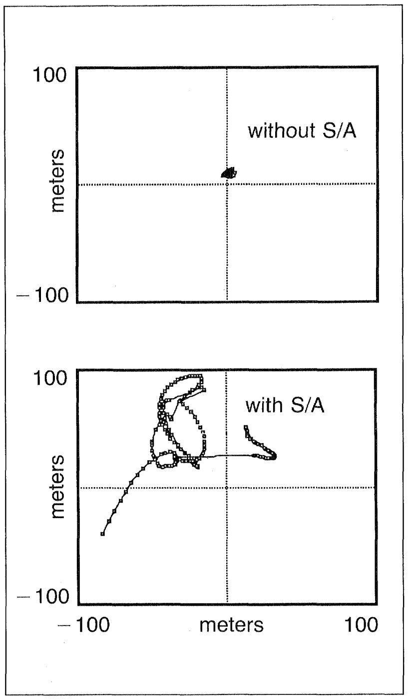


Figure 2: C/A-code position errors with and without SA

SA. The dramatic decrease in horizontal positioning accuracy to ±100 meters is consistent with the DoD policy on selective availability.

CAN WE LIVE WITH SA?

Several GPS user groups can live quite happily with SA-degraded accuracies. However, perhaps just as many users need access to the full system accuracy for high-precision applications. Differential GPS, recognized very early in the life of the system as a remedy for SA errors, comes to the rescue of these high-precision users. This technique can counter both clock dithering and orbital data manipulation. Moreover, it is not considered to pose a security hazard.

Differential GPS operation involves placing a GPS receiver at one or more known locations — the monitor stations — and computing corrections for the range errors observed on the satellite signals. In principle, these corrections are calculated by subtracting the observed pseudoranges from the ranges computed with the known station coordinates, and then are broadcast through an appropriate data communications link to the user. Because errors generated by SA affect measurements at the monitor station and at the user's site in a very similar fashion, the user can correct erroneous measurements with the received differential corrections. This procedure eliminates or greatly reduces the impact of SA on positioning, as discussed in greater detail in the July/August 1990 Innovation column.

This scheme seems to be an easy way to recover the full GPS positioning accuracy. But it is not a perfect cure. In general, the capacity of the data communications link will limit the update rate for the transmitted differential corrections. If the errors introduced by SA change faster than the differential correction update rate, remote users can no longer accurately correct their measurements. Therefore, the degree of error removal will depend on the rate of change of the SA errors in relation to the data communications rate. The data in Figure 1 indicates a range rate error of about 0.2m/sec. Assuming this level of error and a data communications rate of one range correction message per 10 seconds, the differential corrections would be in error by up to two meters after 10 seconds.

Another factor in the effectiveness of the differential corrections is the distance between monitor station and user. Pseudorange errors introduced through changes in the orbital parameters of the satellites are similar only if the monitor station and the user are in the same geographical region. As distance between the stations increases, the corresponding range errors tend to become different. An error of 40 meters in the satellite orbit with the user 1,000 kilometers away from the monitor station, for example, yields a differential correction that is in error by up to two meters.

Let us sum up these arguments. Differential GPS may be the only remedy for SA errors under two conditions: a sufficiently high rate of differential corrections, and short distances between the monitor station and the moving users.

Surveying can be seen as a special application of differential GPS. Surveyors use GPS to measure position differences between survey markers. Among others, they were quick to realize the potential of measurement differencing for error cancellation, and have used it through the last decade to extract unprecedented and unexpected accuracies for static differential positioning — centimeters

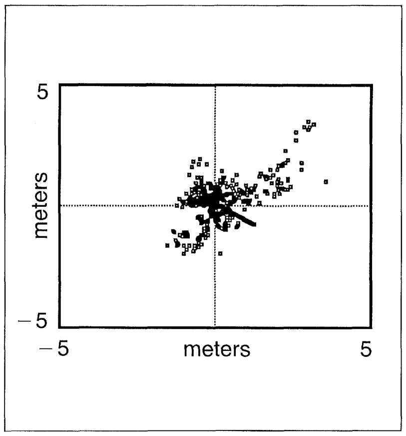


Figure 3: Differential GPS C/A-code position errors with SA

over tens of kilometers. In surveying, the measurements used are carrier phases because inherently they have a higher precision than pseudoranges. (See Innovation column in the January/February 1990 issue of *GPS World* for further details.) No differential corrections need be computed and transmitted in this case. Instead, the measurement data are collected and stored at both sites for postprocessing. This data processing involves direct differencing of measurements between monitor and user station, which eliminates SA errors caused by the clock dithering and greatly reduces the effect of orbital errors on differential positioning. In fact, surveyors had to use this differencing technique even before SA was introduced to achieve the positioning accuracies required in surveying.

Figure 3 illustrates the potential success of differential GPS in eliminating the effects of SA. The same SA-contaminated data that was used for Figure 2 was analyzed to produce the differential position errors shown in Figure 3. For these calculations, though, the measurements were combined with measurements from a second receiver at another known site. The effect of applying differential corrections was simulated by a direct differencing of the C/A-code pseudoranges observed at the two sites, as is routinely done with carrier phases in GPS surveying. The resulting position errors are of the order of ± 5 meters, an increase in accuracy by a factor of 20 compared to the undifferenced result of Figure 2 (lower plot).

A technique similar in principle to differential GPS is used to reduce considerably the SA effects on time transfer. This concept, known as common-view, common-mode time transfer, is based on the assumption that measurements collected by the two receivers involved in time transfer are contaminated by similar SA errors. Corrections transmitted from the reference receiver to the remote receiver reportedly can remove most of the SA errors at the remote receiver site. More information about time and frequency dissemination using GPS and SA-related errors can be found in the July/August 1990 issue of *GPS World* (Peter H. Dana and Bruce M. Penrod, The Role of GPS in Precise Time and Frequency Dissemination).

CONCLUSION

Selective availability is now officially in use, and apparently it is here to stay. Although many low-precision users can live with it, SA is a major step backward from what has been the biggest breakthrough in navigation technology. We have shown how large typical SA errors in GPS measurements and fixes are during 95 percent of the time, based on a small data set. The problem is that at times they could be much larger! In other words, we currently lack a firm and final commitment on the size of errors for five percent of the time. The necessity for a more precise definition of the impact of SA has already been recognized by the DoD. As a result, DoD and Department of Transportation officials are expected to spell out more precisely the accuracy limits of the SPS in the final version of the 1990 Federal Radionavigation Plan.

One thing is certain: the present time is too soon to assess the full impact of SA on position, velocity, time, and frequency transfer for the fully operational system. Instead, perhaps we should concentrate on exploring exciting new ideas such as the combination of GPS with the INMARSAT and Soviet GLONASS systems for integrity control and differential information. Development and realization of these and similar concepts, inherently based on cooperation among nations, may render obsolete the reasons that led to the introduction of selective availability in the first place. ■