Appendix A
Antenna Location

One of the practical problems faced when trying to array antennas is that of providing good a priori information to the combiner. The definition of "good" depends on the technique, and, as was pointed out in Chapter 3, full-spectrum combining in general requires higher-accuracy a priori information.

A particularly important piece of information is the location of the antenna intersection of axes for each element of the array, expressed in a common coordinate system. This is required in order to calculate the difference in phase delay between all elements of the array. It can be a difficult quantity to determine because, in many parabolic antennas designs, the intersection of axes is buried in the middle of a steel shaft or casing, and its location can only be inferred. If the antenna is located inside of a radome, the problem may be even more complicated. In this appendix, a concept is outlined by which the location of the axes could be inferred with high accuracy.

Consider Fig. A-1, which shows a parabolic antenna located somewhere on the face of the Earth. It is assumed that a Global Positioning System (GPS)

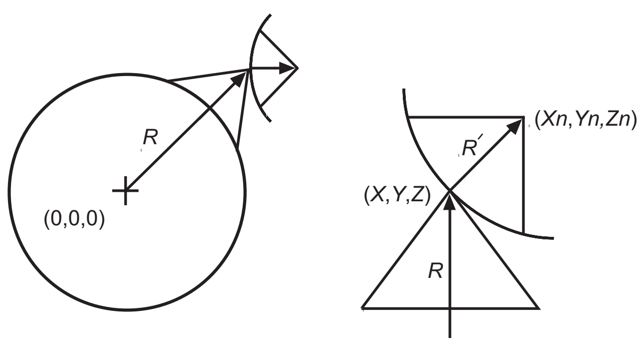

Fig. A-1. Diagram for visualizing the determination of the intersection of axes.

receiver can be placed on the backside of the antenna subreflector (if it is a Cassegrain feed) or the backside of the feed package (if it is a prime-focus feed). Measurement is desired of the quantity R, the vector from the center of the geocentric coordinate system, defined by the dynamics of the GPS constellation, to the intersection of axes of our antenna. The GPS antenna is offset from the intersection of axes by the vector R', and, at any given instant of time, the GPS receiver will measure the vector sum $R + R'$. Thus, the problem is reduced to the determination of R'.

In order to simplify the concept, first it is assumed that the antenna in question has already been aligned in a local coordinate system. The angular readouts have been adjusted to know precisely the direction of true north, i.e., the offsets in azimuth and elevation are known. If a measurement M_1 is made with the antenna pointed so that azimuth = A_1 and elevation = E_1, then three pieces of data are obtained: the $X1$, $Y1$, and $Z1$ coordinates of the GPS antenna relative to the center of the Earth. These are related to the three coordinates of the intersection of axes X, Y, and Z together with the magnitude of the offset vector $|R'|$. This results in three equations with six unknowns. Next, the antenna is pointed to another position, so that azimuth = A_2 and elevation = E_2, and another GPS measurement is made. Denote this measurement as M_2, providing $X2$, $Y2$, and $Z2$. This results in six pieces of data with six unknowns and allows a solution for the unknowns.

In practice, the azimuth and elevation offsets for the antenna may not be known beforehand. It is a relatively simple matter to include this in the vector formulation and, when this is done, eight quantities must be estimated. This will require the antenna to be moved to a third position, $M_{3,}$ to obtain three additional pieces of data from which it is possible to solve for the eight unknowns, etc. The essence of this concept is the employment of the mathematics of multiparameter estimation to solve for something that cannot be measured directly. Critical to this approach is a model (i.e., a set of equations) that relates exactly how the quantity that can be measured relates to what can be inferred.

Real antennas are hardly ever as simple as has been assumed. Their axes never can be made to be exactly orthogonal, the offsets never determined exactly, one or both axes may wobble, etc. Real antennas sag and bend due to thermal effects. In principle, however, all of these effects can be modeled mathematically as rotation matrices and the parameters in the model determined by a sufficient number of measurements, as outlined above.

Obtaining an estimate of the intersection of axes is, of course, only the first part of the problem. It is necessary to understand the accuracy of that estimate, and that requires an error analysis. Measurement errors must be estimated and propagated through the estimation process in order to determine the error on the estimated quantity.

Measurement errors often can be reduced by using appropriate techniques. For instance, raw GPS measurements from a single-frequency receiver have a quoted accuracy of 30 m—hardly adequate for the problem previously described. However, understanding that propagation errors (troposphere and ionosphere) comprise the bulk of the error budget for a GPS measurement allows a considerable reduction of this error. For instance, location of a second GPS receiver somewhere in the vicinity of the GPS receiver on the antenna permits the use of differential measurements. While the individual GPS measurements might be accurate to 30 m, the differential measurements taken at the same time have a potential accuracy of a few mm and can be exploited to determine very precisely the model for the antenna.