

# Multi-Cone Model for Estimating GPS Ionospheric Delays

This model preserves the high accuracy of the conical domain model while providing superior integrity.

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The multi-cone model is a computational model for estimating ionospheric delays of Global Positioning System (GPS) signals. It is a direct descendant of the conical-domain model, which was described in "Conical-Domain Model for Estimating GPS Ionospheric Delays" (NPO-40930), *Software Tech Briefs*, special supplement to *NASA Tech Briefs*, September 2009, page 18. A primary motivation for the development of this model is the need to find alternatives for modeling slant delays at low latitudes, where ionospheric behavior poses an acute challenge for GPS signal-delay estimates based upon the thin-shell model of the ionosphere.

Since ionospheric signal delay contributes error to GPS position and time measurements, it is necessary to estimate the delay to correct and bound this error. Several national and international systems, denoted generally as satellite-based augmentation systems (SBASs), are under development worldwide to enhance the integrity and accuracy of GPS measurements for airline navigation.

A prominent example is the Wide Area Augmentation System (WAAS) of the United States, in which slant ionospheric delay errors and confidence bounds are derived from estimates of vertical ionospheric delay modeled on a grid at regularly spaced intervals of latitude and longitude. The estimate of vertical delay at each ionospheric grid point (IGP) is calculated from a planar fit of neighboring slant delay measurements, projected to vertical using a standard thin-shell model of the ionosphere.

Interpolation on the WAAS grid enables estimation of the vertical delay at the ionospheric pierce point (IPP) of any arbitrary user's measurement. (The IPP of a given user's measurement is the point where the ray path of the measured GPS signal intersects a reference ionospheric height.) The product of the interpolated value and the user's thin-shell obliquity factor provides an estimate of the user's ionospheric slant delay.

Two types of error restrict the accuracy of delay estimates based upon the thin-shell model: (1) error arising from the implicit assumption that, at the IPP, the electron density is independent of

the azimuthal angle, and (2) error due to an invalid obliquity factor (e.g., error due to a suboptimal choice of shell height). Under nominal conditions at mid-latitudes, the magnitude of the error incurred from these sources is small. However, at low latitudes or at mid-latitudes under disturbed conditions, the error grows due to the presence of enhanced ionization, complex ionospheric structure, and large elec-

tron-density gradients. In the conical-domain model, these sources of error are mitigated by eliminating the use of both the thin-shell model and the vertical delay grid. Instead, a user's slant delay to a given satellite is calculated directly by fitting measured slant delays for nearby ray paths to the same satellite.

The conical domain model is so named because the receiver and satellite positions define a cone with the

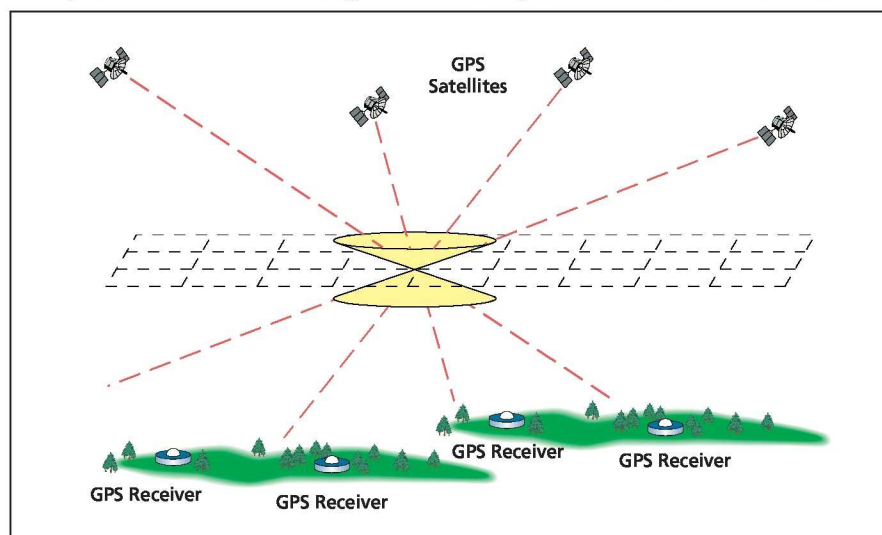


Figure 1. A Conical Domain having a vertex at a given IGP is defined, and a set of pseudo-measurements for ray paths that intersect at the IGP is fit to this conical domain.

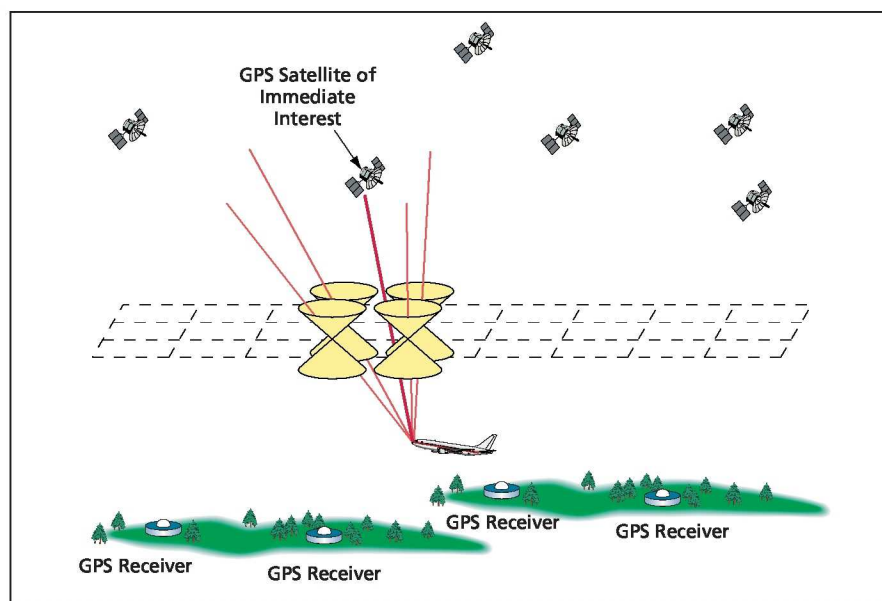


Figure 2. The Slant Delay From a Satellite of Interest to a user airplane is estimated by interpolating among slant delays for ray paths between (a) the user airplane and (b) each of the four adjacent IGPs for which pseudo-measurements have been fit to conical domains as depicted in Figure 1.

satellite position at the vertex. In an SBAS based upon the conical domain model, fits of delay on a grid of IGP are replaced with fits inside cones, each having a GPS satellite at its vertex. A user (e.g., an airplane in flight) within a given cone evaluates the delay to the satellite directly, using (1) the IPP coordinates of the line of sight to the satellite and (2) broadcast fit parameters associated with the cone.

In the context of SBAS, the conical-domain model suffers from one major limitation: each fit is comprised of relatively few measurements. Since the reliability of a fit depends upon the number of its measurements, a small number of fit measurements represent a threat to the integrity of the delay estimates based upon the fit. The multi-cone model, in which measured signals from multiple satellites are incorporated into each delay estimate, has been conceived as a means of obtaining the benefits of the conical-domain model without suffering a potentially serious loss of integrity.

The basic idea of the multi-cone model is to adapt the conical-domain model to obtain fits on an ionospheric grid. The adaptation involves multiple stages. In the first stage, the conical-domain model is used to obtain an estimate of the slant delay for each ray path

that connects a visible satellite to a specified IGP. This requires a separate fit for each satellite. Each delay estimate may be regarded as a pseudo-measurement of a signal for the satellite in question. In the second stage, the conical-domain model is turned upside down in the sense that instead of creating a cone of measurements having a satellite at its vertex and multiple receivers at its base, one forms a cone having a single receiver at the vertex and performs a fit of a set of pseudo-measurements within this cone (see Figure 1).

This process is repeated until fit parameters have been determined for cones at each IGP in a grid. It is then possible to evaluate the slant delay for any ray path that passes through both a user's position and an IGP. To evaluate the slant delay to a satellite of immediate interest from any arbitrary user position, the user first locates the IPP of the signal from that satellite and then identifies the four IGP at the corners of the grid cell that contains this IPP. The estimates of the slant delays for the ray paths through each of these four IGP can then be interpolated to obtain the slant delay between the user's position and the satellite of immediate interest (see Figure 2).

This estimate formally converges to the correct value in the limit as the den-

sities of participating GPS receivers and GPS satellites become very large and, simultaneously, grid cells become more nearly infinitesimal. It should be noted that the user's slant delay estimate contains information from all the signals that have been used to define the cones at the four interpolation IGP (in contrast to fitting only data from signals emitted by the satellite of immediate interest as in the original conical-domain approach). The use of additional information in evaluating each fit serves to improve the integrity of the delay estimate while preserving the accuracy of the conical domain model.

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## High-Sensitivity GaN Microchemical Sensors

**This innovation enables remote detection of chemical/biological toxins in the air.**

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Systematic studies have been performed on the sensitivity of GaN HEMT (high electron mobility transistor) sensors using various gate electrode designs and operational parameters. The results here show that a higher sensitivity can be achieved with a larger  $W/L$  ratio ( $W$  = gate width,  $L$  = gate length) at a given  $D$  ( $D$  = source-drain distance), and multi-finger gate electrodes offer a higher sensitivity than a one-finger gate electrode. In terms of operating conditions, sensor sensitivity is strongly dependent on transconductance of the sensor. The highest sensitivity can be achieved at the gate voltage where the slope of the transconductance curve is the largest.

While GaN-based microchemical sensors have shown very promising performance characteristics, there has not been much understanding on how sen-

sor sensitivity can be engineered or improved. This work provides critical information about how the gate electrode of a GaN HEMT, which has been identified as the most sensitive among GaN microsensors, needs to be designed, and what operation parameters should be used for high sensitivity detection.

The figure shows  $I_{ds}$  (source-drain current) response to  $SF_6$  exposures measured using the GaN HEMT sensors fabricated with  $W = 5, 10, 25,$  and  $50 \mu m$  at  $L = 2 \mu m$ . The sensors clearly demonstrate a higher sensitivity with an increasing gate width.  $I_{ds}$  response measured using GaN HEMT sensors fabricated with  $L = 2, 4,$  and  $8 \mu m$  at  $W = 50 \mu m$  and with  $L = 2 \mu m$  at  $W = 25 \mu m$ ; (in these sensors the source-drain distance is  $DS = L + 4 \mu m$ ) show decreasing sensitivity with an increasing gate length.

Comparison between L4W50, L8W50 and L2W25 sensors, which correspond to DS8W50, DS12W50, and DS6W50 respectively, indicates that the sensor sensitivity is not simply proportional to  $I_{ds}$  or  $W/L$  (or  $W/DS$ ). The higher sensitivity achieved with the L2W25 sensor compared to the L4W50 sensor indicates that the shorter gate length plays a significant role. The results shown here suggest that sensor sensitivity is not simply proportional to the size of the gate electrode or the amount of  $I_{ds}$  of the sensor, and that a short gate length and a source-drain distance are important factors in determining the sensitivity of the sensor.

The robust, high-sensitivity GaN HEMT chemical sensors can be applied to NASA missions including *in-situ* detection of signatures of extraterrestrial life and *in-situ* planetary atmosphere