GPS World *Innovation* Columns

Vol. 1, No. 1 (1990) to Vol. 11, No. 12 (2000)

1.01 GPS: A multipurpose system **Wells, Kleusberg**

Wells, D., and A. Kleusberg (1990). GPS: A multipurpose system. *GPS World*, January/February, Vol. 1, No. 1, pp. 60-63.

Innovation; capabilities of GPS; tomorrow's world today (where am I?; where are you?; how far am I from you?; how far are you from me?; how far am I from you? Give it your best shot. I'm willing to wait; how far am I from you? Give it your best shot. I need to know NOW; which way am I pointing?; what time is it?). GPS works by simultaneously measuring the distance from a GPS receiver to each of several GPS satellites. GPS is the most accurate time transfer method available.

1.02 The limitations of GPS **Kleusberg, Langley**

Kleusberg, A., and R.B. Langley (1990). The limitations of GPS. *GPS World,* March/April, Vol. 1, No. 2, pp. 50-52.

Innovation; three limitations (GPS signal reception, GPS signal integrity, GPS signal accuracy); types of error (satellite errors, signal propagation errors, receiver errors, GPS geometry); improving GPS accuracy. The atmosphere claims its toll on the GPS signal twice. In general, an increase in position accuracy does not come for free.

1.03 Why is the GPS signal so complex? **Langley**

Langley, R. B. (1990). Why is the GPS signal so complex? *GPS World,* May/June, Vol. 1, No. 3, pp. 56-59.

Innovation; the carriers; the codes; the broadcast message; binary biphase modulation.

1.04 Electronic charts and GPS **Casey, Kielland**

Casey, M. J., and P. Kielland (1990). Electronic charts and GPS. *GPS World,* July/August, Vol. 1, No. 4, pp. 56-59.

Innovation; ECDIS — its capabilities (ECDIS display features, safety of navigation features, corrections and updating issues); ECDIS at work (charting problems associated with using ECDIS and GPS); GPS accuracy and reliability issues (the integrity issue, differential operation, how much positional accuracy and integrity does an ECDIS need? how much positional accuracy and integrity can GPS provide? what about selective availability?); future GPS performance. When in differential operation, the limiting GPS integrity factor is the reliability of the differential data link itself.

1.05 The issue of selective availability **Georgiadou, Doucet**

Georgiadou, Y., and K.D. Doucet (1990). The issue of selective availability. *GPS World,* September/October, Vol. 1, No. 5, pp. 53-56.

Innovation; history; implementation; SA effects; can we live with SA?

1.06 Comparing GPS and GLONASS **Kleusberg**

Kleusberg, A. (1990). Comparing GPS and GLONASS. *GPS World,* November/December, Vol. 1, No. 6, pp. 52-54.

Innovation; comparing systems; combining systems.

2.01 The GPS receiver: An introduction **Langley**

Langley, R. B. (1991). The GPS receiver: An introduction. *GPS World,* January, Vol. 2, No. 1, pp. 50-53.

Innovation; the antenna; the RF section; the signal trackers; the microprocessor; user interface; data storage and output; the power supply. Most GPS receivers use precision quartz crystal oscillators, enhanced versions of the regulators commonly found in wristwatches.

2.02 Precise, real-time dredge positioning DeLoach

DeLoach, S. R. (1991). Precise, real-time dredge positioning. *GPS World*, February, Vol. 2, No. 2, pp. 43-45.

Innovation; reasons for development; history of kinematic GPS; preliminary design; operational constraints; practical considerations. There are many marine platforms, such as a large dredge or a floating buoy used as a tide gauge, that should experience little or no loss of signal.

2.03 The orbits of GPS satellites Langley

Langley, R. B. (1991). The orbits of GPS satellites. *GPS World,* March, Vol. 2, No. 3, pp. 50-53.

Innovation; Kepler's Laws; the Keplerian elements; orbit perturbations; launching GPS satellites; orbit data. Newton hypothesized that, given the right initial velocity, a projectile fired from the earth would go into orbit around it. The Master Control Station collects the pseudorange and carrier-phase data obtained by the tracking stations and, with sophisticated software models, predicts the future orbits of the satellites.

2.04 Ionospheric effects on GPS Klobuchar

Klobuchar, J. A. (1991). Ionospheric effects on GPS. *GPS World,* April, Vol. 2, No. 4, pp. 48-51.

Innovation; pseudorange error; error correction; range-rate errors; scintillation effects; magnetic storms; solar cycle; conclusion. How the earth's ionosphere perturbs GPS signals and what can be done about it. When severe magnetic storms occur, the auroral effects can move down into the mid-latitudes, and precise positioning with GPS can be affected by the ionosphere over the entire North American landmass for periods lasting up to one or two days.

2.05 GPS vehicle location and navigation Krakiwsky

Krakiwsky, E. J. (1991). GPS vehicle location and navigation. *GPS World*, May, Vol. 2, No. 5, pp. 50-53.

Innovation; ancient AVLN systems; modern AVLN systems; terrestrially based AVLN; GPS-based AVLN; outlook. This article looks at a combination GPS and electronic chart system for cars and trucks. The 1990s will be the decade in which AVLN systems will blossom at the high end of the market. Correction: In Table 1, NavTel 2000 should read NAVTRAX (see p. 64, Vol. 2, No. 6, June 1991).

2.06 Continuous monitoring of crustal deformation Bock

Bock, Y. (1991). Continuous monitoring of crustal deformation. *GPS World,* June, Vol. 2, No. 6, pp. 40-47.

Innovation; the earthquake process; GPS monitoring; Parkfield alignment array; a Japanese GPS network; Southern California array (network description); handling the data (data storage and dissemination, data processing and software development); prospects for the future. This is an in-depth article on an application of GPS that is of great significance not only to scientists but to society as a whole: the monitoring of earthquake fault motion.

2.07 The mathematics of GPS Langley

Langley, R. B. (1991). The mathematics of GPS. *GPS World,* July/August, Vol. 2, No. 7, pp. 45-50.

Innovation; determining positions from pseudoranges (linearization of the pseudorange equations, inconsistent equations); position accuracy measures (user equivalent range error, other accuracy measures); conclusion. This article looks at some of the mathematics involved in determining a position using GPS pseudorange measurements, and examines some of the ways of gauging the accuracy of GPS positions.

2.08 GPS in civil aviation **McDonald**

McDonald, K. D. (1991). GPS in civil aviation. *GPS World*, September, Vol. 2, No. 8, pp. 52-59.

Innovation; background; applications and benefits; GPS civil limitations; aviation community activity; GPS and GLONASS; implementation concerns. This article is on present and future applications of GPS in civil aviation.

2.09 GPS — satellites of opportunity for ionospheric monitoring **Coco**

Coco, D. (1991). GPS — Satellites of opportunity for ionospheric monitoring. *GPS World*, October, Vol. 2, No. 9, pp. 47-50.

Innovation; investigating the ionosphere; GPS ionospheric measurements; the ideal GPS receiver; past efforts and future plans; benefits for other GPS users. The use of GPS satellites to monitor the ionosphere.

2.10 Time, clocks, and GPS **Langley**

Langley, R. B. (1991). Time, clocks, and GPS. *GPS World*, November/December, Vol. 2, No. 10, pp. 38-42.

Innovation; the quartz crystal resonator; atomic resonators; just a second; universal time; GPS time; relativistic effects; selective availability; conclusion. Cesium clocks are well known for their excellent long-term stability. Not even an atomic clock keeps perfect time.

3.01 Using GPS and ROVs to map the ocean **Peyton**

Peyton, D. R. (1992). Using GPS and ROVs to map the ocean. *GPS World*, January, Vol. 3, No. 1, pp. 40-44.

Innovation; motivation; system description; integration of GPS; applications; conclusion. ROVs are used to map the ocean floor. GPS and packet radio antennas are mounted on the ROV's snorkel.

3.02 Basic geodesy for GPS **Langley**

Langley, R. B. (1992). Basic geodesy for GPS. *GPS World*, February, Vol. 3, No. 2, pp. 44-49.

Innovation; historical perspective; the geoid; geodetic coordinates; WGS 84; NAD 83; UTM; conclusion. Geodesists realized that for higher accuracies, the earth's ellipsoidal shape must be taken into account. In effect, WGS 84's coordinate system was realized by adopting coordinates for more than 1500 U.S. Navy Navigation Satellite System (Transit or Doppler) stations worldwide. See Letters, p. 12, Vol. 3, No. 9, October 1992.

3.03 The Federal Radionavigation Plan **Langley**

Langley R.B. (1992). The Federal Radionavigation Plan. *GPS World*, March, Vol. 3, No. 3, pp. 50-53.

Innovation; the systems (Loran-C, Omega, VOR/DME, TACAN, ILS, MLS, Transit, radiobeacons, GPS); conclusions. Both FAA and DoD are studying the feasibility of replacing VOR/DME with an alternate system such as GPS. Some doubt the need for widely deployed MLS facilities given the improvements recently made to ILS and the potential of global navigation satellite systems. See Letters, p. 12, Vol. 3, No. 8, September 1992.

3.04 Precision long-range DGPS for airborne surveys **Columbo, Peters**

Colombo, O. L., and M.F. Peters (1992). Precision long-range DGPS for airborne surveys. *GPS World*, April, Vol. 3, No. 4, pp. 44-50.

Innovation; carrier-phase differential GPS; the crawl of continents; in search of cycle slips; accuracy over long distances; interpreting data with GPS; the Greenland survey; conclusion. The development of a precise differential GPS positioning technique for airborne surveys and its application to a geophysical investigation of Greenland.

3.05 Measuring the earth's rotation and orientation with GPS — Freedman

Freedman, A. P. (1992). Measuring the earth's rotation and orientation with GPS. *GPS World,* May, Vol. 3, No. 5, pp. 42-50.

Innovation; polar motion, universal time; reference frames; solving for earth orientation; recent work; future plans. Just as GPS has become famous for precise and rapid terrestrial positioning, so, too, it should be able to provide precise and frequent estimates of the earth's orientation in space. The collocation of GPS receivers with VLBI sites links the GPS terrestrial reference frame to the VLBI celestial reference frame. Preliminary work suggests that GPS can be used to measure Universal Time changes accurate to better than 100 microseconds over a few hours.

3.06 High-accuracy GPS marine positioning for scientific applications — Rocken, Kelecy

Rocken, C., and T.M. Kelecy (1992). High-accuracy GPS marine positioning for scientific applications. *GPS World*, June, Vol. 3, No. 6, pp. 42-47.

Innovation; high-accuracy positioning; marine positioning techniques; kinematic positioning (kinematic positioning, resolution of carrier-phase biases); ocean buoy experiments (Scripps pier experiment, Harvest platform experiment, ERS-1 overflight experiment); conclusion. Another innovative use of GPS — precisely determining the height of the ocean surface. In addition to supporting high-accuracy scientific research, low-cost GPS-equipped buoys can provide an accurate sea surface monitoring network to supplement the global tide gauge network. In the future, housing the GPS antenna and receiver in the buoy would be more practical to avoid the high costs of running a ship during GPS data collection. One of the most encouraging findings is that signal multipath noise in the ocean is considerably lower than on land. See Letters, p. 12, Vol. 3, No. 9, October 1992, including Kelecy and Rocken reply to Liu.

3.07 Precise differential positioning and surveying — Kleusberg

Kleusberg, A. (1992). Precise differential positioning and surveying. *GPS World,* July/August, Vol. 3, No. 7, pp. 50-52.

Innovation; carrier-phase positioning; static differential positioning; pseudokinematic surveying; stop-and-go surveying; rapid static surveying; implications and trends. Methods for precise differential GPS positioning and surveying are looked at and associated observation procedures are described. Also on the horizon is the development of data communication links for GPS surveying receivers and real-time in-field data processing and quality control.

3.08 Measuring velocity using GPS — May

May, M. B. (1992). Measuring velocity using GPS. *GPS World,* September, Vol. 3, No. 8, pp. 58-65.

Innovation; velocity users; basic concepts; GPS receiver measurements; GPS receiver processing; unaided GPS velocity results; GPS/INS integration.

3.09 A new chapter in precise orbit determination — Yunck

Yunck, T. P. (1992). A new chapter in precise orbit determination. *GPS World,* October, Vol. 3, No. 9, pp. 56-61.

Innovation; orbit accuracy; dynamic orbit determination; kinematic tracking with GPS; the whole picture; TOPEX/Poseidon demonstration; future missions; experimental results; final comment; acknowledgements. This article is on the use of GPS receivers on board orbiting spacecraft to determine their orbits with unprecedented accuracy.

3.10 Using GPS-equipped drift buoys for search and rescue operations — Leger

Leger, G. T. (1992). Using GPS equipped drift buoys for search and rescue operations. *GPS World*, November, Vol. 3, No. 10, pp. 36-41.

Innovation; satellite telemetry; GPS positioning; variable geometry; sea trials; sensors. This article is on the development of a drifting buoy that mimics the movement of a four-person life raft or a person wearing a life jacket. It is deployed from an aircraft or a ship in a search area to track the unpredictable movements of floating objects being pushed by winds and currents. The drifter determines its precise location using a GPS receiver. Position and sensor data are relayed to a search and rescue (SAR) coordination centre via a geostationary communications satellite. Tracking the movements of a small number of these drifters will aid coast guards in defining accurate search patterns during SAR operations.

4.01 Effect of the troposphere on GPS measurements — Brunner, Welsch

Brunner, F. K., and W.M. Welsch (1993). Effect of the troposphere on GPS measurements. *GPS World*, January, Vol. 4, No. 1, pp. 42-51.

Innovation; Nature of the delay; measurements; meteorological ground data; estimating zenith delays; effects on geodetic networks; conclusions. As they propagate from a satellite to a receiver on the ground, GPS signals must pass through the earth's atmosphere. In previous columns, the effect that the ionosphere—the ionized part of the atmosphere—had on GPS signals has been examined. Here the effect of the nonionized or neutral part, the bulk of which lies in the troposphere, is discussed.

4.02 Heights and GPS — Schwarz, Sideris

Schwarz, K. -P, and M.G. Sideris (1993). Heights and GPS. *GPS World*, February, Vol. 4, No. 2, pp. 50-56.

Innovation; defining heights; GPS heights; relation to other heights; accuracy; conclusions; the future. A GPS receiver determines its position in three dimensions — latitude, longitude, and height. The height coordinate is different from the horizontal coordinates in both how it is defined and how accurately it can be measured. In this column, the authors delve into the problems associated with determining heights from GPS observations.

4.03 Using GPS to determine the attitude of a spacecraft — Martin-Neira, Lucas

Martín-Neira, M., and R. Lucas (1993). Using GPS to determine the attitude of a spacecraft. *GPS World*, March, Vol. 4, No. 3, pp. 49-54.

Innovation; GPS attitude determination; noise, cycle slips, multipath; the invariant phase observable; spin-stabilized satellites; LEOs, HEOs, and GEOs; some test results. It is well known, at least to the readers of GPS World, that a GPS receiver can accurately determine the position and velocity of a moving platform. Less well known is the fact that with only slightly more sophisticated hardware and software, we can also use GPS to determine the orientation or attitude of the platform. Here is described the development of such a GPS-based system for determining the attitude of orbiting spacecraft.

4.04 The GPS observables — Langley

Langley, R. B. (1993). The GPS observables. *GPS World*, April, Vol. 4, No. 4, pp. 52-59.

Innovation; The pseudorange; carrier phase; point positions; relative positions (the single differences, the double difference, the triple difference); other linear combinations; conclusions. In previous columns, the structure of the signals transmitted by the GPS satellites and the basic operations performed by a GPS receiver in acquiring and processing the signals have been discussed. Here we take a closer look at the nature of the observations themselves, the biases and errors that afflict them, and how these effects can be removed or mitigated through modeling and data-differencing techniques.

4.05 Communication links for DGPS **Langley**

Langley, R. B. (1993). Communication links for DGPS. *GPS World*, May, Vol. 4, No. 5, pp. 47-51.

Innovation; Differential corrections (LF/MF, HF, VHF/UHF, mobile satellite communications); conclusion. To improve the positioning accuracy of a moving GPS receiver to the level of 10 metres or better, differential techniques must be used. To obtain such accuracy in real time, a datalink must be established between the moving GPS receiver and a fixed reference station. This article examines some of the communication link alternatives currently available or under development.

4.06 Making sense of GPS for marine navigation training **Shaw**

Shaw, S. G. (1993). Making sense of GPS for marine navigation training. *GPS World,* June, Vol. 4, No. 6, pp. 40-45.

Innovation; As GPS approaches full operational capability, it will bring navigators to the brink of a new era. Teachers of navigation in our maritime colleges and other institutions must adequately prepare their students for this era by fully incorporating GPS into the curriculum. Students must learn the principles of the new technology, but they also must be made aware of its limitations and pitfalls. This month's article tells how the California Maritime Academy in Vallejo is innovatively training budding navigators in the use of GPS. The conceptual shift. Trusting the black box (failure to look out the window; waypoint and route errors; failure to appreciate that the system can err; inability to understand or access available information). Learning to learn GPS. A new century and a new era.

4.07 Effects of the equatorial ionosphere on GPS **Wanninger**

Wanninger, L. (1993). Effects of the equatorial ionosphere on GPS. *GPS World,* July, Vol. 4, No. 7, pp. 48-54.

Innovation; When she was good, she was very, very good, but when she was bad, she was horrid. These lines from the familiar children's nursery rhyme might justifiably be used to describe the ionosphere. Under normal conditions in the mid-latitudes, the ionosphere is for the most part well behaved. GPS receivers can track the satellite signals from near horizon to horizon without difficulty, and the bias contributed by the ionosphere to pseudorange and carrier-phase observations can be readily removed by using dual-frequency observations. However, in the vicinity of the earth's magnetic equator, the ionosphere is at times quite "horrid," making life for the GPS user somewhat difficult. Wanninger describes the behavior of the equatorial ionosphere and how it affects the performance of GPS receivers. Scintillations. Monitoring scintillations. High total electron content. Large horizontal gradients. Conclusions.

4.08 [Showcase issue - no column]

4.09 Inertial navigation and GPS **May**

May, M. B. (1993). Inertial navigation and GPS. *GPS World*, September, Vol. 4, No. 9, pp. 56-66.

Innovation; The Global Positioning System (GPS) and inertial navigation systems (INSs), both of which can be considered discrete systems providing position and velocity information, were once regarded as potentially competing technologies. In this article, we explore the currently more prevalent viewpoint that the complementary or synergistic relationship between GPS and INSs could yield a marriage made in navigation heaven. Inertial navigation operation. History of inertial navigation. Inertial navigation mechanics. INS errors. GPS-INS integration. GPS benefits to INS (Calibration). INS benefits to GPS (Jamming; Velocity; Attitude; Integrity monitoring; Precise positioning). Status. Outlook.

4.10 GPS and the measurement of gravity — Kleusberg

Kleusberg, A. (1993). GPS and the measurement of gravity. *GPS World,* October, Vol. 4, No. 10, pp. 54-56.
Innovation; This article describes an application of GPS in a supporting role for the measurement of gravity. The article is limited to a brief discussion of the importance of gravity measurements for various fields of science and engineering, the problems encountered when measuring gravity on moving platforms, and how GPS can help to overcome these problems. Gravity and gravity anomalies. The measurement of gravity. Status.

4.11 Relativity and GPS — Ashby

Ashby, N. (1993). Relativity and GPS. *GPS World,* November, Vol. 4, No. 11, pp. 42-47 (incomplete).
Innovation; Relativistic effects in the Global Positioning System are surprisingly large, and users must carefully account for them, otherwise the system will not work properly. Important relativistic effects arise from relative motions of GPS satellites and users, and from the gravitational field of the earth. Even the earth's rotational motion requires significant relativistic corrections. This article describes these effects, quantifies them, and relates them to Einstein's fundamental principles: the constancy of the speed of light and the principle of equivalence. Constancy of light speed. Time dilation. The principle of equivalence. Sagnac effect. GPS time. Relativity in GPS. Conclusion. See December Showcase, Vol. 4, No. 12, p. 44, 1993 for the complete Conclusions segment of this article.

4.12 [Showcase issue - no column]

5.01 GLONASS receivers: An outline — Gouzhva et al.

Gouzhva, Y., I. Koudryavtsev, V. Korniyenko, and I. Pushkina (1994) GLONASS receivers - an outline. *GPS World*, January, Vol. 5, No. 1, pp. 30-36
Innovation; Although not as close to full operational capability as the U.S. Navstar Global Positioning System, the Russian Globalnaya Navigatsionnaya Sputnikovaya Sistema or Global Navigation Satellite System (GLONASS) also holds great promise as a "Swiss army knife" for all kinds of navigation, positioning, and timing problems. Unfortunately, there has been a dearth of readily available detailed information on GLONASS and, in particular, on GLONASS user equipment in English. This column will help to remedy this situation with an article on the principles of operation of GLONASS receivers. GLONASS basics; GLONASS signal structure; GLONASS receiver design (antenna, radio frequency converter, digital signal processor, navigation processor, ancillary blocks); Conclusion.

5.02 Detecting nuclear detonations with GPS — Highie, Blocker

Highie, P., and N. K. Blocker (1994). Detecting nuclear detonations with GPS. *GPS World,* February, Vol. 5, No. 2, pp. 48-50
Innovation; Most users of GPS are unaware that the GPS satellites serve a dual role. In addition to carrying the navigation and timing payload, the satellites carry a payload that enables them to detect nuclear weapons bursts; this system is called the Nuclear Detonation (NUDET) Detection System. Starting with the launch of satellite vehicle 8 (PRN 11), the GPS satellites have formed an important component in the U.S. arsenal for monitoring compliance with the nuclear weapon Non-Proliferation Treaty. This column describes the GPS NUDET system.

5.03 Monitoring the earth's atmosphere with GPS — Kursinski

Kursinski, R. (1994). Monitoring the earth's atmosphere with GPS. *GPS World*, March, Vol. 5, No. 3, pp. 50-54

Innovation; The spectrum of GPS uses seems to be limited only by the imagination of its users. Over the past four years, this column has examined many innovative ways to use GPS. Scientists and engineers have reported on their work dredging harbours, monitoring earthquake fault motion, mapping the ocean's surface and floor, studying the earth's rotation, finding survivors of marine accidents, determining the attitude of a spacecraft, and monitoring nuclear detonations — all with the help of GPS. This month's column features yet another innovative use of GPS signals: keeping tabs on the earth's atmosphere. Radio occultation. Technique overview. Spatial resolution. Sources of error. Applications. Opportunities and conclusion.

5.04 On-the-fly ambiguity resolution — Abidin

Abidin, H. Z. (1994). On-The-Fly ambiguity resolution. *GPS World*, April, Vol. 5, No. 4, pp. 40-50

Innovation; Developments in GPS user equipment technology are happening at a dizzying pace. These developments are not just restricted to hardware. Improvements and new concepts in software for processing GPS data have been just as noteworthy. One of the most recent additions to the GPS toolbox is on-the-fly (OTF) ambiguity resolution — determining the correct number of initial integer cycles in carrier-phase measurements, while a receiver is in motion. Developments in OTF ambiguity resolution have taken place at a number of research labs, and software that incorporates such resolution has recently become available from some receiver manufacturers. However, research is ongoing to provide faster and more reliable resolution. This paper explains some of the concepts involved in OTF ambiguity resolution and describes an algorithmic approach to provide fast and reliable ambiguity resolution. OTF ambiguity resolution; The technique; Computational aspects (use of ellipsoidal search space; use the narrow-land pseudorange position; the search space should be well sized); Geometrical aspects (use a longer wavelength; use more satellites; use fixed-reference satellite differencing; use periods of favorable satellite geometry; use a high data rate; use more than one monitor station); Prospects and limitations.

5.05 RTCM SC-104 DGPS standards — Langley

Langley, R. B. (1994). RTCM SC-104 DGPS standards. *GPS World*, May, Vol. 5, No. 5, pp. 48-53.

Innovation; In establishing a real-time differential GPS service, service providers are confronted with many choices. In addition to selecting the GPS receiver to be used at the reference station, they must select an appropriate radio communications link and interface it with the GPS receivers at the reference and user stations. The modulation technique and the content and format of the data to be transmitted to the users must also be specified. In an attempt to standardize some aspects of DGPS operation, the Radio Technical Commission for Maritime Services has recommended a standard receiver interface and the content and formation of data messages. In this article, we will take a brief look at these recommendations. Version 2.1. Differential Corrections. Message Format. Message Types (message type 1; message type 2; message type 3; message type 5; message type 5; message type 6; message type 7; message type 9; message type 16; message types 18-21). Datalink. Equipment Interface. With the current level of selective availability, the SC-104 transmission rate is sufficient to keep the one sigma positioning error to less than 3 metres at a 95 percent probability level, even in the case of 11 satellites.

5.06 Wide area differential GPS — Mueller

Mueller, T. (1994). Wide area differential GPS. *GPS World*, June, Vol. 5, No. 6, pp. 36-44.
Innovation; With real-time differential GPS (DGPS), users can obtain position accuracies better than five metres and, under some circumstances, even better than one metre, utilizing broadcast pseudorange corrections that significantly reduce the effects of satellite position and clock errors (including the contributions of selective availability), and ionospheric and tropospheric propagation delays. However, using DGPS with a single reference station has some drawbacks, including the localization of the highest position accuracies to a relatively small area. To overcome these disadvantages, several research groups are developing the technology of wide area differential GPS (WADGPS). This month's column tells us about WADGPS, its advantages and disadvantages, and the different algorithms that have been developed for its implementation. WADGPS Pros and Cons. Network Architectures. Types of Network Algorithms. Proposed Network Algorithms (measurement domain algorithms; state-space domain algorithms). Performance Estimates.

5.07 RINEX: The receiver-independent exchange format — Gurtner

Gurtner, W. (1994). RINEX: The receiver-independent exchange format. *GPS World*, July, Vol. 5, No. 7, pp. 48-52.
Innovation; The survey in the January 1994 issue of GPS World listed some 50 manufacturers of GPS receivers. Most of these manufacturers use their own proprietary formats for recording or outputting the measurements made by their equipment. This Babel of formats could have been a problem for surveyors, geodesists, geophysicists, and others doing postprocessed GPS surveying who wanted to combine data from receivers made by different manufacturers. Luckily, a small group of such users had the foresight several years ago to propose a receiver-independent format for storing GPS data — RINEX. This format has been adopted as the lingua franca of GPS postprocessing software, and most manufacturers now offer a facility for providing data from their receivers in this format. Werner Gurtner, one of the authors of RINEX, outlines the evolution of the format, its inherent philosophy, and the structure of its files. It is important to define precisely the meanings of the observables in RINEX observation files so that they can be properly interpreted by the processing software. Background. The Format (RINEX observation files; RINEX navigation message files; RINEX meteorological data files). Current and Future Status

5.08 [Showcase issue - no column]

5.09 Laser ranging to GPS satellites with centimetre accuracy — Degnan, Pavlis

Degnan, J. J., and E.C. Pavlis (1994). Laser ranging to GPS satellites with centimetre accuracy. *GPS World*, September, Vol. 5, No. 9, pp. 62-70.
Innovation; In 1960, Theodore H. Maiman, of the Hughes Aircraft Company, successfully operated the first device to generate an intense beam of highly coherent monochromatic radiation. He called his device a laser — for light amplification by the stimulated emission of radiation. The laser has become ubiquitous, with literally hundreds of uses ranging from optical surgery to precision machining. Lecturers use laser pointers; surveyors use laser distance-measuring devices; police officers use laser radar units to catch speeder. Most of us unwittingly use a laser each time we listen to our CD players — the light reflected from the microscopic pits on the CD is generated by a precisely positioned laser. One application of the laser that is not so well known is satellite laser ranging. This column introduces us to satellite laser ranging and describes the efforts to track two of the Navstar GPS satellites using this technique. SLR Principles. GPS Retroreflector Array. SLR Tracking of GPS. Orbital Analysis and Results.

5.10 GPS simulation — May

May, M. B. (1994). GPS simulation. *GPS World,* October, Vol. 5, No. 10, pp. 51-56.
Innovation; Whether one refers to it as virtual reality, augmented reality, or simulation, today's testing facilities enable one to "experience" GPS under dynamic conditions while being in a controlled laboratory environment. The capability to perform repeatable, realistic testing representing varying user, space, and control segment conditions has resulted in significant efficiencies. Test facilities represent the only practical context for the evaluation of responses to many failure modalities. Applications. Mechanization (satellite generator; satellite simulator system; user equipment test facility). Modes of Operation. SA and AS. Current Uses. Outlook.

5.11 GLONASS spacecraft — Johnson

Johnson, N. L. (1994). GLONASS spacecraft. *GPS World,* November, Vol. 5, No. 11, pp. 51-58.
Innovation; Despite the significant economic hardships associated with the breakup of the Soviet Union and the transition to a modern market economy, Russia continues to develop its space programs, albeit at a reduced level compared with that of the Cold War era. In particular, the Russian Global Navigation Satellite System (GLONASS), cousin to the U.S. Navstar Global Positioning system, continues to evolve toward full operational capability with the promise of enhancing the reliability and integrity of positioning using GPS alone. Although Russia is making GLONASS available to the world community, information on certain aspects of its operation is still hard to find. This article gives a detailed description of GLONASS spacecraft, how they are launched, and how the constellation of spacecraft has evolved since the first one was put into orbit in October 1982. Program Background. The Spacecraft (satellite lifetimes). Orbit and Delivery (placing the craft in orbit; deployment phases). Constellation Development. Future Directions.

5.12 [Showcase issue - no column]

6.01 Understanding GPS receiver terminology: A tutorial — Van Dierendonck

Van Dierendonck, A. J. (1995). Understanding GPS receiver terminology: A tutorial. *GPS World,* January, Vol. 6, No. 1, pp. 34-44.
Innovation; Buying a GPS receiver can be a lot more difficult than buying a car. In the Receiver Survey in this issue, no fewer than 275 different receivers are listed, ranging from basic handheld instruments costing a few hundred dollars to geodetic-quality receivers costing, in some cases, quite a bit more than a typical family sedan. In addition to price, these receivers may differ in how they access the GPS signals and how they process them to provide the raw observables or the computed coordinates. A growing lexicon of terms for describing how a GPS receiver works has evolved: codeless, semicodeless, codeless squaring, multibit sampling, all in view, time-to-first-fix — to cite a few. But what do these terms precisely mean and what do they indicate about the capability of a particular receiver? Background. Codeless and Semicodeless (squaring the signals; avoiding squaring's limitations with cross-correlation; codeless vs. semicodeless; performance considerations; interference considerations). Precorrelation Sampling (hard-limiting or 1-bit sampling; multibit sampling; interference considerations). Carrier and Code Tracking (carrier tracking; code-tracking terminology). Satellite-Tracking Strategies. All in View. Time-to-First-Fix. Measurement Accuracy. Receiver Sensitivity.

6.02 New tools for urban GPS surveyors Santerre, Boulianne

Santerre, R., and M. Boulianne (1995). New tools for urban GPS surveyors. *GPS World,* February, Vol. 6, No. 2, pp. 49-54.

Innovation; GPS is often touted as a go-anywhere, do-anything positioning and navigation system with few, if any, limitations. However, there is one real limitation to GPS: The satellite signals will not pass through most obstacles without being severely attenuated. The strength of the signals received inside buildings, for example, is usually well below the tracking threshold of GPS receivers. Outside, other buildings, trees (especially those with dark, wet foliage), and various structures can effectively block the signals. This presents a problem to GPS users in urban settings, particularly GPS surveyors. This article describes two tools that could greatly benefit the urban GPS surveyor. GPS Mission Planning. Soft-Copy Photogrammetry (testing the method; expanding applications). Up the Telescopic Mast. An Updated Surveyor's Toolbox.

6.03 Ocean tide loading and GPS Baker, Curtis, Dodson

Baker, T. F., D.J. Curtis, and A.H. Dodson (1995). Ocean tide loading and GPS. *GPS World,* March, Vol. 6, No. 3, pp. 54-59.

Innovation; Everyone is familiar with the tides in the ocean; those of us living near the seashore or visiting it on holidays have seen the water's ebb and flow. Most of us know a little about what causes the tides: the combined gravitational pulls of the moon and the sun on the oceans cause them to deform slightly or bulge; these bulges may be greatly amplified in narrow, shallow inlets. What may come as a surprise to many is that the solid earth, despite having an average rigidity about twice that of steel, is actually like an elastic ball, and it too deforms in response to tidal forces. A person standing on the earth's surface near the equator moves up and down with respect to the centre of the earth by about half a metre — twice a day! On top of this so-called body tide, there is an even more subtle displacement of the solid earth caused by the weight of the tidal waters. This ocean tide loading displacement and its effect on GPS measurements is the subject of this month's column. Tides in the Earth. Modelling Ocean Tide Loading. Ocean Tide Loading in the U.K. GPS Measurements. Future Developments.

6.04 A new way to fix carrier-phase ambiguities Teunissen et al.

Teunissen, P. J. G., P.J. de Jonge, and C.C.J. M. Tiberius (1995). A new way to fix carrier-phase ambiguities. *GPS World,* April, Vol. 6, No. 4, pp. 58-61.

Innovation; Of the two basic GPS observables, the pseudorange and the carrier phase, the carrier phase is by far the more precise. It has, however, an Achilles' heel: the initial measurements of the carrier phases of the signals received by a GPS receiver as it starts tracking the signals are undetermined, or ambiguous, by an integer number of carrier wavelengths. A GPS receiver has no way of distinguishing one carrier cycle from another. The best it can do is measure the fractional phase and then keep track of phase changes. Therefore, the initial unknown ambiguities must be estimated from the GPS data, and the correct estimates must be integers. There lies the rub: what is the best way to determine the correct integer ambiguities? Much research has been performed to find the most efficient, dependable, and accurate way to fix the ambiguities at their correct integer values. In this article we will learn of a new approach for ambiguity fixing: the least-squares ambiguity decorrelation adjustment method devised by a team of researchers from Delft Geodetic Computing Centre. Why Fix Ambiguities? Integer Least Squares. An Inefficient Search. The Ideal Situation. Decorrelated Ambiguities. The N-Dimensional Case. Test Results (Reduction in elongation; Improvement in precision; Efficiency; A further test).

6.05 Why on-the-fly? DeLoach, Wells, Dodd

DeLoach, S. R., D.E. Wells, and D. Dodd (1995). Why on-the-fly? *GPS World*, May, Vol. 6, No. 5, pp. 53-58.

Innovation; A lot of research and development effort is going into finding fast and efficient ways to resolve carrier-phase ambiguities. Such methods can enable GPS users to realize easily the maximum potential accuracy of GPS phase measurements for almost any application. With a quick and easy-to-implement technique to resolve ambiguities, GPS users can process carrier-phase measurements as easily as pseudorange measurements, even in real time. One such very promising technique is on-the-fly (OTF) ambiguity resolution, which allows ambiguities to be resolved even when a receiver is in motion. This month, we will briefly review the hows and whys of OTF ambiguity resolution and look at a number of very encouraging OTF tests in the marine environment. What is OTF? Why do we Need OTF? What is OTF's Status Today? (Kennebecasis Bay test; The Reversing Falls test; Testing the maximum range of OTF; OTF tide buoy test; OTF reliability test). What is the Impact of OTF?

6.06 DGPS with NASA's ACTS Austin, Dendy

Austin, A., and R. Dendy (1995). DGPS with NASA's ACTS. *GPS World,* June, Vol. 6, No. 6, pp. 42-50.

Innovation; The use of differential GPS (DGPS) is growing at a rapid rate. Witness the ongoing deployment of DGPS-enhanced low- and medium-frequency (LF and MF) beacon stations by the U.S. Coast Guard and other agencies in the United States and elsewhere, the recent introduction of commercial FM subcarrier-based DGPS correction services, and the increased use of private, site- or project-specific DGPS stations using high, very high, or ultrahigh frequency (HF, VHF, or UHF) communications links. These local DGPS operations can yield pseudorange-derived position accuracies at a few-meter level and, in some cases, even better than 1 m. But there are some limitations to these DGPS systems. The VHF and UHF systems are suitable for only line-of-sight use; the LF, MF, and HF systems must contend with noise and the vagaries of propagation; and most of these terrestrial systems are constrained to relatively narrow radio-frequency bandwidths that limit the rate at which DGPS corrections can be transmitted. These constraints may be circumvented by using satellites to transmit the corrections. The use of satellites to transmit DGPS corrections is not a new idea and already some commercial satellite-delivered DGPS services are available. But given their huge potential, much research remains to be done to push the edges of the technology envelope of such services. These limits are being pushed, in part, through a series of tests using a National Aeronautics and Space Administration (NASA) experimental satellite in geosynchronous orbit above a spot about 800 km west of the Galapagos Islands. This satellite, NASA's Advanced Communications Technology Satellite (ACTS), was launched in 1993 to test new satellite communications technologies and new services these technologies could provide. Among these services is DGPS. ACTS DGPS experiments are described and some of the results are given. ACTS technologies (spot beams; onboard switching; high rates). DGPS tests (static tests; kinematic tests). Communications performance (transmission latency; bit error rate). Conclusions and forecast.

6.07 NMEA 0183: A GPS receiver interface standard Langley

Langley, R. B. (1995). NMEA 0183: A GPS receiver interface standard. *GPS World,* July, Vol. 6, No. 7, pp. 54-57.

Innovation; The world of GPS receiver interfaces and data formats is a veritable alphabet soup of acronyms: RS-422-A, RTCM SC-104, AX.25, ARINC 429, TTL, PCMCIA; the list goes on and on. One acronym that has generated a lot of recent interest is NMEA 0183. It is the name of the standard developed by the National Marine Electronics Association for interfacing marine electronic devices, and it has become a standard interface for GPS receivers whether they're used at sea, on land, or in the air. In this month's column, we'll take a brief look at this interface standard and overview its electrical characteristics, data types, and data formats. Electrical characteristics. Data formats. Software.

6.08 [Showcase issue - no column]

6.09 Mathematics of attitude determination with GPS — Kleusberg

Kleusberg, A. (1995). Mathematics of attitude determination with GPS. *GPS World,* September, Vol. 6, No. 9, pp. 72-78.
Innovation; Several "Innovation" columns in earlier issues of GPS World described applications of GPS for the determination of attitude for aircraft, vessels, and spacecraft. These previous articles focused on the performance of GPS attitude systems in terms of accuracy and described the main error sources in GPS signals. The present "Innovation" article complements these earlier ones with a tutorial on the basic mathematics behind attitude description and determination. The equations and derivations in the article use a number of simplifying assumptions that may not be completely valid in real-life applications. The reader should be aware of these limitations, which are listed at the end of the article. The meaning of attitude. Rotation angles and matrices. The local level system. Body fixed system. Attitude from GPS. Practical considerations.

6.10 A GPS glossary — Langley

Langley, R. B. (1995). A GPS glossary. *GPS World,* October, Vol. 6, No. 10, pp. 61-63.
Innovation; The GPS lexicon can be overwhelming for newcomers to the technology. The different languages of the wide range of technologies that comprise GPS can sometimes be confusing to industry experts as well. In this month's column, we present a glossary of some of the more frequently encountered GPS terms — from almanac to Z-count — to assist the newcomer and expert alike. almanac, ambiguity, antispoofing, binary biphase modulation, coarse acquisition, carrier, carrier phase, carrier-to-noise power density, carrier-tracking loop, chip, circular error probable, code-tracking loop, costas loop, cycle slip, delay-lock loop, differential GPS, dilution of precision, doppler effect, double difference, ephemeris, geodetic datum, geodetic height, geoid, geoidal height, GLONASS, GPS time, GPS week, hand-over word, Kalman filter, Keplerian elements, L-band, local area DGPS, microstrip antenna, multipath, multiplexing, narrow correlator, narrow lane, navigation message, NMEA 0183, on-the-fly, orthometric height, precision code, phase-lock loop, precise positioning service, pseudorandom noise code, pseudorange, quadrifilar helix, real-time kinematic, RINEX, RTCM SC-104, selective availability, single difference, spherical error probable, spread-spectrum, standard positioning service, triple difference, coordinated universal time, user equivalent range error, UT1, wide area augmentation system, wide area DGPS, wide-lane observable, world geodetic system 1984, y-code, z-count.

6.11 GPS and the Internet — Langley

Langley, R. B. (1995). GPS and the Internet. *GPS World,* November, Vol. 6, No. 11, pp. 59-63.
Innovation; The Internet is revolutionizing the way we communicate and exchange information. Everyone from government officials to restaurant managers now seems to be using this "supernetwork" to get or give information. Some of the bits whizzing back and forth on it are messages and files that have something to do with GPS. In this month's column we'll take a look at just how the Internet is being used to disseminate information about GPS, GPS data, and related products. GPS on the net. Discussion groups. Internet terminology.

6.12 [Showcase issue - no column]

7.01 The GPS user's bookshelf — Langley

Langley, R. B. (1996). The GPS user's bookshelf. *GPS World,* January, Vol. 7, No. 1, pp. 56-63.

Innovation; In November's column we took a look at the various sources of GPS information in electronic format available through the Internet. This month, we turn to the printed word and present an overview of the growing library of books and other publications about GPS and its many applications. Introductory (the Trimble booklets; Getting Started with GPS Surveying; A Comprehensive Guide to Land Navigation with GPS; the Federal Radionavigation Plan). Intermediate (the Navstar Global Positioning System; Guide to GPS Positioning; Global Navigation — A GPS User's Guide; Aviator's Guide to GPS). Advanced (the red books; Global Positioning System, Theory and Practice; GPS Satellite Surveying; ICDS-GPS-200; Global Positioning System Standard Positioning Service Signal Specification; The Global Positioning System: A Shared National Asset; The Global Positioning system: Charting the Future). Proceedings and journals. Forthcoming (GPS — Theory and Applications; GPS for Geodesy; The Global Positioning System and GIS; Understanding GPS: Principles and Applications).

7.02 The synergy of VLBI and GPS — Gipson

Gipson, J. (1996). The synergy of VLBI and GPS. *GPS World,* February, Vol. 7, No. 2, pp. 49-55.

Innovation; Although developed in the mid-1960s by rival teams of American and Canadian radio astronomers for studying compact extragalactic radio sources such as quasars, very long baseline interferometry (VLBI) was quickly taken up by geoscientists as a tool for studying the earth. VLBI uses two or more radio telescopes to pick up the extremely faint signals from quasars and their kin. The technique is extremely sensitive to the relative positions of the radio telescope antennas and, with the appropriate signal processing, these positions can be determined to the subcentimetre level, even if the baselines connecting the antennas span a continent or an ocean. Gipson describes the VLBI technique, how it has been used to learn more about how the earth "works," and the similarities and differences between VLBI and GPS and their important synergistic relationship. VLBI and geophysics. How an interferometer works. What is a quasar? The VLBI technique. Comparison of VLBI and GPS. Station positions. The future.

7.03 Double duty: Russia's DGPS/DGLONASS maritime service — Chistyakov et al.

Chistyakov, V. V., S.V. Filatchenkov, V.I. Khimulin, and V.V. Kornyenko (1996). Double duty: Russia's DGPS/DGLONASS maritime service. *GPS World,* March, Vol. 7, No. 3, pp. 59-62.

Innovation; The Russian Institute of Radionavigation and Time (RIRT) is developing a differential Global Navigation Satellite System (DGNSS) service that combines GPS and GLONASS differential corrections to provide safe passage to vessels traveling in Russia's coastal waters. RIRT scientists and engineers have developed this single datalink service by taking advantage of the different update rates needed for GPS and GLONASS corrections. This article describes how the service will work, including the different message types that will be transmitted. The authors all work at RIRT in St. Petersburg. System requirements. Message types. By making the structure of DGPS and DGLONASS messages analogous, both manufacturers and users will benefit from DGNSS equipment simplification. Schedule of messages.

7.04 The role of the clock in a GPS receiver — Misra

Misra, P. N. (1996). The role of the clock in a GPS receiver. *GPS World,* April, Vol. 7, No. 4, pp. 60-66.
Innovation; It sounds a little strange but the most precise way of measuring a distance is to use a clock. Time, the quantity most difficult to define, is the one we know how to measure most precisely. In fact, the length of the metre is defined in terms of the length of the second through the adopted value of the speed of light in a vacuum. It is this fundamental relationship (distance = speed x time) that is at the heart of how GPS works. By measuring the time elapsed for a signal to propagate from a satellite to a receiver and multiplying it by the speed of light, a GPS receiver can determine the range to the satellite. But there's a hitch. Any error in the time-keeping capability of the receiver's clock will be reflected in the computed range. In this month's column, Dr. Misra, will review the role of the clock in a GPS receiver and the effect its performance has on GPS position accuracy. How perfect is perfect? Correlations of 4-D estimates. Clock modelling. Clock-aided navigation. Additional benefits (RAIM; carrier-phase processing).

7.05 The promise of a third frequency — Hatch

Hatch, R. R. (1996). The promise of a third frequency. *GPS World,* May, Vol. 7, No. 5, pp. 55-58. See Letter to Editor, McGibney, D.B., "On a different wavelength," Vol. 8, No. 1, January 1997, p. 12.
Innovation; The recently published reports by the National Academy of Public Administration and the National Research Council recommended the implementation of a third GPS navigation frequency. The motivation for a third frequency was to provide an unrestricted means for measuring the induced ionospheric refraction errors on code and carrier-phase measurements. In this month's column, Ron Hatch discusses the implications that the addition of a third frequency would have not only in reducing ionospheric effects but also in assisting in the resolution of carrier-phase ambiguities and hence in permitting centimetre-level, wide-area differential accuracy. Hatch, a principal with the recently formed company Navcom Technology in Wilmington, California, has a long and distinguished involvement with satellite navigation. He has developed a number of unique processing techniques for the U.S. Navy Navigation Satellite System — commonly known as Transit — as well as for GPS. Perhaps his most widely used GPS innovation is the smoothing of code measurements using the carrier phase. The wide lane (code measurement, carrier-phase measurement, calculating the wide lane). The effect of noise. A second wide lane.

7.06 Navigation solution accuracy from a spaceborne GPS receiver — Mitchell et al.

Mitchell, S., B. Jackson, S. Cubbedge, and T. Higbee (1996). Navigation solution accuracy from a spaceborne GPS receiver. *GPS World,* June, Vol. 7, No. 6, pp. 42-50.
Innovation; GPS receivers are being put to work not just on and near the earth's surface but in space as well. More than 20 spacecraft containing GPS receivers have been orbited so far, and another 40-50 spacecraft already in the design or construction stage are slated to carry GPS receivers. Spaceborne GPS receiver applications include position and velocity measurements, precise time referencing, precision orbit determination using differential techniques, and characterization of the earth's atmosphere. GPS data can also be used on board a spacecraft to perform autonomous navigation. In this month's column, we will examine the performance of the GPS receiver on board the DARPASAT spacecraft. DARPASAT was constructed for the Defense Applied Research Projects Agency (DARPA) by Ball Aerospace and Technology Corporation in Boulder, Colorado. GPS nav solution accuracy (data gathering; data selection; data analysis; comparison to ranging solution).

7.07 Gravity and GPS: The G connection — May

May, M. B. (1996). Gravity and GPS: The G connection. *GPS World*, July, Vol. 7, No. 7, pp. 53-57.

Innovation; The advances in GPS and terrestrial gravity-measurement technology are so intertwined that it is difficult to discern which is the driving force. The two fields are intimately connected through fundamental laws of science and through mundane practical necessities. In this column we will explore how research in one field has facilitated advancements in the other. Basic gravitational quantities (disturbance quantities; gravity field spectral power). Quality relationships. Gravity databases (gravimeter measurements; artificial satellites; refined gravity models). Present status. Additional techniques. Future development.

7.08 [Showcase issue - no column]

7.09 International terrestrial reference frame — Boucher, Altamimi

Boucher, C., and Z. Altamimi (1996). International terrestrial reference frame. *GPS World*, September, Vol. 7, No. 9, pp. 71-74. See letter to the editor, "Arbitrary alterations," by Thomás Soler, Vol. 8, No. 2, February 1997, p. 12; and answer by C. Boucher, Vol. 8, No. 2, February 1997, p. 12.

Innovation; To answer the question "Where am I?" we could describe verbally our position with respect to nearby landmarks, but it is usually far more useful to describe our position with respect to a reference system of mathematical coordinates. Such systems covering regional land masses have been established by national survey organizations over the past 100 years or so. With the advent of space techniques in geodesy and navigation, there was a need for the development of global or international reference systems and their realizations through the establishment of coordinate reference frames. Several such systems and frames have been introduced, including the series of U.S. Department of Defense World Geodetic Systems. The highest-accuracy global frame is the International Terrestrial Reference Frame (ITRF) established by the Paris-based International Earth Rotation Service. This column will look at the development of the ITRF and its relationship to GPS. ITRF computation. ITRF datum definition (orientation; origin; scale; time evolution). Transformation parameters. ITRF and GPS (ITRF coordinates for GPS sites).

7.10 Measuring GPS receiver performance: A new approach — Gourevitch

Gourevitch, S. (1996). Measuring GPS receiver performance: A new approach. *GPS World*, October, Vol. 7, No. 10, pp. 56-62.

Innovation; What is the best way to compare GPS receivers? That depends. Many features could be considered: Size, ease-of-use, power requirements, cost, and so forth. Those receiver characteristics are fairly easy to enumerate. But receiver performance or the precision and accuracy of the observables — the pseudorange and carrier phase — and the positions computed from them is a little harder to quantify. Unfortunately, some quoted measures of performance tell us very little about how a receiver actually measures up. In this month's column, Sergei Gourevitch points out the problems with some performance measures and suggests an innovative way to assess a GPS receiver's performance. General considerations. Zero-baseline tests. Test range measurements. The whole story. SVAR. What does it all mean? Very long smoothing times. Dual-frequency receivers.

7.11 GPS for military air surveillance — Van Sickle

Van Sickle, G. A. (1996). GPS for military air surveillance. *GPS World*, November, Vol. 7, No. 11, pp. 56-59.

Innovation; One of the most important and unsung developments of the Second World War was the IFF (Identification Friend or Foe) system. A primitive radar identification system, IFF used a ground-based transmitter to broadcast a pair of coded pulses to aircraft within its range. Friendly aircraft were equipped with a transponder that received the pulses and, if the signal required a response, would transmit a uniquely coded and formatted reply that could be used to determine the specific aircraft's identity. This would then be overlain on a radar display. If an aircraft did not reply or replied with the incorrect code or in the incorrect format, it was assumed to be an enemy aircraft. This system was the progenitor of the modern secondary surveillance radar systems that are used for air surveillance by both military and civil authorities. The modern systems have been able to report an aircraft's altitude, in addition to its identity, for some time now. A new capability is currently being added to civilian systems that will use a GPS receiver on board the aircraft to determine its position and self-report it to air traffic control centers and other aircraft in the vicinity. In this column, these new developments in civil air surveillance will be described and their potential use by the military, which seems to be lagging behind the civil community in this area. What is the problem? The commercial approach. The first steps. The road to ADS-B. The power of CDTI.

7.12 [Showcase issue - no column]

8.01 Coordinates and datums and maps! Oh my! — Featherstone and Langley

Featherstone, W., and R.B. Langley (1997). Coordinates and datums and maps! Oh my! *GPS World*, January, Vol. 8, No. 1, pp. 34-41. See letter to editor by Michael Kennedy, "Coordinates, datums, indeed!" Vol. 8, No. 3, March 1997, p. 12.

Innovation; The walk through the enchanted forest of Oz, with its lions and tigers and bears, was a pretty scary proposition for Dorothy Gale and her friends. Some GPS users find themselves in a similar predicament when they try to understand the enchanted forest of geodesy and the relationship among coordinates, datums, and maps. This column sketches the relationships among the coordinate systems used worldwide for GPS and the coordinate systems and map projections used in various countries. They also discuss how these differences can affect the GPS user when employed incorrectly. Putting GPS on the map. Choose wisely. Transforming coordinates (block shift; Similarity transformations; Projective transformations). Map projections. The links. GPS receiver features. And finally.

8.02 Carrier phase wrap-up induced by rotating GPS antennas — Tetwsky, Mullen

Tetewsky, A. K., and F.E. Mullen (1997). Carrier phase wrap-up induced by rotating GPS antennas. *GPS World*, February, Vol. 8, No. 2, pp. p. 51-57.

Innovation; GPS receivers are ubiquitous. They are now used for a myriad of applications and can be found in the hands of navy frogmen, mounted on tractors, carried aloft by weather balloons, and orbiting in spacecraft. And the miniaturization of receivers allows them to be embedded in such diverse devices as cellular telephones and artillery shells. GPS receivers work more or less the same way regardless of the kind of platform they are attached to. However, some users have recently concluded that, if the platform is spinning, a rotational effect must be accounted for: carrier phase wrap-up. This effect is the change in the GPS carrier phase caused by rotation of a circularly polarized receiving antenna relative to a circularly polarized GPS signal. If the wrap-up effect is not accounted for, a receiver can make significant position fix errors when fewer than four satellites are in view. This column presents an intuitive derivation of the effect and summarizes the results of an innovative procedure to calculate phase wrap-up. Also presented are predictions for a common antenna type — the crossed dipole — and these are compared with GPS measurements collected from a rooftop spinning-antenna experiment. An intuitive view. General model (calculations and analysis; base mounted; circumference mounted). Experimental data. Summary.

8.03 The GPS error budget **Langley**

Langley, R. B. (1997). The GPS error budget. *GPS World*, March, Vol. 8, No. 3, pp. 51-56. Innovation; No measuring device is perfect, whether it be a yardstick or a precision analytical balance. A GPS receiver is no exception. The receiver attempts to determine the distances, or ranges, between its antenna and the transmitting antennas of the satellites whose signals it has picked up. Based on those ranges and a knowledge of satellite locations, the receiver can compute its position. However, several errors corrupt range measurements and consequently propagate into the receiver-computed positions. Here we will examine the different errors that corrupt range measurements made by a stand-along GPS receiver operating under the Standard Position Service (SPS). Although higher positioning accuracies can be achieved with differential techniques — even to the subcentimeter level — we will restrict our attention to the stand-alone receiver, by far the largest "species group" in the GPS user community. We will look at the causes of the SPS errors and their typical magnitudes and what, if anything, can be done to ameliorate them. A satellite's signal (measuring the pseudorange). Ephemerides. GPS, clocks, and time (keeping satellite time; intentional signal degradation; receiver clocks). Propagation delays (ionosphere; troposphere; mapping functions). Multipath. Receiver noise (code tracking loop). Dilution of precision.

8.04 Conquering multipath: The GPS accuracy battle **Weill**

Weill, L. R. (1997). Conquering multipath: The GPS accuracy battle. *GPS World*, April, Vol. 8, No. 4, pp. 59-66.
Innovation; We will take a closer look at multipath and the techniques for mitigating its effects, including some recent innovative receiver design. The multipath problem. Spatial mitigation techniques (special antennas; multiantenna spatial processing; antenna location strategy; long-term signal observation). Receiver processing methods (standard range measurements; a correlation function's leading edge; narrow-correlator technology (1990-93); correlation-function shapes (1994-95); the strobe correlator; modified correlator reference waveforms). How good can it get? Carrier-phase ranging. Receiver testing.

8.05 Performance overview of two WADGPS algorithms **Abousalem**

Abousalem, M. A. (1997). Performance overview of two WADGPS algorithms. *GPS World*, May, Vol. 8, No. 5, pp. 48-58.
Innovation; In response to the current growing demand for low-cost, country- and continent-wide differential GPS (DGPS) positioning, and with the help of the ever-advancing communication and computer technologies, industry innovators have recently developed a variety of real-time DGPS techniques, including wide area differential GPS (WADGPS). The catalyst for this evolution in DGPS has been the accuracy, availability, and accessibility limitations of conventional DGPS techniques. The advantages of WADGPS include coverage of large, inaccessible areas using a minimum number of reference stations. Also, compared with single-reference-station methods, the positioning accuracy degrades much more slowly with baseline length. And, if users employ the correct architecture, WADGPS systems are typically more fault tolerant. This month the author discusses the basic concepts of WADGPS and presents two different algorithms that can be used to implement the technique. Wide Area Differential GPS (orbital errors; atmospheric errors). WADGPS algorithms (measurement domain; position domain; state-space domain). System components (real-time active control points; real-time master active control station; virtual active control points; user segment; integrity monitor stations). Two WADGPS algorithms (measurement domain algorithm; state-space domain algorithm). Test procedure and dataset. Results and analyses. Conclusions.

8.06 GPS receiver system noise **Langley**

Langley, R. B. (1997). GPS receiver system noise. *GPS World*, June, Vol. 8, No. 6, pp. 40-45.
Innovation: How well a GPS receiver performs — that is, how precisely it can measure the pseudorange and carrier phase — largely depends on how much noise accompanies the signals in the receiver's tracking loops. The more noise, the worse the performance. This noise either comes from the receiver electronics itself or is picked up by the receiver's antenna. In this article we'll take a look at noise, discuss its causes, and assess its effect on the GPS observables. Thermal noise. Antenna noise (Electromagnetic radiation). Antenna temperature (GPS antennas). System noise (Cable loss; Receiver temperature). Carrier-to-noise density ratio. Code-tracking loop. Carrier-tracking loop.

8.07 GLONASS: Review and update **Langley**

Langley, R. B. (1997). GLONASS: Review and update. *GPS World,* July, Vol. 8, No. 7, pp. 46-51.
Innovation: The Navstar Global Positioning System is not the only game in town. Russia's GLONASS is also essentially operational and, despite currently having an incomplete constellation, provides civilian stand-alone positioning accuracies typically much better than those of GPS with the current practice of selective availability. In this column we will briefly review the technical characteristics of GLONASS, comparing and contrasting them with GPS. We will also assess the current development and performance of GLONASS and briefly describe GLONASS and combined GPS/GLONASS receivers. GLONASS segments (Control segment; Space segment; User segment). System characteristics (Navigation message; Geodetic datum). GLONASS receivers. GLONASS performance. Combined GPS/GLONASS use. Other developments. Conclusion.

8.08 [Showcase issue - no column]

8.09 The Kalman filter: Navigation's integration workhorse **Levy**

Levy, L. J. (1997). The Kalman filter: Navigation's integration workhorse. *GPS World,* September, Vol. 8, No. 9, pp. 65-71. See Letter to Editor "The ancient mariner revised," by J. C. Sentell, Vol. 9, No. 2, February, p. 12.
Innovation: Since its introduction in 1960, the Kalman filter has become an integral component in thousands of military and civilian navigation systems. This deceptively simple, recursive digital algorithm has been an early-on favorite for conveniently integrating (or fusing) navigation sensor data to achieve optimal overall system performance. To provide current estimates of the system variables — such as position coordinates — the filter uses statistical models to properly weight each new measurement relative to past information. It also determines up-to-date uncertainties of the estimates for real-time quality assessments or for off-line system design studies. Because of its optimum performance, versatility, and ease of implementation, the Kalman filter has been especially popular in GPS/inertial and GPS stand-alone devices. This column introduces us to the Kalman filter and outlines its application in GPS navigation. Equation-free description. A simple example. GPS/INS integration. GPS-only navigation. Practical design. Conclusions

8.10 Comparing GPS ambiguity resolution techniques **Han, Rizos**

Han, Shaowei, and C. Rizos (1997). Comparing GPS ambiguity resolution techniques. *GPS World,* October, Vol. 8, No. 10, pp. 54-61.
Innovation: Centimeter-accurate GPS rapid-static and kinematic positioning require ambiguity resolution to convert ambiguous carrier-phase measurements into unambiguous ranges. During the past decade, the GPS research community has developed many ambiguity resolution techniques with different features and suitabilities for specific applications. In this column, the various techniques and their potential for further improvement are outlined,

compared, and discussed. Special operational modes (Antenna swap; Stop and go; Reoccupation; Single-receiver relative positioning). Observation domain search. Coordinate domain search. Ambiguity domain search. Ambiguity recovery technique. Integrated techniques. Concluding remarks.

8.11 Interference: Sources and symptoms Johannessen

Johannessen, R. (1997). Interference: Sources and symptoms. *GPS World,* November, Vol. 8, No. 11, pp. 44-48.
Innovation: As we become more and more reliant on GPS, it becomes increasingly important to understand its limitations. One such limitation is vulnerability to interference. This column contains a discussion of different kinds of interference, how we may recognize when it occurs, and what we can do to protect ourselves. Interference sources (In-band emissions; Nearby-band emissions; Harmonics; Jamming). How vulnerable is GPS? (GPS and GLONASS differences; Recognizing interference). GPS protection (Manufacturer influence). Consumer advice (Search out the source). In conclusion.

8.12 [Showcase issue - no column]

9.01 GPS accuracy: Lies, damn lies, and statistics van Diggelen

van Diggelen, F. (1998). GPS accuracy: Lies, damn lies, and statistics. *GPS World,* January, Vol. 9, No. 1, pp. 41-45.
Innovation: “There are three kinds of lies: lies, damn lies, and statistics.” So reportedly said Benjamin Disraeli, prime minister of Great Britain from 1874 to 1880. And just as the notoriously wily statesman noted, the science of analyzing data, or statistics, sometimes yields results that one can interpret in a variety of ways, depending on politics or interests. Likewise, we in the satellite navigation field interpret results depending on the information we wish to produce: Using various statistical methods, we can create many different GPS and GLONASS position accuracy measures. It can seem confusing, even misleading, but as we’ll see in this month’s column, there’s some rhyme to our reason. We’ll examine some of the most commonly used accuracy measures, reveal their relationships to one another, and correct several common misconceptions about accuracy. Popular accuracy measures (Ascertaining accuracy: An example; Making valid assumptions; Starting a small test; Closing the circle). Common misconceptions. In conclusion. Deriving the equivalent accuracies table.

9.02 The UTM grid system Langley

Langley, R. B. (1998). The UTM grid system. *GPS World,* February, Vol. 9, No. 2, pp. 46-50.
Innovation: All GPS receivers can provide position information in terms of latitude, longitude, and height, and usually in a variety of selectable geodetic datums. For many purposes, position information in this format is more than adequate. However, when plotting position information on maps or carrying out supplemental calculations using the position coordinates, it can be advantageous to work instead with the corresponding grid coordinates on a particular map projection. One of the most widely used map projection and grid systems is the Universal Transverse Mercator (UTM) system. Many GPS receivers can directly output position information in UTM coordinates. Here we look at the UTM system, see how UTM grid coordinates are related to geodetic coordinates, and indicate the corrections to be applied to grid distances and bearings to get the actual true quantities on the earth’s surface. Coordinates and projections (Down-to-earth coordinates). Mercator’s world (Adopting the ellipsoid). A universal projection (The grid; Military grid reference). An example.

9.03 Pseudolites: Enhancing GPS with ground-based transmitters Cobb, O’Connor

Cobb, S., and M. O'Connor (1998). Pseudolites: Enhancing GPS with ground-based transmitters. *GPS World*, March, Vol. 9, No. 3, pp. 55-60.
Innovation: The Global Positioning System was originally conceived and designed as a stand-alone positioning and navigation system. As such, it is unmatched in its cost-effectiveness, accuracy, geographical coverage, and reliability. Nevertheless, to further improve its integrity, availability, and accuracy, developers have enhanced GPS in many ways. These augmentations include differential GPS, combined GPS and GLONASS operation, and the proposed Wide Area Augmentation System, to name but a few. One other GPS enhancement that may not be as familiar has actually been around longer than any other: ground-based transmitters that broadcast GPS-like signals to supplement those generated by the satellites. Here we examine how these pseudo-satellites, or pseudolites, work and how they are being used. What is a pseudolite? Primary pseudolite uses (Code-based ranging augmentation; Code-phase differential ranging; Carrier-phase differential ranging; Changing geometry; Ambiguity resolution applied; Reverse positioning; Indoor pseudolites). The near-far "problem" (Signal pulsing; P-code use).

9.04 Cellular telephone positioning using GPS time synchronization Klukas et al.

Klukas, R., G. Lachapelle, and M. Fattouche (1998). Cellular telephone positioning using GPS time synchronization. *GPS World*, April, Vol. 9, No. 4, pp. 49-54.
Innovation: In 1996, the number of daily emergency calls from cellular and other wireless telephones in the United States to 911 operators totalled about 60,000. Experts project that this number will exceed 130,000 calls per day by the turn of the millennium. Landline calls to 911 automatically provide a call-back number and the caller's location thanks to the recently implemented Enhanced 911 (E-911) service adopted by most communities in the United States and Canada. However, wireless calls do not include this information and often those callers do not know or have trouble describing their exact location, making it difficult for public service operators to rapidly dispatch emergency services. Recognizing the need to make wireless telephones compatible with E-911 emergency calling systems, the Federal Communications Commission (FCC) has directed wireless service companies to enact certain improvements to their network operations. One of these is to provide automatic location identification of wireless 911 calls to within 125 metres (distance-root-mean-square). In this column, we will examine a system that has the potential to meet the FCC's requirement by locating an analogue cellular telephone using differences in arrival times of the telephone's signals at multiple network cell sites. The system uses GPS to make the time measurements to the required accuracy. TOE Estimation. System Description (Time tagging with GPS; Full correlation with MUSIC; Position estimation). Simulations. Field tests.

9.05 The effect of weather fronts on GPS measurements Gregorius, Blewitt.

Gregorius, T., and G. Blewitt (1998). The effect of weather fronts on GPS measurements. *GPS World*, May, Vol. 9, No. 5, pp. 52-60.
Innovation: On the southeast coast of England, not very far from where the Battle of Hastings occurred, lies Herstmonceux Castle — a fifteenth-century manor house that was, for many years, the home of the Royal Greenwich Observatory (RGO). Although the skies above the castle are generally clearer than those above RGO's original home in the London borough of Greenwich, the frequently cloudy and rainy conditions are less than ideal for astronomy. RGO, therefore, built new telescopes on La Palma in the Canary Islands and moved most of its administrative and research facilities to Cambridge in 1990. The same poor conditions dreaded by astronomers, however, are ideal for studying weather fronts in relation to GPS. The grounds of Herstmonceux Castle (now owned by Canada's Queen's University and operated as an international study center) house an International GPS Service (IGS) station. This site has provided the authors with a wealth of data for their studies of the effects of weather fronts on GPS measurements, which they recount in this month's column.

Atmospheric Delay. The Positioning Effect. What is a Weather Front? (Out in front; Sample fronts). The Delay Effect (Delay estimation models; Testing the models). Fronts and GPS Precision (Improving repeatability; Vertical velocity; The horizontal factor). Remedies and Possibilities (Supplementing with satellites; Fixing the time series; Other options). Conclusion.

9.06 The NSTB: A stepping stone to WAAS — Hansen

Hansen, A. (1998). The NSTB: A stepping stone to WAAS. *GPS World*, June, Vol. 9, No. 6, pp. 73-77
Innovation: The accuracy, integrity, and availability of the Standard Positioning Service are currently insufficient for the aviation community to use GPS as a primary means of navigation for en route travel or for nonprecision and Category I approaches to airports. To permit such use, the Federal Aviation Administration, in concert with industry and academic partners, is developing the Wide Area Augmentation System (WAAS). A prototype WAAS — the National Satellite Test Bed (NSTB) — is already in operation. The NSTB affords researchers and system developers the opportunity to validate the WAAS architecture, software algorithms, hardware, and terrestrial and satellite communications systems using live GPS signals. In this month's column, the author outlines some of the research and development work involving the NSTB being carried out at Stanford University. WAAS in Practice (Reference stations; Error models). The Stanford Connection (Displayed data; Custom configurations and displays). WAAS Metrics (Accuracy; Integrity; Availability). Flight Testing.

9.07 A primer on GPS antennas — Langley

Langley, R. B. (1998). A primer on GPS antennas. *GPS World*, July, Vol. 9, No. 7, pp. 73-77.
Innovation: The GPS receiver is a marvel of modern electronic engineering. By processing the signals transmitted by the constellation of orbiting Navstar satellites, its sophisticated circuitry can deliver position, velocity, and time information to a user anywhere on or near the earth's surface, 24 hours a day, every day. But before the receiver can use the signals, they must first be captured. This is the task of the receiver's antenna. GPS signals are relatively weak compared with the signals from broadcasting stations and terrestrial communications services, and a GPS antenna is specially designed to work with these feeble signals — a coat hanger will not do! In this month's column, the author takes a look at the GPS antenna. This will only be an introduction to the complex subject of antenna design and construction, but it should enable you to better understand antenna specifications and how your receiver's antenna works. Fields and Waves. Antenna Characteristics (Impedance; Standing wave ratio; Bandwidth; Gain pattern; Ground planes; Phase-center variation; Other factors). Low Noise Preamp. Transmission Lines. Loose Ends. Conclusion.

9.08 [Showcase issue - no column]

9.09 RTK GPS — Langley

Langley, R. B. (1998). RTK GPS. *GPS World*, September, Vol. 9, No. 9, pp. 70-76
Innovation: Novare, the Latin root of the word innovation, means to make new. And that is exactly what scientists and engineers working with the Global Positioning System have been doing ever since the conception of GPS in the early 1970s. Not only have they discovered many new GPS applications, they have devised new ways to use the GPS signals. One of their most recent innovations is RTK, real-time kinematic, GPS — a technique that provides position accuracy close to that achievable with conventional carrier-phase positioning, but in real time. In this month's column we'll briefly examine RTK GPS, emphasizing one of the system's critical components: the radio link. A Fix on Accuracy (Craft positioning). Carrier-Phase Positioning (Using the carrier phase; Postprocessing; Real time; Correction message formats). RTK System Architecture. The Data Link (Propagation distances; Predicting

signal path loss; Analyzing the link's viability). RTK Solutions (Resolving ambiguities on-the-fly; GLONASS advantages). Conclusion.

9.10 GPS MATLAB toolbox review — Tetewsky, Soltz

Tetewsky, A. K., and A. Soltz (1998). GPS MATLAB toolbox review. *GPS World*, October, Vol. 9, No. 10, pp. 50-56.

Innovation: Simulate, as defined by the Concise Oxford Dictionary of Current English, means to "imitate conditions of (situation etc.) with model, for convenience or training." Very often in the fields of science and engineering, we need to simulate a situation — just as the definition indicates — before it occurs to help us design or understand a system or its components. So it is with GPS. We can carry out GPS simulations using either hardware — which we briefly examined in a previous column — or software, which we'll take a look at this month. Our discussion will take the form of a review of four GPS simulation packages that use the popular and versatile MATLAB programming language. GNSS toolbox. Constellation toolbox. SatNav toolbox. GPS signal simulation toolbox. Our Approach (Table abbreviations). The Review. Simulation Challenges (First things first; Problem two; Challenge three; Pinning down P4; The key to five; Last but not least). Our Experiences (Comments and suggestions; Orion and Constell; GPSoft; Navsys). Overall Suggestions.

9.11 The GPS end-of-week rollover — Langley

Langley, R. B. (1998). The GPS end-of-week rollover. *GPS World*, November, Vol. 9, No. 11, pp. 40-47.

Innovation: At a few seconds after midnight, Universal Time, on August 22, 1999, the GPS week counter will roll over from 1023 to zero. Although perhaps a little less momentous than the so-called Y2K problem, it has the potential to cause difficulties for some GPS users. In this month's column, we'll examine this event, why it will occur, and the anticipated consequences. GPS Time (Time differences; Z count; Time of week). The Rollover. Receiver Effects (Pinning down the problem). Conclusion.

9.12 [Showcase issue — no column]

10.01 GLONASS to GPS: A new coordinate transformation — Bazlov et al.

Bazlov, Y. A., V. F. Galazin, B. L. Kaplan, V. G. Maksimov, and V. P. Rogozin (1999). *GPS World*, January, Vol. 10, No. 1, pp. 54-58.

Innovation: Although GLONASS is currently operating with a fraction of its full complement of satellites, interest in and use of the system continues to grow as evidenced in part by the International GLONASS Experiment (IGEX) currently underway. In addition to fostering cooperation between the international research community and Russian organizations responsible for GLONASS, IGEX has specific set objectives, which include determining the transformation parameters between coordinate frames of the Parametry Zemli 1990 (PZ-90) system used by GLONASS and the World Geodetic System 1984 (WGS 84) used by GPS. The results of a recently completed Russian project to relate the two systems will assist the IGEX efforts. In this month's column, the team of Russian researchers responsible for that project describe the study and its results. Transformation Model. The Experiment. Analysis. Conclusion. Acknowledgments.

10.02 The stochastics of GPS observables — Tiberius et al.

Tiberius, C., N. Jonkman, and F. Kenselaar (1999). The stochastics of GPS observables. *GPS World*, February, Vol. 10, No. 2, pp. 49-54.

Innovation: We live in a noisy world. In fact, the laws of physics actually preclude complete silence unless the ambient temperature is absolute zero — the temperature at which molecules have essentially no motion. Consequently, any electrical measurement is affected by noise. Although minimized by GPS receiver designers, noise from a variety of sources both external (picked up by the antenna) and internal (generated within the receiver) contaminates GPS observations. This noise will impact the results we obtain from processing the observations. In this month's column, we investigate possible ways of minimizing this impact by considering the random nature, or stochastics, of GPS noise. Mathematical Background (Functional model; Stochastic model). Experiments (Elevation angle; Cross correlation; Time correlation; Probability distribution; Further considerations). Concluding remarks.

10.03 The integrity of GPS **Langley**

Langley, R. B. (1999). The integrity of GPS. *GPS World*, March, Vol. 10, No. 3, pp. 60-63.
Innovation: How truthful is GPS? Can you believe the position that your GPS receiver computers? The GPS Standard Positioning Service is designed to provide a horizontal position accuracy of at least 100 metres, but such accuracy cannot be guaranteed 100 percent of the time. Satellite or ground system failures could cause a receiver to use erroneous data and compute positions that exceed its normal accuracy level. This month's column explores the different approaches to ensuring GPS signal integrity, including satellite self-checks, receiver autonomous integrity monitoring, and augmented systems. Performance Parameters (Accuracy; Availability; Continuity; Integrity). GPS Integrity (Satellite self-checks; Master control station). RAIM. Snapshot Approaches (Range comparison; Least-squares residuals; Parity). RAIM Availability. Exclusion and Isolation. Aviation Requirements. Augmented GPS Systems (DGPS; WAAS; LAAS). Conclusion. Acknowledgments.

10.04 GPS: A new tool for ocean science **Komjathy et al.**

Komjathy, A., J. L. Garrison, and V. Zavorotny (1999). GPS: A new tool for ocean science. *GPS World*, April, Vol. 10, No. 4, pp. 50-56.
Innovation: There is an old adage in science and engineering: One person's signal is another person's noise. Most GPS users consider signals arriving at their receiver's antenna from nearby reflecting surfaces (multipath) to be noise, as their presence reduces positioning accuracy by interfering with the signals received directly from the satellites. Some researchers, however, are using GPS signals reflected off the ocean surface as a valuable new information source in remote-sensing applications. By analyzing the reflections, they can determine such characteristics as wave heights, wind speeds, and wind direction. In this month's column, one group of researchers describes this innovative remote-sensing technique and some of the interesting results it has already obtained. Bistatic Surface Scattering. Signal Modeling (Theoretical model; Wind-speed remote sensing). Delay-Doppler mapping (Bistatic GPS scatterometer; Remote-sensing aircraft). Wind-Speed Retrieval. Concluding remarks.

10.05 Dilution of precision **Langley**

Langley, R. B. (1999). Dilution of precision. *GPS World*, May, Vol. 10, No. 5, pp. 52-59.
Innovation: Dilution of precision, or DOP: we've all seen the term, and most of us know that smaller DOP values are better than larger ones. Many of us also know that DOP comes in various flavors, including geometrical (GDOP), positional (PDOP), horizontal (HDOP), vertical (VDOP), and time (TDOP). But just what are these DOPs? In this month's column, we examine GPS dilution of precision and how it affects the accuracy with which our receivers can determine position and time. Geometry: A Simple Example. Pseudorange Measurements (The covariance matrix; UERE). The DOPS (The tetrahedron; HDOP versus VDOP; Latitude; More satellites). Conclusion. Acknowledgment.

10.06 Aircraft landings: The GPS approach **Dewar**

Dewar, G. (1999). Aircraft landings: The GPS approach. *GPS World*, June, Vol. 10, No. 6, pp. 68-74.
Innovation: The Global Positioning System, considered by many to be the greatest advance in aviation since the invention of the jet engine, will revolutionize the operation of aircraft all around the world. Not only will it direct pilots to the vicinity of an airport, it will also be

able to guide a plane along a runway approach route and even permit automatic landings. To enable more efficient operations, air navigation service providers are designing new approach procedures for aircraft using GPS. In this month's column, George Dewar examines these new GPS approaches and how they differ from approaches using conventional navigation aids. Approach Basics (Precision and nonprecision approaches). Conventional Procedures (VORs and NDBs). GPS Approaches ("T" configuration). Design Process (Final segment; Missed approach segment; Waypoint position calculation; Intermediate segment; Initial segment). Flyby, Flyover Waypoints. Flight Inspection (System errors). Conclusion. Acknowledgment.

10.07 Tropospheric Delay : Prediction for the WAAS user Collins, Langley

Collins, P. and R. B. Langley (1999). Tropospheric Delay: Prediction for the WAAS user. *GPS World*, July, Vol. 10, No. 7, pp. 62.
Innovation: The weather—it affects us all. Sometimes disastrously with vicious storms; sometimes pleasantly with sunshine and warm breezes. It also affects GPS. But, whereas bad weather might disrupt our lives, causing us to curtail or postpone an activity, GPS continues to perform—it’s an all-weather system. Rain, snow, fog, and clouds all have a negligible effect on GPS. However, unseen weather—temperature, pressure, and humidity variations throughout the atmosphere—does affect GPS observations. These parameters determine the propagation speed of radio waves, an important factor that must be accounted for when processing GPS or other radiometric observations. Because we cannot predict their exact values ahead of time, these invisible weather variables are a source of error in GPS positioning and navigation. In this month's column, we examine the atmosphere's effect on GPS and discuss how we’ve attempted to model it for users of the forthcoming Wide Area Augmentation System. The Tropospheric Delay. Delay Models. Developing a New Model (UNB3). Methodology. Average Model Performance. Extreme Delay Errors (Extreme locations; Forecasting extremes; Look-up table). Position Determination Impact (Maximum bias). Conclusions. Acknowledgments.

10.08 [Showcase issue — no column]

10.09 New and improved: The broadcast interfrequency biases Wilson et al.

Wilson, B. D., C. H. Yinger, W. A. Feess, and C. Shank (1999). New and improved: The broadcast interfrequency biases. *GPS World*, September, Vol. 10, No. 9, pp. 56-66.
Innovation: "Better today than yesterday; better tomorrow than today." This often quoted maxim nicely describes the ongoing efforts by scientists and engineers to improve the Global Positioning System's accuracy, ease of use, and range of application. During the relatively short operational lifetime of GPS, we have witnessed many improvements, such as a range of differential GPS techniques, more accurate satellite orbit ephemerides, and smaller, more powerful receivers. Researchers have also improved the models, or descriptions, of several biases that affect GPS observations including carrier-phase windup, satellite yaw attitude, and antenna phase-center offsets. One of the latest GPS enhancements is an improvement of the interfrequency bias values contained in the navigation message broadcast by GPS satellites. Single-frequency receivers use these values to account for differential satellite hardware delays in the broadcast clock corrections. The new values were determined through a collaborative effort by a team of analysts from the National Aeronautics and Space Administration’s Jet Propulsion Laboratory (JPL) — managed by the California Institute of Technology, The Aerospace Corporation, and several Department of Defense agencies. In this column, some of the team members discuss the importance of the interfrequency bias and how they obtained the new values. Interfrequency Bias Use. Improvement History. The New Values (GIM maps; GIM and T_{GD}; New versus old). Validation (WADGPS; Single-

frequency). Additional benefits (Time transfer; Ionospheric research). Future developments. Conclusions. Acknowledgments.

10.10 The view from above: GPS on high-altitude spacecraft — Powell

Powell, D. T. (1999). The view from above: GPS on high-altitude spacecraft. *GPS World*, October, Vol. 10, No. 10, pp. 54-64.
Innovation: Spaceborne GPS applications occur across a wide range of orbit types. To date, the majority of such applications have been for low-earth orbit spacecraft, but GPS offers significant advantages to space vehicles in geostationary and other high-altitude orbits as well. Making GPS work for high-altitude spacecraft, however, presents some unique technical challenges. This article discusses some of those challenges and how they are being met. Orbital Motion. Ground Tracking. Spacecraft GPS Navigation (Satellite views; The GPS broadcast antenna; Side-lobe signals; Backside antennas). GEO Spacecraft (Weak signals; Availability gaps). HEO Spacecraft. Spacecraft GPS Equipment (Hardware options). Falcon Gold Experiment. Conclusions.

10.11 GPS and leap seconds: Time to change? — McCarthy, Klepczynski

McCarthy, D. D., and W. J. Klepczynski (1999). GPS and leap seconds: Time to change? *GPS World*, November, Vol. 10, No. 11, pp. 50-57.
Innovation: Since ancient times, we have used the Earth's rotation to regulate our daily activities. By noticing the approximate position of the sun in the sky, we knew how much time was left for the day's hunting or farming, or when we should stop work to eat or pray. First sundials, water clocks, and then mechanical clocks were invented to tell time more precisely by essentially interpolating from noon to noon. As mechanical clocks became increasingly accurate, we discovered that the Earth does not rotate "like clockwork," but actually has a slightly nonconstant rotation rate. In addition to periodic and irregular variations caused by atmospheric winds and the interaction between the Earth's core and the mantle, the tidal interaction of the Earth and the Moon causes a secular slowing down of the Earth's rotation. So rather than use the variable time scale based on the Earth's rotation, we now use time scales based on extraordinarily precise atomic time, the basis for all the world's civil time systems — Coordinated Universal Time (UTC). However, because of the desire to keep UTC more or less in synchronization with the Earth's rotation as an aid in determining navigation fixes using astronomical observations, leap seconds are added to UTC — currently about every 18 months. In contrast, the time scale used to regulate the Global Positioning System — GPS Time — is a "pure" atomic time scale without leap seconds. In this month's column, the authors suggest that the practice of adding leap seconds to UTC be done away with or at least modified, as more and more navigators adopt Global Navigation Satellite Systems as their primary means of positioning. A Brief History (Increasing accuracy; The move to Cesium). International Atomic Time. Options for UTC (Continue current procedure; Discontinue leap seconds; Change the tolerance for UT1-UTC; Redefine the second; Periodic insertion of leap seconds). Conclusion.

10.12 [Showcase issue — no column]

11.01 Enhancing GPS: Tropospheric delay prediction at the Master Control Station — Hay, Wong

Hay, C. and J. Wong (2000). Enhancing GPS: Tropospheric delay prediction at the Master Control Station. *GPS World*, July, Vol. 11, No. 1, pp. 56-62.
Innovation: As Mark Twain reportedly quipped, "Everyone talks about the weather, but nobody ever does anything about it." Not so at the GPS Master Control Station. In this month's article, Curtis Hay and Jeffrey Wong tell us the Master Control Station's plans to improve the modeling of the weather-related tropospheric propagation delay when processing the data collected at the GPS ground segment monitoring stations. The troposphere — or

more correctly, the whole electrically-neutral part of the atmosphere — imposes an additional delay on GPS signals ranging from a little more than 2 meters for a signal arriving from directly overhead, to more than 20 meters at an elevation angle of 5 degrees. Improved modeling of this delay will reduce the error of the GPS satellite ephemerides and clock corrections transmitted in the navigation message. The proposed changes will benefit all GPS users, military and civilian alike. The Skies Above. From Filter to Signal. Weather Data Inaccuracy. Model Problems. Another Option. Room for Improvement. Improving the MCA. Acknowledgments.

11.02 Time and frequency transfer: High precision using GPS phase measurements

Schildknecht, Dudle

Schildknecht, T. and G. Dudle (2000). Time and frequency transfer: High precision using GPS phase measurements. *GPS World*, February, Vol. 11, No. 2, pp. 48-52.
Innovation: "What time is it?" This question is asked an untold number of times each day. And the replies? They vary both in accuracy and precision, from "it's about one-thirty" to "10 hours, 32 minutes, and 3.682 nanoseconds." In both cases there is an implicit or explicit reference to some standard of time, accepted as a reference. We have long since abandoned the Earth's rotation as a time standard because its rotation rate varies from day to day and year to year. Instead, we rely on an ensemble of atomic clocks maintained by time-keeping laboratories around the world. The clocks are intercompared to establish a global standard. Over the years, a variety of intercomparison techniques have been developed, but the timekeeping community has looked for ever higher accuracies. Intercomparisons are now routinely carried out using a simple GPS technique that has an accuracy limited to about one nanosecond, when the results are averaged over one day. But scientists would like to compare clocks with even higher accuracies over shorter intervals of time. In this column, two scientists from Switzerland — a country famous for its time pieces — describe a new GPS-based clock comparison technique, one that approaches the level of performance of the clocks themselves. Geodetic GPS Processing. IGS Product Potential. Accessing the Receiver Clock. Local Receiver Delays. An International Effort (Frequency transfer; Time transfer experiment). Conclusions. Acknowledgments.

11.03 Slope monitoring using GPS : A multi-antenna approach Ding et al.

Ding, X., Y. Chen, D. Huang, J. Zhu, M. Tsakiri, and M. Stewart (2000). Slope monitoring using GPS: A multi-antenna approach. *GPS World*, March, Vol. 11, No. 3, pp. 52-55.
Innovation: The Earth's surface in continually deforming. Some of these deformations, such as solid-earth tides and post-glacial rebound, are benign. Some, such as land ruptures caused by earthquakes and volcanic eruptions, are devastating. One particularly common deformation is the landslide. Although usually localized, landslides often cost the lives of many and damage millions of dollars worth of property. In this month's column, we examine the current development of an innovative technique to monitor potentially unstable slopes and existing landslides using GPS. Unlike the standard GPS method, where a GPS receiver is required for each point to be monitored, the new method allows multiple points to be monitored with a single receiver. This approach employs a specially designed switching box to link a receiver to a number of GPS antennas, thereby significantly reducing the cost per monitoring point and making GPS a more viable tool for monitoring the stability of slopes and other structures subject to localized deformation. Deformation Monitoring (Manual survey; The array approach). Multi-Antenna System (Receivers and antennas; Data link; Data processing center; Antenna switching; Motion detection and warnings). Test Results. Conclusion. Acknowledgments.

11.04 Smaller and smaller: The evolution of the GPS receiver Langley

Langley, R. B. (2000). Smaller and smaller: The evolution of the GPS receiver. *GPS World*, April, Vol. 11, No. 4, pp. 54-58.

Innovation: We have reached another GPS milestone. Just a few months ago, *GPS World* celebrated its 10th anniversary. The first issue of the magazine (a bimonthly in its first year of publication) appeared in January/February 1990. The “Innovation” column has appeared in every regular issue of *GPS World*, and this month’s column is number 100. Throughout the column’s 10-year history, we have examined many innovative developments in the GPS world, including improvements in precise positioning, velocity determination, and the transfer of time; in applications such as real-time dredge positioning, monitoring the deformation of the Earth’s crust, the Earth’s rotation, and the state of the ionosphere; and the use of GPS on various platforms such as submersible vehicles, aircraft, and satellites. Many of these developments were possible because of advances in GPS receiver technology. The technology has resulted in GPS receivers becoming smaller and more convenient to use and recently permitted receivers so small that they can be incorporated into cellular telephones and other devices. On the occasion of the 100th “Innovation” column, what better time to review the progress of GPS receiver technology through the past 20 years and to take a peek into its future. Essential Elements (Antenna; A front end; Correlators; Microprocessor and memory; Power supply). Receiver Rundown (The Macrometer; The TI 4100; Here come the handhelds). The Workings of a Chipset (Processing the digital signal). Wrist-Mount GPS. Anything but Disappearing. Semiconductor Basics.

11.05 Fixing the ambiguities : Are you sure they’re right? Joosten, Tiberius

Joosten, P. and C. Tiberius (2000). Fixing the ambiguities: Are you sure they’re right? *GPS World*, May, Vol. 11, No. 5, pp. 46-51.

Innovation: Fast and precise relative satellite positioning demands resolution of the integer cycle ambiguities. Only then will the corresponding carrier-phase measurements act as if they were high-precision range measurements, thereby allowing the receiver coordinates to be estimated with comparable high precision. Researchers have studied the GPS ambiguity problem for the past 20 years and have proposed a wide variety of methods to resolve ambiguities. So far, most of these methods have concentrated on the *estimation* of the ambiguities. The problem of addressing the *correctness* of the integer numbers obtained, often referred to as “ambiguity validation,” has received considerably less attention. The “mission” of this article is to point out that ambiguity resolution is not strictly a matter of computing integer values for the ambiguities. Before really fixing or constraining the ambiguities to the computed integers in a final baseline computation, we should assess their accuracy. In other words, we should ask ourselves “How sure am I that these values are correct?” In this contribution, we will look at how we might answer this question and discuss some new developments in dealing with the stochastic properties of the integer ambiguity estimator. The ambiguity success rate is presented as a tool for determining the probability of correct integer estimation. Integer Ambiguity Estimation. Ambiguities are Stochastic. Ambiguity Success Rate. Conclusion. The LAMBDA Method. How to Compute Ambiguity Success Rate.

11.06 The GPS accuracy improvement initiative Hay

Hay, C. (2000). The GPS accuracy improvement initiative. *GPS World*, June, Vol. 11, No. 6, pp. 56-61.

Innovation: The Global Positioning System has become an international utility. While originally designed to serve the armed forces of the United States and its allies, it has evolved into a dual-use system with civil users greatly outnumbering their military counterparts. The predicted further growth of GPS is astounding. The global market for GPS goods and services is expected to exceed $8 billion this year and $16 billion by 2003. In addition to its ease of use, and worldwide, all-weather operation, GPS owes its popularity to the dependable high accuracy with which positions and time can be determined. Although GPS was already better than many other navigation systems, the termination of selective availability last month instantly increased at least five fold the accuracy of standalone civil GPS. And things are going to get even better. In a few years, the first satellites with C/A-code on L2 will be launched, and a couple of years later satellites with a third civil frequency. In addition to these spacecraft hardware augmentations, a number of other upgrades to GPS are being implemented, which will further improve GPS accuracy. One of these upgrades goes by the name Accuracy Improvement Initiative, and in this column the authors will introduce the initiative and describe its benefits to military and civil GPS users alike. Key AII Features. Three OCS Changes. NIMA Tracking Data. Redesigned Kalman Filter. More Frequent Uploads (Enabling the increase). Expected Improvement (Other accuracy initiatives; Atomic clock replacement at the remote monitor stations; Monitor station multipath mitigation; Improved tropospheric delay prediction; Increased use of rubidium clocks). At the End of AII. Acknowledgments.

11.07 GPS, the ionosphere, and the solar maximum Langley

Langley, R. B. (2000). GPS, the ionosphere, and the solar maximum. *GPS World*, July, Vol. 11, No. 7, pp. 44-49.

Innovation:

Oh, it was wild and weird and wan, and ever in camp o'nights
We would watch and watch the silver dance of the mystic Northern Lights.
And soft they danced from the Polar sky and swept in primrose haze;
And swift they pranced with their silver feet, and pierced with a blinding blaze.

So wrote Canadian poet Robert W. Service in the "Ballad of the Northern Lights." The northern lights, also known as Aurora Borealis, are a product of the complex relationship between the Sun and the Earth. More frequent auroras at more southerly latitudes are evidence of the period of maximum solar activity now upon us. The solar maximum, which occurs approximately every 11 years, also brings with it more active ionospheric conditions. The more frequent ejections of high-energy electromagnetic radiation and particles from the Sun around the time of the solar maximum results in greater ionospheric electron densities and more variable densities. And as the signals from the GPS satellites must pass through this more active ionosphere on their way to Earth-bound receivers, there are potential problems for GPS users. In this column, we will look at how solar activity affects the ionosphere, how the ionosphere affects GPS, and how these effects can be ameliorated to reduce their impact. The ionosphere. Solar Activity (Space weather). Refraction Index. TEC Variability. Corrections and Models. Ionospheric Scintillation (Signal fading). Conclusion. Acknowledgments.

11.08 [Showcase issue — no column]

11.09 The new L5 civil GPS signal Van Dierendonck, Hegarty

Van Dierendonck, A. J. and C. Hegarty (2000). The new L5 civil GPS signal. *GPS World*, September, Vol. 11, No. 9, pp. 64-71.

Innovation: Many newcomers to GPS are surprised to learn that work on system development actually began in the early 1970s. The basic structure of the signals transmitted by the GPS satellites has not changed significantly in the ensuing quarter century — a very long time on the technology development time scale. But modernization of GPS is now underway. Selective Availability, the purposeful degradation of positioning accuracy afforded civil users, was switched off in May resulting in at least a five-fold improvement in accuracy. Further accuracy improvements will stem from enhancements to the GPS control segment recently initiated. But, perhaps the most significant of the GPS modernization efforts are the new signals that will be transmitted by future GPS satellites. The C/A-code will be added to the L2 signal of Block IIR satellites beginning with launches in 2003 along with new military signals on L1 and L2. With the C/A-code on both L1 and L2, civil users will be afforded accurate, real-time ionospheric delay correction, further enhancing the accuracy of positions, velocities, and time. And the Block IIF satellites, starting with launches perhaps as early as 2005, will feature a completely new, dedicated civil signal. The new civil signal, called L5, will be transmitted on a frequency of 1176.45 MHz in a band set aside by the International Telecommunication Union for the aeronautical radionavigation service. Although the L5 signal will be a "safety-of-life" signal for aircraft navigation, it also will serve as a robust third signal for all users. The signal design recently was completed by a special working group assembled by RTCA, the private, not-for-profit corporation that develops consensus-based recommendations for the federal government regarding aviation-related communications, navigation, surveillance, and traffic management system issues. In this column, the authors detail the proposed structure of the new L5 signal. L5 Signal Parameters. SC-159 L5 Signal Requirements. User Requirements. The Signal Structure (Two-components signal; Neuman-Hoffman codes). The Code Structure (Code chipping rate and accuracy; Code period and improved cross-correlation; L5 coder implementation; Code selection and correlation properties). The Data Structure. Conclusion. Acknowledgments.

11.10 Navigation 101 : Basic navigation with a GPS receiver **Langley**

Langley, R. B. (2000). Navigation 101: Basic navigation with a GPS receiver. *GPS World*, October, Vol. 11, No. 10, pp. 50-54.
Innovation: The uses of GPS are virtually limitless, from monitoring the bulges of volcanoes to synchronizing communications over cellular-telephone networks. With GPS applications becoming more and more specialized, some users may have lost sight of the fact that, first and foremost, GPS is a navigation system — a system that anyone can use any time, and almost anywhere. In this month's column, we present a primer on this most basic use of GPS. Where am I? Getting From A to B (Position; Bearing; Distance; Course and track; Desired track; Course made good; Speed; Speed made good; Cross-track error; Estimated time on route; Estimated time of arrival; Map displays). Augmented Navigation. Conclusion.

11.11 A common time reference: Precise time and frequency for warfighters

Beard, White

Beard, R., and J. White (2000). A common time reference: Precise time and frequency for warfighters. *GPS World*, November, Vol. 11, No. 11, pp. 38-45.
Innovation: The use of the Global Positioning System as the primary and most accurate means of disseminating time and frequency information has created an inherent vulnerability within some military systems. As a growing and diverse mix of military positioning, communications, sensing and data processing systems are using precise time and frequency from GPS, the precise accuracies required for their interoperability are becoming more stringent. Consequently, a new system architecture for providing a common time reference to the operating forces and their related subsystems is being developed. This architecture will provide a robust alternative to the former implementations of GPS as a time and frequency subsystem and mitigate the vulnerabilities of those systems to possible GPS countermeasures. In this month's column, the authors describe their proposed common time reference approach and its relationship to present GPS time and frequency usage. They suggest a robust architecture comprising distributed time standards and precise time and frequency standards which reduces the sensitivities to GPS anomalies and lack of continuous contact. Utilization of existing resources and interconnection of these interoperable systems at the fundamental level of time and frequency generation will enable them to function together more effectively. Network-Centric Warfare. System Time Utilization (Independent systems; Multiple systems). Time Dissemination via GPS. CTR Architecture. Time Dissemination Interfaces. Clock Comparison Systems. Composite Time. Local Distribution Media. A System of Systems. Acknowledgment. Precise Clocks.

11.12 {Showcase issue — no column]