

GNSS Solutions® Tutorials

September 21-22, 2009 • Savannah, Georgia

	TRACK 1	TRACK 2	TRACK 3	TRACK 4	TRACK 5
Monday AM 8:30-12:00	CN405: Fundamentals of GNSS I with Emphasis on GPS Chris Bartone, Ohio University	CN425: GNSS Signals & Systems with emphasis on Galileo Tony Pratt, Orbstar Consultants	CN431: GNSS Receiver Design I: RF Front-End Theory and Design Sanjeev Gunawardena, Ohio University	CN460: Introduction to Strapdown Inertial Navigation Systems I Kevin Dutton, Honeywell International	CN480: Fundamentals of Kalman Filtering for GPS/INS Integration I Mohinder S. Grewal, California State Univ, Fullerton
Monday PM 1:30-5:00	CN406: Fundamentals of GNSS II with Emphasis on GPS Chris Bartone, Ohio University	CN426: GNSS Signal Performance with emphasis on Galileo Tony Pratt, Orbstar Consultants	CN432: GNSS Receiver Design II: Baseband Signal Processing and Implementation Sanjeev Gunawardena, Ohio University	CN461: Introduction to Strapdown Inertial Navigation Systems II Kevin Dutton, Honeywell International	CN 481: Fundamentals of Kalman Filtering for GPS/INS Integration II Mohinder S. Grewal, California State Univ, Fullerton
Monday EVE 6:45-9:30	CN420: GPS Modernization and Relation to other GNSS Thomas Stansell, Stansell Consulting	CN413: GNSS RAIM Christophe Macabiau, ENAC	CN409: Precise Timekeeping and GNSS Demetrios Matsakis, U.S. Naval Observatory	CN471: Integrated Navigation Systems for Miniature Aerial Vehicle Applications Demoz Gebre-Egziabher, P.E., Univ of Minnesota	Open (check web site for updates)
Tuesday AM 8:30-12:00	CN410: Fundamentals of DGNSS Hans-Jürgen Euler, inPosition gmbh, Switzerland	CN433: Receiver Signal Processing for Future GNSS Signals - Introduction Olivier Julien, ENAC	CN441: GNSS Antennas I - Fundamentals Chris G. Bartone, P.E., Ohio University	CN462: Applications of Strapdown Inertial Navigation I Andrey Soloviev, University of Florida	CN 482: Fundamentals of GPS/INS Integration I Mohinder S. Grewal, California State Univ, Fullerton
Tuesday PM 1:30- 5:00	CN415: Fundamentals of GNSS for Baseline RTK & Network RTK applications Hans-Jürgen Euler, inPosition gmbh, Switzerland	CN434: Receiver Signal Processing for Future GNSS Signals - Advanced Olivier Julien, ENAC	CN445: GNSS Antennas II - Special Topics Rama Rao, Mitre Corporation	CN463: Applications of Strapdown Inertial Navigation II - Integrated Inertial Navigation Systems Andrey Soloviev, University of Florida	CN 483: Fundamentals of GPS/INS Integration II Mohinder S. Grewal, California State Univ, Fullerton



Dr. Chris G. Bartone, P.E. is an associate professor at Ohio University with over 26 years of profession experience in communications, navigation, and surveillance systems. He received his Ph.D. from Ohio University in 1998, a MSEE from the Naval Postgraduate School in 1987, and BSEE from Penn State in 1983. He previously worked for the Naval Air Warfare Center, performing RDT&E on CNS systems. Chris received the RTCA William E. Jackson Award in 1998 for his outstanding contribution to aviation in the area of DGPS. At Ohio University, Dr. Bartone has developed and teaches a number of GPS, radar, and wave propagation classes. His research concentrates on all aspects of navigation. He is a member of the ION, the IEEE, and the International Loran Association. He is very active with the ION; chaired several programs; Chair, ION Outreach Committee; and currently the Editor, ION Virtual Navigation Museum. Chris is a licensed profession engineer in the state of Ohio.



Thomas A. Stansell is a pioneer of satellite navigation with over 49 years of experience, beginning in 1960 at the Johns Hopkins University Applied Physics Laboratory, later with Magnavox, Leica, and now an independent consultant. He has led many firsts in Transit, GPS, and Glonass receiver technology and played a key role and contributed crucial ideas to the design of all modernized GPS signals: L5, L2C, M-code, and L1C, with lead roles for L2C and L1C. He is an ION Fellow and has received multiple awards, including: GPS JPO Navstar, ION Weems, IEEE PLANS Kershner, and ION Kepler. Tom is an influential GPS consultant advising the GPS Wing and other organizations on GNSS modernization issues.



Dr. Hans-Jürgen Euler has over 2 decades of experience with GPS and its applications including precise surveying in post-processing and real-time. In the late 80's, as a Ph.D student at Technical University of Darmstadt, Germany, he pioneered the fast integer ambiguity resolution technique. These fundamental methods are still the key factor for fast and robust phase integer ambiguity resolution. In 1990 he worked at The Ohio State University on inertial with kinematic GPS followed by developments for real-time applications at Terasat, Germany. For 14 years at Leica Geosystems he developed the GPS algorithms for real-time and post-processing software. In 2002 he became a Leica GNSS Research Fellow. For more than 10 years he has worked actively in the RTCM Subcommittee 104 on interoperable standards, where he serves as Chair of the RTCM SC104 working groups for network RTK and Galileo. Since 2006 Hans-Jürgen works for his own company inPosition gmbh in Switzerland. He consults and concentrates on development for positioning applications with a particular focus on GNSS including Network RTK.



Dr. Tony Pratt has over 40 year of experience with Signal Processing and GPS. He graduated with a B.Sc. and Ph.D. in Electrical Engineering from Birmingham University, UK in 1967. He has held teaching positions at Loughborough University, UK, Yale University, IIT, New Delhi, University of Copenhagen, and holds a full special professorship at University of Nottingham; his teaching is primarily in signal processing, electronics, probability theory, and satellite navigation system design. He has worked for or consulted to industry for Navstar Ltd, Peek, Parthus, QinetiQ Ltd, UK, Cambridge Positioning Systems, now part of the CSR plc group, and European Space Agency. Dr. Pratt is a Consultant to the UK Government in the development of the Galileo Satellite System and has played key roles in the signal design and international negotiations. He runs two companies, OrbStar Consultants and OrbStar Ltd providing various services to the GNSS sector. Dr Pratt has published numerous papers on signal processing, sonar, and satellite navigation. He published more than 50 papers and holds over 40 patents.



Dr. Christophe Macabiau graduated as an electronics engineer in 1992 from the ENAC (Ecole Nationale de l'Aviation Civile) in Toulouse, France. Since 1994, he has been working on the application of satellite navigation techniques to civil aviation. He received his Ph.D. in 1997 and has been in charge of the signal processing lab of the ENAC since 2000. His research now also applies to vehicular, pedestrian and space applications, and includes advanced GNSS signal processing techniques for acquisition, tracking, interference and multipath mitigation, GNSS integrity, as well as integrated GNSS-inertial systems and indoor GNSS techniques.



Dr. Olivier Julien is an assistant professor with the Signal Processing and Telecommunications laboratory of ENAC, Toulouse, France. He received his PhD from the Department of Geomatics Engineering at the University of Calgary, Canada. He is involved in many R&D projects including GNSS receiver design, multipath and interference mitigation techniques, and GNSS interoperability. He is the recipient of the 2006 Bradford W. Parkinson award.



Dr. Sanjeev Gunawardena is a Senior Research Engineer and Co-Principal Investigator with the Ohio University Avionics Engineering Center (AEC). He is the primary developer of multi-frequency instrumentation-grade GNSS receiver RF front-ends, field programmable gate array (FPGA)-based next-generation GNSS processors, and high performance multi-sensor data collection systems for scientific research at AEC. In 2002, he demonstrated the first-documented realtime continuously-processing implementation of the FFT-based GNSS parallel code correlation algorithm and the first known realtime reconfigurable GPS receiver employing both time and frequency-domain processing in its baseband processor. He was awarded the 2007 RTCA William E. Jackson Award for his outstanding contribution to aviation for the application of transform-domain GNSS receiver technology for high-fidelity GPS performance monitoring. Dr. Gunawardena received B.S. in engineering physics, B.S.E.E., M.S.E.E. and Ph.D. in electrical engineering from Ohio University. He has taught courses in ASIC design, VHDL, FPGA design, GNSS signal processing and advanced satellite navigation.



Dr. Demetrios Matsakis is Head of the U.S. Naval Observatory's Time Service Department and has been employed at the USNO for almost 30 years. He has worked on time scales, atomic fountains, trapped-ion clocks, pulsars, VLBI (Very Long Baseline Interferometry), CEI (Connected Element Interferometry), atmospheric modeling, water vapor radiometers, maser amplifiers, and molecular radio astronomy. He received his Ph.D. in Physics at U.C. Berkeley studying under Dr. Charles Townes and his undergraduate degree in Physics from MIT. Dr. Matsakis has published over 100 scientific papers, and is ex-President of the International Astronomical Union's Commission on Time. He teaches in a private capacity.



Dr. Rama Rao is a Principal Engineer at the MITRE Corporation where he works on problems related to antenna technology for GPS navigation systems, EHF military satellite communications systems and terrestrial communications covering a wide range of frequency bands. He received his Ph. D. degree from Harvard University where he also served as an Assistant Professor of Applied Physics. Prior to joining MITRE he held technical staff positions at M. I. T. Lincoln Laboratory and at the Sperry Research Center; he was also a Research Associate at M.I.T. and an Adjunct Professor at Northeastern University in Boston. Dr. Rao holds ten U.S. patents and his last three patents are related

to GPS antennas. He is the lead author of a forthcoming book on "GNSS Antennas" to be published by Artech House.



Dr. Kevin Dutton received his BS in Aeronautical Engineering from Rensselaer Polytechnic Institute in 1988 and his MS degree in Astronautics from the George Washington University in 1993. In 1989 he began work at NASA Langley Research Center on advanced spacecraft trajectory optimization. In 1993 he worked in the area of GPS to obtain his PhD in EE from Ohio University in 2003, studying various aspects of the GPS and INS, including attitude determination, relative navigation, and tightly coupled GPS/INS Kalman filter design. In 2004, Dr. Dutton accepted a position with Honeywell in Clearwater, Florida as the lead designer of the Sea-Based JPALS GPS/INS relative navigation Kalman filter.



Dr. Gebre-Egziabher is an associate professor of Aerospace Engineering and Mechanics at the University of Minnesota, in Minneapolis, Minnesota. His research is in the areas navigation, guidance and control with a particular emphasis on application of estimation theory to avionics sensor fusion and system integration issues. Dr. Gebre-Egziabher received a Bachelor of Science degree in Aerospace Engineering from the University of Arizona, a Master of Science degree in Mechanical Engineering from George Washington University and a Ph.D. in Aeronautics and Astronautics from Stanford University.



Dr. Andrey Soloviev is a Research Assistant Professor at the University of Florida. Previously he served as a Senior Research Engineer at the Ohio University Avionics Engineering Center. He holds B.S. and M.S. in Applied Mathematics and Physics from Moscow University of Physics and Technology and a Ph.D. in Electrical Engineering from Ohio University. His current research focuses on all aspects of multi-sensor integrated navigation and applications of synthetic aperture signal processing techniques for GNSS. Andrey currently serves as the ION Land Representative. He received the RTCA William E. Jackson Award in 2002 for the development of frequency-domain INS algorithms and the ION Early Achievement Award in 2006 for outstanding contributions to deeply integrated Inertial/GPS and advanced GPS signal processing.



Mohinder S. Grewal, P.E., is a Professor of Electrical Engineering at California State University, Fullerton (CSUF). He was an architect of the GEO Uplink Subsystem (GUS) for WAAS, including the GUS clock steering algorithm. He co-authored "Kalman Filtering Theory & Practice Using MATLAB," Third Edition, Wiley & Sons, 2008, and "Global Positioning Systems, Inertial Navigation, & Integration," Second Edition, Wiley & Sons, 2007. Grewal has published over 50 papers in IEEE and ION refereed journals and proceedings, including the ION "Redbook," (Volume VII), and numerous technical reports. Dr. Grewal was listed in "50+ GPS Leaders to Watch" in GPS World May 2007 issue. In February 2009, he received the Orange County Engineering Council (OCEC) Distinguished Engineering Educator Award. Dr. Grewal is a Senior Member of IEEE, Fellow of the Institute for the Advancement of Engineering, and member of the Institute of Navigation. He is a registered engineer in the State of California.

Images: GPS SV image courtesy Lockheed Martin. Galileo satellite image courtesy ESA. P. Carril

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TRACK 1 MONDAY AM & PM

MONDAY, 8:30am-12:00 pm, Room 1
CN405 Fundamentals of GNSS I with emphasis on GPS (3.0 CEU)
Dr. Chris Bartone, P.E., Ohio University

Updated

This course emphasizes the fundamentals of GNSS with emphasis on GPS. The core functions needed to be performed in obtaining a user solution using GPS in an error free environment will be covered. The course concludes with an illustration of a user state calculation, performance metrics (i.e., DOPS) and an error budget in GPS.

- Introduction to Positioning and Satellite Navigation
- GPS Segments: Control, Space, User
- Coordinate frames and datum's used in GNSS
 - ECI, ECEF, LLH, MSL, WGS-84, ITRF, conversions, etc.
- GPS signal structure formats for current and future signals.
 - Basic/Legacy GPS: C/A, P(Y) code formats
- Modernized GPS, Galileo, Glonass (Overview)
- GPS Link Budget
- GPS Navigation Message Data Format Descriptions
- Calculation of the GPS space vehicle (SV) position using the broadcast Kepler parameters (ephemeris and almanac)
- GPS Time Considerations
- Calculation of user state (i.e., position and time)
- Associated performance parameters (i.e., dilution of precision)
- GPS error budget (overview)

MONDAY, 1:30pm-5:00 pm, Room 1
CN406 Fundamentals of GNSS II with emphasis on GPS (3.0 CEU)
Dr. Chris Bartone, P.E., Ohio University

Updated

This course emphasizes the fundamentals of GNSS with emphasis on GPS in the presence of various error sources. The course provides details on the source and nature of various error source in satellite navigation systems, their impact, and methods for mitigation. The course concludes with an illustration of an error-state calculation, and provides an introduction to differential GNSS.

- GPS • GPS error budget (review)
- Overview of receiver technologies and tracking loops
- Overview of antenna technologies
- Satellite orbit errors and clock errors
- Signal Multipath Error characterization and mitigation techniques
 - Code phase multipath
 - Carrier phase multipath
- Error mitigation by smoothing
- Atmosphere Errors:
 - Troposphere error sources
 - Characterization and mitigation (simple)
 - Ionosphere error sources
 - Characterization and mitigation (simple)
- GNSS Receiver Autonomous Integrity Monitoring (RAIM)-overview
- Precise Point Positioning (PPP)
 - Concept, implementation, limitations
- Introduction to differential GNSS (DGNSS) and different ways to implement it.

Images: GPS SV image courtesy Lockheed Martin, Galileo satellite image courtesy ESA - P. Carril

TRACK 2 MONDAY AM & PM

MONDAY 8:30am-12:00pm, Room 2
CN425: GNSS Signals and Systems with emphasis on Galileo (3.0 CEU)
Dr. Tony Pratt, Orbstar Consultants

Updated

This course provides a solid foundation of GNSS Signal formats and emphasizes the new signal and services for Galileo. Details on GNSS signal formats, spreading codes, and their characteristics are provided. Major topics include:

GNSS System Overview:

Introduction to different GNSS Providers:

- GPS, Glonass, Galileo, Beidou, Compass, IRNSS, QZSS
- Signal Spectra in L1, L2, L5, E1, E5, E6 and related bands

Signal Characteristics

- Modulation types: CDMA, BPSK, BOC, AltBOC, MBOC, TBOC, CBOC, FDMA
- Signal Spectra and signaling requirements,
- Signal Multiplexing - many services on a single carrier
 - o Quadrature phase, Interplex, Modified Interplex, CASM, Majority Voting, Spatial summation; Phase Plane Plots
- Spreading Codes and signal reception by correlation or convolution
 - o Gold codes, m-sequences, random sequences, primary, secondary codes

Power Requirements in Space

- Signal Power Budget, spreading loss
 - Background noise, inter and intra system noise
 - Iso-flux antenna, antenna patterns and gain, understanding circular and elliptic polarization
- Navigation Message Structure
- GPS and Galileo
 - Error detection, forward error correction, parity checking
 - Ephemeris and Clock models

MONDAY 1:30pm-5:00pm, Room 2
CN426 GNSS Signal Performance with emphasis on Galileo (3.0 CEU)
Dr. Tony Pratt, Orbstar Consultants

Updated

This course provides a solid foundation for the performance of GNSS Signal formats and emphasizes the new signal and services for Galileo. Details on GNSS signal spreading codes and their performance in noise, multipath, and interference are provided. Additionally, the performances of the Galileo signals are characterized with respect to the GPS signal formats. Major topics include:

Interference Aspect for GNSS Signals:

- Interference consideration for GNSS spreading codes
 - Inter & Intra interference between Galileo & GPS
 - Galileo/GPS satellite power control
 - Spectral Separation Coefficients (SSC) with lists for SSC values

Signal generation effects at the satellite:

- GNSS satellite signal generation and filter effects
- GNSS satellite antenna effects

Link Performance Characterizations:

- Down link signal link budgets
- Signal-to-Noise ratio budgets
- User range error
 - Cramer-Rao lower bound on tracking performance
- Multipath consideration for Galileo & GPS signals
 - Relationship to transmitted & receiver bandwidth

TRACK 3 MONDAY AM & PM

MONDAY, 8:30am-12:00pm, Room 3
CN431 GNSS Receiver Design I: RF Front-End Theory and Design (3.0 CEU)
Dr. Sanjeev Gunawardena, Ohio University

NEW

This course is the first of a two-part sequence covering the design and practical implementation of GNSS receivers using the latest developments in RF and digital signal processing technologies. This first course covers the design of single and multiband GNSS RF front-ends. The course material is presented from both a theoretical and practical perspective using case studies.

- GNSS signals overview: Link budget, signal structure, power spectrum, spreading codes, correlation properties, thermal noise, and system noise figure.
- GNSS front-end architectures: Single versus dual conversion, analog versus digital down-conversion, direct RF sampling.
- Frequency planning and control: Image frequencies, bandwidth and filter selection, reference clock types and parameters, PLL synthesizers, phase noise, and cost-performance tradeoffs.
- RF/IF components: Parameters important to GNSS signal processing: component selection guidelines for amplifiers, filters, mixers and oscillators.
- Implementation intricacies: component-induced multipath, crosstalk, etc.
- Sampling subsystem: ADC specifications, impact of sampling resolution and jitter, automatic gain control, dynamic range considerations.
- GNSS front-end design techniques and case studies
 - o Modular design using connectorized components
 - o PCB-level design using discrete RF components
 - o Commercial GNSS MMICs for portable electronics

MONDAY, 1:30pm-5:00pm, Room 3
CN432 GNSS Receiver Design II: Baseband Signal Processing and Implementation (3.0 CEU)
Dr. Sanjeev Gunawardena, Ohio University

NEW

This course is the second of a two-part sequence covering the design and practical implementation of GNSS receivers using the latest developments in RF and digital signal processing technologies. This second course covers digital signal processing techniques. The course material is presented from both a theoretical and practical perspective using case studies.

- GNSS signals overview: Signal structures of GPS and Galileo.
- Signal correlation: Time, frequency, and transform-domain techniques. Coherent versus non-coherent integration. Advanced correlator architectures for multipath mitigation and signal quality monitoring.
- Processing complexity: complexity vs realtime implementation.
- Signal Acquisition: threshold statistics, search algorithms, fast acquisition techniques.
- Acquisition-to-tracking transition: Acquisition verification, bit synchronization, and false-lock detection techniques.
- Tracking: FLL, PLL and DLL, loop tightening/transitioning techniques, noise bandwidth, tracking performance, block (batch) processing and loopless tracking techniques.
- Measurement computation: Navigation databit extraction and decoding, TOT and TOR counters, pseudorange and carrier-phase measurements.
- Implementation techniques and platforms (including case studies):
 - o Matlab®-based non-realtime algorithms
 - o Bitwise software algorithms for general-purpose microprocessors
 - o FPGA-based processing engines and design overview
 - o Commercial GPS processor chipsets

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TRACK 1 TUESDAY AM & PM

TUESDAY, 8:30am-12:00 pm, Room 1
CN410 Fundamentals of Differential GNSS applications (3.0 CEU)
Dr. Hans-Jürgen Euler, inPosition gmbh, Switzerland

Updated

This course emphasizes the fundamentals of differential GNSS baseline techniques with focus on DGPS and an introduction to DGPS RTK applications. The course will explore the various error mitigation techniques and methods for improving the navigation to sub-meter and high-precision positioning. Performance aspects with respect to accuracy, integrity, continuity, and availability will be presented. Main topics include:

- Introduction to DGPS techniques and different ways to implement it (overview)
- Mitigation of error in GNSS applications: (SV, atmosphere, antenna, multi-path)
- Differential pseudo-based navigation error mitigation techniques
- Overview of differential services available
 - Space Based Augmentation Systems (e.g., WAAS, EGNOS, etc.)
 - Commercial services
- Date link: RTCM SC104 standard for DGNSS
 - Message outline and philosophy
 - The different messages for DGNSS
- Precise differential techniques via carrier phase ambiguities
- Multi-frequency advantages
- Summary of standards for RTK applications:
 - RTCM SC104 V2
 - RTCM SC104 V3

TUESDAY, 1:30pm-5:00pm, Room 1
CN415 Fundamentals of GNSS Baseline RTK and Network RTK applications (3.0 CEU)
Dr. Hans-Jürgen Euler, inPosition gmbh, Switzerland

Updated

This course emphasizes the fundamentals of GNSS Baseline RTK techniques with focus on GPS Baseline RTK applications, including Network RTK applications. The course will explore the various methods for error mitigation. The short-comings and merits of different approaches are analyzed. Main topics include:

- DGNSS techniques and their limits (overview)
- Algorithms for Integer Ambiguity Searches as the key for precise positioning
- Error sources of RTK and their mitigation
 - Antenna phase center variations (absolute & relative)
 - Tropospheric residual errors
 - Ionospheric residual errors
- Limitations of Baseline RTK
- General idea of Network RTK to overcome baseline length-dependent influences
- Analysis of different concepts in Network RTK
 - Virtual Reference Stations (also called VRS, iMAX and similar)
 - Area Correction Parameters (FKP German abbreviation)
 - Master-Auxiliary Concept
 - Computed Reference Stations
- Importance of interoperability when providing Network RTK services
- Aspects of other GNSS on Network RTK
- New trends in Network RTK

Images: GPS SV image courtesy Lockheed Martin, Galileo satellite image courtesy ESA - P. Carril

TRACK 2 TUESDAY AM & PM

TUESDAY, 8:30am-12:00pm, Room 2
CN433 Receiver Signal Processing for Future GNSS Signals - Introduction (3.0 CEU)
Dr. Olivier Julien, Ecole Nationale de l'Aviation Civile (ENAC)

Updated

This course concentrates on future GNSS (with emphasis on GPS and Galileo) signal processing and aspects in GNSS receiver design and performance. It also provides an evaluation of the future signals with respect to the current GPS C/A signal in terms of receiver performance and complexity. The main topics:

Reminder on future transmitted civil GNSS signals:

- Binary Offset Carrier (BOC) modulation, pilot channel and secondary code,
- Structure of future GPS and Galileo civil signals on L1/E1 and L5/E5 bands: Components, modulations (BPSK, QPSK, MBOC, TMBOC, CBOC, ALTBOC) and spectral representation

The correlation operation:

- Correlator output model in the presence of thermal noise,
- GPS and Galileo main correlation functions

Acquisition of future GNSS signals:

- Joint data/pilot acquisition detectors,
- Impact of BOC-based modulations on acquisition performance, and
- Secondary code acquisition

Phase tracking architectures and performances of future GNSS signals:

- Use of the pilot channel for phase tracking, and
- Phase tracking performance using future GPS and Galileo signals

Code tracking architectures and performances of future GNSS signals:

- Use of the pilot and secondary code for code tracking,
- Investigation of basic BOC tracking
- Tracking of BOC-based signals and application to future GPS and Galileo signals: (architecture, performance in thermal noise, tracking ambiguity problem)

TUESDAY, 1:30pm-5:00pm, Room 2
CN434 Receiver Signal Processing for Future GNSS Signals - Advanced (3.0 CEU)
Dr. Olivier Julien, Ecole Nationale de l'Aviation Civile (ENAC)

Updated

This course provides an excellent overview of future GNSS signal processing and the many aspects that affect GNSS receiver performance. The course first investigates specific receiver tracking architectures dedicated to future civil GNSS signals, and then characterizes the resistance of these signals towards-multipath and interference environments with respect to GPS C/A.

The main topics to be covered by this course are:

Advanced code tracking architectures:

- Introduction to typical tracking techniques against BOC-related tracking ambiguity,
- MBOC tracking for wide-band and narrow-band receivers, and
- ALTBOC tracking for wide-band and very-wide-band receivers

Multipath effects on tracking:

- Multipath model and impact on code and phase tracking
- Phase tracking multipath envelopes for future GNSS civil signals
- Code tracking multipath envelopes for future GNSS civil signals

Interference effects on tracking:

- Main interference threats and models in L1 and E5 bands
- Impact of future GNSS signals' structure on the receiver capability to mitigate narrow- and wide-band interference
- Introduction to pulsed interference effects and mitigation on GPS L5 and Galileo E5

TRACK 3 TUESDAY AM & PM

TUESDAY, 8:30am-12:00pm, Room 5
CN441 GNSS Antennas I - Fundamentals (CEU: 3.0)
Dr. Chris G. Bartone, P.E., Ohio University

Updated

This course emphasizes the fundamentals of antenna for GNSS. A solid basis for understanding fundamentals of antennas, antenna types, design, development, tests, and implementation aspects of GNSS antennas will be covered including:

- Fundamentals of Antennas:
 - Antenna pattern and field descriptions
 - Mismatch losses (Γ , SWR, polarization)
 - Wave and antenna polarization
 - Antenna and receiver noise figure considerations
 - Antenna aperture
 - The Friis transmission equation
- Antenna Types: linear, helix, patches, arrays
- Common GNSS Antennas
- Antenna Specifications
- Antenna Siting Issues: Mask angle, multipath, etc.
- Antenna Multipath considerations: design, metrics, and technology comparison (patch, survey, integrated multipath limiting antenna (IMLA))
- Test/Design and Evaluation:
 - Computer simulation tools
 - Component level evaluations
 - Antenna test range options
 - Field test characterization
- Phase and group delay calibration (overview)

TUESDAY, 1:30pm-5:00pm, Room 5
CN445 GNSS Antennas II - Special Topics (CEU: 3.0)
Dr. Rama Rao, Mitre Corporation

Updated

This course explores recent developments in GNSS antennas of specific interest to many users. Topics include:

- Multiband GNSS Antennas
 - Spiral, Microstrip & Other Geodetic Quality Broadband Antennas for Modernized GPS, Galileo & Glonass
- Handset Antennas for Assisted GPS & Location Based Services
 - Ceramic Loaded Quadrifilar Helix, Planar Inverted F & Ceramic Microstrip Antennas
- Adaptive Antenna Arrays:
 - Multiple Element Antenna Arrays for Reducing Interference and Jamming
 - Brief Introduction to Power Minimization, Space Time & Frequency Adaptive Processing, Polarimetric Array & Beam Forming Antenna Arrays
- Active GPS Antennas
 - Metrics for Evaluating Active GPS Antennas
 - Measurement of G/T
- Ground Plane & Aircraft Fuselage Effects
 - Mitigation of Ground Plane Effects (Rolled Edge, Electronic Band Gap, Resistivity Taper, Multiband Choke Ring, Reduced Surface Wave Microstrip)
 - Effects of Aircraft Fuselage on GPS Avionic Antennas; Scale Model Tests & Verification from GTD Codes; Body Masking, Multipath, Phase Center Variation
- Antenna Effects on GNSS Observables:
 - Antenna Gain & Beamwidth ; Low Elevation Masking Angle; Effects on PDOP
 - Antenna Phase Center Variation (PCV), Carrier Wrap in Spinning Missiles
 - Group Delay and Bandwidth Effects on GNSS BOC Signal Waveforms

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TRACK 4 MONDAY AM & PM

MONDAY, 8:30am-12:00 pm, Room 4 CN460 Introduction to Strapdown Inertial Navigation Systems I (3.0 CEU)

Dr. Kevin Dutton, Honeywell International

This course emphasizes the physics and mathematics of strapdown inertial navigation systems. It provides sufficient information for the user to construct their own free inertial navigation solution. Main topics include:

- Basic inertial navigation with two-dimensional examples
- Vector and matrix notation and mathematics
- Coordinate frames: Inertial, Earth-Centered, Earth-Fixed, Local-Level (East/North/Up, North/East/Down, Wander), Body, transformations
- Attitude Fundamentals and Representations
 - Direction Cosine Matrix (DCM)
 - rotation vector and Euler angles
 - quaternions
- Earth geoid and gravity model
- Strapdown inertial navigation equations
- Vertical channel dynamics
 - inherent instability in vertical channel
 - stabilization of vertical channel using external information
- Coning and sculling
 - Definitions and compensation
- Integration of navigation equations
 - attitude update
 - velocity update
 - position update

MONDAY, 1:30am-5:00 pm, Room 4 CN461 Introduction to Strapdown Inertial Navigation Systems II (3.0 CEU)

Dr. Kevin Dutton, Honeywell International

This course emphasizes the fundamentals of strapdown inertial navigation sensors – the types of sensors and their errors and their behavior. The course also discusses sensor and system specifications. Main topics include:

- Strapdown inertial navigation error equations and performance
- Alignment techniques
 - gyro-compass alignment
 - in-flight alignment
 - at-sea alignment
 - transfer alignment
- Inertial sensors
 - gyroscopes
 - accelerometers
- Sensor errors and error models
 - Gauss-Markov random process
 - bias
 - scale factor
 - misalignment
 - non-orthogonality
 - size effects
- Sensor calibration techniques
- Sensor specifications
- Inertial navigation system performance and specifications

TRACK 5 MONDAY AM & PM

MONDAY, 8:30am-12:00pm, Room 5 CN480: Fundamentals of Kalman Filtering for GPS/INS Integration I (3.0 CEU)

Dr. Mohinder S. Grewal, P.E., California State University, Fullerton

This course emphasizes the fundamentals of Kalman filtering with application to GPS/INS integration. It addresses subtleties, problems, and limitations of estimation theory as applied to real world situations encountered in GPS, INS, and navigation and provides application examples. Attendees are encouraged to bring their laptop with Matlab® to these courses.

Main topics include:

- What is a Kalman Filter
- Discrete Kalman Filter
- Continuous Kalman Filter
- Relationship Between Discrete and Continuous Process Noise
- Example (1 State)
- Example (6 States) with MATLAB®
- Measurements as Scalars (No Matrix Inversion)
- Problems and Solutions

MONDAY, 1:30pm-5:00pm, Room 5

CN 481: Fundamentals of Kalman Filtering for GPS/INS Integration II (3.0 CEU)

Dr. Mohinder S. Grewal, P.E., California State University, Fullerton

Fundamentals Part II continues topics from Part I. This course discusses fundamentals of Kalman filtering application to non-linear systems and emphasizes implementation issues as applied to GPS and INS. Attendees are encouraged to bring their laptop with Matlab® to these courses.

Main topics include:

- Nonlinear Kalman Filters
- Examples
- Sigma Point Kalman Filter (Unscented)
- Square Root Filtering
- Example with MATLAB®
- Prefiltering
- Divergence and Effective Cures

TRACK 1 MONDAY EXTENDED EVENING

MONDAY, 6:45pm-9:30pm, Room 1 CN420: GPS Modernization and Relation to other GNSS (2.5 CEU)

Thomas Stansell, Stansell Consulting

This course provides information on many aspects of GPS modernization and how these efforts relate to other GNSS systems; the course covers topics on GPS modernization, including signals and satellite capabilities, interoperability with Galileo signal formats and services, QZSS, Glonass, Compass and other GNSS concepts. Major topics include:

- Motivations for modernization
- GPS Modernization:
 - L2C, L5, M-code, and L1C signals
 - Galileo interoperability
 - Performance trade-offs and applications
 - Improved GPS III functionality
 - Program status and schedule
 - New capabilities
- Relationship to other GNSS
 - Quasi-Zenith Satellite System (QZSS)
 - Galileo
 - Glonass
 - Chinese Compass and Beidou-2
 - Indian Regional Satellite System
- GNSS Compatibility and Interoperability
 - Interoperability improvement opportunities
 - Performance improvement opportunities

TRACK 2 MONDAY EXTENDED EVENING

MONDAY, 6:45pm-9:30pm, Room 2 CN413 GNSS RAIM (2.5 CEU)

Dr. Christophe Macabiau, ENAC

This course provides information on obtaining integrity in GNSS applications. An overview of the different ways to obtain GNSS integrity for civil aviation will be discussed followed by details on receiver autonomous integrity monitoring (RAIM) approach. The course concludes with several practical examples. Major topics include:

- GNSS Integrity for integrity aviation:
 - Requirements for civil aviation applications
 - Integrity monitoring techniques: ABAS, GBAS, SBAS, Galileo, GIC
 - RAIM Fault detection, Fault Exclusion
- RAIM:
 - Algorithm specifications from high level requirements
 - Measurement model, threat model
 - Detection criterion (fault detection, fault exclusion)
 - Horizontal, Vertical, and other Protection Level (PL) computation
 - Assumptions for RAIM performance evaluation
 - Practical examples

Future of RAIM:

- GPS/Galileo RAIM for civil aviation
- RAIM for other applications

Images: GPS SV image courtesy Lockheed Martin. Galileo satellite image courtesy ESA - P. Carril

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TRACK 4 TUESDAY AM & PM

TUESDAY, 8:30am-12:00pm, Room 4

CN462 Applications of Strapdown Inertial Navigation I (3.0 CEU)

Dr. Andrey Soloviev, University of Florida

Expanded

This course focuses on practical applications of the strapdown inertial technology. Types of inertial applications are discussed. Challenges of using strapdown inertial navigation system (INS) for practical application areas are addressed. Specific application examples for stand-alone and integrated INS navigation are considered with the emphasis on INS specification requirements and INS performance characteristics. Main topics include:

- Types of strapdown INS applications:
 - Stand-alone applications
 - INS as a core part of integrated navigation systems
- Inertial sensors:
 - Sensor specifications – what do they mean and how to “read” them
 - Main sensor technologies, their current state and perspectives
- Challenges of using strapdown inertial in practical application areas:
 - Sensor and packaging errors
 - Vibrations
 - Sculling and coning errors
- Example stand-alone INS applications:
 - Long-term inertial coasting for aviation applications
- Example integrated INS applications:
 - GPS/INS integration for weak GPS signal processing

TUESDAY, 1:30am-5:00pm, Room 4

CN463 Applications of Strapdown Inertial Navigation II - Integrated Inertial Navigation Systems (3.0 CEU)

Dr. Andrey Soloviev, University of Florida

NEW

This course considers the use of inertial navigation system (INS) for multi-sensor integrated applications. The emphasis is on the integration of INS with GNSS-alternative navigation aids such as video cameras and laser radars. The course introduces a generic approach for multi-sensor fusion that uses INS as a core navigation sensor. Types of the integrated solution are discussed and specific integration examples are provided. As a particular case study, the multi-sensor fusion approach is applied to integrate the INS with laser radar (ladar) for navigation in GNSS-denied environments. Main topics include:

- Generic approach for INS-based multi-sensor navigation
- Review of Kalman filter principles
- Types of the multi-sensor integrated solution
- Loose integration
- Tight integration
- Deep Integration
- Range domain formulation of the INS-based multi-sensor fusion
- Case study: Ladar/INS integration for GNSS-denied navigation
- Introduction to ladar-based navigation
- Two-dimensional INS/ladar mechanization
- Extension into a three-dimensional case
- Performance demonstration with actual data

TRACK 5 TUESDAY AM & PM

TUESDAY, 8:30am-12:00pm, Room 5

CN 482: Fundamentals of GPS/INS Integration I (3.0 CEU)

Dr. Mohinder S. Grewal, P.E., California State University, Fullerton

NEW

This course covers the fundamentals of inertial navigation equations in Strapdown systems, GPS/INS configurations, integration and modeling of INS errors. Attendees are encouraged to bring their laptop with Matlab® to these courses.

- Main topics include:
- Fundamentals of Inertial Navigation
 - Coordinate Transformations
 - INS Descriptions
 - INS Vertical Channel Instability, Schuler Oscillation, Coriolis Effect, Coning and Sculling, and Gravity Modelling
 - Sensor Specifications and Models
 - Application of Kalman Filtering to Inertial Navigation Systems & GPS with Examples
 - o Feed Forward/Feedback Configuration
 - o Tightly/Loosely Coupled
 - o Deep INS/GPS
 - INS Error Models for Strapdown System (23 States)
 - Extended Kalman Filter Mechanization and Software Modules

TUESDAY, 1:30pm-5:00pm, Room 5

CN 483: Fundamentals of GPS/INS Integration II (3.0 CEU)

Dr. Mohinder S. Grewal, P.E., California State University, Fullerton

NEW

Building on Part I topics, this course gives examples of tightly and loosely coupled systems to large scale problems, such as 8, 11, 17, 21 and 23 states with GPS and DGPS. Attendees are encouraged to bring their laptop with Matlab® to these courses.

- Main topics include:
- Simplified Models for Strapdown System
 - INS Error Models & Sensor Parameters
 - Tightly Coupled (4 States by Hand)
 - 8 error state Estimation with 4 pseudorange and 4 delta pseudorange with MATLAB.
 - Tightly Coupled (8, 11 States with MATLAB®)
 - Tightly and Loosely Coupled (17 States with MATLAB®)
 - Tightly and Loosely Coupled with DGPS (21 States with MATLAB®)

TRACK 3 MONDAY EXTENDED EVENING

MONDAY, 6:45-9:30pm, Room 3

CN409 Precise Timekeeping and GNSS (2.5 CEU)

Dr. Demetrios Matsakis, U.S. Naval Observatory

Updated

This course emphasizes the modern timekeeping art, with emphasis on radionavigation. The fundamentals of timekeeping including GPS, UTC, and time transfer will be presented. Timekeeping using radionavigation systems, including chip scale atomic clocks for user equipment will be discussed.

Major topics include:

- Basics of Timekeeping
 - Fundamentals
 - Statistics
 - Timescale creation
 - Generation of Coordinated Universal Time (UTC)
 - Clock Steering
 - Generation of GPS Time
 - Time Transfer
- Radionavigation
 - GPS as a user and provider of precise time
 - Galileo and interoperability
 - Glonass
 - eLoran
- Parade of Clocks
 - From Stonehenge to Optical combs
 - Predictions for future

TRACK 4 MONDAY EXTENDED EVENING

MONDAY, 6:45pm-9:30pm, Room 4

CN471 Integrated Navigation Systems for Miniature Aerial Vehicle Applications (2.5 CEU)

Dr. Demoz Gebre-Egziabher, P.E., University of Minnesota

Updated

This course discusses issues associated with integrated navigation systems for navigation, attitude determination and control of small aerial vehicles.

Main topics include:

- Overview of issues associated with miniature aerial vehicle navigation
 - o Overview of multi-sensor systems
 - o Applications of low cost multi-sensor systems
- Sensors, sensor characterization and calibration
 - o GPS for position, velocity, and attitude
 - o Inertial sensors
 - o Magnetometers
 - o Air data sensors
- Case studies of integrated navigation and attitude determination systems
 - o Single and Multi-antenna GNSS/INS systems
 - o Low cost inertial systems with non-GNSS aiding

Images: GPS SV image courtesy Lockheed Martin. Galileo satellite image courtesy ESA - P. Carril

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	TRACK 1	TRACK 2	TRACK 3	TRACK 4	TRACK 5
Monday AM 8:30-12:00	<input type="checkbox"/> CN405: Fundamentals of GNSS I (Chris Bartone)	<input type="checkbox"/> CN425: GNSS Signals & Systems with emphasis on Galileo (Tony Pratt)	<input type="checkbox"/> CN431: GNSS Receiver Design I: RF Front-End Theory and Design (Gunawardena)	<input type="checkbox"/> CN460: Intro to Strapdown Inertial Navigation Systems I (Kevin Dutton)	<input type="checkbox"/> CN480: Fundamentals of Kalman Filtering for GPS/INS Integration I (Mohinder Grewal)
Monday PM 1:30-5:00	<input type="checkbox"/> CN406: Fundamentals of GNSS II (Chris Bartone)	<input type="checkbox"/> CN426: GNSS Signal Performance with emphasis on Galileo (Tony Pratt)	<input type="checkbox"/> CN432: Receiver Design II: Signal Processing (Sanjeev Gunawardena)	<input type="checkbox"/> CN461: Intro to Strapdown Inertial Navigation Systems II (Kevin Dutton)	<input type="checkbox"/> CN 481: Fundamentals of Kalman Filtering for GPS/INS Integration II (Mohinder Grewal)
Monday EVE 6:45-9:30	<input type="checkbox"/> CN420: GPS Modernization and Relation to other GNSS (Thomas Stansell)	<input type="checkbox"/> CN413: GNSS RAIM (Christophe Macabiau)	<input type="checkbox"/> CN409: Precise Timekeeping and GNSS (Demetrios Matsakis)	<input type="checkbox"/> CN471: Integrated Navigation Systems for Miniature Aerial Vehicle Applications (Demos Gebre-Egziabher)	<input type="checkbox"/> Open (check web site for updates)
Tuesday AM 8:30- 12:00	<input type="checkbox"/> CN410: Fundamentals of DGNSS (Hans-Jürgen Euler)	<input type="checkbox"/> CN433: Receiver Signal Processing for Future GNSS Signals - Introduction (Olivier Julien)	<input type="checkbox"/> CN441: GNSS Antennas I - Fundamentals (Chris Bartone)	<input type="checkbox"/> CN462: Applications of Strapdown Inertial Navigation I (Andrey Soloviev)	<input type="checkbox"/> CN 482: Fundamentals of GPS/INS Integration I (Mohinder Grewal)
Tuesday PM 1:30- 5:00	<input type="checkbox"/> CN415: Fund. of GNSS Baseline RTK & Network RTK applications (Hans-Jürgen Euler)	<input type="checkbox"/> CN434: Receiver Signal Processing for Future GNSS Signals - Advanced (Olivier Julien)	<input type="checkbox"/> CN445: GNSS Antennas II - Special Topics (Rama Rao)	<input type="checkbox"/> CN463: Applications of Strapdown Inertial Navigation II – Integrated (Andrey Soloviev)	<input type="checkbox"/> CN 483: Fundamentals of GPS/INS Integration II (Mohinder Grewal)

Registration Information:

Selection: Choose any time slot. An entire track, or move around to suite your needs, see www.GNSSolutions.com/ION_GNSS_2009_Tutorials_Seminars.html for course syllabi, prerequisites, intended audiences, alternative track recommendations and updates.

Cost: See table below. Special discounts available (one discount per person/order), detailed at www.GNSSolutions.com/Registration_info.html

- Competitive Pricing – Quality You Can Count On.
- Group discounts: Available for organizations that register 3 or more attendees at the same time, see www.GNSSolutions.com/Registration_info.html for details.
- Flexibility discount: For attendees who want to take some tutorials elsewhere and some from GNSS Solutions, see www.GNSSolutions.com/Registration_info.html
- ION Members discount: Receive a \$30 discount (not valid with student registration).
- Student discount: Full-time Student Rate of \$125 per ½ day session (\$115 for extended evening) with proof of full-time student status and official school ID.

Handout Booklet: Comprehensive course handout, professionally bound, color where needed, with every tutorial.

Registration Options: Fill out this form & fax it securely via SSL to: 740-205-4123 (f) or 877-444-5770 (f), (US & Canada)

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Payment Options: Credit card, check, transfer, 1556, PO, Cash or on-line at www.GNSSolutions.com.

Walk-in Registrations on-Site: Welcome at any time; if we run out of notes, we will mail them to you.

Location: Marriott Savannah Riverfront, 100 General McIntosh Blvd., Savannah, GA 31401 (free day parking) - Great location!

Times:
 7:00 am Coffee/Sign-in begins
 8:30 am-12:00 pm Morning Sessions
 1:30 pm-5:00 pm Afternoon Sessions
 6:45 pm-9:30 pm Extended Evening Sessions

Coffee/drinks/snacks
throughout the day

Register to win: Every paid tutorial attendee will be entered to win a handheld GPS Receiver; one entry for each tutorial.

Registration/Attendees Information:

Name: _____

Organization: _____

Address: _____

City: _____

State/Prov./Country: _____

Zip/Postal Code: _____

Phone: _____

Fax: _____

Email: _____

Preregister me now, I will pay later.

Certificate of Completion:
Individualized with name, tutorials
and CEUs listed.

Payment Information:

Total Fee (USD): _____

Card Type (circle one): Visa Master Card American Express

Discover/Novus Dinners Club JCB

Card Number: _____

Card Expiration Date: _____ Cardcode: _____

Signature: _____

Fees:

Number of 1/2 day Sessions	Competitive Pricing – Quality You Can Count On			
	Early Registration (Before 31 Aug)		Standard Registration (After 31 Aug)	
	Total Cost for 1/2 Day Sessions	Add an Extended Evening Session	Total Cost for 1/2 Day Sessions	Add an Extended Evening Session
1	\$399	\$289	\$429	\$319
2	\$798	\$289	\$858	\$319
3	\$998	\$251	\$1,049	\$264
4	\$1,245	\$212	\$1,279	\$220

Total Payment:

Total 1/2 day fees: _____

Extended evening fee: _____

Group discount: See website or call _____

Flexibility discount: _____

ION Member discount: _____

Total fee due: _____

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