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Stanford University **since 1993**
Kleiner Perkins, Mayfield, Sequoia Capital Professor in the School of Engineering
Director of the Center for Position Navigation and Time
Associate Chair of the Department of Aeronautics and Astronautics

Principal Investigator of Federal Aviation Administration grants to augment the Global Positioning System (GPS). Stanford work includes the development and prototyping of the wide area augmentation system (WAAS), and the local area augmentation system (LAAS). WAAS already has over thirty million land and maritime users and began aircraft operations in July of 2003. LAAS will enable automatic landings at critical, high-traffic airports. A provably safe prototype will be deployed at Memphis in 2006. Stanford work also covers the potential use of Loran to augment GPS with high power terrestrial signals that would be difficult to jam and would enable a host of indoor applications.

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Worcester Polytechnic Institute **1986-1993**
Associate Professor of Electrical and Computer Engineering

Principal Investigator for the US Coast Guard research contract to design and prototype a medium frequency (MF) radio system to broadcast differential GPS corrections to maritime users. Today, this system covers much of the world's coastline and provides differential GPS data to 1.5 million users. The U.S. Congress has mandated that this system be extended to provide inland coverage for the continental United States. Lead designer of the signal and first receiver for this MF broadcast system.

Megapulse Inc. **1975-1977 and 1979-1984**
Engineering Specialist and Manager.

Contributed to the design of the first solid state Loran transmitter. Today over 30 of these transmitters provide Loran coverage to most of the Northern hemisphere. Also invented a signaling scheme so that each Loran transmitter can send 10 to 200 bits per second of data without degrading the navigation performance of the signal.

Consultant to Industry **since 1985**

Advised the corporations on issues related to wireless communications and avionics. Services include analysis, synthesis, and evaluation of existing systems, the design of commercial receivers and transmitters, and analysis of international regulatory agreements that govern the allocation and use of radio spectrum. Most significant relationships are with SiRF and Rosum.

Education

B.S. in Electrical Engineering from the Univ. of Massachusetts at Amherst, 1975
M.S. in Electrical Engineering from the Univ. of Illinois at Urbana-Champaign, 1979
PhD. in Electrical Engineering from the Univ. of Illinois at Urbana-Champaign with a dissertation on spread spectrum multiple access communications, 1983

Honors

2005 Elected to the National Academy of Engineers
2004 Fellow of the Institute of Electrical and Electronics Engineers
2001 Best Academic Paper at the Fifth International Symposium on Satellite Navigation Technology and Applications, Canberra, Australia, July 2001
2001 Fellow of the Institute of Navigation
2000 Kepler Award from the Satellite Division of the Institute of Navigation
1999 President of the Institute of Navigation
1997 Burka Award for the Best Paper in the Journal *Navigation*
1996 Thurlow Award from the Institute of Navigation
1990-2001 Over 18 "Best Paper of Session" awards at conferences on Global Positioning
1988 Joseph Satin Distinguished Fellowship for Excellence in Teaching and Research

Invited Seminars on Satellite Navigation: University of Texas-Austin, Massachusetts Institute of Technology, Lincoln Laboratories, University of Washington, Princeton University, Clemson University, University of Illinois at Urbana-Champaign, University of Wales, University of Nottingham, Royal Melbourne Institute of Technology, Boeing Defense and Space Group, Navtech Seminars, Information Systems Laboratory at Stanford University

Recent Talks:

1. "Status of LAAS and WAAS," invited presentation to Munich Satellite Navigation Summit, March 2005
2. "GPS Modernization: Capabilities of the New Civil Signals," invited presentation to the Tenth Australian International Aerospace Congress, Brisbane, Australia, August 2003
3. "Navigating by Satellite: A U.S. Perspective," invited talk for the Conference on Issues of Risk and Responsibility in Contemporary Engineering and Science: French and U.S. Perspectives, Stanford, April 8, 2003
4. "Landing Airplanes Using GPS," invited presentation for the K.D. Wood Colloquium at the University of Colorado-Boulder, April 11, 2003
5. "A Global Concern – Interference from Ultra-Wideband," plenary talk at IONGPS02 in Portland Oregon on September 24, 2002
6. "GPS for Aviation: Present and Future", plenary talk for the Fifth International Symposium on Satellite Navigation Technology and Applications, Canberra Australia, July 2001
7. "The Future of Aircraft Navigation", plenary talk for the Global Navigation Satellite Symposium, Edinburgh, May, 2000
8. "Integrity of the Wide and Local Area Augmentation Systems", plenary talk at IONGPS98 in Nashville, September 15, 1998

Other Information: Effectively brings academic resource to real world challenges. Academic output includes more than one hundred articles on wireless communication and satellite navigation, and effective teaching at Worcester Polytechnic Institute and Stanford University. At the same time, his research effort has resulted in the deployment of two operational navigation systems. The first system began operation in 1995, and today is used by over 1.5 million marine and land users. The second system also has over one million land users, and became operational for aircraft in 2003. Effective innovation is also evidenced in ten U.S. patents and many international patents. These include novel algorithms to: combat GPS multipath, mitigate skywave interference in medium frequency radio broadcast, and combine ranging information from GPS satellites and low earth orbiting (LEO) communication satellites.

Per Enge (Books, Patents and Journal Articles)

Books:

1. Parkinson, J. Spilker, P. Axelrad and P. Enge, editors of *Global Positioning System: Theory and Applications,* American Institute of Aeronautics and Astronautics, 1996. Within this collection, co-authored the following three chapters:
   - B. Parkinson and P. Enge, "Differential GPS," pp. 3-50;
   - P. Enge and A.J. Van Dierendonck, "Wide Area Augmentation System," pp. 117-142;
   - P. Enge and F. Van Graas, "Integration of GPS and Loran-C," pp. 169-186.
2. Misra and P. Enge, *Global Positioning System: Signals, Measurements and Performance*, Ganga-Jumuna Press, 2nd edition, 2006

Patents Issued:

1. R. E. Phelts and P. Enge, "Multipath and Tracking Error Reduction Method for Spread-Spectrum Receivers," U.S. Patent 6,868,110B2, Issued March 15, 2005, Assigned to Stanford University
2. F. Bauregger, T. Walter, D. Akos and P. Enge, "Dual-Element Micro-strip Patch Antenna for Mitigating Radio Frequency Interference," U.S. Patent 6,930,639, Issued August 16, 2005, Assigned to Stanford University
3. P.K. Enge and N. Talbot, "Method and Receiver Using Low Earth Orbiting Satellite Signal to Augment the GPS," U.S. Patent No. 5,944,770, 2000.
4. P.K. Enge and N. Talbot, "Method and Receiver Using Low Earth Orbiting Satellite Signal to Augment the GPS," U.S. Patent No. 5,812,961, 1998.
5. P.K. Enge and D. Young, "Multi-tone DGPS Beacon Transmitter and Receiver," U.S. Patent No. 5,745,075, April 28, 1998.
6. P. Enge, D. Farmer and J. Schipper, "Adaptive Multipath Equalization," U.S. Patent No. 5,630,208, May 13, 1997.
7. P. Enge, T. Walter and Y.C. Chao, "Wide Area Differential GPS Reference System and Method," U.S. Patent No. 5,621,646, April 15, 1997.
8. P. Enge, D. Farmer and B. Westfall, "Adaptive Noise Cancellation," U.S. Patent No. 5,465,413, November 7, 1995.
9. P.K. Enge, P.R. Johanessen and J. Bussgang, "Method and Apparatus for Meteor Scatter Communications Via Loran Communication Signals," U.S. Patent No. 5,278,568, January 11, 1994.
10. P.K. Enge, "Method of and Apparatus For Loran-C Message Communication With Reduced Skywave Navigation Location Errors and the Like," U.S. Patent No. 4,821,038, April 11, 1989.
11. P.K. Enge, "Method of and Apparatus For Message Communication On Loran-C Navigation Signal Broadcasts and the Like With Reduced Navigation Errors," U.S. Patent No. 4,800,391, January 24, 1989.
12. P.K. Enge and R.B. Goddard, "Method of and Apparatus For Reduced Cycle Slip Error in Loran-C and Similar Radio Frequency Signal Reception, Particularly in Vehicles Undergoing Acceleration," U.S. Patent No. 4,743,912, May 10, 1988.

Journal Articles: (GPS student names appear in bold.)

1. **D. Gebre-Egziabher**, A. Razavi, P. Enge. J. Gautier, S. Pullen, B. Pervan and D. Akos, "Sensitivity and Performance Analysis of Doppler-Aided GPS Carrier-Tracking Loops," *Journal of the Institute of Navigation*, Vol. 52, No. 2, Summer 2005

2. **J. Lee**, S. Pullen, and P. Enge, "Sigma-Mean Monitoring for the Local Area Augmentation." Accepted for publication in the IEEE Transactions on Aerospace and Electronic Systems
3. **J. Lee**, S. Pullen, P. Enge, B. Pervan, and L. Gratton, "Monitoring GPS Satellite Orbit Errors for Aircraft Landing Systems." Accepted for publication in the AIAA Journal of Aircraft
4. Jason Rife, Sam Pullen, Boris Pervan and Per Enge. "Paired Overbounding for Nonideal LAAS and WAAS Error Distributions." Accepted for publication in the IEEE Transactions on Aerospace and Electronic Systems.
5. P. Enge, "Retooling the Global Positioning System," *Scientific American*, May 2004
6. **D. Gebre-Egziabher, C.O.Lee Boyce**, J. D. Powell and P. Enge, "An Inexpensive DME-Aided Dead Reckoning Navigator," Journal of Navigation, Vol 50, No. 4, Winter 2003-2004, pp. 247-263.
7. **J. Blanch**, T. Walter and P. Enge, "Ionospheric Threat Model Methodology for WAAS," *Journal of the Institute of Navigation*, Vol. 49, No. 2, pp. 103-108, Summer 2002
8. **D. Gebre-Egziabher**, J. D. Powell and P. Enge, "Design and Performance Analysis of a Low-Cost, Aided Dead Reckoning Navigation System," *Gyroscopy and Navigation* (translated into Russian), Vol. 35, No. 4, pp. 83-92, 2001.
9. T. Walter, **A. Hansen, J. Blanch**, P. Enge, T. Mannucci, X. Pi, L. Sparks, B. Iljima, B. El-Arini, R. Lejeune, M. Hagen, E. Altshuler, R. Fries and A. Chu, "Robust Detection of Ionospheric Irregularities," *Journal of the Institute of Navigation*, Vol. 48, No. 2, pp. 89-100, Summer 2001.
10. **J. Nichols, A. Hansen**, T. Walter and P. Enge, "High Latitude Measurements of Ionospheric Scintillation Using the National Satellite Testbed," *Journal of the Institute of Navigation*, Vol. 47, No. 2, pp. 112-120, Summer 2000.
11. T. Walter, P. Enge and **A. Hansen**, "Integrity Equations for the WAAS MOPS," *Selected Papers on Satellite Based Augmentation Systems: Published and Invited Papers*, Institute of Navigation, pp. 165-186, 1999.
12. **A. Hansen**, T. Walter and P. Enge, "Real-time Tomography Using Terrestrial GPS Sensors," *Selected Papers on Satellite Based Augmentation Systems: Published and Invited Papers*, Institute of Navigation, pp. 319-338, 1999.
13. J.P. Fernow, D. O'Laughlin, T. Hsiao, J. Reagan, **R. Fuller**, T. Walter, **D. Dai**, P. Enge and D. Powell, "Interoperability of Satellite-Based Augmentation Systems," *Selected Papers on Satellite Based Augmentation Systems: Published and Invited Papers*, Institute of Navigation, pp. 399-424, 1999.
14. R. Hatch, **J. Jung**, P. Enge, and B. Pervan, "Civilian GPS: The Benefits of Three Frequences", *GPS Solutions*, Vol. 3, No. 4, pp. 1-9, 2000.
15. P. Enge, "Local Area Augmentation of GPS for the Precision Approach of Aircraft," *Proceedings of the IEEE*, Special Issue on GPS, Vol. 87, No. 1, pp. 111-132, January 1999.
16. P. Enge and P. Misra, "Scanning the Special Issue/Technology on the Global Positioning System," *Proceedings of the IEEE*, Special Issue on GPS, Vol. 87, No. 1, pp. 3-15, January 1999.
17. P. Enge, D. Young and B. Butler, "Two Tone Diversity to Extend the Range of DGPS Radiobeacons," *Journal of the Institute of Navigation*, Vol. 45, No. 3, pp. 161-172, Fall 1998, *Winner of the 1998 Burka Award for the Best Paper in the Journal of the Institute of Navigation.*
18. B. Pervan, **D. Lawrence, K. Gromov, G. Opshaug, J. Christie, P.Y. Ko, A. Mitelman**, S. Pullen, P. Enge and B. Parkinson, "Flight Test Evaluation of an Alternative Local Area Augmentation System Architecture," *Journal of the Institute of Navigation*, Vol. 45, No. 1, pp. 31-38, 1998.
19. P. Enge, "WAAS Messaging System: Data Rate, Capacity and Forward Error Correction," *Journal of the Institute of Navigation*, Vol. 44, No. 1, pp. 63-76, Spring 1997. Also reprinted in *Selected Papers on Satellite Based Augmentation Systems: Published and Invited Papers*, Institute of Navigation, pp. 139-164, 1999.
20. **K. Breivik**, B. Forssell, C. Kee, P. Enge and T. Walter, "Estimation of Multipath Error in GPS Pseudorange Measurements," *Journal of the Institute of Navigation*, Vol. 44, No. 1, pp. 43-52, 1997.

21. C. Kee, T. Walter, P. Enge and B. Parkinson, "Quality Control Algorithms on WAAS Wide Area Reference Stations," *Journal of the Institute of Navigation*, Vol. 44, No. 1, pp. 53-62, 1997.
22. **S. Lo**, C. Kee, and P. Enge, "Algorithms for Crossover Point Determination," Computers & Mathematics with Applications, Vol. 33, Issue 11, pp. 117-131, June 1997.
23. C. Kee, T. Walter, **Y.C. Chao, Y.J. Tsai**, P. Enge and B.W. Parkinson, "Comparison of Master Station Algorithms for the Wide Area Augmentation System," *AIAA Journal of Guidance, Control and Dynamics*, Vol. 20, No. 1, pp. 170-176, January-February 1997.
24. P. Enge, T. Walter, S. Pullen, **C. Kee, Y.C. Chao** and **Y.J. Tsai**, "Wide Area Augmentation of the Global Positioning System," *Proceedings of the IEEE*, Vol. 84, No. 8, pp 1063-1088, August 1996.
25. **A. Barrows**, P. Enge, B. Parkinson & J. D. Powell, "Evaluation of a Perspective View Cockpit Display for General Aviation Using GPS," *Journal of the Institute of Navigation*, Vol. 43, No. 1, pp 55-70, 1996.
26. T. Thorsteinsson, G. Gunnarsson, G. Gudmundsson, G. Tryggvasson, P. Enge, D. Young, L. Shenyblatt, B. Westfall, C. Daniell and J. Helgason, "Iceland's Network of Differential GPS Radiobeacons," *Journal of the Institute of Navigation*, Vol. 42, No. 4, pp. 557-580, 1995-96.
27. P. K. Enge, E. Swanson, R. Mullin, K. Ganther, A. Bommarito and R. Kelly, "Terrestrial Radio Navigation Technologies," invited paper for *Journal of the Institute of Navigation*, Vol. 42, No. 1, pp. 61-108, 1995.
28. P.K. Enge, "The Global Positioning System: Signals, Measurements and Performance," invited paper for the *International Journal on Wireless Information Networks*, Vol. 1, No. 2, pp. 83-105, April 1994.
29. P.K. Enge, D. Young, L. Sheynblatt and B. Westfall, "DGPS Field Trials, Which Compare Type 1 and Type 9 Messaging," *Journal of the Institute of Navigation*, Vol. 40, No. 4, pp. 395-408, 1993-94.
30. P.K. Enge, "Forward Error Correction for Radiobeacon Broadcast of Differential GPS Data," *IEEE Transactions on Aerospace and Electronics Systems*, Vol. 29, No. 1, pp. 323-333, January 1993.
31. P.K. Enge, P.L. Levin, **A. Hansen** and R. Kalafus, "Coverage of GPS/Radiobeacons," *Journal of the Institute of Navigation*, Vol. 39, No. 4, pp. 363-381, 1992-93.
32. **K.E. Olson** and P.K. Enge, "Forward Error Correction for an Atmospheric Noise Channel," *IEEE Transactions on Communications*, Vol. 40, No. 5, pp. 863-872, May 1992.
33. **J. Pisano**, P.K. Enge and P. Levin, "Using GPS to Calibrate Loran-C," *IEEE Transactions of Aerospace and Electronics Systems*, Vol. 27, No.4, pp. 696-708, July 1991, also Proceedings of the Third International Technical Meeting of the Satellite Division of The Institute of Navigation, Colorado Springs, pp. 207-216, Sept. 1990, *Best of Session Award*.
34. P. Enge and **K. Olson**, "Medium Frequency Broadcast of Differential GPS Data," *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 26, No. 4, pp. 607-617, July 1990.
35. P.K. Enge, F. Vicksell, R. Goddard and F. van Graas, "Combining Pseudoranges From GPS and Loran-C For Air Navigation," *Journal of the Institute of Navigation*, Vol. 37, No. 1, pp. 95-112, 1990. Also *Best Paper* at the 1989 Meeting of the International Loran Society. Also reprinted in Volume V of the GPS Red Books, papers on GPS published in the Journal of the Institute of Navigation.
36. P.K. Enge and J. McCullough, "Aiding GPS With Calibrated Loran-C," *Journal of the Institute of Navigation*, Vol. 35, No. 4, pp. 469-482, 1988.
37. P.K. Enge and G. Noseworthy, "Cross-rate Synchronization of Loran-C Using GPS," *Journal of the Institute of Navigation*, Vol. 35, No. 3, pp. 335-346, 1988.
38. P.K. Enge, R.M. Kalafus and M.F. Ruane, "Differential Operation of the Global Positioning System: An Introduction," *IEEE Communications Magazine*, Vol. 26, No.7, pp. 48-60, July 1988.
39. P.K. Enge and D.V. Sarwate, "Spread Spectrum Multiple Access Performance of Orthogonal Codes: Impulsive Noise," *IEEE Transactions on Communications*, Vol. COM-36, No.1, pp. 98-106, Jan. 1988.
40. P.K. Enge, M.F. Ruane and **D. Langlais**, "Coverage of a Radiobeacon-based Differential GPS Network," *Journal of the Institute of Navigation*, Vol. 34, No. 4, pp. 307-324, 1987.

41. P.K. Enge and D.V. Sarwate, “Spread Spectrum Multiple Access Performance of Orthogonal Codes: Linear Receivers,” *IEEE Transactions on Communications*, Vol. COM-35, No. 12, pp. 1309-1319, Dec. 1987.