

# CURRICULUM VITAE ET STUDIORUM (LAST UPDATE: 08/05/2003)

## CONTACT INFORMATION

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## DEGREES

October 1995

Ph.D. in Telecommunication Engineering, University of Pisa.

Thesis title: "*Rivelazione coerente in clutter misto di tipo K e Gaussiano mediante statistiche di ordine superiore*" (Coherent detection of radar targets in the presence of a mixture of K-distributed and Gaussian clutter using higher order statistics).

Advisor: Prof. Lucio Verrazzani.

Oct. 1991-Oct. 1994:

Ph.D. student in Telecommunication Engineering at the DII, University of Pisa.

November 1990

Laurea degree (*cum laude*) in Electrical Engineering, University of Pisa.

Thesis title: "*Prestazioni di ricevitori per ottica coerente*" (Digital coherent optical communication in the presence of multiplicative noise).

Advisors: Prof. Umberto Mengali and Prof. Marco Luise.

Nov.1983-Nov. 1990

Student of Electronic Engineering at the University of Pisa (5 years legal term plus one year devoted to the *laurea* thesis work).

## CAREER

Oct. 2000 - present

Associate Professor, DII, University of Pisa, Pisa, Italy.

Jul. 1996 – Feb. 1997

Visiting Researcher, Department of Electrical Engineering, University of Virginia, Charlottesville, USA.

Jun. 1993 – Oct. 2000

Assistant Professor, DII, University of Pisa, Pisa, Italy.

Nov. 1990 – Apr. 1991

TELETTRA (now part of ALCATEL) grantee for research work on "Coherent optical communications systems."

## TEACHING

- Oct. 2001 - present Signal Theory I (2<sup>nd</sup> year in the “Corso di Laurea” (Laurea degree) in Electronic Engineering) and Random Signal Theory (3<sup>rd</sup> year in the “Corso di Laurea” in Telecommunication Engineering) as an Associate Professor, DII, University of Pisa, Italy.
- Oct. 2000 – Sep. 2001 Signal Theory I and Communication Systems (2<sup>nd</sup> year in the “Diploma di Laurea” and “Corso di Laurea” in Electronic Engineering) as an Associate Professor, DII, University of Pisa.
- Apr. 1993 – Sep. 2000 Signal Theory I (3<sup>rd</sup> year in the “Corso di Laurea” in Telecomm. Eng.) and Signal Theory II (4<sup>th</sup> year in the “Corso di Laurea” in Telecomm. Eng.) as an Assistant Professor, DII, University of Pisa.
- Apr. 1993 – May 1993 Seminar “Wiener and Kalman filtering” for the class of Signal Theory II (4<sup>th</sup> year in the “Corso di Laurea” in Telecomm. Eng.).

## HONORS/AWARDS

- 2001 IEEE Aerospace and Electronic Systems Society’s Barry Carlton Award for 2001 Best Paper for the paper (co-authored with P. Lombardo, M. Greco, A. Farina, and B. Billingsley) that was published in the July 2001 issue of the *IEEE Transactions on Aerospace and Electronic Systems*.
- 1991 SIP (now Telecom) award for the 1990 best Laurea thesis in Telecommunications.

## ADVISING - Ph.D. theses co-supervised

- Oct. 2001 – present **Federica Bordoni**, presently working at the DII of the University of Pisa on multichannel spectral estimation techniques for multibaseline SAR interferometry and on multiple targets detection and estimation in surveillance radar.
- Oct. 1999 – Oct. 2001 **Monica Montanari**, *Sensor Array Processing with Application to STAP and Interferometric SAR*; now with the Ocean Engineering Department of the Massachusetts Institute of Technology (Post-doctoral associate).
- Oct. 1994 – Oct. 1997 **Maria S. Greco**, *Ground and Sea Non-Gaussian Clutter: Statistical Analysis and Adaptive Radar Detection*; now with the DII of the University of Pisa (Assistant Professor).
- Oct. 1993 – Oct. 1996 **Fabrizio Lombardini**, *Distributed Radar Detection in Non-Gaussian Clutter*; now with the DII of the University of Pisa (Assistant Professor).

## **EXPERTISE AND GENERAL INTERESTS**

Prof. Gini's professional expertise encompasses statistical signal processing, estimation and detection theory, statistical methods for data analysis, poly-spectral analysis, non-Gaussian signal detection and estimation, decentralized detection, multichannel signal processing, performance bounds evaluation, non-stationary and cyclostationary signal analysis, with applications to radar and digital communications. He authored or co-authored about 60 journal papers and 50 conference papers.

## **CURRENT RESEARCH GOALS**

- Space-time adaptive detection of subspace random signals in correlated non-Gaussian background;
- Texture modeling and retrieval of high resolution sea clutter for constant false alarm rate (CFAR) radar detection;
- Non-stationary high resolution sea clutter analysis and characterization;
- Design and analysis of estimation algorithms for cross-track and along-track multichannel SAR interferometry;
- Multibaseline processing and performance prediction for accurate digital elevation map (DEM) generation robust to data noise, phase ambiguity, and blind angles;
- Modern spectral estimation techniques for multichannel InSAR processing against correlated multiplicative noise, model order estimation of multicomponent multibaseline InSAR signals corrupted by correlated multiplicative noise;
- Along-track SAR interferometry (ATI-SAR) for ocean surface current velocity measurement in the presence of bimodal data power spectral density (dual-Bragg effect);
- Pseudo-monopulse methods for multiple radar target direction-of-arrival (DOA) estimation, joint detection and estimation of multiple radar targets present in the same range-azimuth resolution cell of a surveillance radar system with a mechanically rotating antenna.
- Modeling, estimation and classification of sounds generated by marine mammals in the Tyrrhenian sea, experimental evaluation with real data.

## **PROJECTS AND FUNDING**

### **Proposals Submitted as Principal Investigator (for the UNI-PI Research Team):**

- 2003 *Multimode Synthetic Aperture Radar (Multichannel SAR with COSMO-SkyMed)*, proposal submitted to the "Payload Radar Technological Unit" of the Italian Space Agency (ASI)
- 2003 *Signal and Image Processing for Alimentary Safety ALLSAFE*, FET Open Short Proposal (STREP Project) to the IST Program of the European Commission's Sixth Framework Program (Call Identifier IST-2.3.4.1)

2003 *Advanced target detection strategies for high resolution radar*, proposal submitted to the United States Army Research, Development, and Standardization Group (USARDSG), UK Office.

2003 *Tecnologie e Tecniche di Elaborazione Abilitanti basate su Antenne Multicanale per la Stima del Movimento con il SAR di COSMO/SkyMed (Multichannel Antennas Signal Processing Technologies and Techniques for Motion Estimation Using the COSMO/SkyMed SAR System)*, Expression of Interest (EoI) for the Italian Space Agency (ASI), 2003-2005 National Space Program, Theme: Earth Observation.

2003 *Sviluppo ed integrazione di tecniche di telerilevamento e diagnostica elettromagnetica per l'individuazione e il monitoraggio di aree in frana (Development and Integration of Remote Sensing and Electromagnetic Diagnosis Techniques for Landslides Determination and Monitoring)*, Expression of Interest (EoI) for the Italian Space Agency (ASI), 2003-2005 National Space Program, Theme: Earth Observation.

#### **Principal Investigator:**

2003-2004 *Radar target detection in the presence of signal deception*, funded by Alenia-Marconi Systems (AMS).

2001-2006 *Object oriented simulation and novel technologies for the modelling of complex environmental systems*, INTERREG III-A, funded by the European Community (EU).

2002-2003 *Model-based advanced methods for topographic map reconstruction using interferometric multichannel radar systems*, funded by the University of Pisa.

2002-2003 *Non Cooperative Target Recognition*, funded by Alenia-Marconi Systems (AMS).

#### **Participation to:**

2000 *Radar Theory and Techniques*, preparation of educational CDs in the framework of the TELECOM project funded by the Tuscany Region (Italy).

1997-2000 *Novel methodologies for the integration, processing, and analysis of data from spaceborne sensors for the monitoring of the hydrosphere, rainfall phenomena, and of the ground*, funded by the Italian Space Agency (ASI).

1998-2000 *Signal processing of underwater acoustic signals: analysis of physical and biophysical phenomena*, INTERREG II, funded by the European Community (EU).

1994-1996 *Decentralized detection and tracking with multisensor radar systems*, funded by the Mariteleradar Institute of the Italian Navy.

1994-1996 *Model-based analysis, coding and synthesis of multidimensional images*, project funded by the Ministry of University and Scientific Research (MURST).

1991-1994 *Environmental remote sensing microwave sensors and data integration*, project funded by the Ministry of University and Scientific Research (MURST).

1989-1991 *Technologies for wideband optical communications*, funded by the Italian Council of Research (CNR).

**Consulting for:**

2003: INSIS System Engineering, Marconi-Selenia Communications

2002: Comune di Fucecchio (Italy)

**SERVICES**

**Professional Society**

- IEEE Member since 1992 and Senior Member since January 1, 2000.
- Associate Editor for the IEEE TRANS. ON SIGNAL PROCESSING since July 31, 2000.
- Member of the Signal Processing Theory and Methods (SPTM) Technical Committee (TC) of the IEEE Signal Processing Society since January 2003.
- Associate Member of the Sensor Array and Multichannel (SAM) Technical Committee (TC) of the IEEE Signal Processing Society since November 2002.
- Guest co-editor of the special issue of the *Eurasip Signal Processing* journal on “*New trends and findings in antenna array processing for radar,*” to appear mid 2004.
- Member of the Technical Committee for the 2004 IEEE Workshop on *Sensor Array and Multichannel* (SAM), Barcelona, Spain, July 2004.
- Member of the Technical Committee for the 2003 IEEE International Symposium on *Signal Processing and Information Technology* (ISSPIT), Darmstadt, Germany, 14-17 December 2003.
- Organizer of the special session on “Signal Processing for Radar Applications” at the IEEE International Symposium on *Signal Processing and Information Technology* (ISSPIT), Darmstadt, Germany, 14-17 December 2003.
- Member of the Organizing Committee for the *Tyrrhenian International Workshop on Remote Sensing* (TIWRS), Elba Island, Italy, September 2003.
- Co-organizer of the special session on “Multichannel SAR Interferometry” at the *IEEE International Radar Conference*, Adelaide, Australia, September 2003.
- European Liaison, *IEEE International Radar Conference*, Adelaide, Australia, September 2003.
- Member of the Technical Program Committee for the *IEEE International Radar Conference*, Adelaide, Australia, September 2003.
- Treasurer for the 2003 IEEE Workshop on *Signal Processing Advances in Wireless Communications* (SPAWC), Rome, Italy, June 2003.
- Member of the Technical Committee for the 2003 IEEE-EURASIP Workshop on *Nonlinear Signal and Image Processing* (NSIP), Grado, Italy, June 2003.

- Session Chairman, *International Conference on Signal Processing*, Beijing, China, October 1998.
- Reviewer for the following international journals: *IEEE Trans. on Aerospace and Electronics Systems*; *IEEE Trans. on Signal Processing*; *IEEE Trans. on Communications*; *IEEE Trans. on Information Theory*; *IEEE Trans. on Systems, Man, and Cybernetics*; *IEEE Signal Processing Letters*; *IEE Proceedings - Radar, Sonar and Navigation (Part-F)*; *IEE Proceedings - Vision, Image and Signal Processing*; *Electronics Letters*; *Signal Processing (Elsevier)*; and international conferences: *Fifth Communication Theory mini-conference (London UK, 1996)*; *Radar 2002 (Edinburgh, UK)*, *ICASSP 2002 (Orlando, Florida)*; *NSIP 2003 (Grado, Italy)*; *ICASSP 2003 (Hong Kong, China)*; *Radar 2003 (Adelaide, Australia)*, *ICIP 2003 (Barcelona, Spain)*.

### University

- **Department committees:**
  - 2001-present. Member of the Permanent Committee of the Ph.D. in Information Engineering (Electronics, Computer Science, and Telecommunications), University of Pisa.
  - 2000-present. Member of the “Giunta” (Board of Governors) of the DII.
  - 2000-2001. Secretary of the “Corso di Laurea” (Laurea degree) in Telecommunication Engineering.
  - 1999-2000. Member of the “Didactic Committee” of the “Corso di Laurea” in Telecommunication Engineering.
  - 1993-present. Member of Graduate committees and Advisor of Laurea Theses
- **Faculty committees:**
  - 2000-present. Member of the “Library Committee” of the Faculty of Engineering.
  - 2000-present. Member of the “Research Committee” of the Faculty of Engineering.
- **International Committees:**
  - Mar. 2002. Opponent for Ph.D. Defense in Sweden (Göteborg).

### Short courses/Invited lecturers

- *Coherent radar detection in non-Gaussian clutter environment*, DII, University of Pisa, course for professors and researchers of the University of Warsaw and Lodz, in the framework of European Community Project TEMPUS-PHARE JEP 7403 entitled *Modern Technologies in Telecommunications for New Polish Educational System*, Pisa, Italy, July 1995.
- *The modified Cramér-Rao bound and its applications to digital communications*, Department of Electrical Engineering, University of Virginia, Charlottesville, Virginia, September 1996.

- *Distributed radar detection with multiple local free parameters: a hierarchical optimization approach*, annual meeting of the Italian Telecommunication and Information Theory Group, Cernobbio, Italy, June 1998.
- *Coherent detection and fusion in high resolution radar systems*, Departement Avionique et Systemes, ENSICA, Toulouse, France, June 1999.
- *Frequency estimation of radar/sonar signals against correlated non-Gaussian noise*, SDEM, University of Corse, Corte, France, June 2000.
- *Novel methodologies for the integration, processing, and analysis of data from spaceborne sensors for the monitoring of the hydrosphere, rainfall phenomena, and of the ground: goals and findings*, plenary meeting of the ASI project on Remote Sensing, CNIT, Pisa, November 2001.
- *Multichannel cross-track synthetic aperture radar interferometry*, Department of Signals and Systems, Chalmers University of Technology, Göteborg, Sweden, February 2002.
- *Introduction to and comments on "On Detection and Estimation of Multiple Sources in Radar Array Processing"* (for J. Eriksson's Ph.D. defense) as Faculty Opponent at the Chalmers University of Technology, March 2002.
- *Advanced spectral estimation techniques for multibaseline interferometric SAR systems*, Department of Electrical and Computer Engineering, University of Minnesota, Minneapolis, Minnesota, May 2002.
- *Advanced spectral estimation techniques for multibaseline interferometric SAR systems*, Department of Information Engineering, University of Pisa, Pisa, Italy, June 2002.
- *Multibaseline SAR interferometry*, Statistical Image Processing Group, National Council of Research (ISTI-CNR), Pisa, Italy, July 2002.
- *Multiple Target Estimation by Exploiting the Amplitude Modulation Induced by Antenna Scanning*, Alenia-Marconi Systems, Rome, Italy, July 2002.
- *Multibaseline SAR interferometry*, final meeting of ASI project on Remote Sensing, CNIT, Pisa, September 2002.
- *Multiple Radar Targets Detection and Estimation*, Alenia-Marconi Systems, Rome, Italy, November 2002.

### **Tutorials given at International Conferences**

- May 1999      *Coherent detection and fusion in high resolution radar systems* (3 h.), International Conference on Radar, Brest, France (co-speaker: Prof. Alfonso Farina).
- May 2000      *Advanced Radar Detection and Fusion* (3 h.), IEEE International Radar Conference, Washington D.C., USA (co-speaker: Prof. Alfonso Farina).

### **Other Teaching Activities**

- Jan.–Apr. 2001    *Digital Communications*, within the IFTS 2000/01 formation program entitled "Telecommunication technician expert in telecommunication

networks and multimedia systems,” funded by the Tuscany Region and co-organized by the University of Pisa.

Jan.–Mar. 2001 *Radar detection in the presence of clutter*, Ch. 4 of the educational CD “Radar Theory and Techniques,” within TELECOM project.

Jan.–Oct. 1998 *SPECAN, a graphic interface tool for the spectral analysis of radar and sonar signals*, an educational interactive CD based on MATLAB for the Laboratory of the course “Signal Theory II” at the University of Pisa and at the Italian Naval Academy (Livorno).

## SCIENTIFIC COLLABORATIONS AND RELATED PUBLICATIONS

- Prof. **Alfonso Farina**, Radar & Technology Division, Alenia-Marconi Systems, Rome, Italy ([J5], [J10], [J17], [J18], [J25], [J26], [J28], [J30], [J33], [J38], [J39], [J43], [J44], [J45], [J46], [J53], [J54], [J52], [J58], [J60], [J61], [C4], [C6], [C11], [C13], [C14], [C19], [C21], [C23], [C24], [C27], [C31], [C39], [C40], [C46], [C43], [46]).
- Prof. **Georgios B. Giannakis**, Department of Electrical and Computer Engineering, University of Minnesota, Minneapolis, MN, USA ([J16], [J22], [J24], [J29], [J48], [C15], [C16], [C18], [C20], [C26]).
- Prof. **Pierfrancesco Lombardo**, Department “INFOCOM”, University of Rome “La Sapienza,” Rome, Italy ([J18], [J43], [J46], [C4], [C6], [C14], [C19]).
- Dr. **Kevin J. Sangston**, Electromagnetics Application Lab, Georgia Tech Research Institute, Atlanta, GA, USA ([J25], [C11], [C14], [C21]).
- Dr **Peter H. Lee**, TRW, Space & Technology Division, Space & Electronics Group, Redondo Beach, CA, USA ([J5]).
- Prof. **Tong G. Zhou**, School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA, USA ([J48]).
- Dr. **Barry J. Billingsley**, Massachusetts Institute of Technology, Lincoln Laboratory, Lexington, Massachusetts, USA ([J26], [J45], [J46], [C19], [C31]).
- Prof. **Pramod K. Varshney**, Department of Electrical and Computer Engineering, Syracuse University, Syracuse, NY, USA ([J34], [NC2], [C22]).
- Prof. **Hugh D. Griffiths**, Department of Electronic and Electrical Engineering, University College London, London, UK ([J23], [J42], [C25], [C29], [C30]).
- Dr. **James H. Michels**, Air Force Research Laboratory/Sensors Directorate/SNRT, Rome, NY, USA ([J31]).
- Dr. **Olivier Besson**, Department of Avionics and Systems, ENSICA, Toulouse, France ([J29], [J42], [C26], [C30]).
- Profs. **Umberto Mengali**, **Ruggero Reggiannini**, and **Marco Luise**, Department of Information Engineering, University of Pisa, Pisa, Italy ([J1], [J2], [J15], [J21], [J41]).
- Prof. **Salah Bourennane**, Ecole Nationale Supérieure de Physique de Marseille, Marseille, France ([NJ2], [C32], [C33]).
- Prof. **Andreas A. Jakobsson**, Department of Electronic Engineering, King's College London, UK ([C45], [C48]).
- Prof. **Hing Cheung So**, Department of Computer Engineering & Information Technology, City University of Hong Kong, Hong Kong ([J62]).

## LIST OF PUBLICATIONS

### INTERNATIONAL JOURNALS

- [J1] F. Gini and M. Luise, "Asynchronous Polarization Diversity Receivers for Coherent Optical Communications: A Performance Review," *European Trans. on Telecommunications*, vol. ETT-5, No. 3, pp. 307-318, May-June 1994.
- [J2] F. Gini, M. Luise, and R. Reggiannini, "Analysis and Design of a DPSK Optical Heterodyne Receiver in the Presence of Laser Phase Noise and Frequency Detuning," *International Journal of Communication Systems*, vol. 8, pp. 129-141 (1995), by John Wiley & Sons.
- [J3] F. Gini, M.V. Greco, and L. Verrazzani, "Detection Problem in Mixed Clutter Environment as a Gaussian Problem by Adaptive Pre-Processing," *Electronics Letters*, vol. 31, No.14, pp. 1189-1190, July 1995.
- [J4] G. Corsini, F. Gini, M.V. Greco, and L. Verrazzani, "Cramér-Rao Bounds and Estimation of the Parameters of the Gumbel Distribution," *IEEE Trans. on Aerospace and Electronic Systems*, vol.31, No.3, pp. 1202-1204, July 1995.
- [J5] A. Farina, F. Gini, M.V. Greco, and P. H. Lee, "Improvement Factor for Real Sea-Clutter Doppler Frequency Spectra," *IEE Proceedings Part-F*, vol.143, No 5, pp. 341-344, October 1996.
- [J6] F. Gini, "Estimation Strategies in the Presence of Nuisance Parameters," *Signal Processing*, vol. 55, No. 2, pp. 241-245, 1996.
- [J7] F. Gini, "Sub-optimum Coherent Radar Detection in a Mixture of K-Distributed and Gaussian Clutter," *IEE Proceedings Part-F* , vol. 144, No.1, pp. 39-48, February 1997.
- [J8] F. Berizzi, G. Corsini, and F. Gini, "A HOS Based Algorithm for Autofocusing of Spotlight SAR Images," *Electronics Letters*, vol. 33, No.7, pp. 628-629, March 1997.
- [J9] F. Gini, F. Lombardini, and L. Verrazzani, "Decentralized CFAR Detection with Binary Integration in Weibull Clutter," *IEEE Trans. on Aerospace and Electronic Systems*, vol. 33, No. 2, pp. 396-407, April 1997.
- [J10] A. Farina, F. Gini, M.V. Greco, and L. Verrazzani, "High Resolution Sea Clutter Data: A Statistical Analysis of Recorded Live Data," *IEE Proceedings Part-F*, vol. 144, No. 3, pp. 121-130, June 1997.
- [J11] F. Gini, F. Lombardini, and L. Verrazzani, "Robust Monoparametric Multi-Radar CFAR Detection Against Non-Gaussian Spiky Clutter," *IEE Proceedings Part-F*, vol. 144, No.3, pp. 131-140, June 1997.
- [J12] F. Gini, "A Cumulant-Based Adaptive Technique for Coherent Radar Detection in a Mixture of K-Distributed Clutter and Gaussian Disturbance," *IEEE Trans. on Signal Processing*, vol. 45, No. 6, pp. 1507-1519, June 1997.

- [J13] F. Gini and F. Lombardini, "Comments on Optimal Multiple Level Decision Fusion with Distributed Sensors," *IEEE Trans. on Aerospace and Electronic Systems*, vol. 33, No. 3, pp. 1037-1040, July 1997.
- [J14] F. Gini, F. Lombardini, and L. Verrazzani, "An Efficient Approach to Decentralised Detection System Optimisation," *Electronics Letters*, vol. 33, No. 21, pp. 1818-1819, October 1997.
- [J15] F. Gini, R. Reggiannini, and U. Mengali, "The Modified Cramér-Rao Bound in Vector Parameter Estimation," *IEEE Trans. on Communications*, vol. 46, No. 1, pp. 52-60, January 1998.
- [J16] F. Gini and G. B. Giannakis, "Frequency Offset and Symbol Timing Recovery in Flat Fading Channels: A Cyclostationary Approach," *IEEE Trans. on Communications*, vol. 46, No. 3, pp. 400-411, March 1998.
- [J17] A. Farina and F. Gini, "Calculation of Blanking Probability for the Sidelobe Blanking (SLB) for Two Interference Statistical Models," *IEEE Signal Processing Letters*, vol. 5, No. 4, pp. 98-100, April 1998.
- [J18] F. Gini, M.V. Greco, A. Farina, and P. Lombardo, "Optimum and Mismatched Detection Against K-Distributed plus Gaussian Clutter," *IEEE Trans. on Aerospace and Electronic Systems*, vol. 34, No. 3, pp. 860-876, July 1998.
- [J19] F. Gini, "A Radar Application of a Modified Cramér-Rao Bound: Parameter Estimation in Non-Gaussian Clutter," *IEEE Trans. on Signal Processing*, vol. 46, No. 7, pp. 1945-1953, July 1998.
- [J20] F. Gini, F. Lombardini, and L. Verrazzani, "Decentralised Detection Strategies Under Communication Constraints," *IEE Proceedings Part-F*, vol. 145, No. 3, pp. 199-208, August 1998.
- [J21] F. Gini, M. Luise, and R. Reggiannini, "Cramér-Rao Bounds in the Parametric Estimation of Fading Radiotransmission Channels," *IEEE Trans. on Communications*, vol. 46, No. 10, pp. 1390-1398, October 1998.
- [J22] F. Gini and G. B. Giannakis, "Generalized Differential Encoding: A Nonlinear Signal Processing Perspective," *IEEE Trans. on Signal Processing*, vol. 46, No. 11, pp. 2967-2974, November 1998.
- [J23] F. Lombardini, H. D. Griffiths, and F. Gini, "Ocean Surface Velocity Estimation in Multi-Channel ATI-SAR Systems," *Electronics Letters*, Vol. 34, No. 25, pp. 2429-2431, December 1998.
- [J24] F. Gini and G. B. Giannakis, "Hybrid FM-Polynomial Phase Signal Modeling: Parameter Estimation and Cramér-Rao Bounds," *IEEE Trans. on Signal Processing*, vol. 47, No. 2, pp. 363-377, February 1999.
- [J25] K. J. Sangston, F. Gini, M.V. Greco, and A. Farina, "Structures for Radar Detection in Compound Gaussian Clutter," *IEEE Trans. on Aerospace and Electronic Systems*, vol. 35, No. 2, pp. 445-458, April 1999.

- [J26] J. B. Billingsley, A. Farina, F. Gini, M. V. Greco, and L. Verrazzani, "Statistical Analyses of Measured Radar Ground Clutter Data," *IEEE Trans. on Aerospace and Electronic Systems*, vol. 35, No. 2, pp. 579-593, April 1999.
- [J27] F. Gini, F. Lombardini, and L. Verrazzani, "Coverage Area Analysis for Decentralized Detection in Weibull Clutter," *IEEE Trans. on Aerospace and Electronic Systems*, vol. 35, No. 2, pp. 437-444, April 1999.
- [J28] F. Gini, A. Farina, and F. Lombardini, "Effects of Foliage on the Formation of K-Distributed SAR Imagery," *Signal Processing*, vol. 75, No. 2, pp. 161-172, June 1999.
- [J29] O. Besson, G. B. Giannakis, and F. Gini, "Improved Estimation of Hyperbolic Frequency Modulated Chirp Signals," *IEEE Trans. on Signal Processing*, vol. 47, No. 5, pp. 1384-1388, May 1999.
- [J30] F. Gini, M.V. Greco, and A. Farina, "Clairvoyant and Adaptive Signal Detection in Non-Gaussian Clutter: a Data-Dependent Threshold Interpretation," *IEEE Trans. on Signal Processing*, vol. 47, No. 6, pp. 1522-1531, June 1999.
- [J31] F. Gini and J. H. Michels, "Performance Analysis of Two Covariance Matrix Estimators in Compound-Gaussian Clutter," *IEE Proceedings Part-F*, vol. 146, No. 3, pp. 133-140, June 1999.
- [J32] F. Gini and M.V. Greco, "A Suboptimum Approach to Adaptive Coherent radar Detection in Compound-Gaussian Clutter," *IEEE Trans. on Aerospace and Electronic Systems*, vol. 35, No. 3, pp. 1095-1104, July 1999.
- [J33] F. Gini and A. Farina, "Matched Subspace CFAR Detection of Hovering Helicopters," *IEEE Trans. on Aerospace and Electronic Systems*, vol. 35, No. 4, pp. 1293-1305, October 1999.
- [J34] F. Gini, F. Lombardini, and P.K. Varshney, "On Distributed Signal Detection With Multiple Local Free Parameters," *IEEE Trans. on Aerospace and Electronic Systems*, vol. 35, No. 4, pp. 1457-1466, October 1999.
- [J35] F. Gini, "Performance Analysis of Two Structured Covariance Matrix Estimators in Compound-Gaussian Clutter," *Signal Processing*, vol. 80, No. 2, pp. 365-371, February 2000.
- [J36] F. Gini, M. Montanari, and L. Verrazzani, "Estimation of Chirp Radar Signals in Compound-Gaussian Clutter: A Cyclostationary Approach," *IEEE Trans. on Signal Processing*, vol. 48, No. 4, pp. 1029-1039, April 2000.
- [J37] F. Gini, M. Montanari, and L. Verrazzani, "Maximum Likelihood, ESPRIT, and Periodogram Frequency Estimation of Radar Signals in K-distributed Clutter," *Signal Processing*, vol. 80, No. 6, pp. 1115-1126, June 2000.
- [J38] A. Farina and F. Gini, "Blanking Probabilities for SLB System in Correlated Gaussian Clutter plus Thermal Noise," *IEEE Trans. on Signal Processing*, vol. 48, No. 5, pp. 1481-1485, May 2000.

- [J39] A. Farina and F. Gini, "Design of SLB Systems in the Presence of Correlated Ground Clutter," *IEE Proceedings Part-F*, vol. 147, No. 4, pp. 199-207, August 2000.
- [J40] F. Gini, M. Greco, M. Diani, and L. Verrazzani, "Performance Analysis of Adaptive Radar Detectors Against Non-Gaussian Real Sea Clutter Data," *IEEE Trans. on Aerospace and Electronic Systems*, vol. 36, No. 4, pp. 1429-1439, October 2000.
- [J41] F. Gini and R. Reggiannini, "On the Use of Cramér-Rao-Like Bounds in the Presence of Random Nuisance Parameters," *IEEE Trans. on Communications*, Vol. 48, No. 12, pp. 2120–2126, December 2000.
- [J42] O. Besson, F. Gini, H. D. Griffiths, and F. Lombardini, "Estimating Ocean Surface Velocity and Coherence Time Using Multichannel ATI-SAR Systems," *IEE Proceedings Part-F*, Vol. 147, No. 6, pp. 299-308, December 2000.
- [J43] F. Gini, M. Greco, A. Farina, and P. Lombardo, "Note on Optimum and Mismatched detection Against K-Distributed plus Gaussian Clutter," *IEEE Trans. on Aerospace and Electronic Systems*, Vol. 37, No. 1, pp. 296-297, January 2001.
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[BC1] F. Gini, G.B. Giannakis, M. Greco, L. Verrazzani, G.T. Zhou, *Texture, Modelling, Estimation and Validation Using Real Sea Clutter Data*, ASI Project “Novel Methodologies for the integration, processing, and analysis of data from spaceborne sensors for the monitoring of the hydrosphere, rainfall phenomena, and the ground,” Enzo Dalle Mese Ed., pp. 28-53, November 2002.

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#### **TEACHING PUBLICATIONS**

[D1] F. Gini, *Esercizi di Teoria dei Segnali II*, Editrice Tecnico Scientifica, July 1996 (in Italian).

## DETAILED RESEARCH ACTIVITY

Prof. Gini's research activities focused on problems of statistical signal processing with applications to radar and digital communications. The main past and present research themes, with the related publications, can be grouped as follows:

- Optical communication systems: [J1], [J2], [TR1], [TR2].
- Multisensor radar systems with decentralized detection: [NJ1], [J9], [J11], [J13], [J14], [J20], [J27], [J34], [J47], [NC1], [NC2], [C1], [C2], [C7], [C9], [C10], [C22], [TR3], [TR4], [TR5], [TR6].
- Modeling and statistical analysis of recorded live sea and ground radar clutter data: [J5], [J10], [J26], [J45], [J46], [J49], [C13], [C19], [C31], [C34], [C39].
- Detection and estimation of radar signals in non-Gaussian clutter: [J3], [J7], [J8], [J12], [J18], [J25], [J28], [J30], [J31], [J32], [J33], [J35], [J37], [J40], [J43], [J44], [J51], [J53], [J54], [C4], [C5], [C6], [C8], [C11], [C12], [C14], [C21], [C23], [C24], [C27], [C28], [C33], [TR9].
- Modeling and estimation of non-stationary or cyclostationary signals: [NJ2], [J16], [J22], [J24], [J29], [J36], [J48], [NC3], [C3], [C15], [C16], [C18], [C20], [C26], [C32], [TR7], [TR8], [BC1].
- Estimation performance lower bounds in the presence of random nuisance parameters: [J4], [J6], [J15], [J19], [J21], [J41], [C17].
- Statistical signal processing for multichannel SAR interferometry: [J23], [J42], [J56], [J57], [J59], [C25], [C29], [C30], [C35], [C36], [C37], [C38], [C41], [C42], [C47], [C45], [C48], [C49], [TR10], [TR11], [BC2].
- Detection and estimation of multiple radar targets: [J17], [J38], [J39], [J50], [J55], [J52], [J58], [J60], [J61], [C40], [C46], [C43], [C44], [TR12], [TR13].

Some of the results of these research activities formed the material of the tutorials “*Advanced topics on radar detection in non-Gaussian background*,” given at the Intl. Conf. on Radar held in Brest in May 1999, and “*Advanced detection and fusion*,” given at the IEEE Intl. Radar Conf. held in Washington D.C. in May 2000, co-speaker Prof. Alfonso Farina. As a by-product of five years of research activity, a list of about 700 references clustered according to ten different topics related radar signal processing was written and published in the *IEEE Trans. on AES* [J44] to facilitate the work of other colleagues of the radar community. A descriptive overview of Prof. Gini's original contributions to these research fields follows.

## OPTICAL COMMUNICATION SYSTEMS

The research concerning the effects of the multiplicative laser phase noise on the performance of coherent optical communication systems has been carried out within the framework of the project “*Technologies for wideband optical communications*” funded by the Italian Council of Research (CNR) and by the TELETTRA company. The research has

focused on the design of robust detection algorithms for digital signals in the presence of laser phase noise which is modeled as wideband complex multiplicative noise. The results of this work allowed to design a novel digital receiver robust against laser phase noise and a frequency offset between the transmit and receive lasers. The work is described in the two technical reports [TR1] and [TR2] and has produced the two journal publications [J1] and [J2].

#### **MULTISENSOR RADAR SYSTEMS WITH DECENTRALIZED DETECTION**

The research activity concerning multisensor radar systems with decentralized detection has been developed in the framework of the national MURST (Italian Ministry of Research) projects entitled “*Model-based analysis, coding and synthesis of multidimensional images,*” MURST entitled “*Environmental remote sensing microwave sensors and data integration,*” and in the framework of a three-year contract from the Institute MARITELERADAR of the Italian Navy [TR3], [TR4], [TR5], [TR6]. This activity concerns with the synthesis and analysis of decision fusion algorithms for multiradar systems operating in high traffic environments in presence of non-Gaussian impulsive disturbance [NJ1], [J9], [J11], [J27], [NC1], [C1], [C2]. In this framework, the most important contribution is the development of an efficient algorithm for the joint hierarchical optimization of the decision rules of local sensors and fusion center [J14], [J34], [C22]. The algorithm applies to many different radar system configurations and clutter environments. Its performance was investigated for radar systems operating in non-stationary and non-Gaussian environments [J9], [J27], [NC2]. Additionally, an estimation algorithm has been proposed which guarantees the CFAR behavior of the radar network [J4], and a new robust approach has been developed to design the local sensors in the presence of changes of the clutter spikiness [J11], [C7], [C9], [C10]. The effects on optimization of the joint decision rules of the presence of capacity constraints on the communications channels between local sensors and fusion center is a very important problem which was analyzed in [J20]. To reduce the resulting losses and pathological effects, a new technique was proposed based on a proper randomization of the decision rules at both sensors and fusion center [J20].

#### **MODELING AND STATISTICAL ANALYSIS OF RECORDED LIVE SEA AND GROUND RADAR CLUTTER DATA**

The performance of ground-based surveillance radars strongly depends on the presence of undesired objects, clutter in the radar jargon. For many years, in radars with low resolution capabilities, the clutter echoes were considered as having a Gaussian probability density function (pdf). In modern radar systems operating at low grazing angle or with high resolution, the statistics of the clutter have been observed to deviate from Gaussianity. The disturbance is spiky and the spikes are detected and processed by the tracking algorithms. The understanding of clutter behavior and the modeling of the non-Gaussian clutter, both in the spectrum and in the distribution, are problems of fundamental interest in the radar community for successful

radar design and performance prediction. To design signal processing algorithms that exploit the amplitude and correlation knowledge of sea and ground clutter, a preliminary statistical analysis is necessary under different operational conditions.

The research activity about the clutter modeling and analysis has been carried out within the project “*Novel methodologies for the integration, processing, and analysis of data from spaceborne sensors for the monitoring of the hydrosphere, rainfall phenomena, and of the ground*” funded by the Italian Space Agency (ASI) during the four years 1997-2000. In the last three years, Prof. Gini also supported the Principal Investigator in the scientific coordination of the thirteen research groups participating the project. In this period Prof. Gini has developed a fruitful cooperation with researchers of Alenia-Marconi Systems, MIT Lincoln Laboratory, TRW, Rome Air Force Research Laboratory, and Defense Research Establishment Ottawa (DREO). This research aimed at the validation of statistical models proposed in the literature for clutter in high resolution coherent radar systems, in the attempt to overcome the limitations of the classical Gaussian model. To this purpose, models with a well-grounded physical meaning and a good mathematical tractability have been considered and refined. Particular attention has been devoted to the *compound-Gaussian model*. According to this model, the complex signal, composed by the in-phase (I) and quadrature (Q) components, is the product of a Gaussian process, the *speckle*, and a real random variable referred to as the *texture*, which represents the underlying fluctuating local power of the clutter. This model includes as particular cases many of the distributions generally used to model the disturbance in radar and communication systems, such as, e.g. the Gaussian, the Gaussian mixture, the generalized Gaussian, the K, the Weibull, the Cauchy, the generalized Cauchy, and the generalized Laplace. To validate the clutter models both classical and novel *ad-hoc* statistical techniques have been applied; among the latter, the higher order cumulant analysis and the modified Kolmogorov-Smirnov statistical test [J10], [J26]. The performed analyses concern the amplitude pdf and the spatial and temporal correlations of the texture and speckle components [J5], [J10], [J26], [J40], [C13]. Moreover, it was investigated the impact of the power spectral density (PSD) shape both on the performance of the classical detector designed to operate against ground or sea clutter [J5] and on the focusing of K-distributed radar images [J28]. As concerning the MIT-LL ground clutter data, a novel double-exponential model for the PSD was proposed and validated against previously proposed models, i.e. the Gaussian and power-law spectral models [J45], [J46], [C19], [C31]. More recently, the research addressed the estimation and validation of cyclostationary models to characterize the temporal fluctuation of high resolution sea clutter texture. A statistical model has been derived for the radar echoes, which is based on a compound-Gaussian process modulated by a cyclostationary process. Because of the quasi-periodic structure of the sea surface, due to the presence of waves with different wavelengths, the sea clutter intensity is well characterized cyclostationary process and the non-negative sea clutter texture can be modeled as a sum of cosinusoidal terms and a constant term. Sea clutter data cyclostationarity was verified by means of a statistical analysis performed on the data [J48], [J49], [C34], [C39]. The problem of estimating the characteristic

parameters of the texture, i.e., amplitudes, frequencies and phases of the cosinusoidal terms was solved taking into account the presence of the speckle, which is correlated multiplicative noise. Different super-resolution spectral estimators (time-averaged MUSIC, ESPRIT and RELAX) were derived and applied to estimate the texture sea clutter process in the presence of complex, wideband, zero mean, Gaussian distributed speckle with unknown spectral shape [J48], [J49]. The performance of the estimation algorithms have been analyzed by processing real sea clutter data, recorded by the X-band experimental IPIX radar. The interest of this research is both theoretical and practical. This new model is of fundamental importance for the CFAR detection of radar targets embedded in high resolution spiky clutter observed over time intervals greater than the radar coherent processing interval.

### **DETECTION AND ESTIMATION OF RADAR SIGNALS IN NON-GAUSSIAN CLUTTER**

Modern radar systems generally operate in non-homogeneous and non-stationary clutter environment. In this condition the amplitude statistics and the power spectral density of the disturbance are unknown. Typically, radar detectors should *(i)* adaptively estimate the disturbance characteristics in order to apply the best processing algorithm to minimize the disturbance effects, *(ii)* have constant false alarm rate (CFAR) behavior, and *(iii)* have low computational complexity. While the radar detection against Gaussian disturbance has been largely investigated in the past, the coherent detection of target against a background of non-Gaussian distributed clutter is a problem that has gained importance in the radar community only in the last decade. In high resolution radar systems the disturbance cannot be modeled as Gaussian distributed and the classical detectors suffer from high losses. Then, according to the adopted disturbance model, optimum and sub-optimum detectors have been designed and their performance have been analyzed against a non-Gaussian background.

This research activity has been carried out in cooperation with researchers of Alenia-Marconi Systems, Georgia Tech Research Institute (GTRI), and Rome Air Force Research Laboratory. The first step of this work was the design of the optimum algorithm for detecting a completely known radar signal or with unknown amplitude and initial phase against disturbance which is modeled as a mixture of correlated Gaussian and non-Gaussian clutter. The performance were evaluated and compared to that of the classical matched filter detector [J18], [C4] and [C6]. The adaptive version of this detector is based on the estimation of disturbance high order statistics (HOS) and was investigated in [J12], [J19], and [C5]. HOS are used to separately estimate from secondary data the correlation structures of the disturbance Gaussian and non-Gaussian components. Separate estimation of these quantities is necessary for the practical implementation of the detection algorithm. The problem of detecting fluctuating random signals, possibly with unknown parameters, against correlated non-Gaussian clutter modeled as a compound-Gaussian process has been deeply investigated exploiting different degrees of knowledge on target and clutter statistical characteristics. A generalized likelihood ratio test (GLRT) detector and a fully adaptive constant false alarm rate (CFAR) detector were derived and different novel interpretations of the detection algorithms

were provided in order to highlight the relationships and the differences among them and the links with the Gaussian clutter case. A very important theoretical result was the proof that the GLRT detector may be recast into an estimator-correlator form and into another form, namely a whitening matched filter, which is the optimum detector against Gaussian disturbance, compared to a data-dependent threshold (DDT). Each interpretation suggested different ways to implement the optimum detector and allowed to derive sub-optimum detectors easier to implement than the optimum and with very low losses.

The CFAR detector was obtained following different approaches, e.g. it was obtained by approximating in a linear fashion the optimal nonlinear data-dependent threshold of the GLRT detector. The DDT interpretation is highly important also for the practical implementation of the receiver because it tells that any detector implemented for operation in Gaussian noise may be modified for operation in compound-Gaussian clutter by replacing the constant threshold with a data-dependent threshold. Thus, essential aspects of a practical detector, namely the stages prior to the threshold comparison, would already be in place and would not need modification. The main results of these research work were published in [J7], [J25], [J30], [J32], [J40], [C8], [C11], [C14], [C21]. The adaptive version of those algorithms, which estimate the clutter covariance matrix, was proposed and analyzed in [J3], [J12], [J30], [J32], [C21]. A novel estimation algorithm which guarantees the CFAR property to the detector was derived in [J3] and then its performance deeply investigated in [J31] and [J35], and compared to that of the maximum likelihood (ML) estimator in [J51].

The important cases of target signal partially unknown or modeled as a subspace random process have been analyzed in [J33], [J36], [J37], [J47], [C23], [C24], [C28], and [C32]. The problem of detecting subspace random signals against correlated non-Gaussian clutter exploiting different degrees of knowledge on target and clutter statistical characteristics has been tackled in [J53] and [J54]. The clutter process has been modeled by the compound-Gaussian distribution. In [J53], the optimum Neyman-Pearson (NP) detector, the generalized likelihood ratio test (GLRT), and a constant false alarm rate (CFAR) detector are sequentially derived both for the Gaussian and the compound-Gaussian scenarios.

Different interpretations of the various detectors have been provided to highlight the relationships and the differences among them. In particular, it was shown how the GLRT detector may be recast into an estimator-correlator form and into another form, namely a generalized whitening matched filter (GWMF), which is the GLRT detector against Gaussian disturbance, compared to a data-dependent threshold. In [J54], the proposed detectors are tested against both simulated data and measured high resolution sea clutter data to investigate the dependence of their performance on the various clutter and signal parameters. Numerical examples concern a Space-Time Adaptive Processing (STAP) scenario and a ground-based surveillance radar system scenario. The problem of the presence of a coherent interference detected by the antenna sidelobes has been investigated in [J17], [J38], [J39].

## **MODELING AND ESTIMATION OF NON-STATIONARY OR CYCLOSTATIONARY SIGNALS**

In many radar, sonar, and digital communication applications, the received signals are non Gaussian, non linear, or non stationary. The analysis of such signals cannot be carried out by means of only time-invariant second-order statistics, as for stationary linear Gaussian processes. For this reason the concepts of correlation and power spectral density have been extended in the literature to higher order moments, cumulants and poly-spectra, i.e. higher order statistics (HOS). Non stationarity in the data has been extensively modeled and investigated through time-varying parametric signals; in particular cyclostationary processes have been used to model signals which show periodicities in some statistics of second or higher than the second order moments or cumulants. Signals of this type, which have been extensively used in radar, sonar, and digital communication applications, are the polynomial phase signals (PPS) and the hybrid PPS with a frequency modulated component (PPS-FM). PPS are usually found when there is a relative motion between the source of the signal and the receiver, such as in airborne Doppler radar, synthetic aperture radar (SAR), and SAR interferometry applications. PPS-FM signals also appear in radar applications, e.g., to model the jet engine modulation (JEM) phenomenon or the backscattering from an helicopter. The problem of estimating the parameters of PPS and PPS-FM signals has been tackled in [J8], [J24], [J36], [J37], [C12], [C18], [C28], [C32] with regard to radar and SAR applications, in [J24], [J29], [C20], [C26] with regard to sonar applications, and in [J16], [J22], [C15], [C16] with regard to digital communications. Where necessary, the presence of multiplicative noise has also taken into account jointly with the additive disturbance (colored clutter plus thermal noise).

The multiplicative noise models the speckle or the multipath effect in radar and SAR applications and the digital data modulation or the fading effect in digital communications. This research activity has been funded partially by the ASI in the framework of the project “*Novel methodologies for the integration, processing, and analysis of data from spaceborne sensors for the monitoring of the hydrosphere, rainfall phenomena, and of the ground*”, partially by the European Community (EU) with the INTERREG-II project, and partially by the Office of Naval Research (Grant N00014-93-1-0485).

## **ESTIMATION PERFORMANCE LOWER BOUNDS IN THE PRESENCE OF NUISANCE PARAMETERS**

In parallel to the research activity on the estimation of radar and digital communication signal parameters, Prof. Gini has studied the problem of deriving theoretical lower bounds on the estimation accuracy in the presence of random nuisance parameters [J6]. His main contribution is the generalization of a modified Cramér-Rao lower bound (MCRLB) to the case of complex observable and multidimensional unknown desired and nuisance parameters [J15], [J19], [J21], [C17]. This bound is very useful in those cases where the signal and/or the disturbance contain random nuisance parameters and the classical CRLB cannot be found in

closed form. The relationship of the MCRLB with other Cramér-Rao-like bounds previously proposed in the literature has been investigated in [J41]. The relative merits of these bounds are discussed, both in terms of their tightness and ease of calculation. Moreover, an extension of the Miller-Chang bound (MCB) has been derived and analyzed. The extended MCB is easy to calculate, tighter than the MCB and than the MCRLB, but as the MCB it only applies to *locally unbiased* estimators, i.e., those estimators that are unbiased for *all* values of the nuisance parameters, while the CRLB and the MCRLB apply to estimators that need only be unbiased *on the average*, over the ensemble of the nuisance parameters. The latter condition is far less restrictive than the former.

### STATISTICAL SIGNAL PROCESSING FOR MULTICHANNEL SAR INTERFEROMETRY

Synthetic aperture radar *cross-track* interferometry (XTI-SAR) is a powerful and increasingly expanding technique allowing estimation of three dimensional terrain images, producing a digital elevation model (DEM) of the remotely sensed scene with high spatial resolution and height accuracy. The surface height is estimated from the phase difference between two complex SAR images obtained by two sensors slightly separated by a cross-track baseline. An accurate radar reflectivity image can also be obtained by fusion of the two available SAR images. The InSAR technique is finding many applications in radar remote sensing, e.g. for topographic and urban mapping, geophysics, forestry, hydrology, glaciology, sighting for cell phones, flight simulators. Accurate measurements of radar reflectivity is very useful for vegetation and snow mapping, forestry, land-use monitoring, agriculture, soil moisture determination, mineral exploration, and again for hydrology and geophysics. Conventional single-baseline InSAR uses two receiving channels and provides a mean for measuring the third dimension (elevation), but has no resolving capability along this dimension. In situations where the sensed scene presents highly sloping surfaces such as mountainous areas, or discontinuous surfaces, e.g. cliffs, the received signal is the superposition of the echoes backscattered from several terrain patches, which are mapped in the same range-azimuth resolution cell, but have different elevation angles. This is called the layover phenomenon. In these conditions, both height and reflectivity maps are heavily distorted. To overcome this problem, it has been recently proposed to exploit baseline diversity. Multibaseline interferometry was originally proposed to reduce problems of data noise and phase ambiguity. These effects can degrade both SAR and InSAR imagery of terrain radar reflectivity and height.

In this framework, Prof. Gini's addressed the problem of retrieving the radar reflectivity and height of layover areas in the presence of speckle. The problem was formulated as that of estimating a multicomponent sinusoidal signal corrupted by multiplicative complex correlated Gaussian noise and additive white Gaussian noise. Application of non-parametric (Beamforming, Capon, APES) and parametric (least squares, root MUSIC, RELAX) spectral estimators for spatial frequency, which is related one-to-one to the terrain height, and radar reflectivity estimation has been investigated for a multilook scenario. In particular, the

multilook extensions of RELAX and APES were derived and applied to the InSAR problem [J50], [J55], [J56]. Performance analysis was investigated through calculation of the Cramér-Rao lower bound and Monte Carlo simulation [C35], [C38]. The method of least squares, coupled with Capon for frequency estimation, multilook APES, and multilook RELAX turned out to provide accurate estimates for undistorted multibaseline image formation of layover areas. Design system trade-offs have also been investigated, involving interferometer sensitivity, speckle decorrelation, and resolution along elevation for varying overall baseline; baseline optimization has been investigated in conjunction with the problem of selecting the best estimation algorithm, and the benefit offered by parametric methods were quantified [C37]. Performance loss deriving from the possible lack of a uniform array structure have been analyzed in [C36]. The problem of estimating the number of layover sources in the presence of correlated multiplicative noise was also addressed in [J57] and [C47].

The dual technique of *along-track* SAR interferometry (ATI-SAR) is also of increasing interest. It employs two antennas separated by an along-track baseline corresponding to a short time lag and enables the production of Doppler shift and coherence time maps of the ocean surface, to monitor surface currents and waves. Recently, the use of multichannel (i.e. multibaseline or multiple-time lag) interferometric SAR systems has been proposed in the literature to solve some well-known problems intrinsic in the classical two-channel techniques (e.g., phase ambiguity and unwrapping errors, data noise, and layover for the cross-track technique). However, the estimation algorithms of the useful parameters are generally suboptimal and does not fully exploit the information content in the multichannel signal. Prof. Gini's research activity regarding these topics aimed to derive and analyze statistically efficient algorithms for multichannel ATI systems, able to provide Doppler and coherence estimates of the ocean surface currents with improved accuracy [J23], [J42], [C25], [C29], [C30].

This research activity has been carried out in collaboration with the Department of Electronic and Electrical Engineering, University College London, in the framework of the EC TMR Program (Grant N. ERBFMBICT972702), and has been partially funded by the ASI in the framework of the project "*Novel methodologies for the integration, processing, and analysis of data from spaceborne sensors for the monitoring of the hydrosphere, rainfall phenomena, and of the ground.*" Some work related to the solution of the layover problem is in progress (see [C45]), in the framework of the "*British-Italian Partnership Program for young researchers.*"

Research activity on advanced ATI-SAR techniques for the estimation of maps of currents, sea coherence time, and Bragg frequency with high spatial resolution and in difficult conditions, such as absence of detailed wind information, smooth water surface, is now in progress. The resulting high resolution non-distorted multi-feature estimates should convey very rich information concerning oceanographic processes, and in particular pollution from oil slicks.

## DETECTION AND ESTIMATION OF MULTIPLE RADAR TARGETS

In most of modern radar systems, the target direction of arrival (DOA) is estimated by the monopulse technique, which in principle can work with just a single pulse. When one angular coordinate is needed, the price to pay is the need for two tightly matched receiving channels: the sum ( $\Sigma$ ) and the difference ( $\Delta$ ) channels. The estimate of the target DOA is a function of the ratio of the  $\Delta$  and  $\Sigma$  channel outputs. When multiple targets are present in the range-azimuth cell under test, the monopulse system provides an erroneous DOA measure, somewhere in the direction of the “power centroid” of all the targets. Prof. Gini’s research concerns with the problem of detecting and estimating multiple radar targets present in the same range-azimuth resolution cell of a surveillance radar system with a mechanically rotating antenna. In the first phase of the research, the number  $M$  of targets were assumed to be a priori known and it was tackled the “estimation problem,” i.e. the problem of estimating target complex amplitudes, Doppler frequencies, and directions of arrival [J52], [J58], [J60], [C40], [C46], [C43].

An algorithm based on the asymptotic maximum likelihood (AML) was derived [J60] and a method based on the RELAX approach was proposed to implement the AML estimator in an efficient way [J58]. The RELAX approach allows to decouple the problem of jointly estimating the parameters of the  $M$  signal components into a sequence of simpler problems, in which we estimate separately the parameters of each component. The proposed solution avoids the need of a difference channel by exploiting knowledge of the antenna main beam pattern. In this second phase of the research, it was tackled the “detection problem,” which consists of determining the number  $M$  of targets. First, the target parameters are estimated assuming a maximum number of possible targets. Subsequently, these estimates are used in a sequentially hypotheses test (SHT) procedure [J61], [C44]. The statistic of the test at each step of the SHT procedure is derived using an asymptotic expression of the generalized likelihood ratio test (GLRT) statistic.

Two methods to select the thresholds have been proposed and investigated: the actual grid (AG) method and the equivalent grid (EG) method. The AG method guarantees that the global probability of false alarm, i.e. the probability of overestimating the number of targets, is upper bounded. Performance of the proposed SHT detector is investigated through Monte Carlo simulation. Different case studies have been considered to demonstrate its ability to correctly estimate the target multiplicity in a typical surveillance radar scenario. Numerical results suggest the use of the SHT-AG method for solving the detection problem and of the AML-RELAX for the estimation problem. This work has been funded by Alenia-Marconi Systems (AMS) through the contract “*Non Cooperative Target Recognition.*”