Introduction: BACKGROUND, GOAL AND CONTENT OF THE LECTURE SERIES ON POLARIMETRIC SAR INTERFEROMETRY

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ABSTRACT

Scientists and engineers already engaged in the fields of radar surveillance, reconnaissance and scattering measurements, for instance, generally gain their specialist knowledge in Polarimetry by working through scientific papers and specialised literature available on the subject. Usually, this is a time consuming exercise, as it is difficult for a newcomer to collate material especially on Polarimetry but also on Interferometry and related subjects. Presently, the treatment of basic Polarimetry concepts, in the currently available literature, lacks a coherent framework of theory, and, moreover, several basic definitions and conventions are not yet unified sufficiently under the light of physical principles. This Lecture Series is an attempt to readdress this problem.

The aim of this Lecture Series is to provide a substantial and balanced introduction to the basic theory, scattering concepts, systems and applications typical to polarimetric and interferometric radar reconnaissance and surveillance, and to introduce the cutting-edge technologies, new ideas and methodologies as well. The following topics will be addressed: Basics, advanced concepts and applications of both radar Polarimetry and SAR Interferometry, cross track and along track Interferometry, single and dual pass Interferometry, differential interferometry, Interferometry errors and accuracy, polarimetric SAR processing and image analysis, decomposition theorems, polarimetric interferometry and polarimetric-interferometric SAR image analysis, processing principles, calibration, Polarimetric SAR analysis and applications, Digital Elevation Models, realized and future airborne and space-borne systems as Examples E-SAR, SIR-C/X-SAR, SRTM, ERS-1/2, RadarSAT, ENVISAT/ASAR, TerraSAR-X, Tandem-X, and CARTWHEEL.

1. BACKGROUND

The use of high resolution radar especially SAR is indispensable for surveillance, reconnaissance and remote sensing. Radar Polarimetry and Radar Interferometry are advancing rapidly. Each target is a specific polarization transformer and, therefore, these technologies are increasing the target identification and classification capability decisively. With multi polarization the target fine-structure, target orientation, symmetries, and material constituents can be re-covered with considerable improvement above that of standard 'amplitude-only' radar. With radar interferometry the target's spatial structure can be explored, and differential interferometry, presently, is the most sensitive all weather technique for change detection. In 'Polarimetric Interferometric SAR' it is possible to recover co-registered textural and spatial information simultaneously, including the extraction of ground based stealth targets, the development of Digital Elevation Maps etc. as well. Among surveillance and reconnaissance techniques, the polarimetric and interferometric SAR attracts currently the most appreciable and outranking attention because of its capabilities for 3-D high resolution imaging with abundant additional information Then, by either designing 'Multiple Dual-Polarization Antenna POL-IN-SAR' systems or by applying advanced 'POL-IN-SAR image compression techniques' will result in 'Polarimetric Tomography' which is an important progress in Foliage Penetration Radar and Ground Penetration Radar as well.

2. OBJECTIVES

Scientists and engineers already engaged in the fields of radar surveillance, reconnaissance, and scattering measurements, for instance, generally gain their specialist knowledge in Polarimetry by working through

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scientific papers and specialised literature available on the subject. Usually, this is a time consuming exercise, as it is difficult for a newcomer to collate material especially on Polarimetry but also on interferometry and related subjects. Presently, the treatment of basic Polarimetry concepts, in the currently available literature, lacks a coherent framework of theory, and, moreover, several basic definitions and conventions are not yet unified sufficiently under the light of physical principles. This Lecture Series is an attempt to readdress this problem. The aim of this Lecture Series is to provide a substantial and balanced introduction to the basic theory, scattering concepts, systems and applications typical to polarimetric and interferometric radar reconnaissance and remote sensing.

Goal of the Lecture Series is, therefore, to bring the knowledge of the Participants to a level, which enables them to understand the very modern results presented in the new literature and at respective conferences as well with respect to the advances of Interferometry, Polarimetry, Polarimetric SAR Interferometry, and the application possibilities as well.

3. TOPICS TO BE COVERED

Basics, advanced concepts, and applications of both radar Polarimetry and SAR Interferometry, cross track and along track Interferometry, single and dual pass Interferometry, differential Interferometry, respective errors and accuracy, polarimetric SAR processing and image analysis, decomposition theorems, polarimetric Interferometry, and polarimetric interferometric SAR image analysis, processing principles, calibration, polarimetric SAR analysis and applications, Digital Elevation Models as well as realized and future airborne and space-borne systems will be mentioned as examples.

The most modern and progressive space-borne missions related to the topics of the Lecture Series during the last ten years were the both space shuttle missions SIR-C/X-SAR and SRTM/X-SAR flown twice in April and September 1994 (SIR-C/X-SAR), and once in 2000. SIR-C/X-SAR was equipped with two fully polarimetric SAR in L- and C-Band and a HH polarized X-Band SAR. It allowed fully polarimetric simultaneous imaging of the earth surface and additionally in an experimental mode Two Pass interferometric imaging also. These data lead to the first experimentally validated interferometric Polarimetry results (Papathanassiou).

The SRTM was a topographic mission and established a Digital Elevation Model of 80% of the earth’s surface by means of Single Pass Interferometry, it was up to now the only Single Pass Interferometer in space (Keydel). Both missions were exemplary for the most important techniques, technologies, system parameters like calibration etc., and application possibilities as well. Therefore, they mainly will be used as examples throughout the following lectures. However, the main driver for the whole thematic is application. Therefore, beside the explicitly established Application Chapter each lecture contents application examples also..

The systems and application topics of interferometry and to some extent of Polarimetry will be considered and presented in the lectures of the LS by Wolfgang Keydel. The respective polarimetric Interferometry part will be presented by Martin Hellmann. However, each lecture will content special applications also.

4. Terms

4.1 SAR

Synthetic aperture radar (SAR) is a coherent side-looking radar which builds a large aperture along its flight path by means of a computer measuring and storing amplitude, frequency, phase, and polarization of signals reflected from observed targets ore pixels on ground respectively. The length of the synthetic aperture is determined from the dwell time on a single pixel depending on both the width of the real antenna beam for the range gate which houses the pixel and the platform velocity. The system utilizes the Doppler frequency for pixel positioning. That is, it uses the effect whereby targets perpendicular to the satellite flight path at some instant in time have return signal frequencies equal to the Doppler centre frequency (DCF) and targets fore (aft) of perpendicular have greater (lesser) frequencies, respectively. For a strictly side looking SAR holds DCF=0. During processing all signals with DCF=0 will be arranged on a line perpendicular to the flight pass.SAR images three dimensional targets, especially land and sea surfaces, in two dimensional maps.

Each pixel within the map is complex consisting of amplitude and phase. Therefore, both the amplitudes and the phases can be arranged to a two dimensional image of the observed scene, an example is depicted in Fig.1.

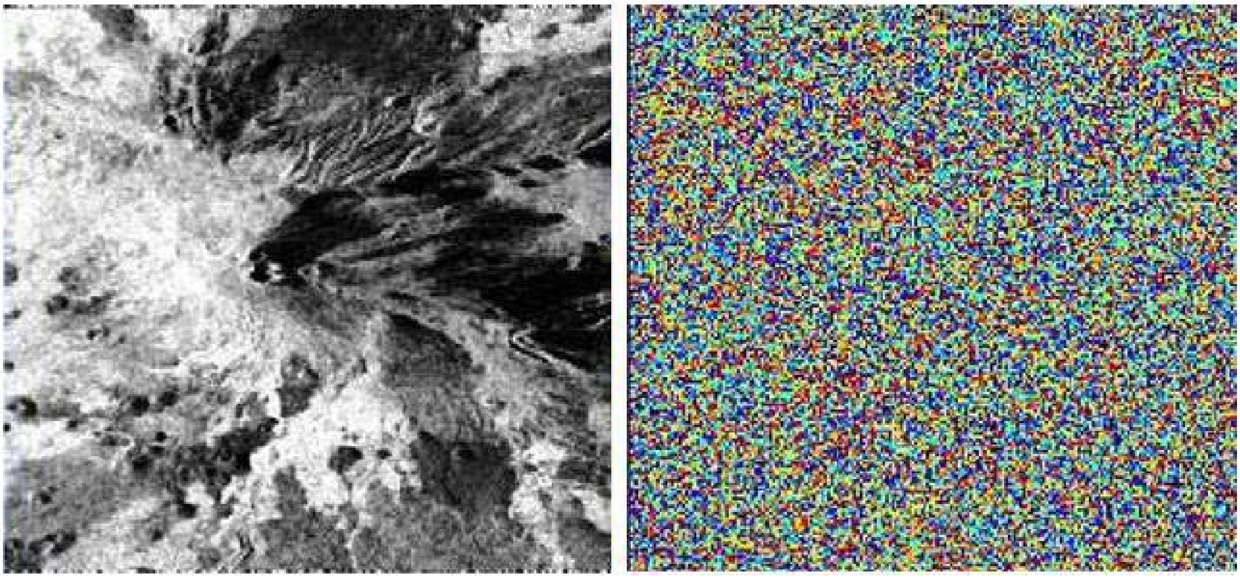

Fig.1 SAR image of the volcano Mount Etna in Italy, taken by the X-SAR/ SIR-C sensor (2.5cm wavelength) mounted on the space shuttle. Left: amplitude of the complex image , right: the phase showing no recognizable structure. The amplitude is brighter on the left side of the mountain than on the right side due to the look direction of the radar from the left side. Surface slopes towards the radar increase the backscattering, those away from the radar cause a decreasing amplitude.

SAR images show some typical specialties compared to optical images: The azimuth resolution of SAR is independent from range which leads to a lack of perspective; therefore, SAR images of three dimensional landscapes are looking like two dimensional maps, however, there is no resolution in elevation. The special SAR geometry causes special image errors like shadowing, fore shortening and lay over Fig.2. Radar shadows are areas with no radar signal return, here the Signal to Noise Ratio is Zero, SNR=0. Foreshortening and layover are look angle effects which cause relief displacements of three dimensional objects like mountains, towers, etc... Foreshortening causes a compression of the areas with ascending slope and a spread of the descending slope. When lay over effects occur several areas can disappear from the SAR image.

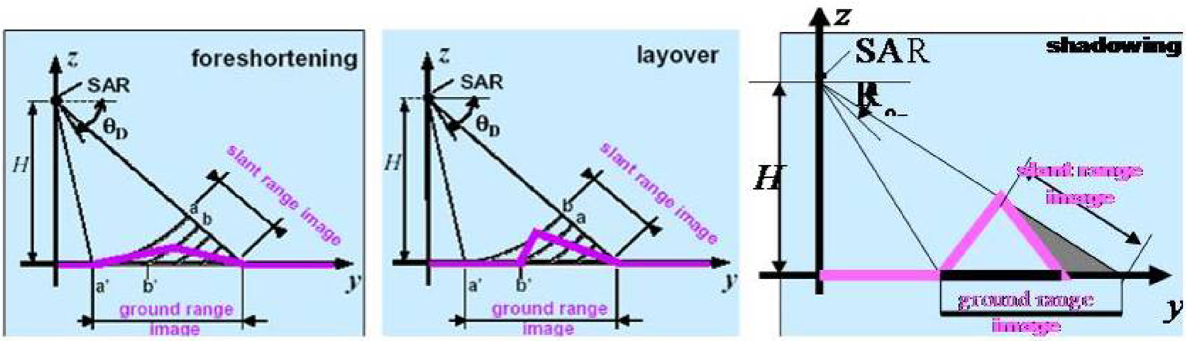

Fig. 2, Geometric distortions in SAR Images: **foreshortening** (left), the slope of local terrain is less than incidence angle leading to **layover** (middle) for steep terrain, the slope of local terrain is less than the incidence angle also, and **shadowing** (right) the descending slope is less than the incidence angle, leading to SNR = 0,i. e. no signal.

A simple but effective SAR processing model considers SAR as a Microwave Transducer (MT) which observes the real world's reflectivity ρ in order to produce an estimate of it. This Output is called SAR image ***I*** and represents an estimate of reflectivity. A SAR Imaging System is based upon two different data acquisitions for along-track (azimuth), and slant range scanning. Such an MT is not perfect: in particular, its ability to spatially resolve two points on the image is not arbitrarily fine: resolution is the quantity used to measure such a limitation. The generated image (i.e., the backscattering reflectivity estimate) is affected by a multiplicative noise, the so called speckle which arises from the interference of the elementary returns within each resolution cell [*Raney,*in Henderson 1998], because SAR is a coherent System.

4.2 Interferometry

Interferometry employs the interference of Electromagnetic Waves for purposes of angel and distance measurements respectively. Principally, the distance R between radar and an observed point P can be expressed in terms of the wavelength λ of the used Electromagnetic Wave with:

$$R = 2n\lambda + \Delta\lambda$$

n is an integer and the term nλ corresponds to the number of wavelength's which fits to the distance R completely, the term Δλ represents the remaining fraction of the wavelength, i.e. the phase of the wave.

A radar interferometer is a receiving system which determines the angle of arrival of a wave or the different length r corresponding to Δλ of the propagation passes of two wave trains coming from the same scattering point respectively by phase comparison of the signals received at separate antennas or at separate points at the same antenna (N. N. IEEE 491).

Phases, presently, can be measured with an accuracy of about 5° corresponding to a fraction of about 1/70 of a wavelength. Therefore, for distance measurements as well as for angle measurements an interferometer is the most sensitive measurement instrument with an extremely high degree of accuracy. Conditio sine qua non, however, is the mutual coherence of the 2 compared signals. The basics of Interferometry will be presented in Chapter 2 of that Lecture Series by Wolfgang Keydel

4.3 Polarimetry

Polarization is the orientation of the electric ***E*** vector in an Electromagnetic Wave*,* frequently "horizontal" (H) or "vertical" (V) in conventional imaging radar systems. Polarization is established by the antenna, which may be adjusted to be different on transmit and on receive. Reflectivity of microwaves from an object depends on the relationship between the polarization state, the objects material properties, and the geometric structure of the object. Common shorthand notation for band and polarization properties of an image file is to state the band, with a subscript for the receive and the transmit state of polarization, in that order. Thus, for example, L_{HV} indicates L-band*,* horizontal transmitt polarization, and vertical receive polarization. Possible states of polarization in addition to vertical and horizontal include all angular orientations of the E vector, and time varying orientations leading to elliptical and circular polarizations. (Henderson) Principally holds: Each scatterer is a polarization transformer. Polarimetry is the measurement of the polarization properties of an electromagnetic wave.

The complete state of a scattered Electromagnetic Wave can be described by the Scattering Matrix ***S*** which connects the received field vector $\boldsymbol{E_r}$ with the transmitted field vector $\boldsymbol{E_t}$ (Börner).

$$\begin{bmatrix} E_H^r \\ E_V^r \end{bmatrix} = \begin{bmatrix} S \end{bmatrix} \begin{bmatrix} E_H^t \\ E_V^t \end{bmatrix} = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \begin{bmatrix} E_H^t \\ E_V^t \end{bmatrix} \quad (1)$$

The complex scalar components of the Electric Field vector can be expressed as

$$E_p^k = \left| E_p^k \right| e^{i\varphi} \tag{2}$$

p characterizes the polarization and k=t,r the different "directions" (transmit t, receive r) . The elements of the Matrix ***S*** are complex also and, therefore, the matrix contents 8 independent parameters. These figure reduces to 5 independent parameters in case of backscattering and if the reciprocity theorem holds, i.e. for

$$S_{VH}=S_{HV}$$

The phase decomposition which can be performed in polarimetric SAR can estimate for three orthogonal scattering mechanisms (Cloude and Pottier1996). For example, in a simplified model the three different scattering mechanisms can be described as: 1. a **single bounce** contribution from point scatterers; 2. a **double bounce** contribution from vertical structures like house walls etc standing vertical on a horizontal area; and 3. a **diffuse (volume) contribution** from statistical distributed scatterers like tree leaves and branches. The respective Pauli matrices are:

$$S_1 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, S_2 = \begin{bmatrix} \cos 2\alpha & \sin 2\alpha \\ \sin 2\alpha & \cos 2\alpha \end{bmatrix}, S_3 = S_{dfiffus} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \tag{3}$$

This formulation of the 3 Matrices takes into account the influence of the lateral horizontal incidence angle α at extended long line scatterers, structures like fences long walls etc., also. An example is depicted in Fig.3. However, it is not possible wi$_t$h this technique to separate the contributions of the same scattering mechanism distributed over different heights. These topics will be considered and presented in the lectures of the LS by Wolfgang M. Börner and Eric Pottier.

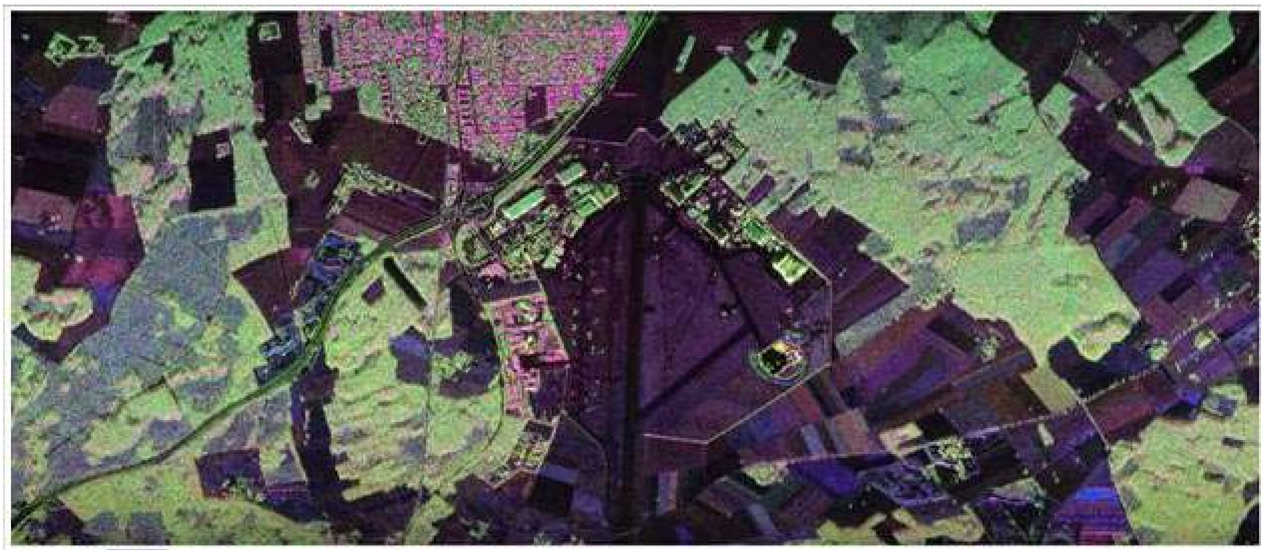

Fig.3, fully polarimetric SAR Image (Oberpfaffenhofen area, E-SAR, L-Band, resolution 1 m x 2m) color coded with respect to three different scattering mechanisms expressed through Pauli Matrices: **S1, blue, HH+VV, single and odd bounce contributions from point scatterers; S2, red, HH-VV, double and even bounce contributions from vertical structures like house walls etc; S3, green, HV+VH diffuse (volume) contribution from statistical distributed scatterers like tree leaves and branches.**

4.4. Polarimetric Interferometry

Polarimetric SAR Interferometry was a first step in the abatement of the scattering ambiguity problem in the height direction. By combining interferometric and polarimetric techniques, it enables the separation of different scattering mechanisms within a resolution cell and at the same time, the estimation of the associated heights.

Both, Radar Polarimetry and Radar Interferometry are phase sensitive techniques. Whereas with Radar Polarimetry textural fine-structure, target-orientation, -shape, -symmetries, and -material constituents can be recovered with considerable improvements above that of standard 'Amplitude-only Polarization Radar'. With radar Interferometry the spatial (in depth) structure can be explored.

In 'Polarimetric-Interferometric Synthetic Aperture Radar (POL-INSAR) Imaging' it is possible to recover such co-registered textural plus spatial properties simultaneously. This includes the extraction of 'Digital Elevation Maps (DEM)' from either 'fully Polarimetric (scattering matrix) or Interferometric SAR image data takes' with the additional benefit of obtaining co-registered three-dimensional 'POL-IN-DEM' information. An example is depicted in Fig.4.

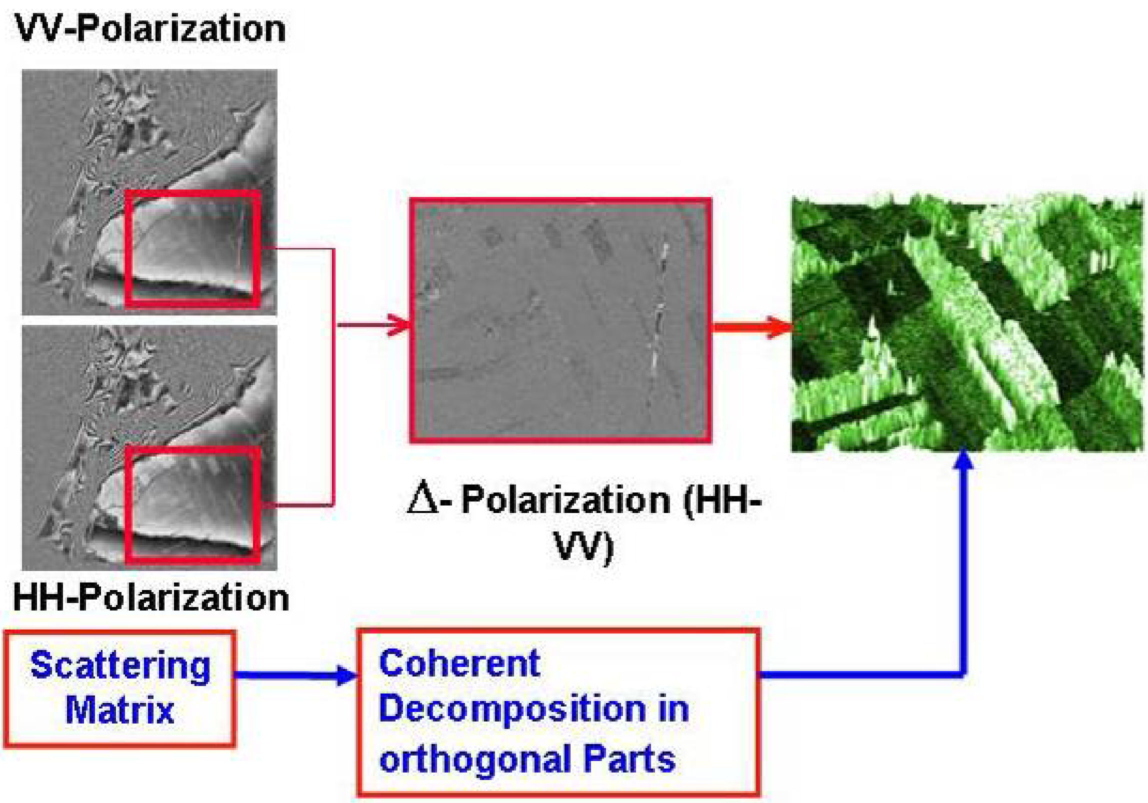

Fig.4, Example for Overlay Polarimetry with HH- and VV- Interferograms: fully polarimetric one pass data taken with E-SAR in L-Band over the Solothurn area in Switzerland. Through the vertical vegetation (Corn) passes the horizontally polarized component mainly undisturbed down to the ground, whereas the vertical polarized part is reflected on top. In principle, the vegetation layer acts as a Polarization Filter.

POL-IN-SAR Imaging when applied to 'Repeat-Pass Image Overlay Interferometry', provides differential background validation and measurement, stress assessment, and environmental stress-change monitoring capabilities with hitherto unattained accuracy.

More recently, by applying multiple parallel repeat-pass imaging along stacked (altitudinal) or displaced (horizontal) flight-lines will result in 'Tomographic (Multi-Interferometric) Polarimetric SAR Stereo-Imaging', including foliage and ground penetrating capabilities. The Scheme is depicted in Fig.5 (Reigber, Moreira 2000) More details are given in section 4 of the Application Chapter of this Lecture Series.

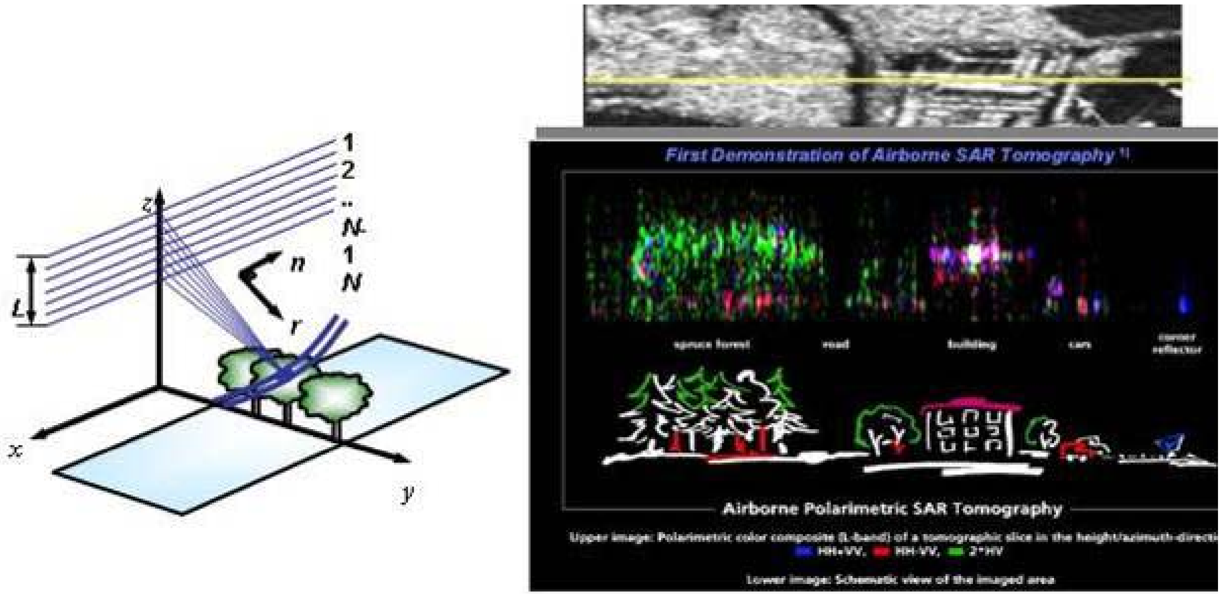

Fig.5. Scheme and result of SAR Tomography. Left: Multi baseline imaging geometry with Synthetic Apertures in azimuth (flight path x -direction) and height (z-direction). Right: Middle image: Polarimetric color composite in the Pauli basis of a tomographic slice taken from a cut along the yellow line in the SAR image in the upper part in the height/azimuth-direction, (blue = HH + VV, red = HH — VV, green HV+VH). Lower image: Schematic representation of the imaged area. (Reigber, Moreira 2000) This image will be used und described in more detail in the Application Chapter of this Lecture Series in section 4. The polarimetric Interferometry together with some special applications will be considered and presented during the LS by Martin Hellmann.

The accelerated advancement of these modern SAR imaging techniques is of direct relevance and of paramount priority to wide-area dynamic battle-space surveillance (Cloude 2004), cartographic applications (Hellmann 1999), local-to-global environmental ground-truth measurement and validation, stress assessment, and stress-change monitoring of the terrestrial covers (Papathanassiou et al. 2004).

4.5 Coherence

An Electromagnetic wave is called coherent as long as it has a constant phase. Two Electromagnetic Waves ore two signals respectively are mutually coherent if they have fixed phase relations to each other.

Principally, due to statistical influences, instrument effects like phase noise and extended bandwidth, propagation influences and scattering properties etc. Electromagnetic Waves can not be coherent ad infinitum. The length of a wave train during which it is coherent is called Coherence length, the respective time is the coherency time. Therefore, a statistical definition of coherence is appropriate including both the deterministic and the statistic part by introduction of the Coherence degree which can be explained and introduced as follows. The total power transported in the free space by two arbitrary Electromagnetic Waves written as

$$P = \frac{1}{Z_0}\left\langle \left(E_1(t)+E_2(t)\right)\left(E_1(t)+E_2(t)\right)^* \right\rangle = \frac{1}{Z_0}\left\{ \left\langle E_1(t)^2 \right\rangle + \left\langle E_1(t)^2 \right\rangle + \left\langle E_1(t)E_2^*(t) + E_1^*(t)E(t) \right\rangle \right\}$$
$$P = \left\langle P_1 \right\rangle + \left\langle P_2 \right\rangle + \frac{2}{Z_0}\left\langle E_{10}(t)E_{20}(t)\cos(\varphi_1(t)-\varphi_2(t)) \right\rangle \qquad (4)$$

with $E_1(t)=E_{10}(t)\exp[i\varphi_1(t)]$ and $E_2(t)=E_{20}(t)\exp[i\varphi_2(t)]$ for real E_{10} and E_{20}

The brackets < > mean the statistical expectation value, $Z_0 = 120\pi\ \Omega$ is the impedance of the free space.

The term $\left\langle E_{10}(t)E_{20}(t)\cos(\varphi_1(t)-\varphi_2(t))\right\rangle$, the mean of the product of the two waves, describes the mutual correlation. $\left\langle E_{10}(t)E_{20}(t)\cos(\varphi_1(t)-\varphi_2(t))\right\rangle = 0$ results for completely de-correlated i.e. incoherent fields, if for instance the phases are time dependent and equally distributed between 0 and 2π respectively.

For $\left\langle E_{10}(t)E_{20}(t)\cos(\varphi_1(t)-\varphi_2(t))\right\rangle < 0$ results $P < \left\langle P_1\right\rangle + \left\langle P_2\right\rangle$,

For $\left\langle E_{10}(t)E_{20}(t)\cos(\varphi_1(t)-\varphi_2(t))\right\rangle > 0$ results $P > \left\langle P_1\right\rangle + \left\langle P_2\right\rangle$.

This, principally, describes the fluctuation of the power. The speckle in radar images is such a interference phenomenon. This is the basis for the definition of the Correlation Coefficient C by standardization also:

$$C = \frac{\left\langle (E_1(t)E_2^*(t))\right\rangle}{\sqrt{\left\langle E_1(t)E_1^*(t)\right\rangle\left\langle E_2(t)E_2^*(t)\right\rangle}} \tag{5}$$

It is always $-1 \leq C \leq +1$. C=1 means variation in conformity, C=-1 means E_1 and E_2 will vary in opposition. The coherence is defined as the absolute value of C:

$$\gamma = \left|C\right| = \frac{\left|\left\langle (E_1(t)E_2^*(t))\right\rangle\right|}{\sqrt{\left\langle E_1(t)E_1^*(t)\right\rangle\left\langle E_2(t)E_2^*(t)\right\rangle}} \tag{6}$$

It is always $0 \leq \gamma \leq 1$, $\gamma = 0$ means complete incoherence, $\gamma = 1$ means complete coherence.

If the phase of a wave is random and (directly or in effect) uniformly distributed over an interval of length 2π, it will be called incoherent. In that case the mean power densities of incoherent waves may be added algebraically. If the phase of a wave is constant, it will be called a coherent wave. The total power density of coherent waves is obtained by summing the individual vector fields. That means: determining the total power from the resulting total field, in particular, if n coherent waves of equal power are all in phase, the total power is equal to n^2. Furthermore it becomes evident that the coherence is a statistical quantity. This definition does not exhaust all possibilities: if the phase of the wave is random, but not uniformly distributed over the basic phase cycle, the wave is neither coherent nor incoherent, there is a continuous transition from pure coherence to pure Incoherence. The Coherence, however, is the most important Parameter in SAR Interferometry, Polarimetry and Polarimetric Interferometry as well.

5. References

5.1 References used in the introduction

Boerner W.M., et al, "Polarimetry in Radar Remote Sensing: Basic and Applied Concepts", Chapter 5 in F.M. Henderson, and A.J. Lewis, (eds.), *Principles and Applications of Imaging Radar,* vol. 2 of Manual of Remote Sensing, (ed. R.A. Reyerson), Third Edition, John Willey & Sons, New York, 1998, ISBN: 0-471-29406-3.

Cloude S.R., D.G. Corr, M.l. Williams: FOPEN Using Polarimetric SAR Interferometry, Proceedings EEUSAR 2004, 5th Conference on Synthetic Aperture Radar, May 25-27, Ulm, Germany pp.255 - 262

Cloude S R, E. Pottier, "A Review of Target Decomposition Theorems in Radar Polarimetry", IEEE Transactions on Geoscience and Remote Sensing, Vol. 34 No. 2 March 1996, pp 498-518

Hellmann M., Classification of Full Polarimetric SAR-Data for Cartographic Applications, PHD-Thesis Technical University Dresden, Faculty for Electro Techniques, October 1999

Henderson F.M., and A.J. Lewis, (eds.), *Principles and Applications of Imaging Radar,* vol. 2 of Manual of Remote Sensing, (ed. R.A. Reyerson), Glossary p.820, Third Edition, John Willey & Sons, New York, 1998, ISBN: 0-471- 29406

Keydel, W., Hounam D., Pac R., Werner M.: X-SAR/SRTM - Part of a global Earth Mapping Mission. RTO Meeting Proceedings 61, Space-Based Observation Technology, RTO MP-61, ISBN 92-837-1050-9, October 2000, p. 32 ff

N.N., IEEE Standard Dictionary of Electrical and Electronic Terms, IEEE, Inc. New York, NY

Papathanassiou K.P., "Polarimetric SAR interferometry," Ph.D. dissertation. Univ. Technol., Graz, Austria, 1999.

Papathanassiou K.P., I. Hajnsek, R.Scheiber, S.Cloude, Forest Height Estimation using Dual-Pol InSAR Configurations, Proceedings EUSAR 2004, 5th Conference on Synthetic Aperture Radar, May 25-27, Ulm, Germany pp.93 -96

Reigber A, A. Moreira, "First Demonstration of Airborne SAR Tomography Using Multi-Baseline L Band Data", IEEE Transactions on Geoscience and Remote Sensing, Vol. 38/5, pp 2142-2152, September 2000

5.2 Remarks to the References used for the whole Lecture Series

Each lecture of this Lecture Series contents a large amount of references, more than are citied in the manuscript expressis verbis. Goal is to give the participants a large overlook over the activities of the last decade including early basic papers which were the main initials of the respective topics. However, the development of Radar Interferometry, Radar Polarimetry and Polarimetric Radar Interferometry, the respective airborne and space-borne Systems and there proposed applications as well has been grown during the last 15 years dramatically. Presently it is still advancing very rapidly and, therefore, it is neither possible to cite all the new publications nor is it possible to establish a complete list of all respective publications made during the last time period.

Beside the **Transactions of the IEEE Geosciences and Remote Sensing Society (TGARSS)** which are a most important forum there are some very important symposia and workshops which regularly present the respective state of the art and where each paper contents a further list of references.

Exemplary for many others are the EUSAR Conferences (performed in a two years cycle in Germany), the annually performed IGARSS Conferences and the CEOS Workshops. EUSAR is a special meeting tailored for techniques, technology, systems and technical applications of SAR. It summarizes regularly the state of the art of SAR. IGARSS is a yearly performed Remote Sensing Conference, it is preferably application oriented covering the whole area of remote sensing and presents not only SAR but all kinds of sensors. Each of these events has own websites in the internet.

EUSAR, European Conference on Synthetic Aperture Radar, circularly every two years
Information on EUSAR is available under:
www.vde.de/VDE/Fachgesellschaften/ITG/Publikationen/KonferenzUndFachberichte
There are for each EUSAR respective proceedings available which content the most presentations on about 4 -7 sheets. Example: Proceedings EUSAR 2004, 5th Conference on Synthetic Aperture Radar, May 25-27, Ulm

CEOS
Some of the last important CEOS Workshops are exemplary listed below:
CEOS'99 SAR WORKSHOP, 27 -28 Mai 2004.Ulm Germany
Ceos Workshop on Applications of SAR Polarimetry and Interferometric Polarimetry, 14 .16 January 2003, ESRIN Frascati, Italy
Advanced SAR Workshop 2003, June 25-27, 2003, Saint Hubert, Quebec, Canada

CEOS SAR Workshop, September 2002, London
More respective remarks can be found in the Internet, key words. "CEOS SAR Workshops"

IEEE International Geoscience and Remote Sensing Symposia. IGARSS, circularly every year.
Information on IGARSS is available under:
http://www.ewh.ieee.org/soc/grss/igarss.html
There are for each IGARSS respective proceedings available which content the most presentations on about 4 -7 sheets. Example: Proceedings of IEEE International Geoscience and Remote Sensing Symposium IGARSS 2003, 21st-25th July, 2003. Toulouse, France.

6. The Lecturers

6.1 Prof. Dr. Wolfgang Martin Boerner

Professor emeritus and Director of the UIC-ECE Communications, Sensing & Navigation Laboratory Department of Electrical Engineering and Computer Science,. University of Illinois, Chicago, USA.

He received a Ph.D. on Electrical Engineering from the University of Pennsylvania, Philadelphia, in1967, and a M.Sc. Degree from the Electrical Engineering Technical University Munich, Germany, in 1963. He holds multiple Dr. honoris causa Degrees from the Friedrich-Alexsnder University Erlangen Nuremberg, Germany, 2003, from the University of Rennes, France, 2003; from the Tomsk State University Cluster, 2000.Fellowships: IEEE; SPIE; International Society for Optical & Photogrammetric Engineering; American Optical Society; Society for Exploration Geophysics; IEEE Distinguished Lecturer, 1995-97, Memberships: Russian Academy of Transportation; Sciences Editorial Board of International Remote Sensing Society; Editorial Board of SPIE Proceedings on Sensing and Imaging; Editorial Board of International Series and Monographs on Advanced EM Wave Theory and Applications; Editorial Board of International Institute of Physics and many others. His research interests include: Electromagnetic, inverse scattering, modern optics, geo-electromagnetism, electromagnetic imaging, remote sensing, wideband radar and optical Polarimetry.
He has authored 30 Books &Monographs, over 150 Journal Papers & more than 500 other Publications.

6.2 Dr. Martin Hellmann

Martin P. Hellmann received his Diploma (M.S.) degree in electrical engineering from Technical University of Darmstadt, Germany in 1995, the Ph.D. degree in electrical engineering from the Technical University of Dresden, Germany in 2000. From 1995 to 1996 he was working with the IANUS group of the Technical University of Darmstadt, Germany. From 1996 to 1999, he was working on classification of polarimetric SAR at the Radio Frequency Institute of the German Aerospace Research Center DLR in Oberpfaffenhofen, Germany. Within the European Training and Mobility for Young Researches Program (EC TMR Radar Polarimetry Network) he worked as a post doc for the Danish Defense Research Establishment DDRE, in Copenhagen, Denmark, (1999 to 2000), for Applied Electromagnetics AEL St. Andrews, Scotland, (2000 to 2001) and the Laboratoire Antennes Radar Telecom ART at the University of Rennes, France (2001). His work covered various applications of polarimetric radar data, from land mine detection to analysis of Polarimetric SAR data. Since 2001 he is working for the German Aerospace Research Center DLR.

6.3 Dr. Wolfgang Keydel

He used to be Director of DLR Radio Frequency Institute in Oberpfaffenhofen, Germany, until his retirement in 2001. From 1967 until 1978 he worked as Scientist & System Engineer with AEG-TELEFUNKEN Co. (today EADS) in Ulm, Germany. He received a Dr. rer. nat. Degree in 1967, and a "Diploma" as Physicist in1963 both from Philipps University Marburg, Germany. He received a Dr. Ing.-E.h. (Dr. honoris causa) Degree from University Erlangen-Nürnberg, Germany, in 2003.Memberships: IEEE-GRSS (Fellow) Awards Committee; VDE/ITG; DGON; Electromagnetic Academy (US); Consultant for several EU –Projects; Guest Prof. at Kepler University Linz, Austria; Tongji University Shanghai, China; regular Lectures on Microwave Remote Sensing at the Ludwig-Maximilians-University Munich; Germany.

Research Interests: Radio Frequency and Radar - Systems, -techniques, and - technology, mainly SAR and its application to reconnaissance and remote sensing. He authored 3 Books as Co-Author, more than 250

Journal and Proceeding Articles, more than 30 written external Reports etc. beside many internal Reports, and holds 16 Patents.

6.4 Prof. Dr. Eric Pottier

He is full professor at the University of Rennes 1, France, since 1999 and is head of the Radar Polarimetry Group of the Antenna, Radar and Telecommunication Laboratory. He received both a PhD Degree in 1990 and a MSc-Degree in 1987 in signal processing and telecommunications. Current research and education activities: Analogue electronics, microwave theory and radar imaging with emphasis in radar Polarimetry, including radar image processing, polarimetric scattering modelling, supervised/unsupervised polarimetric segmentation and basic theory.

He is Coordinator of the research group's Quantitative Data Inversion of the European Project TMR on Radar Polarimetry, member of the U.S. Navy Research Interaction program on Wideband Interferometric and Polarimetric Surveillance and Sensing He authored five books, 19 papers in refereed journals and more than 120 papers in proceedings.