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13. ABSTRACT (Maximum 200 words) To investigate the temporal and spatial polarization characteristics of military background clutter in order to improve target versus clutter discrimination. In particular, the use of polarization information at millimeter wavelength for the purpose of decreasing the false alarm rate for target detection in severe background clutter is to be investigated. In order to prove the polarimetric contrast enhancement and the Polarimetric Matched Signal/Image Filter (PMSF/PMIF) concepts, measurement data sets are to be identified and used for testing. The basic underlying polarimetric radar target phenomenology for partially polarized and partially coherent scattering from rough surfaces is to be further advanced.			
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In this context, I wish to express my sincerest thanks and deep felt gratitude to Dr. Walter A. Flood for backing me up, to Dr. James W. Mink for supporting me through periods of severe work stress (16-18 hrs./day, 7 days/week for months on end) and to Dr. Karl Heinz Steinbach for supporting international cooperation especially with radar polarimetrists in Western Europe, Poland and Russia.

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On top of this heavy research engagement, I tried to keep abreast with my dedicated involvement in supporting to the best of my abilities the current paradigm shift from military to environmental defense toward a new historical period of enlightened renaissance in protecting and safeguarding our global environment.

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PART I: TECHNICAL REPORT

I.0 SYNOPSIS (General Overview)

With the advent of RAM-coated, low RCS, fast moving targets occluded and well camouflaged into a military surface-flora-cluttered terrain, a naval sea-cluttered ocean background and/or the littoral coastal zones and with that of advanced wideband jamming techniques, novel methods of high resolution ultra-wideband target detection, target versus clutter discrimination, and real-time target identification must be developed which can be utilized with other hitherto established methods. Very encouraging results were obtained during the recent Mid-East air-strikes for the optical spectral regions using electro-optic devices. These truly high resolution optical sensing and imaging methods, however, did not perform well during adverse weather and dust/sandstorm conditions. In order to overcome these unresolved obstacles in future land/sea strike actions, near-infrared, millimeter-to-centimeter wave technology needs to be rapidly advanced which however will require complete utilization of electromagnetic vector wave target interrogation capabilities, i.e., the full integration of polarization information into sensing and imaging models is warranted.

Thus, the standard micro/millimeter wave radar sensing methods must be upgraded to make full use of amplitude, phase plus polarization information, and over wide bands. One, but not exclusively the only one, of such new approaches would be ultra-wideband impulsive radar target detection and characterization of shape, size, material constituents and exhaust effluents within the entire electromagnetic region from ULF/ELF/VLF $\rightarrow$ 30MHz $\rightarrow$ 3GHz $\rightarrow$ 3THz $\rightarrow$ 3PHz, exploring the specific spectral behaviours, which differ widely from spectral region to region. In most of these methods, the polarization dependence was often neglected, although it can be shown that this is erroneous and that for truly high resolution imaging and sensing we need to utilize all available information the electromagnetic wave allows us to recover. But, in order for rapidly advancing the required (ultra)wideband sensing and imaging technologies, first we must further advance theory and techniques of direct and inverse methods especially as regards (ultra)wideband surveillance. There exist several related polarimetric wideband approaches which need to be investigated separately, compared, and evaluated as to their optimal spectral-band applicabilities.

In this research, it is the objective to develop a more uniform approach to wideband polarimetric sensing and imaging based on the P.I.'s extensive contributions to this area as summarized in

[0.1] W-M. Boerner, et al, eds., Inverse Methods in Electromagnetic Imaging,
(B-1) Proceedings of the NATO-ARW-IMEI'83, Bad Windsheim, FRG, 1983 Sept 18-24,
C-143, Pts 1&2, Dordrecht, D. Reidel, 1985

and

[0.2] W-M. Boerner, et al, eds, Direct and Inverse Methods in Radar Polarimetry,
(B-3) Proceedings of NATO-ARW-DIMRP'88, Bad Windsheim, FRG, 1988 Sept 18-24,
NATO-ASI Series C, Vol. C-350, Pts 1&2, Dordrecht, Kluwer Acad. Publ., 1992

In these four volumes, a significant step toward the solution of these difficult, still unresolved problems is made. Whereas, at optical frequencies and also at cm-to - sub-mm wavelength (3GHz - to - 3THz) mainly the geometric and physical optics imaging algorithms apply, at VHF/UHF/microwaves (30MHz to 3GHz) the entire vector diffraction behaviour must be incorporated into the development of effective polarimetric wideband matched signal/image filter approaches.

A significant step toward a solution of this problem was achieved with the development of the polarimetric matched signal/image filter concepts (PMSF/PMIF). These

polarimetric (wideband) algorithms are based on the full utilization of the complete vector nature of electromagnetic (vector) waves, i.e., in addition to amplitude, frequency and phase also polarization state information of the transmitted and received waves is integrated into vector signal (bin-by-bin) and tensor image (pixel-by-pixel) processing. Although it is known that the detection of low RCS, RAM-coated targets can only be achieved by long-term integration (ensemble averaging) of repeated pulse trains; here, at the same time, the consecutive pulse trains are polarization coded so that by longer term integration the 2x2 Sinclair matrix [S] and/or the 4x4 Kennaugh matrix [K] descriptions of the targets with/without background scatter can be recovered for the coherent and the partially coherent cases, respectively. The extra cost of adding a complete polarimetric processor at the current state of polarimetric technology are relatively acceptable in relation to the decisive improvements made, and those complete polarimetric doppler sensing and imaging methods will definitely be required for precision air strike action during adverse weather, smoggy, and sand/dust storm conditions. Whereas, it seems that for extremely low grazing angles, clutter plays a less performance deteriorating role, certainly at moderate (air-borne operating) depression angles, terrain and ocean background clutter cannot be neglected.

For example, the alternate polarimetric matched filter approaches of Poelman's **Multinotch Polarization Clutter Suppression Filter (MNPCSF)** has proven to yield highly improved target versus clutter detection ratios of about 17db as compared to standard CFAR; and similarly our (W-M. Boerner, et al) **POL-SAR PMIF** for target image extraction against a strong camouflaging background clutter scene has provided superior target versus clutter image discrimination and separation. In addition, it has been clearly demonstrated that the availability of complete polarization information in target downrange, crossrange, SAR and ISAR imaging will provide invaluable information on target geometry and material decomposition at higher frequency bands (800 MHz to 40 GHz). Because these methods apply in principle also at wavelengths comparable to overall size and extension of the characteristic target body and sub-structures, polarimetric wave scattering mechanisms are hence also essential for radar wave interrogation of naval vessels down to 30 MHz and below. Also, at the extremely low frequency end of the spectrum VLF (3 KHz - 300 KHz) → ELF (3 Hz - 3 KHz) → ULF (3 μ Hz - 3 Hz), signatures of nature and man-induced disturbances display highly sensitive polarization-dependent behaviour. In addition, if a truly "ultra (ULF - ULTRA-Violet) wideband sharp spiky impulse without carrier frequency" is to be realized, the conventional multi-spectral frequency domain polarization state description must be replaced by a truly time-domain polarization descriptor which has yet not been fully developed. Depending on the spectral band of operation, the total spectral width and the spectral content of the impulsive wave, various mixed-purely frequency versus purely time-domain, and mixed frequency/time domain (wavelet) approaches need to be investigated in depth and so do we need to pay more attention to polarimetric doppler signatures of dynamic background scatterers.

With the recent advent of **UWB Polarimetric Multi-spectral and Impulse radar and SAR systems**, the feasibility of developing wideband interferometric radar and SAR systems has opened up entirely new methods of discriminating moving and/or vibrating low observables against stationary and motional background by extracting "quasi-instantaneous" interferograms. Whereas amplitude-only interferometric radar approaches provide lateral translational information, polarimetric scattering matrix radar will enable precise determination of instantaneous rotational motion, i.e., the specification of the complete instantaneous vector of motion. Then, by implementing recently highly advanced **Inertial Navigation Systems (INS)**, **Self-correcting Motion Compensation (SMC)**, **Global Positioning Systems (GPS)** and **Differential Global Positioning Systems (DGPS)** technology makes possible "**Repeat-Track SAR Image Interferometry (SARII)**" with repeat flight delay times of the order of minutes, hours, days, weeks, months in order to extract '**Moire fringe interferograms**' from "**precision-overlays of POL-SAR images**" which will strongly enhance the detection of

differential changes that have occurred in the background environment (e.g., soil disturbances during shallow land mine deployment; determination of tectonic stress accumulation before an earthquake, etc.)

I.A. OBJECTIVES AND STATEMENTS OF WORK: To investigate the temporal and spatial polarization characteristics of military background clutter in order to improve target versus clutter discrimination. In particular, the use of polarization information at millimeter wavelength for the purpose of decreasing the false alarm rate for target detection in severe background clutter is to be investigated. In order to prove the polarimetric contrast enhancement and the Polarimetric Matched Signal/Image Filter (PMSF/PMIF) concepts, measurement data sets are to be identified and used for testing. The basic underlying polarimetric radar target phenomenology for partially polarized and partially coherent scattering from rough surfaces is to be further advanced.

I.B. BACKGROUND (why should we further advance radar polarimetry!): Radar Polarimetry, i.e., utilization of complete electromagnetic vector wave information, has become an indispensable tool in modern electromagnetic sensor technology both in the civil and the military sectors and increasingly more in environmental remote sensing of the terrestrial and planetary atmospheres and crusts. From the outset, we emphasize that by incorporating coherent polarimetric phase and amplitude information into radar signal and image processing, one can anticipate and already is witnessing a breakthrough, which is at least comparable to that brought about by the advent of holography and computer assisted (Radon projection) tomography and its application to Synthetic Aperture Radar (SAR), Real Aperture Radar (RAR), Inverse Synthetic Aperture Radar (ISAR), and Synthetic Aperture Radar Image Interferometry (SARII).

In early RADAR (Radio Detection and Ranging) only amplitude information of the electromagnetic wave at a suitable frequency was utilized, which since its conception at the turn of the century, has become a key element in civil and military operations on land, at sea, and in the air. Then, some fifty to sixty years later, it was possible to build wide-band radar systems, which in addition to frequency and amplitude, also utilize relative and absolute phase information for resolving physical features of scatterers and the background environment (vehicles, ships, aircraft, space objects, terrestrial and planetary surfaces). The increased resolution capability has provided the means of extending the original RADAR concept of radio detection and ranging to include capabilities for high resolution mapping, profiling and imaging unrelated to either detection and ranging. However, in order to further improve on high resolution techniques for carrying out traditional radar tasks of search, track, and weapon control in increasingly difficult surveillance environments with increasing simultaneous target camouflaging capabilities and occlusion under optically opaque screens; in addition, to amplitude, frequency, relative and absolute target phase also, complete coherent polarization information must be incorporated into the target versus background clutter image contrast enhancement algorithms. These complete scattering matrix radars are known as POL-RAD or POL-DOP-RAD systems.

In high resolution polarimetric radar imaging, and especially at extremely short wavelength in the CMW and MMW region, it is the objective to utilize the complete vector nature of electromagnetic waves, i.e., in addition to amplitude, frequency and phase, also polarization state information of the transmitted and received waves is incorporated into signal and image (pixel-by-pixel) processing, requiring a 2×2 Sinclair matrix $[S]$ and/or a 4×4 Kennaugh matrix $[K]$ description of the scatterers for the coherent and partially polarized cases, respectively. Although there still exist some "grey areas" in both theory and techniques of radar polarimetry, especially as relates to the treatment of the partially coherent case, in recent years considerable progress was made in theory, device technology and algorithm

development for broad-band polarimetric vector signal and image processing modules including the utilization of polarimetric wavelets (ondulettes), of neural networking, etc., which in a next step are to be developed for polarimetric ultra-wide-band impulsive radar imaging methods. Therefore, in keeping abreast with the dynamic advances, an up-to-date state-of-the-art assessment is required together with the identification of viable new high-resolution polarimetric radar techniques, which will be able to address the rapidly changing needs of military operations of the future in dealing with "extremely low RSC" targets "well camouflaged" into increasingly more complex background environments.

More recently, with the advent of highly improved Inertial Navigation Systems (INS), Selfcorrecting Motion Compensation (SMC), Global Positioning Systems (GPS) and more advanced Differential Global Positioning Systems (DGPS) technology rather accurate in-flight ultrawideband (UWB) as well as repeat-track (with periods of minutes, hours, days, weeks, months) POL-SAR image interferometry has become feasible. Whereas, in in-flight POL-SARII provides interferograms of minute quasi instantaneous dynamic changes of image scenes (e.g., rapid motion displacements of low observable projectile or surface skimmer), repeat-track time-delayed flight passes over one and the same image scene with delay times of the order of minutes, hours, days, to weeks --- months yield Moire fringe interferograms of surface and volumetric underburden deformations (e.g., changes due to motion of armored vehicles occluded under thick vegetation cover; or surface deformation due to tectonic stress accumulation and deceleration before, during and after a seismic stress release, i.e., earthquake, etc.). Whereas, mono-amplitude SARII will provide analysis of lateral motion and/or surface deformations, POL-SARII will in addition provide accurate rotational motion analysis. Thus, we are in the final stages of realizing complete, truly polarimetric Doppler radar (SAR) image interferometry which soon will totally change wide area surveillance.

The New Challenge: Planetary Environmental Protection and Defense

We find that our greatest threat today is not from other nations trying to conquer us, but from our own capacity to destroy our environment and with it ourselves along with our planetary flora and fauna. Indeed, this is the greatest enemy of our times, one that we need to recognize and fight before we lose a battle that we did not foresee. To counter this imminent threat continuously hardening due to the unabating population explosion, we propose a new post-war role for the US military in a global environmental defense initiative in which our military capabilities would be restructured into a planetary environmental defense force.

Scientific and engineering expertise in the US defense research establishment must now be redeployed to develop the needed technologies. While we must continue to safeguard valuable technologies more 'glasnost' in the defense research is called for facilitating its transfer to the industrial and academic sectors as well as to other environmental agencies of state and federal governments. Recently, for example, we learned that the adaptive optical system and high power lasers developed for SDI could have obviated the need for the visible light spectrum part of the Hubble Space Telescope. This technology with its obvious civil and industrial applications was far too long kept under wraps. One of the most pressing issues in **Environmental Planetary Defense is Wide Area Global Environmental Surveillance** with the ultimate goal of the instantaneous detection, automated recognition and/or prediction of major impending environmental catastrophes which need not be created necessarily by man himself but, which may also arise from the ever-active deep-earth internal forces which affect our biosphere by such natural catastrophes as earth/sea-quakes with their related tsunamis, by volcano-eruptions and by major global weather changes, such as major flood episodes, also being induced by global earth-internal next to solar causes. Thus, we need to explore the specific "instantaneous disaster-prevention and mitigation capabilities of the entire electromagnetic spectrum for wide-area global environmental surveillance", including: (i) the lower

ULF (below 1mHz: Earth-internal and coupled extra-terrestrial "gravitational sources" (with periods of days, weeks, months and years) which could trigger major global weather/climate changes; which, if detected early enough, could allow for sufficient time for some wide area disaster mitigation); (ii) the upper ULF and ELF (1mHz - 1KHz: earth/seaquake and volcano activation precursor radiation; which if detected early enough, could lead to "well planned, deep earth disaster mitigation"); (iii) ELF-MF (1KHz - 1MHz: detection of otherwise "low observable objects" traversing the ionospheric fluid layer or skimming along the terrestrial surface which create acousto-electromagnetic, coupled terrestrial- ionospheric resonance phenomena); (iv) HF-VHF (1MHz - 1GHz: Ultra-wideband detection of low observables embedded in noisy background clutter, plus, passive wide area environmental security surveillance including penetration capabilities such as through foliage and into lossy soils); (v) m-sub-mm (about 1GHz - 100GHz: High Resolution target sensing and imaging in a wide area terrestrial boundary layer environment including polarimetric doppler radar and satellite IR imagers deployment for the sensing of severe storms and hail for relevant disaster prediction and warning); (vi) mm-IR (20GHz - 100THz: Molecular spectroscopy and radiometric imaging); (vii) IR/ OPT/UV (10THz - 10PHz: High resolution lidar sensing and imaging above the ionosphere and in atmospheric and oceanic environments: blue-green laser). By implementation of in-flight and repeat-track POL-SAR image interferometry also minute changes such as "mine-deployment" or surface deformation due to tectonic and hydrologic stress accumulation can be analyzed with ever increasing accuracy. During the past decade the development of the required relevant high-technology base was, in principle, pioneered in many pertinent disciplines such as in global multi-channel bulk data signal & image sensing, neural networking, parallel computer processing, in photonic signal/image transfer, and in spectral data fusion, which now allows us to approach the development of intelligent self-reliant automated sensors to be deployed in space and on surveillance aircraft (AWACS) in "HIGH RESOLUTION INSTANTANEOUS DETECTION, SENSING, SPECIFICATION, IMAGING AND IDENTIFICATION" of "GLOBAL ENVIRONMENTAL THREATS", so that "disaster mitigation" procedures may be enacted in time for regional and global disaster reduction and prevention. Further, promotion of these global concepts of ENVIRONMENTAL PLANETARY DEFENSE, will strongly benefit the future solidification and strengthening of our integral defense R&D&E as well as that of the pertinent, highly refocused, defense industry as was analyzed by us in

[0.3] W-M. Boerner, J.B. Cole, (invited), FROM MILITARY TO PLANETARY ENVIRON-
(W-64) MENTAL DEFENSE: The Challenge of the Next Century, and a Viable New Role of the US Military in an "ENVIRONMENTAL PLANETARY DEFENSE INITIATIVE" on a Global Scale, Proc. NSIA-DEFENSE INDUSTRY AND THE ENVIRONMENTAL AGENDA-SYMPOSIUM'91, Oct. 9-10, Sheraton Premier Hotel at Tyson Corner, Vienna, VA, pp. 314-330, Nov. 1991, (available from Dr. D. Brent Pope, editor, NSIA, Suite 300, 1025 Connecticut Ave., NW, Washington, DC 20036-5405),

and

[0.4] W-M. Boerner and J.B. Cole, From Military to Planetary Towards
(P-33) Environmental Defense: A New Role for World Militaries in an International Environmental Defense Initiative, Parts 1&2, IEEE Journal on Society and Technology, Vol. No. 3, July 1993, (14 pgs.), in print. (also in reduced form in H. Mott and W-M. Boerner, eds, Radar Polarimetry, SPIE Proc., Vol. 1748, pp. 12-22).

I.C. OVERALL ACCOMPLISHMENTS: During the past ten years, basic research studies on the fundamentals of coherent and partially coherent radar polarimetry were carried out within the UIC-EECS/CL with applications to target detection in clutter, target and background clutter classification, target iamging, and identification. As a result of these investigations the underlying fundamental theory of polarization radar technology was revised, corrected and generalized and the related polarimetric radar target phenomenology, originally introduced by Dr. Edward M. Kennaugh, was reformu-

lated in a physically more transparent three-step target versus clutter optimization procedure. Also, we have clarified existing misconceptions about the valid use of the restricted versus the generalized ρ -formulated unitary transformation matrix presentation of the optimal polarization Null/Max theory of Kennaugh and Huynen in the anti-monostatic (forward propagation) and monostatic (backward scatter) cases. Using the generalized polarization ratio ρ formulation of the unitary change of polarization state transformation, a novel and self consistent presentation of the polarization fork concept is introduced, which is the most complete formulation hitherto available. Specifically, we have shown that a clear distinction between the forward propagation (scattering) and the backward scattering cases, i.e., the anti-monostatic and the monostatic transmitter-target-receiver arrangements must be made requiring the standard eigenvalue/vector and similarity transform versus the mathematically novel con-eigenvalue/vector and con-similarity matrix approaches. For the monostatic reciprocal case ($S_{AB} = S_{BA}$) it is shown via a corrected con-eigenvalue/vector approach and con-similarity transformation that there exist in total five pairs of characteristic polarization states: The orthogonal cross-polarization null and co-polarization state pairs, being identical and sharing one main circle with the co-polarization null and the orthogonal cross-polarization maximum state pairs, the latter being at right angles (on the polarization sphere) to the cross-polarization null pairs; and another newly identified pair: the orthogonal cross-polarization saddle point extrema which are normal to the plane (main or target characteristic circle) spanned by the other four pairs on the polarization sphere. With this complete and unique con-eigenvalue/vector and con-similarity transformation mathematical description of Huynen's polarization fork concept, it is now readily possible to resolve the remaining unanswered questions in the polarimetric radar target optimization problem for the coherent case, and also for the partially polarized cases.

A new approach for dealing with partially coherent radar scatter was introduced by establishing a firm and transparent foundation for the Kennaugh-Stokes operator approach based on the coherency (density) matrix formulation for describing time-dependent canonical targets such as fluctuating dipoles, oscillating raindrops, ocean wave scatterers, etc, for purposes of target signal enhancement and clutter rejection under partially coherent conditions. Specifically, it is shown that the concept of "mean optimal (Null, Max, Sad) polarization states" is highly useful also in the case as a partially polarized wave treatment.

For the broadband coherent transient cases the concept of the time-domain representation of polarization has been advanced, and serious consideration is given to the advancement of ultra-wideband polarimetric doppler radar concepts for which no true carrier frequency is assumed to exist. Although the effective use of UWB Impulsive Radar Concepts for the pursuit of detecting Low RCS-targets, such as a STEALTH-class aircraft, is very questionable, there does indeed exist a multitude of hitherto untouched target detection methods such as inflight UWB (impulse) Repeat-Track (time-delayed flight overpasses) POL-SAR Image Interferometry, which indeed require the rapid advancement of UWB and other multi-band POL-SAR systems technologies.

Using matrix optimization and group-theoretic approaches the properties of co- and cross-polarization nulls and maxima on the Poincaré sphere are established for the general multistatic cases. Based on the bistatic scattering matrix phenomenology, the objective of this research is to develop multistatic narrow-to-broad-band air-target/air-multipath (background reflection) target discrimination algorithms using complete polarimetric scattering matrix data. At high frequencies the electromagnetic scattering from a complex object is modeled by certain interactive scattering centers located on one and the same target and/or including one or more target exterior multipath generated target image scattering centers. For this investigation, we are developing high frequency (physical optics) monostatic and bistatic scatter-

ing matrix plate models of such scattering centers. For these simple and other more complex scattering matrix model representations the single scattering center formulation is derived and then extended to two and three scattering center models. The bistatic scattering matrix for a multipath scattering problem, involving an isolated scattering center over an infinite plane reflecting surface has been derived. The difference between this case and the two-scattering-center model has been clearly demonstrated.

By analyzing these model scattering matrices, the electromagnetic inverse problem of recovering the high frequency scattering centers from multistatic polarimetric data is being investigated. Specifically, based on a knowledge of the location and the local geometries of these scattering centers, which can be recovered from multistatic scattering matrix data, the development of target classification, imaging, and identification algorithms have been advanced using novel polarimetric pattern recognition methods derived from the polarization null theory for both the monostatic and the bistatic cases.

Simultaneously, electromagnetic vector inverse scattering theories which utilize complete relative phase scattering matrix radar data were developed which allow straightforward interpretation of polarimetric radar measurement data in terms of the characteristic geometrical and material features of isolated and distributed targets for both the monostatic and the bistatic coherent cases.

The various developed target detection, classification, imaging, and identification algorithms are verified using polarimetric instrumentation radar data provided by various DOD/NASA (JPL) research radar instrumentation facilities. The obtained results are very promising and our research has now reached a more mature phase so that the established fundamental theories can be further advanced on a mission-oriented basic and exploratory developmental 6.15 and 6.2 level.

During the pre/active/post contract phases, major efforts were made to advance the understanding for urgent attention toward utilizing our expertise in polarimetric radar and radiometer remote sensing to environmental issues of national and global concern, which include: (i) air/space detection of hostile targets within the terrestrial boundary layer; (ii) the instantaneous detection of hostile objects/subjects in severe environmental background clutter (for example, drug-smugglers in Carribean; advanced electronic air-strike operations during adverse (foggy-to-stormy) weather conditions as for example, during crucial phases of the recent Mid-East military actions; etc.); (iii) the automated recognition of differential changes in image scenes, such as observed before, during and after the deployment of mine-fields by POL-SARII techniques; and (iv) the instantaneous detection of sources of toxic environmental pollutants. We are confident to state that high resolution complete polarimetric (scattering matrix) Doppler radar (POL-RAD, POL-RAR, POL-SAR, POL-ISAR, POL-SARII) methods and technologies will become of paramount importance to solving these problems, which has already become a serious issue of National Planetary Defense (see [0.3] and [0.4]); namely, the problem of **INSTANTANEOUS DETECTION, AUTOMATED RECOGNITION & LOCALIZATION AND SHORT-TO-LONG-DURATION IDENTIFICATION OF SOURCES OF MILITARY & ENVIRONMENTAL POLLUTION AND THREAT.**

I.D. MAJOR NATIONAL & INTERNATIONAL RESEARCH TRAVEL INTERACTION AND EXCHANGES:
During the tenure of this research contract study, major relevant global political changes have occurred and we are witnessing hopefully the end of the post-WWII Cold War period, i.e., factually the end of WWII or the "WAR ERA (1912-1990)", and with it the creation of a new world order which will dictate the choice, i.e., a new revised selection, of our allies for the coming decades [w-64, P-33].

Here, I wish to clearly state with confidence that indirectly and also directly I was engaged rather strongly in the "East-West thawing of relations" which lead: (i)

to the re-unification of East and West Germany; (ii) to the ideological changes within the USSR Academy of Sciences, Research Laboratories and of the All-Union R&D&M Institutes of Electronic and Radar Equipment; and, subsequently, to a rapid reapproachment of scientists from within East-West scientific centers; and (iii) to near future research exchanges between the USSR (CIS), NATO-Europe, USA, and the Asia NW Pacific Rim (Taiwan, Japan, China and Korea). However, it is re-emphasized here that in all of these interactions strict care is taken in safeguarding sensitive information and also in identifying new rapidly focusing threats. Documentation available on request!

As a result of our interactions, various counter-visits (USA to NATO-Europe, USSR and Eastern Europe, PR China, Taiwan, Japan and Korea, vice versa) have taken place as summarized in my National and International Research Travel Interaction Reports T-1 to T-24. One of the main objectives of these international interactions was and is the promotion of research interaction on the advancement of "Direct and Inverse Methods in High Resolution Polarimetric Radar Imaging" and its application to the "Instantaneous Detection Localization/Ranging, Automated Recognition, Discrimination and Short-to-Long-Term Identification of Hostile Objects and Pollutants in the Remote Sensing of Terrestrial and Planetary Environments".

These aspects of global environmental planetary surveillance also became a strong component of my 1990-1994 summer research engagement as an awardee of a US NAVY ASEE (American Society for Engineering Education)-SFRP (Summer Faculty Research Program) Distinguished Senior Professorship with the US Navy, Naval Ocean Systems Center (NCCOSC-NRAD), San Diego, CA in collaboration with NAWC(NAWCADWAR, NAWCWDCL/PMTC/DTRC), NRL, NCSC, NOARL, ARL, MI-LAB, MI-COM, RADC, LLNL and LANL on "Ultra-wideband Polarimetric Interferometric Impulse Radar, Large Area Ocean Seasurface & Coastal Sensing and Imaging". As analyzed in detail in those reports one of the main objectives was and remains the strengthening of the "global planetary environmental defense" obligations of our US Department of Defense which includes the US Navy, the US Marines, the US Air Force and the US Army and its Corps of Engineers at the same levels.

In concluding this summary section, I wish to stress that we have made very considerable progress among NATO and WARSAW pact member countries, including especially the USA, Canada and components of the former USSR together with Scandinavia to further advance this concept of developing the deep-rooted understanding that it must — from now-on into the future of our existence on this terrestrial sphere — be the prime objective of our defense departments to contribute their fair share to "global planetary environmental protection and defense". This concept was further substantiated during the May 1990 counter-visits of six USSR radar polarimetrists to the USA (see T-6/10), of our active involvement in the USA-USSR joint program on the "Preservation of the Terrestrial Large Lakes: Save the Great Lakes Baikal/Michigan Environmental Theatre Festival, Lake Baikal & Ulan Ude, Buryat, Eastern Siberia, USSR, 1990 August 17-Sept 04 (See T-8) and of another countervisit of ten (10) Buryatian scientists, businessmen, artists and elected State representatives to Chicago (1990 Dec 17-to-1991 Jan 02) as summarized in Travel Interaction Report T-10 and in Technical Report R-14. During the post-contract phase several additional East-West interactions supported in part by the USARDSG(UK) were carried out (T-) which dealt with the promotion of the concept of establishing worldwide a network of 'International Regional Centers of Environmental/Ecologic Research, Education, Policy, Archiving and Defense' such as the 'BICER' (Baikal International Center of Environmental Research) at Lystvianka, SE Baikal Lake, Siberia, Russia; the proposed 'GLICER' (Great Lakes International Center of Environmental Research) at Fort Sheridan, Lake County, IL/USA; and the contemplated 'VICER' (Vyborg (Baltic Sea) International Center of Environmental Research) at Vyborg, Karelia, CIS; as summarized in

[0-5] W-M. Boerner, Research Travel Report on 1993 June 21 - July 09(16)
(T-21) SCANDINAVIA-CIS MEASUREMENT CAMPAIGN AND CONFERENCE PRESENTATION
(NINF-PFM: SOGNEFJORD'93; DTH/DDRE: KOPENHAGEN'93; MIIGA: MOSCOW'93;
TIACSR: TOMSK'93; SPIAP: ST.-PETERSBURG'93; SPCSE: KARELIAN LAKES'93;
PIERS: PASADENA'93), 1993 August 10 (70 pages), UIC-EECS/CSL:
USARDSG(UK)/NAWCADWAR(50C), 1993 August 10.

I.E. Specific Research Accomplishments:

During various, recent Polarimetric Radar research retreats, workshops and symposia, it has become very evident that indeed several crucial fundamental subtleties in 'the basic theory of radar polarimetry' are not fully explored. Therefore, in order to further advance polarimetric radar imaging and signal processing for incoherently distributed, temporally and dynamically moving scatterers, it was found necessary to readdress specific sub-tasks, and to revisit various basic concepts of radar polarimetry which in spite of earlier claims still are and in part remain unresolved.

As a result of our analytic and computer-numeric investigations of both [S] and [K] matrix data sets, we have continued with our re-visitation of the basic polarimetric radar theory, dealing separately with: E.1, Coherent Polarization Radar Theory; E.2, Time-domain Treatment of Polarization for the Coherent Case; E.3, Partially Coherent Polarization Radar Theory; E.4, The Development of P.O. Inverse Scattering Theories and Its Applications to the Polarimetric Radar Target Identification Problem; E.5, Polarimetric Doppler (POL-DOP-RAD) and Imaging (POL-SAR/POL-RAR/POL-ISAR) Radar Analysis: The Development of the Polarimetric Matched Signal Filter (PMSF) and the Polarimetric Matched Image Filter (PMIF) Concepts; E.6, Polarization Vector Tomography and its Application to the Detection and Imaging of Objects Submerged in Inhomogeneous Media; E.7, Polarimetric Low Frequency Inversion Methods for the Detection, Localization and Identification of Nature & Man-Induced ULF/ELF/VLF of Noise and Intelligible Signal Sources; E.8, High Resolution Infrasonic/Near-Infrasonic Telemetry of Distant Disturbances; and E.9, In-flight UWB (Impulse/Doppler) and Repeat-Track Multiband POL-SAR Image Interferometry. In addition, polarimetric backscatter modeling for isolated and distributed scatterers applicable to the mm-wave (30 GHz - 120 GHz) regime was further advanced in a separate study for the US Army Missile Laboratory (R-6).

I.E.0 Preparation of the FINAL MANUSCRIPT for the PROCEEDINGS of the NATO-ARW-
(B-3) DIMRP'88 on "Direct and Inverse Methods in Radar Polarimetry", Bad Windsheim, FRG (West Germany), 1988 Sept 18-24, Parts 1 and 2, NATO-ASI Series C, Vol. C-350, (Mathematical & Physical Sciences), DORDRECHT, NL: Kluwer Academic Publishers, Jan. 1992.

Next to guiding, supervising, and carrying out contract research, truly the main time-consuming efforts during 1986 to 1992 — and a long time thereafter — were expended on putting together the final manuscript of these Proceedings and in paying off the very considerable personal debts incurred. This enormous task included (i) the translation and re-editing of two major Soviet state-of-the-art reviews plus seven (7) contributed papers; (ii) the careful reediting of more than twenty-five incomplete papers which needed to be returned to the authors repeatedly; (iii) editing of the discussion working group reports; (iv) editing of a main Introduction, and the State-of-the-Art Review in context with the content of the Proceedings; (v) co-ordinating, categorizing and assembling of the individual manuscripts; and (vi) the acquisition of additional research funds for completing the truly horrendous editing job. This task was finally completed by 1991 August 30 (See FINAL REPORT, [5-13], for ARO Grant DAAL-03-89-K-0075 for details), but the struggle of searching for additional funds for paying back the enormous debts has yet to be completed. (1993 Feb.15) and is still an ongoing malaise.

[E.0-1] W-M. Boerner, et al (eds.), Direct and Inverse Methods in Radar Polarimetry (B-3) Proceedings of the NATO-ARW-DIMRP'88, Bad Windsheim, FRG, 1988 September 18 - 24, NATO-ASI Series C (Math & Phys. Sci.) Vol C-350 (2 Parts: 2,000 pages); Dordrecht, NL: Kluwer Academic Publishers, Jan 1992.

I.E.1 Coherent Polarization Radar Theory: In order to further advance on the optimization procedures for the partially polarized cases, it was found necessary to develop optimization procedures of 4x4 Stokes reflection or Kennaugh matrices [K] associated with the "degenerate coherent" case which must result in precisely the same results as those obtained from optimizing the 2x2 Sinclair matrix [S]. Different approaches were introduced on determining the characteristic polarization states, first introduced by Kennaugh [B-1] and further extended by Huynen [B-3], who introduced the "polarization fork" concept [B-2]. In carefully analyzing these concepts, which define the basic principle of radar polarimetry, crucial mathematical errors were found as assessed in:

[E.1-1a] A.B. Kostinski and W-M. Boerner, "On Foundations of Radar Polarimetry", (P-4) IEEE Trans A&P, Vol AP-34, No 12, Dec 1986, pp 1395-1404;

[E.1-1b] H. Mieras, Comments, "On Foundations of Radar Polarimetry", IBID, pp (P-4) 1470-1471;

[E.1-1c] A.B. Kostinski and W-M. Boerner, Reply to Comments by H. Mieras, "On (P-4) Foundation of Radar Polarimetry", IBID, pp 1471-1473;

dealing mainly with the proper definition of "polarization state", and the introduction of "correct coordinate systems" as addressed in:

[E.1-2a] IEEE Standard Test Procedure for Antennas, ANSI/IEEE Std. 149-1979 (Revision of IEEE Std. 149-1965),

[E.1-2b] Radar Polarimetry, AMTA, Ninth Annual Meeting, Seminar 11, Seattle, WA, (p-7) 1987, September 28 - October 2. (IEEE Proceedings, Fall, 1990, submitted under new authorship: Chan, C-Y.).

In the latter paper, we have identified several crucial inconsistencies in the basic equations of radar polarimetry, which we found rather common in the past, recent and current literature on the subject.

Employing the correct formulation of radar polarimetry, we have considered the problem of optimizing the signal versus clutter-like polarization ratio for the case in which scattering matrix element measurements can be obtained well below the "clutter decorrelation time" in terms of a purely incoherent scattering matrix approach in:

[E.1-2c] A.B. Kostinski and W-M. Boerner, "On the Polarimetric Contrast (P-5) Optimization", IEEE Trans. A&P, Vol 35, No 8, pp 988-991, August 1987.

In these papers, a three-step-procedure for determining the optimal transmit/receive polarization states, i.e., the maximum and minimum polarization states (co-pol max) as well as the mismatch polarization states (co-pol nulls) were developed. Although this coherent approach, first introduced in the M.Sc. thesis:

[E.1-2d] C-Y. Chan, Studies on the Power Scattering Matrix of Radar Targets, (p-4/7) UIC-EECS/CSL, 1980,

is being belittled to be highly unrealistic, it turns out to provide the proper conceptual approach for dealing with measurable data sets collected with "Complete

Polarimetric Coherent Doppler Radar Systems", provided the individual "quasi-instantaneous coherent scattering matrices [S]" are obtained well below the decorrelation and scintillation times of clutter which is a truly realistic requirement that can be satisfied for advanced POL-DOP-RAD systems.

These methods (E1.1-to-2) did, however, not allow for the proper derivation of Huynen's polarization fork concept which was derived in a rather incomplete, non-transparent approach in Huynen's dissertation [B-2] from Kennaugh's earlier work [B-3]. Thus, in spite of extensive studies on "the basic principle of radar polarimetry", a final rigorous and complete formulation still is warranted. Different approaches were introduced for determining these characteristic polarization states by using the voltage equation (Kennaugh, 1949-54), the eigenvalue problem of the power scattering matrix (Huynen, 1970; Chan and Boerner, 1981; Davidovitz and Boerner, 1986; Kostinski and Boerner, 1986), the restricted unitary transformation matrix techniques (Boerner, et al, 1981; Davidovitz and Boerner, 1986), and more recently, a slightly generalized unitary transformation matrix approach of:

[E.1-3a] A.P. Agrawal and W-M. Boerner, "Re-development of Kennaugh's Target
(P-11) Characteristic Polarization State Theory Using the Polarization Transformation Ratio Formalism for the Coherent Case", IEEE Trans. Geo. Science & Remote Sensing, Vol 26, No 1, January, 1989, pp 1 - 13;

Whereas the formulation in [E.1-3a] allowed for the determination of the additional cross-polarization maximum pair, it was not sufficient for the complete description of Huynen's fork presentation and another additional pair, the orthogonal cross-pol saddlepoint extrema could not be determined by this method. This feat was accomplished in the following two papers, where it is shown that for the monostatic reciprocal case there exist in total five unique pairs of characteristic polarization states for the symmetric scattering matrix:

[E.1-3b] W-M. Boerner and A-Q. Xi, "The Characteristic Radar Target Polarization
(P-15) State Theory for the Coherent Monostatic and Reciprocal Case Using the Generalized Polarization Transformation Ratio ρ Formulation, Archiv der Elektrischen Uebertragung, AEU, Vol 44, No 4, pp. 273-281, 1990, July/August;

[E.1-3c] A-Q. Xi and W-M. Boerner, "Determination of the Characteristic
(P-26) Polarization States of the Target Scattering Matrix [S(AB)] for the Coherent, Monostatic and Reciprocal Propagation Space", J. Opt. Soc. Am., Part A, Optics & Image Sciences Series 2, Vol. 9, Nov. 3, March 1992.

Specifically, in addition to the two fundamental orthogonal pairs (already established by Kennaugh (1952) and by Huynen (1970)), the orthogonal cross-polarization null and orthogonal co-polarization max pairs which are identical; there exist another two distinct pairs of orthogonal cross-pol max and cross-pol saddlepoint extrema. The diameters joining the three distinct pairs of orthogonal polarization state extrema are at right angles to one another on the polarization sphere. The fifth pair, the co-pol null pair lies in the plane spanned by the co-pol max (cross-pol null) and the cross-pol max pairs, which determines the target characteristic circle on the polarization sphere, and the angle between the co-pol nulls is bi-sected by the diameter joining the cross-pol nulls on the polarization sphere as was first established by Kennaugh (1952) by the method of induction without providing a 'closed-loop' analysis as given in [E.1-3b/c].

During the development of the 'Critical Transformation Point' or 'Generalized Polarization State Transformation Ratio ρ ' formulations', it was found that still several inconsistencies existed due to the "pseudo-eigenvalue/vector optimization" problem associated with the "monostatic symmetric scattering matrix case". In analyzing the

distinct differences between the anti-monostatic (straight-line forward) and the monostatic (purely backward) transmitter-scatterer-receiver arrangements, it was found in collaboration with Dr. Ernst Lüneburg that great care must be taken in distinguishing the two cases with (i) the anti-monostatic (forward propagation) arrangement satisfying the standard eigenvalue/vector optimization and matrix similarity transformation, whereas, (ii) the recently developed con-similarity algebra applies strictly to the monostatic case as is further analyzed in [E.1-3d] and [E.1-3e].

[E.1-3d] E. Lüneburg and W-M. Boerner, The Backscatter Operator in Radar
(P-39) Polarimetry, Its Con-eigenvalue/vector and Con-similarity Representations, and Its Applications, in print, AEÜ, Vol. 48 (1994)

[E.1-3e] E. Krogager, E. Lüneburg and W-M. Boerner, Analysis of the Absolute and
(P-43) Relative Phase Conditions of Transformation Matrices for the 2x2 Sinclair [S] and 3x3 Covariance [Σ] Matrices in Radar Polarimetry, J. Optical Soc. Amer. Part 1A, Optics & Imaging Sci., Series 2, Vol. E76B, 1993, in print.

In developing optimization methods for determining the characteristic polarization states for the partially coherent case, one need to optimize the Mueller matrix [M] for the forward scattering case, and equivalently the Kennaugh 4x4 backscatter power density matrix [K] for the monostatic cases, respectively. But as there indeed exists a multitude of contradicting solutions in the current literature, it was found meritorious to first analyze in depth the optimization of the Mueller matrix [M] and the Kennaugh matrix [K] for the "degenerate coherent" forward and backward scattering cases, respectively; and to compare results with those obtained in [E.1-3a to e]. The three-step-procedure [E.1-1a-1c], and the Kennaugh Stokes reflection matrix $[K] = [\bar{M}]$ optimization approach for the "degenerate coherent Mueller matrix" case are treated in:

[E.1-4a] W-L. Yan and W-M. Boerner, "Optimal Polarization States Determination of
(P-27) the Stokes Reflection Matrices $[\bar{M}_p]$ for the Coherent Case, and of the Kennaugh Matrix [K] for the Partially Polarized Case", Journal of Electromagnetic Waves and Applications, JEW, Vol. 5, No. 10, pp. 1123- 1150, Oct. 1991.

[E.1-4b] Y. Yamaguchi et al, and W-M. Boerner et al, "Characteristic Polarization
(P-20) States of Coherently Reflected Waves Based on the Stokes Vector Formulation in Radar Polarimetry", Japan Journal for Electronics and Communications Engineering (JIEECE), Vol AP/90-35, pp 23-30, 1990 July 19.

All of these methods are compared in:

[E.1-5a] W-M. Boerner, W-L. Yan, A-Q. Xi and Y. Yamaguchi, "ON THE BASIC PRINCIPLES
(P-28) OF RADAR POLARIMETRY (invited review): The target characteristic polarization state theory of Kennaugh, Huynen's polarization fork concept, and its extension to the partially polarized case, IEEE Proceedings, Special Issue on Electromagnetic Theory, Vol. 79, No. 10, pp. 1538-1550, Oct. 1991

and further pursued in:

[E.1-5b] W-M. Boerner, C-L. Liu and X. Zhang, Comparison of the Optimization Proce-
([P-32]) dures for the 2x2 Sinclair and the 4x4 Mueller/Kennaugh Matrices in Coherent Polarimetry and Its Application to Radar Target Versus Background Clutter Discrimination in Microwave Sensing & Imaging, Int'l. Journal on Advances in Remote Sensing (IJARS), (EARSel), Boulogne-Billancourt, France), Vol. 2, No. 1-1, pp. 55-82, Jan. 1993.

which also includes a complete assessment of and comparison with a reformulated covariance matrix approach similar to that introduced recently by Tragl ([E.3-6a]) and Lüneburg et al in [0-2].

It is shown how each of the four basic methods contributes partially toward a complete understanding, although more approaches may still be required for completely resolving all of the unanswered questions for the coherent case. In particular, definite care must be taken in separating the anti-monostatic from the monostatic cases. However, we conclude that the "generalized polarization transformation ratio ρ unitary matrix formulation" provides hitherto the most complete method for deriving Huynen's polarization fork concept (in contrast to the derogatory comments made during a NAV-AIR review by Phil Blacksmith, R.C. Hansen and some pompous HDL-laborers). In extension of Kennaugh's (1952) and Huynen's (1970) results of the assumed existence of only three pairs of characteristic polarization states (co-pol maxs identical to cross-pol nulls; co-pol nulls), it is shown in [E.1-3b/c, E.1-5] that there exist in total five unique pairs of characteristic polarization states for the symmetric scattering matrix of which two pairs, the cross-pol null and the co-pol max pairs are identical; whereas, the cross-pol max and the cross-pol saddle point pairs are distinct. These three pairs of orthogonal characteristic states are also right angles on the polarization sphere. The fifth pair, the co-pol null pair lies in the plane spanned by the co-pol max/cross-pol null and the cross-pol max pairs, specifying the plane of the target characteristic circle to which the cross-pol saddle point pair is orthogonal. Thus, with the aid of this generalized polarization ratio ρ -unitary transformation matrix formulation, Kennaugh's and Huynen's "basic principles of radar polarimetry" can be elegantly introduced, clearly demonstrating the correctness of Huynen's polarization fork concept [E.1-3b/c, E.1-5]. Also, it allows for the elegant and simple mathematical rotation of the polarization fork into Huynen's standardized fork expressed in terms of Pauli's spin matrices $[\sigma_i]$ and the Kennaugh-Huynen target characteristic parameter set $(\phi, \nu, \tau, \gamma, \rho(\alpha, \delta))$. However, still an optimization procedure for determining the characteristic polarization states directly from a decomposition of $[S]$, $[T]$ and/or $[K]$, $[M]$ in terms of the Pauli spin matrices $[\sigma_i]$ was not achieved either by Kennaugh, Huynen or by Cloude (see Proc. NATO-ARW-DIMRP'88, [B-3], papers I-4 and III-2), or in the Soviet literature (see ibid, [B-3], papers O-3, O-4 and IV-3). This approach has now been successfully tackled in the forthcoming paper

[E.1-6a] W-M. Boerner and X. Zhang, "Determination of the target characteristic
(p-8) polarization states by direct optimization of the Pauli spin matrix
 $[\sigma_i, i = 0,1,2,3]$ decomposition of the coherent Sinclair matrix $[S]$, ETT
(European Transactions on Communications), in preparation (1994).

It was found that the corresponding power expressions and power density plots for the co-pol power P_c , the cross-pol power P_x and the total power $P_2 = P_c + P_x$ can best be achieved by using the "degenerate coherent case" Stokes reflection matrix $([M_2] = [\bar{M}_c] + [\bar{M}_x], [\bar{M}_x], [\bar{M}_c])$ optimization procedures developed in [E.14a-c].

The M.Sc. thesis research studies of Yan, Wei-Ling also provided the means of distinction that need to be made between using the complete coherent polarization procedures of [E.1-3a-c] associated strictly with the "matched-two-antenna" case rendering the latter to be rather limited:

[E.1-6b] W-L. Yan, "Optimal Polarization States of the Stokes Reflection Matrix
(m-7) $[\bar{M}_p]$ and the Mueller Matrix $[M]$ ", M.Sc. Thesis, Electrical Engineering &
Computer Science Dept., Graduate College, University of Illinois at
Chicago, Chicago, IL, May 13, 1991.

as also shown in

- [E.1-6c] Y. Yamaguchi, et al, and W-M. Boerner, Characteristic Polarization States of Coherently Reflected Waves Based on the Stokes Vector Formulation in Radar Polarimetry, Japan Journal for Electronics and Communications Engineering (JJECE), Vol. AP/90-35, pp. 23-30, 1990 July 19 (in English). (P-20)

In the pursuit of optimizing the Mueller and Kennaugh matrix procedures, a great deal of confusion was created by employing ill-defined or "too loosely" defined covariance matrix approaches for which, at times, the basic feature vector and the optimization constraints were not defined correctly as was discussed in greater detail during "ICAP' 91, Special Sessions on 'Radar Polarimetry I, II' (1991 April 15-18)". Therefore, and mainly on the outstanding, yet in complete dissertation research of Tragl (see [B-3] paper No. II-9), we have initiated a major attack of this important optimization problem in

- [E.1-6d] W-M. Boerner, C-L. Liu and X. Zhang, "A rigorous optimization procedure for alternate co-variance matrix formulations in radar polarimetry, ETT, in preparation (1993/1994). (p-9)

In our treatment of the coherent polarization radar case, we have also approached the extension to the non-reciprocal and bistatic transmitter-scatter-receiver configurations in [E.1-1a-1c] and in:

- [E.1-7a] N. Davidovitz and W-M. Boerner, "Extension of Kennaugh's Optimal Polarization Radar Target Concept to the Asymmetric Scattering Matrix Data", IEEE Trans. on Antenna & Propagation, Vol. AP-34, pp 569-574, April 1986. (P-9)

in which it is shown that another two characteristic parameters in addition to the five introduced, for example, by Huynen, are required to fully exploit the polarimetric properties of Kennaugh's target characteristic operator theory. Another alternate approach of determining optimal polarization states for the bistatic case was recently given in:

- [E.1-7b] S.K. Cho and C.M. Chu, "Optimal Polarization in Bistatic Scattering", Siam J. Appl. Math., Vol 49(5), October 1989, pp 1473-1479, (P-3)

dealing primarily with the bistatic reciprocal scattering cases via a generalized Kennaugh method, which is being analysed further in:

- [E.1-7c] C.L. Liu, X. Zhang, and W-M. Boerner, "A Rigorous Assessment of the Characteristic Polarization State Concept for the Bistatic Coherent Case, (in preparation: dissertation research), IEEE-Trans AP-S. (p-9)

and

- [E.1-7d] W-M. Boerner and Z.H. Czyż, "A Rigorous Formulation of the Characteristic Polarization State Concept and its Solution for the Bistatic Coherent Case", ETC, Vol. 4, No. 6 (Nov/Dec) 1994. (p-15)

Although the general bistatic case renders a unique definition of the term "co-polarized" and "cross-polarized" rather incomplete, it is found expedient for solving various multi-static polarimetric radar imaging and detection problems as discussed below. In all of above papers, the one-antenna transceiver and the two (separate) transmit and receive antennae cases are strictly to be distinguished; and the matching condition, introduced in [E.1-1a] only applies to the monostatic two-separate-antenna case. Also, we need to emphasize that no distinction between the anti-monostatic and monostatic standard versus con-eigenvalue/vector and standard versus con-similarity aspects of these truly complicated mathematical formulations of bistatic radar polarimetry is made and that a host of unresolved basic problems

still must be tackled.

Major research investigations may still be required to resolve these fundamental issues which, in part, have been addressed in the following major monographs on the subject matter:

- [E.1-9a] W-M. Boerner and W-L. Yan, "Basic Principles of the Radar Polarimetry and Its Applications to Target Recognition Problems with Assessments of the Historical Development and of the Current State-of-the-Art", Proceedings of the NATO-ASI: Electromagnetic Modeling and Measurements for Analysis and for Synthesis Problems, Il Ciocco, Castevecchio, Pascoli, Tuscany, Italy, 1987, August 10-21; B. de Neumann and J. Skwierzczynski, eds., NATO-ASI, Applied Sciences, Series E, Vol. E-199, Martinus Nijhoff Publishers, Kluwer, Dordrecht, NL: 1991, pp. 311-363.
- [E.1-9b] W-M. Boerner, W-L. Yan and A-Q. Xi, Editor, Proceedings of NATO-ARW on Direct and Inverse Methods in Radar Polarimetry, Bad Windsheim, FRG, 1988, Sept. 18-24, NATO- ASI Series C, Mathematical & Physical Sciences Vol. C-350, Pts. 1&2, Kluwer Academic Publishers, Dordrecht, NL, 1992.
- [E.1-9c] W-M. Boerner, Basic Principles in Radar Polarimetry Chp. 2, in "Polarimetric Technology Handbooks", J.W. Battles, Editor IIT-RI/GACIAC, CHICAGO, IL (Publishers), pp. 11-98, Oct. 1991.
- [E.1-9d] W-M. Boerner, W-L. Yan and A-Q. Xi, "BASIC RELATIONS OF WIDEBAND RADAR POLARIMETRY: The Characteristic Radar Polarization States for the Coherent and Partially Polarized Cases" (78 pages) in J.D. Taylor, editor, Introduction to Ultra-Wideband Impulsive Radar Technology Handbook, Boca Raton, Florida: The CRC Press, Inc., 1992 (Fall).
- [E.1-9e] E. Lüneburg, The Backscatter Operator in Radar Polarimetry and Its Mathematical Presentations, DLR-IHFT Report, 1994.

Specific isolated research tasks are considered in the M.Sc. theses and dissertations (Ph.D. theses) of

- [E.1-10a] W-L. Yan, "Optimal Polarization States of the Degenerate Coherent Stokes Reflection Matrices $[M_p]$ and of the Mueller Matrix $[M]$ ", M.Sc. thesis, University of Illinois at Chicago, Graduate College, Chicago, IL, May 13 1991.
- [E.1-10b] W-L. Yan, "Optimal Polarization States of the Mueller Matrix for the Partially Polarized Case", Ph.D. dissertation, in preparation (Fall 1992),
- [E.1-10c] A.Q. Xi, "A Unified Theory of Radar Polarimetry for the Coherent Monostatic and Bistatic Cases", Ph.D. Dissertation, UIC-EECS/CL, University of Illinois at Chicago, 1992 (Fall).
- [E.1-10d] X-Zhang, "A group-theoretic approach to the Optimization Procedures for Alternate Matrix Formulations in Radar Polarimetry", Ph.D. dissertation, University of Illinois at Chicago, Graduate College, Fall 1994.

I.E.2 Time-Domain Treatment of Polarization for the Coherent Case: The concept of the "elliptic polarization state" formulation is, strictly speaking, a (continuous wave: CW) frequency domain concept and its applicability ought to be restricted to narrowband harmonious wave analysis. However, in high resolution radar target analysis, as for example, in broadband ISAR, and high resolution transient downrange

target mapping, a "time-domain" treatment of the linear polarization state is needed. Thus, instead of decomposing a "transient polarimetric" signal response into its frequency domain "polarization state phasors," for an incident impulsive wave of "fixed polarization state"; we conceptually assume that very short "left and right sensed circularly polarized" plane wave pulses interrogate with the target. Then, conceptually, the incident "circularly polarized plane wave pulse" illuminates each of the target scattering structures downrange with "all possible" linear polarization (wobbling through all tilt angles $0 \leq \phi \leq \pi$) states. The target structure, in turn, backscatters electromagnetic energy so that the electric field vector orientation is characteristic of substructure geometry. Thus, the transient backscatter response exhibits what might be viewed as a time-varying polarization state, containing sub-structure information (for example, be horizontal for a wing, vertical for vertical stabilizer, etc.). While the behavior of the electric field vector of wideband electromagnetic signals differs from that of a monochromatic wave, the transient polarization response formalism, however, closely resembles the monochromatic polarization formalism in that tilt and ellipticity become time-dependent, resulting in a time-dependent locus on the polarization sphere. Furthermore, it is conceptualized that the Kennaugh and Huynen target characteristic operator (polarization fork) approach can be generalized for its use to the broadband case.

Various basic concepts are being handled in the Ph.D. thesis:

[E.2-1a] Mr. Liu, Chuan-Li, "A Time-Dependent Analysis of Polarization", Ph.D. ([d-10]) Dissertation, UIC-EECS/CSL, University of Illinois at Chicago, Spring 1992.

expanding on the doctoral thesis of:

[E.2-1b] Neil F. Chamberlain, "Radar Target Identification of Aircraft Using Time Domain Polarimetric Signatures," OSU-ESL, 1989,

and similar studies by Dr. Carl E. Baum, Kirtland AFB, Albuquerque, NM, which were discussed in detail during the "First Los Alamos Symposium on Ultra-Wideband Radar, 1990, March 5-8, and on 1990 March 8 at Kirtland AFB.

With the advent of truly UWB polarimetric impulse radars certainly much more attention must be paid to advancing this still highly under-developed sub-field of time domain vector scattering and diffraction theory for both the coherent and partially coherent cases as is being attempted by Zhivotovsky in [0.2].

I.E.3 Partially Coherent Polarization Radar Theory: Although the downrange polarimetric target signatures investigated in the NADC study,

[E.3-1] W-M. Boerner, et al, Graphical Depiction of Targets Using Polarized Radar Data, Final Report UIC-EECS/CL/NADC - 87.06.15, Naval Air Development Center, Warminster, PA, 18974-5000, NADC-Rep No. 87.163-50, 1987, June 15 (508 pages),

are obtained with a coherent pulse compression radar system, the theory of partial polarization is relevant, because we were to investigate Huynen's Mueller matrix decomposition theory, which is supposedly based on the concept of partial coherence. We are very confident to state that Huynen's Mueller matrix decomposition theory was developed at a time when the theories of partial coherence and partial polarization were still in a developmental phase and, therefore, Huynen's Mueller matrix phenomenology may require major revisions or, at least, reformulations. For example, the very pertinent aspects of con-similarity algebras were only developed during the 1980ies. In analyzing this problem of optimizing the contrast of partially polarized waves, we have come to the first conclusion that hitherto no correct

approach exists. We refer here to a very recent paper by the main contributor(s) to the partial theory of coherence and polarization:

[E.3-2a] K. Kim, L. Mandel and E. Wolf, "Relationship between Jones and Mueller Matrices for Random Media", Journal Opt. Soc. Am. A, Vol. 4, No. 3, pp. 433-437, July, 1987,

in which many existing misconceptions including some of Huynen's are spelled out. Therefore, we embarked on an entirely new approach in,

[E.3-2b] A.B. Kostinski, B.D. James and W-M. Boerner, "On the Optimal Reception of ([P-8]) Partially Polarized Waves", J. Opt. Soc. Am. (subm. December, 1986, acc. May, 1987), Josa, Part A, Optics & Image Sciences, Series 2, Vol. 5, No. 1, January, 1988, pp. 58-64.

of the optimization of the Mueller matrix, i.e. the determination of the optimal Stokes vectors associated with a specific Mueller matrix of which there exist eight and which do not agree with the optimal polarization states introduced by Huynen [9]. In that paper, we focus on optimal intensity reception of partially polarized waves scattered off a fluctuating object (ensemble of scatterers) of known polarization properties expressed in terms of the measured Mueller matrix elements. Expressions for total available intensity as well as adjustable polarization-dependent intensity are derived in a clear and novel manner via the coherency matrix approach. We note that our results satisfy both the Barakat realizability condition and the Kattawer-Fry Mueller matrix inequalities, which are only in part, identical with Huynen's inequalities as discussed in greater detail in our NADC Final Report, [Sect. 3.3]. The question of uniqueness of Huynen's Mueller matrix decomposition theory was recently put in doubt also in:

[E.3-3a] R.M. Barnes, Roll — Invariant Decompositions for the Polarization Covariance Matrix, Session IV, Paper 5, Polarimetric Technology Workshop, US Army Missile Command, 1988, August 16-18 (to be published with GACIAC, Spring, 1989),

[E.3-3b] S.R. Cloude, Fundamentals of Statistical Polarimetry, NATO-ARW-DIMRP' 88, (P-32) Paper No II-3, Bad Windsheim, FRG, 1988 Sept 18-24 (to appear in its Proceedings, to be published with D. Reidel Publ. Co, Dordrecht, Netherlands, 1989/90), [E.3-3c] S.R. Cloude, Target Decomposition Theories in Radar Scattering, Electronics Letters, Vol 21, No 1, 1985, Jan 3, pp 22-24 (also see: IBID, On the Co-Variance and Mueller-Matrix Optimization in Radar Polarimetry, NATO-ARW-DIMRP'88, Paper No XI-2, Bad Windsheim, FRG, 1988, Sept 18-24 (see [0.2]),

which is also being addressed in greater detail in Yan and Boerner [E.1-4a], [E.1-6b], [E.1-9a-d], and [E.1-10a/b] where various errors in [E.3-2b] and [E.3-3b/c], and similar co-variance matrix approaches are discussed.

During the past four years, several alternative attempts of decomposing the covariance matrices related to be the Stokes reflection and Mueller matrices surfaced at the MIT Electromagnetics Lab. (J.A. Kong, A. Swartz, et al) and MIT Lincoln Laboratory (R.M. Barnes, L.M. Novak, et al) leading to ill-conceived "optimal Polarimetric Classifier" and Polarimetric Matched Filter" approaches, as for example, in:

[E.3-4a] R.M. Barnes, "Roll-Invariant Decomposition for the Polarization Covariance (P-32) Matrix", Proceedings (Third) Polarimetric (Radar) Technology Workshop, 1988, Aug, 16-18, Rocket Auditorium, Redstone Arsenal, AL (GACIAC, IIT-RI, Chicago, IL, 1990),

- [E.3-4b] L.M. Novak, M.B. Sechtin, M.J. Cardullo, "Studies of Target Detection
(P-31) Algorithms which Use Polarimetric Radar Data", Proceedings 21st ASILOMAR
Conference on Signals, Systems & Computers, Pacific Grove, CA, November
2-4, 1987.
- [E.3-4c] J.A. Kong, A. Swartz, H. Yueh, L.M. Novak and R. Shin, "Identification of
(P-31) Terrain-Cover Using the 'Optimal Polarimetric Classifier'", J. Electromag-
netic Waves and Applications, Boston, December, 1987.

Co-investigations at several European (RSRE/Dundee: S.R. Cloude; DLR/Oberpfaffenhofen: Tragl & Lüenburg; IRESTE/Nantes: E. Pottier and J. Saillard; DDRE: E. Krogager) and US (JPL: J.J. van Zyl, A.J. Freeman and E. Krogager; ERIM: I.J. LaHaie and D. Herrick; GIT-RAIL: W.A. Holm and E. Krogager; UIC-EECS/CL: A.B. Kostinski & W-M. Boerner, W-M. Boerner & E. Lüenburg) centers of comparing the MIT-LL covariance matrix with our rigorous Mueller and Kennaugh matrix approaches clearly demonstrated inconsistencies. During Special Sessions organized by W-M. Boerner for the:

- [E.3-5a] 1989 PIERS (Progress in Electromagnetic Research Symposium), Session XI,
(C-27/30) Direct and Inverse Methods in Radar Polarimetry, Paper 2, Comparison of
Methods for Mueller Matrix Optimization;
- [E.3-5b] 1990 JIPR-I (International Conference on 'Radar Polarimetry', IRESTE,
(C-47/49) Nantes, France, 1990 March 20-22;
- [E.3-5c] 1991 PIERS (Progress in Electromagnetic Research Symposium) Session
DIMRP (Direct and Inverse Methods in Radar Polarimetry), July 1991;
- [E.3-5d] 1991 ICAP, (Int'l Conference on Antennas and Propagation) York, UK, 1991
(C-68/69) April 15-18, Special Sessions (organized in collaboration with S.R.
Cloude), Radar Polarimetry I, II,
- [E.3-5e] 1991 ICEAA (Second Int'l Conference on Electromagnetics in Aerospace
(C-85/89) Applications), Torino, Italia, 1991 Sept. 17-20, Sessions PR-I: Polari-
metric Radar Theory & Scattering, PR-II: Polarimetric Radar Theory &
Scattering, PR-III: Polarimetric Radar Metrology & Signal Processing;
- [E.3-5f] 1991 MIKON (9th Microwave Conference of Poland) RYDZYNA-ZAMEK, Poland,
(C-70/72) 1991 May 20-24, Special Session 8: Radar Polarimetry (organized in
collaboration with Dr. Zbigniew H. Czyz), May 1991.
- [E.3-5g] 1991 WMIS (EC/EARSEL Workshop on Microwave Imaging and Sensing) Alpbach,
(C-95/96) Tyrol/Austria, 1991 Dec. 24 (co-organized with K.J. Langenberg, M.
Chandra and S.R. Cloude).
- [E.3-5h] 1992 SPIE Laser & Radar Engineering Symposium Ultra-wideband Radar
(C-97) Session, 1992 Jan 19-24, L.A. Airport Hilton, Los Angeles.
- [E.3-5i] 1992 URSI-IC:F/MSF (International Commission F, Microwave Signatures
(C-104/5) Conference), Igls-Innsbruck, Tyrol/Austria, 1992 July 1-3.
- [E.3-5j] 1992 Int'l IEEE-APS/URSI-USNC/NEMP Symposium (Special Sessions on Radar
(C-106/08) Polarimetry 92 July 19-20), Chicago, IL 1992 July 18-25.
- [E.3-5k] 1992 SPIE-OE/OESE Polarimetry Conferences (Radar Polarimetry Conference
(C-109/13) & Workshop, 92 July 22-25), San Diego, CA 1992 July 19-24.
- [E.3-5l] 1992 APMC (Asia Pacific Microwave Conference) Adelaide, So. Australia,
(C-114/16) 1992 Aug. 11-13 with 'WISP: Wideband Imaging and Sensing Polarimetry
(ULF-UV)'.

- [E.3-5m] 1992 JIPR-2, Nantes, Normandie, France 1992 Sept. 8-10 (Second Int'l Workshop on Radar Polarimetry).
(C-119/21)
- [E.3-5n] 1992 ISAP-V (Fifth Japanese Int'l Symposium on Antennas & Propagation), Sapporo, Hokkaido, Japan, 1992 Sept. 21-25.
(C-122/27)
- [E.3-5o] 1993 PIERS (Progress in Electromagnetics Research Symposium) CAL-TECH/NASA-JPL, Pasadena, CA, 1993 July 12-16 (Six Special Contiguous Sessions on Radar Polarimetry).
(C-129-38)
- [E.3-5p] 1993 IEEE-IGARSS, Tokyo, Japan, Aug. 18-21 (Four Special Session on Radar Polarimetry).
(C-139/48)
- [E.3-5q] 1993 URSI-GA, Kyoto, Japan, 1993 Aug. 25 - Sept. 02, (Two Special Session on Vector Interse Scattering Methods).
(C-149/57)
- [E.3-5r] 1994 MIKON (10th Microwave Conference of Poland) Książ Zamek, Selsia/Poland, 1994 May 30 - June 02, Two Special Workshop Sessions on Radar Polarimetry (Z.H. Czyż & W-M. Boerner).
(C-160)
- [E.3-5s] 1995 IEEE-ISAP/URSI-NRSM, Seattle, WA, 1994 June 19-24 (Two Special Sessions on Radar Polarimetry).
(C-161/64)
- [E.3-5t] 1994 PIERS, ESA-ESTEC, Noordwijk, NL (Six (6) Special Sessions on Polarimetry), 1994 July 11-15.
(C-165/68)
- [E.3-5u] 1994 IEEE-IGARSS, CAL-TECH/JPL, Pasadena, CA, 1994 August 8-12 (Five (5) Special Sessions on Polarimetry), 1994 August 8-12.
(C-169-72)

it is clearly being demonstrated that the "covariance matrix optimization procedures" is not unique, because it violates energy conservation principles and, thus, these methods should be discarded unless energy conservation constraints are introduced and a more rigorous formulation is found as was attempted in

- [E.3-6a] K. Tragl, E. Lüneburg, A. Schroth and V. Ziegler, "A Polarimetric Covariance Matrix Concept for Random Radar Targets", ICAP'91, paper No. 8D-3, IEEE Conf. Proc. Vol. 333, Pt. I, pp. 1.396-1.399 (also see: Ph.D. thesis of Tragl).
(P-32)
- [E.3-6b] E. Lüneburg, V. Ziegler, K. Tragl and A. Schroth "Polarimetric Covariance Matrix Analysis of Random Radar Targets, NATO-AGARD-EPP Symposium on "Target and Clutter Scattering and Their Effects on Military Radar Performance", Ottawa, Canada, 1991 May 6-10, Proceedings pp. 27.1-27.12, 1991.
(P-32)
- [E.3-6c] W-M. Boerner, C-L. Liu and X. Zhang, Comparison of the Optimization Procedures for the 2x2 Sinclair and the 4x4 Mueller/Kennaugh Matrices in Coherent Polarimetry and Its Application to Radar Target Versus Background Clutter Discrimination in Microwave Sensing & Imaging, Int'l Journal on Advances in Remote Sensing (IJARS), (EARSeL), Boulogne-Billancourt, France), Vol. 2, Nov. 1, pp. 55-82.
(P-32)
- [E.3-6d] E. Krogager, E. Lüneburg and W-M. Boerner, Analysis of the Absolute and Relative Phase Conditions of Transformation Matrices for the 2x2 Sinclair [S] and 3x3 Covariance [E] Matrices in Radar Polarimetry, J. Optical Soc. Amer., Part 1A, Optics & Imaging Sci., Series 2, Vol. E76B, 1993, in prt.
(P-43)

This and similar approaches are assessed rigorously in [E.1-3d/e] and in [E.1-6b]; where a proper optimization procedure, consistent with those introduced in [E.1-1/2/3/4/5] is introduced leading to identical solutions.

During the execution of this contract, primarily, we have re-addressed the contrast optimization problem of the Mueller, Kennaugh and Stokes reflection matrices in [E.1-4b], where it is shown, as summarized in [E.1-5], that a decomposition of the total Stokes reflection matrix $[\bar{M}_2]$ into co-pol $[\bar{M}_c]$ and x-pol $[\bar{M}_x]$ channel power terms is not so straightforward as in the "degenerate coherent" Mueller matrix cases. For the partially coherent and also for the partially polarized cases one need first distinguish between the completely polarized and completely unpolarized components for the optimization of the scattered energy density $\vec{g}_s = [M]\vec{g}_T$, which, as was shown in [E.1-7b/c/d] must be carefully distinguished from $[\bar{M}_p]$ derived for the "degenerate coherent case" in [E.1-4a]. Introducing the degree of polarization $p = (g_1^2 + g_2^2 + g_3^2)/g_0$, the scattered energy density may be separated into four categories [E.1-4a, 4b]

- g_{s0} Total energy density in the scattered wave before it reaches the receiver (OC-1);
- pg_{s0} Completely polarized part of the intensity; i.e., the adjustable intensity because one may adjust the polarization state of the receiver to ensure polarization matching (OC-2);
- $(1 - p)g_{s0}$ Noise of the unpolarized part: regardless of the receiver polarization state, one half of the unpolarized part, i.e., $g_{s0}(1-p)/2$ is always accepted (OC-3);
- $(1 + p)g_{s0}$ Maximum of the total receivable intensity $\{pg_{s0}\} + \{(1 - p)g_{s0}/2\} = \{(1 + p)g_{s0}/2\}$, i.e., the sum of the matched polarized part and one half the unpolarized part. However, if the polarized part is mismatched (cancelled with proper receiver tuning), the total received power is minimal and equal half the unpolarized power, i.e., $(1 - p)g_{s0}/2$ (OC-4).

A rigorous comparison of existing optimization procedures is currently investigated in the dissertation research of Yan, Wei-Ling [E.1-10a/b]; and novel optimization procedures are presented in [E.1-4a,b]; and in

- [E.3-7a] X. Zhang and W-M. Boerner, "Comparison of Optimization Procedures of the Mueller/Kennaugh Matrices for the Partially Polarized Case and the Degenerate Coherent Case", IEEE Trans GSRS, in preparation (Fall 1994).

For example, it is shown that in the dissertation:

- [E.3-7b] Jacob J. van Zyl, "On the Importance of Polarization in Radar Scattering Problems", Ph.D. Thesis, California Institute of Technology, Pasadena, CA, January, 1986,

the criterion OC-1 is considered, whereas, in [E.3-2b] it is criterion OC-2, and for Cloude's method, it is criterion OC-4. In order to optimize the contrast of desired (target) versus undesirable (clutter) signal, it is shown in [E.3-6a] that OC-2 must be maximized with minimizing OC-3 at the same time.

Although we highly admire the contributions made by Dr. J. Richard Huynen to radar polarimetry and to radar target phenomenology, in particular, as summarized in his revised dissertation,

[E.3-7c] J.R. Huynen, Phenomenological Theories of Radar Targets, Ph.D. Thesis (B-1/3) (1970), First Revised Edition, November 1987, P.Q. Research, 10531 Blandor Way, Los Altos Hills, CA 94022,

the methodologic assessment of the uniqueness of Huynen's phenomenologies deserves further analysis, as initiated in [E.1-9a-d] to [E.3-5a/b], before we will be able to accept or reject its applicability.

Although it is shown that for the partially coherent case, no complete optimization procedures for determining the optimum polarization states yet exist; however, for the partially polarized case, for which the wave incident on the scatterer is completely polarized, a solution of the optimization problem can be found:

[E.3-7d] W-M. Boerner, W-L. Yan, A-Q. Xi and Y. Yamaguchi, "ON THE PRINCIPLES OF ([P-28]) RADAR POLARIMETRY (invited review): The target characteristic polarization state theory of Kennaugh, Huynen's polarization fork concept, and its extension to the partially polarized case", IEEE Proceedings, Special Issue on Electromagnetic Theory, Vol. 79, No. 10, pp. 1538-1550, Oct. 1991.

[E.3-7e] W-M. Boerner, C-L. Liu and X. Zhang, Comparison of the Optimization Procedures for the 2x2 Sinclair and the 4x4 Mueller/Kennaugh Matrices in Coherent Polarimetry and Its Application to Radar Target Versus Background Clutter Discrimination in Microwave Sensing & Imaging, Int'l Journal on Advances in Remote Sensing (IJARS), (EARSel), Boulogne-Billancourt, France), Vol. 2, Nov. 1, pp. 55-82.

In all of the cases investigated, it was demonstrated that, also, for the partially polarized case there exist five pairs of characteristic polarization states (18); however, whereas, for the coherent case ($p=1$) the absolute (normalized) power maximum at the co-pol max (ρ_{cm1}) and co-pol nulls ($\rho_{cm1,2}$) locations become

$$P_{\max}^C(\rho_{cm1})/m^2 = 1 \text{ and } P_{cn1,2}^C(\rho_{cn1,2})/m^2 = 0, \text{ respectively;}$$

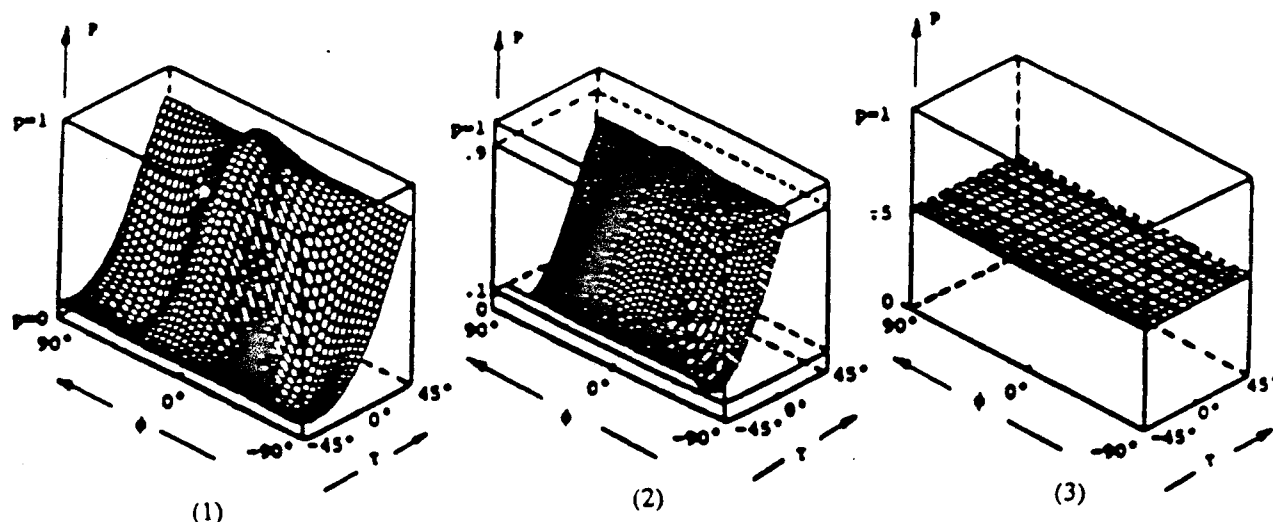


Fig. Dependence of received power density plots on degree of polarization p :
(a) $p = 1$, (b) $p = .8$, (c) $p = 0$

we find that for the partially polarized case ($0 > p > 1$) the maximum normalized value will always be reduced by $(1 - p)/2$ and the achievable minimal normalized

power can never be less than $(1 - p)/2$, and that according to (17d) for the completely unpolarized case ($p = 0$), the minimal and maximal achievable normalized powers become equal and in the limit approach by $g_{S0} = .5$; i.e., the power density plot is flat in the extreme unpolarized case as illustrated in the figure.

Thus, from the comparison of our results, we conclude that the optimal polarization state theory will also be highly useful for treating the partially dual polarization radar reception problem. In extension of previous results it was found that there exist eight distinct characteristic polarization states for the symmetric matrix case, the three pairs of orthogonal pairs whose diameters are mutually orthogonal on the polarization sphere: the X-pol null pair (identical to co-pol max pair), the x-pol max pair and the x-pol saddle (turning point) pair. In addition, there exists a pair of co-pol nulls lying in the plane spanned by the x-pol-null and the x-pol max pairs, the target characteristic plane with the line (diameter) joining the two x-pol nulls bisecting the angle between the two co-pol nulls on this target characteristic circle. As a result of these unique polarization fork properties, one can show that once the two co-pol nulls have been found, the entire polarization fork can be recovered; i.e., for the description of a radar target we require the specification of two distinct points on the polarization sphere, whereas, only one for the description of a completely polarized wave. In particular, our polarization transformation ratio ρ formulation is in complete agreement with Huynen's formulation and shows, given a measured matrix $[S]$, that the Huynen target characteristic parameters m , ϕ_m , ν , γ , δ_m and α_m , can be uniquely determined; or inversely, given these parameters the scattering matrix $[S]$ can be uniquely reconstructed. Hence, the resulting Huynen fork concept represents a unique example of a fundamental polarimetric radar inverse problem.

I.E.4. Optimal Polarimetric Contrast Enhancement Coefficients: 'OPCEC'

Next to determining the eigenvalue and optimization problems for $[S(AB)]$, $[G(AB)]$, $[\Sigma(AB)]$, $[K]$ and $[M]$ and its optimal (characteristic) polarization states, representing "a formidable still not completely resolved problem for either symmetric or definitely for the asymmetric cases", equally important, the exact and correct expressions for the enhancement of the optimal contrast between two classes of scatterers or scatterer ensembles must be determined. This specific optimization problem was first considered in depth by Russian and Ukrainian radar polarimetrists, and we refer to the recent review by Kozlov et al ([0.2]. In general, these two distinct classes of scatterers may be defined as 'T' and 'C', where 'T' defines, for example, the desirable (useful) scatterer (target:'T') and 'C' the undesirable scatterer ensemble (clutter:'C') against which 'T' is to be discriminated or to be contrasted. The formal development of these 'OPCEC' expressions associated with a specific matrix description in terms of either $[S(AB)]$, $[G(AB)]$, $[\Sigma(AB)]$, $[K]$, $[M]$ and/or any combination of such, is also still unresolved, yet solutions are in need for introducing more meaningful and polarimetrically unique definitions for the polarimetric co/cross-polar 'signal-to-clutter ratio', co/cross-polar detection merit factors, etc. In the following, some of these 'OPCEC' expressions are introduced for the separate cases of 'a priori' knowledge on $[S(AB)]$, $[G(AB)]$, $[\Sigma(AB)]$, $[K]$ and/or $[M]$, where in most cases unique 'OPCEC' expressions for the mixed co/cross-polar power density and or relative phase coefficient problems must still be found.

OPCEC for $P_{C/X}(\rho)$ given $[S(AB)]$ for T and C: 'opcec $[S]$ '

Several distinct solutions for either the co/co, cro/cross, cross/co, cross/cross power density 'T' versus 'C' optimization cases exist, where

$$\text{opcec}\{[S]\} = \frac{P_{C/X}([S(AB)T])}{P_{C/X}([S(AB)C])} = \frac{\vec{h}_{A,B}^T [S(AB)T] \vec{E}_T}{\vec{h}_{A,B}^T [S(AB)C] \vec{E}_T}$$

The solution is obtained from using the Lagrange multipliers method, and it is strongly dependent on the solution of the 'point scatterer' polarization fork solution (Boerner, Liu, Zhang, [E.4-1a]; Boerner [E.4-1b], Yan, Xi, Yamaguchi).

[E.4-1a] W-M. Boerner, C-L. Liu and X. Zhang, Comparison of the Optimization
(P-32) Procedures for the 2x2 Sinclair and the 4x4 Mueller Matrices in Coherent Polarimetry and Its Application to Radar Target Versus Background Clutter Discrimination in Microwave Sensing & Imaging, Int'l Journal on Advances in Remote Sensing (IJARS), (EARSeL), Boulogne-Billancourt, France, Vol. 2, No. 1-1, pp. 55-82, Jan. 1993.

[E.4-1b] W-M. Boerner, W-L. Yan, A-Q. Xi and Y. Yamaguchi, "ON PRINCIPLES OF RADAR
(P-28) POLARIMETRY (invited review): The Target Characteristic Polarization State Theory of Kennaugh, Huynen's Polarization Fork Concept, and Its Extension to the Partially Polarized Case", IEEE Proceedings, Special Issue on Electromagnetic Theory, Vol. 79, No. 10, pp. 1538-1550, Oct. 1991.

OPCEC for $P_{C/X}(\rho)$ given $[G(AB)]$ for T and C: 'opcec [G]'

Also, this solution [E.4-2a] depends, in general, on the polarization fork solutions, using the Lagrange multipliers method for solution

$$\text{opcec}\{[G]\} = \frac{P_{C/X/T}([G(AB)T])}{P_{C/X/T}([G(AB)C])} = \frac{\vec{e}_{X/C/T}^+ [G_T] \vec{E}_T}{\vec{e}_{X/C/T}^+ [G_C] \vec{E}_T}$$

as shown in [E.4-2a]/[E.4-2b].

[E.4-2a] M. Tanaka and W-M. Boerner, Optimum Antenna Polarization for Polarimetric
(P-35) Contrast Enhancement, ISAP'92, Sapporo, Hokkaido, Japan, 92 Sept. 21-25, Special Sessions on WISP.A-1.3/A-2.5.

[E.4-2b] W-M. Boerner, M. Tanaka, Y. Yamaguchi, E.J. Eom and E. Lüneburg,
(C-150) Development of OPCEC for the analysis of depolarization due to rain, snow, ice and surface scatter utilizing POL-RAD and POL-SAR measurements, URSI-GA'93, Kyoto, Japan, Session F1.1, 1993 Aug. 25-Sept. 02.

[E.4-3] W-L. Yan and W-M. Boerner, "Optimal Polarization States Determination of
(P-27) the Stokes Reflection Matrices $[\vec{M}]$ for the Coherent Case, and of the Mueller Matrix $[M]$ for the Partially Polarized Case", Journal of Electromagnetic Waves and Application, JEW A, Vol. 5, No. 10, pp. 1123-1150, Oct. 1991.

[E.4-4a] C-Y. Chan, Studies of the (Graves) Power Scattering Matrix of Radar
(P-4/7) Targets, M.Sc. Thesis, UIC-EECS/CSL, University of Illinois at Chicago, Chicago, IL, 1981.

[E.4-4b] A.I. Kozlov, A.I. Logvin and L.Z. Zhivotovsky, (invited), "Review of Past
(B-3) and Current Research in the USSR on the Fundamentals and Basics of Radar Polarimetry and Resolution Radar Imaging", Paper 0-3, pp. 45-60, in W-M. Boerner et al., eds., "Direct and Inverse Methods in Radar Polarimetry", Proceedings of the NATO-ARW-DIMRP'88, NATO ASI Series C: Math & Phys. Sci., Vol. C-350, Part 1, Kluwer Academic Publishers, Dordrecht, NL, 1992.

- [E.4-4c] D. Giuli, Polarization Diversity in Radar, Proc. IEEE, Vol. 74(2), pp. (B-3) 245-269, Feb. 1986.
- [E.4-4d] W-M. Boerner and M. Tanaka, The Derivation of the Optimal Contrast Enhancement Coefficients (OPCEC) for the [S] versus [T], [G] versus [F], [K] versus [M] and [Σ] versus [T^3] Matrices, IEICE, Trans. AP, Vol. 59A, 1994, in print.
- [E.4-5a] J.J. van Zyl, On the Importance of Polarization in Radar Scattering Problems, Ph.D. Dissertation, California Institute of Technology, Pasadena, CA, Jan. 1986.
- [E.4-5b] J.J. van Zyl, C.H. Papas and C. Elachi, On the Optimum Polarization of Incoherently Reflected Waves, IEEE Trans. Ant & Prop., AP-35, Vo. 7, pp. 818-825, July 1987.
- [E.4-5c] H.A. Zebker and J.J. van Zyl, Imaging Radar Polarimetry, Proc. IEEE, Vol. (B-3) 79, No. 11, pp. 1583-1607, Nov. 1991.
- [E.4-5d] Y. Yamaguchi, K. Sasagawa, M. Sengoku, T. Abe, W-M. Boerner, W-L. Yan and (P-41) A-Q. Xi, Characteristic Polarization States of Coherently Reflected Waves Based on the Stokes Vector Formulation in Radar Polarimetry, Japan Journal for Electronic and Communication Engineering, JIEECE, Vol. AP/90-35, pp. 23-30, July 1990.

OPCEC for $P_{C/X}(\rho)$ and $P_{C\perp}$ given $[\Sigma(AB)]$ for T and C: 'opcec $[\Sigma(P_i)]$ '

From inspection of the definitions of $[\Sigma(AB)]$ and $[\Sigma(\rho^\perp)]$, it is apparent that in general, a distinct combination of optimal contrast enhancement relations between two scatterer classes 'T' and 'C' exists, involving either $P_C(T)$ versus $P_C^\perp(C)$ or $P_C(C)$, $P_X(C)$; $P_X(T)$ versus $P_C(C)$, $P_C^\perp(C)$ or $P_X(C)$; or versus its complex conjugate, etc., and similar expressions can be found for $R_C(\rho)$, $R_X(\rho)$, etc., depending on the specific nature of $[\Sigma(AB)_T]$ and $[\Sigma(AB)_C]$. Little, yet is known, and the solutions for optimizing $[\tilde{M}_T]$ versus $[\tilde{M}_C]$ must first be established [E.4-3] in order to interpret the solutions for these cases as is shown in [E.4-1], which is appended to this report.

OPCEC for $P_{C/X}$ given [K] or [M] for T and C: 'opcec $[M_i]$ '

In general, a partially coherent wave $\vec{g}$ can be decomposed according to [E.4-4a] into its completely polarized component $\vec{g}_q$ and unpolarized component $\vec{g}_u$, and it is the total polarized energy of the desired scatterer 'T' which is to be optimized by minimizing the respective power contribution of the undesirable scatterers 'C'. Again, several meaningful distinct opcec $[M_i]$ may be defined (Kozlov [E.4-4b], Ioannidis, Hammers, 1979 [E.4-4c]; Tanaka, Boerner, 1992 [E.4-4d]) depending strongly on the particular nature of the scattering scenario under investigation. The solution of this rather complex multiparameter polarimetric optimization problem depends strongly on that for finding a complete set of solutions for the single scatterer solution of [M] and [Σ], and the opcec solutions for $[\Sigma(AB)]$. Here one of many possible distinct opcec definitions developed in (Tanaka, Boerner, 1992 [E.4-4d]) is introduced, assuming that $[M_T]$ and M_C are known and the ratio of the completely polarized components $(g_o^q)_T$ is to be optimize versus $(g_o^q)_C$ such that

$$\text{opcec}\{[M(g_0^q)]\} = \frac{(g_0^q)_T}{(g_0^q)_C} = \sqrt{\frac{(g_{T1}^2 + g_{T2}^2 + g_{T3}^2)}{(g_{C1}^2 + g_{C2}^2 + g_{C3}^2)}} = \sqrt{\frac{\vec{g}_T [\vec{M}_T]^T [\vec{M}_T] \vec{g}_T}{\vec{g} [\vec{M}_C]^T [\vec{M}_C] g_T}}$$

with $[M]$ denoting a $i \times j$ subset of $[M]$ where $[\vec{M}]_{ij}$, $i = 1, 2, 3$; $j = 0, 1, 2, 3$, etc. Various other solutions are considered in (van Zyl, 1986 [E.4-5a], van Zyl, Papas, Elachi, 1987 [E.4-5b], Zebker, van Zyl, 1987-1991 E.4-5c)) using the Lagrange multipliers method.

Unresolved Polarimetric Contrast Enhancement Optimization Problems

Whereas for the coherent point scatterer cases, the optimization problems for the contrast enhancement between two scatterers are straight-forward, this is absolutely not so far the partially coherent case for which strictly the Kennaugh or Mueller matrices need to be optimized for the sub-millimeter wave to optical spectral regions. However, in case the co/cross-polar phases can be recovered from dual polarization coherent radar transmit/receive systems, or from multiple transmit/receive coherent polarization radar systems, the implementation of the covariance matrix approach becomes feasible simplifying the Polarimetric Contrast Enhancement Optimization problem considerably as is shown in various contributions in Boerner et al. [0.2], and the Corrected Polarimetric Covariance Matrix presentation will soon play a key role in POL-RAD/SAR vector signal/tensor image processing within the microwave to sub-millimeter wave spectral regions. However, in LIDAR POLARIMETRY, currently we still need to implement the complete stochastic Kennaugh and Mueller matrix optimization analysis, i.e., the complete partially coherent treatment, because 'phase correlation' of two orthogonal laser channels is technologically still not completely feasible.

I.E.5 The Development of PO Inverse Scattering Theories and Its Application to the Polarimetric Radar Target Identification Problem

During all of our polarimetric radar target investigations, we always were concerned with the electromagnetic radar inverse problem in order to relate measureables with target features. In this context, special attention was given to the extension of the Kennaugh-Cosgriff radar target ramp response identity to the complete polarimetric and to the bistatic cases first reported in

[E.5-1a] E.M. Kennaugh and R.L. Cosgriff, 'The Use of Impulsive Response in Electromagnetic Scattering Problems', in 1958 IRE National Conv. Rec., part I, (B-1) pp. 72-77.

[E.5-1b] E.M. Kennaugh, 'Interpretations of the Physical Optics Approximation in the Time Domain', Proceedings of the Second Symposium on Ground Identification of Satellites, the MITRE Corporation, Bedford, MA, 2-4 Oct. 1967, (B-1) pp. 81-88.

and further extended in

[E.5-1c] E.M. Kennaugh and D.L. Moffatt, 'The Use of Transient and Impulse Response Approximations in Electromagnetic Scattering Problems', Vol. I, Radar Target Identification, Department of Electrical Engineering, Ohio State University, Columbus, Ohio, Sept. 1977.

and

[E.5-1d] E.M. Kennaugh and D.L. Moffatt, Transient and Impulse Response Approximation, Proc. IEEE, Vol. 53, 1965, pp 893-901.

Using Radon's theory on the reconstruction of n -dim. manifolds from $(n-r)$ -dim. projections (1917), it was first shown by us how Kennaugh's impulse response identity can be Radon-transformed into the P.O. far field inverse scattering identity, (also known as Bojarski's identity), in

[E.5-2a] Y. Das and W-M. Boerner, 'On Radar Target Shape Estimation Using Algorithms for Reconstruction from Projections', IEEE Trans. Ant. & Propag., (B-1/3) Vol. 26(2), pp. 274-279, March 1978,

and further extended in

[E.5-2b] W-M. Boerner, C-M. Ho and B-Y. Foo, 'Use of Radon's Projection Theory in Electromagnetic Inverse Scattering', IEEE Trans. Ant. & Propag., Vol. 29, (B-1/3) Special Issue on Inverse Methods in Electromagnetics, pp. 336-341, March 1981.

which opened many new avenues of approach in electromagnetic radar inverse problems.

Utilizing results of Bennett's time domain inverse scattering methods

[E.5-3a] C.L. Bennett, 'Time Domain Inverse Scattering', IEEE Trans. Ant. & Propag., Vol. 29, (B-1/3) Special Issue on Inverse Methods in Electromagnetics, pp. 213-219, March 1981.

[E.5-3b] C.L. Bennett, et al, 'Space Time Integral Equation Approach to the Large Body Scattering Problem', final report on contract F30602-71-C-0162, RADCR-73-70, AD763794, Sperry Rand Research Center, Sudbury, MA, May 1973.

it is shown how, from polarimetric scattering matrix $[S]$ measurements, the principal curvatures at the specular point may be recovered and how the scattering matrix elements may be related to the target silhouette area function and the two principal curvatures, for the monostatic case in

[E.5-4a] B-Y. Foo, S.K. Chaudhuri and W-M. Boerner, 'A High Frequency Inverse Scattering Model to Recover the Specular Point Curvatures from Polarimetric Scattering Data', IEEE Trans. Ant. & Propag., Vol. 32, #11, pp. 1174-1178, (B-1) Nov. 1984.

and for the bistatic case in

[E.5-4b] B-Y. Foo, S.K. Chaudhuri and W-M. Boerner, Polarization Correction and ([P-13]) Extension of the Kennaugh-Cosgriff Target-Ramp Response Equation to the Bi-static Case with Applications to Electromagnetic Inverse Scattering, IEEE Trans Ant. 7 Propag., Vol. AP-38, No. 7, July 1990, pp. 964-972.

and applied to the interpretation of the Huynen parameters in

[E.5-4c] S.K. Chaudhuri, B-Y. Foo and W-M. Boerner, "A Validation Analysis of (B-1) Huynen's Target-Descriptor Interpretations of the Mueller matrix Elements in Polarimetric Radar Returns Using Kennaugh's Physical Optics Impulse Response Formulation", IEEE Transactions on Antennas & Propagation, Vol. AP-34, No. 1, pp. 11-20, January 1986. (J)

and to POL-SAR image analysis in [E.6-2].

A rigorous succinct overview of all currently available results on the monostatic and bistatic extensions of the polarization correction to the P.O. target ramp impulse response was recently worked out in

- [E.5-5a] A. Schatzberg, 'Physical Optics Polarization Correction of Backscattering from Conducting Smooth Convex Shapes', in W-M. Boerner, et al, 'Direct and Inverse Methods in Radar Polarimetry', Proceedings of NATO-ARW-DIMRP'88, Bad Windsheim, FRG, 1988 Sept. 18-24, Dordrecht: NATO-ASI C-350, Kluwer Academic Publishers, 1992 (paper No. II-1).

currently being continued in a joint effort and presented in

- [E.5-5b] W-M. Boerner, A. Schatzberg, "The Importance of Polarimetry in Time-Domain ([P-16]) Inverse Scattering - Theory and Applications", 1991 Progress in Electromagnetic Research Symposium (PIERS), Cambridge, MA/USA, 1991 July 01- 05, IP2, 16:10.

in which also Huynen's torsional curvi-linear surface parameters are assessed as treated in

- [E.5-6] J. R. Huynen, Theory and Measurement of Surface Torsion, in W-M. Boerner, (B-1) et al, 'Direct and Inverse Methods in Radar Polarimetry, Proceedings of NATO-ARW-DIMRP'88, Bad Windsheim, FRG, 1988 Sept. 18-24, Dordrecht: D. Reidel Publ. Co., 1991 (paper No. II-1) (Paper No. II-6).

Because of the fact that these torsional surface parameters indeed play an important role in polarimetry radar target analysis as well as in further advancing the 'Physical Theory of Diffraction', we have currently introduced a joint effort on further investigating this rather complicated problem.

- [E.5-7] P. Ya. Ufimtsev, A Schatzberg F.A. Molinet, H. Mieras and W-M. Boerner, ([P-17]) Interpretation of the Torsional Curvature Term in Vector Differential Geometry and the Formulation of the Corresponding Vector Inverse Problem in Radar Polarimetry, (1994/95), in preparation;

In pursuit of this innovative, hitherto untreated problem, a systematic and exhaustive literature review on teh 'Polarimetric Monostatic and Bistatic Extensions' of PO RCS analyses resulted in the derivation of complete polarimetric scattering matrix formulations for oblique incidence on edges, wedges, cone-tips, polarimetric creeping wave contributions from closed canonical shapes (circular, prolate/oblate elliptic cylinders, oblate, prolate and generalized spheroids) implementing known and hitherto unpublished results of the 'Geometrical Theory of Diffraction: GTD', the 'Physical Theory of Diffraction: PTD' and other more rigorous vector diffraction analyses, presented in

- [E.5-8a] F.A. Molinet and W-M. Boerner, Multi-static Polarimetric Scattering Matrix (B-8) Analyses of Canonical Curvilinear Shapes (Circular/Elliptic Cylinder; Prolate/Oblate/Generalized Spheroids; Wedges, Edges and Cone-Tips) Implementing GTD and PTD, in preparation, Advances in Modern Optics, 1994/95.

- [E.5-8a] F.A. Molinet and W-M. Boerner, Recent Advances in Polarimetric Inverse (C-132) Scattering of Complex Structured Radar Targets Using the Geometrical and Physical Optics and the Geometrical and Physical Theory of Diffraction, PIERS'93, CAL-TECH/JPL, Pasadena, CA, Paper No. 2-7, July 12-16, 1993.

I.E.6 Polarimetric Doppler Radar (POL-DOP-RAD) and Imaging (POL-SAR/POL-RAR/POL-SCAT/POL-ISAR) Radar Analysis: The Development of the Polarimetric Matched Signal Filter (PMSF) and Polarimetric Matched Image Filter (PMIF) Concepts

In most of the conventional optical/IR/mm & sub-mm/microwave imaging systems little attention was paid to the vector nature, i.e., polarization state transformation properties of electromagnetic waves. Commonly transmission occurred at one fixed

transmit polarization (antenna/source) state and reception at another fixed polarization state, usually being the co-polarized (source) or cross-polarized states. Thus, allowing measurement of only one component of the 2x2 Sinclair matrix (with four 'coherent' complex elements) or of the 4x4 Mueller matrix (with sixteen 'incoherent' real power flux density terms). Adding, step-by-step, the measurements of both co-polarized, one or both pairs of co/cross-polarized received radar cross-sections on a bin-by-bin (basis for down/cross-range radar) or pixel-by-pixel for microwave holographic imaging) basis, as reported first in

[E.6-1a] W-M. Boerner, H. Gniss, K. Magura, R. Kay H. Ermert, H. Brand, Polarization dependence of image fidelity in microwave holographic mapping systems, 1987, AP-S Symp. Washington, DC, 1978, May 15-19, Proc. pp. 38-41.

[E.6-1b] W-M. Boerner, Polarization Microwave Holography: An Extension of Scalar (B-1/3) to Vector Holography 1980 SPIE Int'l. Optics Computing Conference, Washington, DC, 1980 April 9, Paper No. 231-23, pp. 188-198, (1980).

that the incoherent superimposition of the squared moduli of the elements of [S] or that of diagonal elements M_{ii} ($i = 1, 2, 3, 4$) of [M] are invariants for a chosen orthogonal polarization basis, which is also known as the span or trace invariant where

$$\text{span}\{[S(AB)]\} = \text{trace}\{[M]\} = ||S_{AA}||^2 + ||S_{AB}||^2 + ||S_{BA}||^2 + ||S_{BB}||^2$$

The comparison of this specific invariant with that of the relative co-polarization phase $\{\frac{1}{2}(\phi_{HH} - \phi_{VV})\}$ specular electric curvature $\{\frac{1}{2}(k_u - k_v)/k\}$ identity, developed in [E.5-4a/b], and given by

$$\frac{1}{2}(\phi_{HH} - \phi_{VV}) = \arctan\left\{\frac{|k_u - k_v|}{2k}\right\}$$

is compared in

[E.6-2a] W-M. Boerner, B-Y. Foo and J.J. Eom, Interpretation of the Polarimetric ([P-6]) Co-Pol Phase Term $(\phi_{HH} - \phi_{VV})$ in High Resolution POL-SAR Imaging Using the JPL CV-990 L-Band POL-SAR Data, IEEE Trans GSRS, Vol. GE-25, No. 1, pp. 77-82, Jan 1987.

demonstrating that either relationship provides highly improved complete image formation. Furthermore, the relative co-polarization phase term is also related to gradual and sudden changes in dielectric permittivity (ϵ) and conductivity (Q), i.e., the relationship to the polarization state transformation sensitive terms, $V\epsilon/\epsilon$ and $V\sigma/\sigma$, need to be further explored.

The statistical properties of the relative co-polarization phase (correlation) expressions were further pursued in

[E.6-2b] H-J. Eom and W-M. Boerner, Rough Surface Incoherent Backscattering of (P-21/17) Spherical Waves, ICEICE Trans. Comm., (Japan), Vol. E74, No. 1, pp. 105-108, Jan. 1991.

[E.6-2c] H-J. Eom and W-M. Boerner, Statistical Properties of the Phase Difference (P-22) Between Two Orthogonally Polarized SAR Signals, IEEE Trans. GSRS, Vol. 29(1), pp. 182-184, Jan. 1991.

and for specific dielectrically loaded semi-circular troughs in

- [E.6-2d] T.J. Park, H.J. Eom, G.Y. Hur, W-M. Boerner and Y. Yamaguchi, TM
(P-30) Scattering from a Dielectric-Loaded Semi-Circular Trough in a Conducting Plane, IEICE Trans. Comm., (Japan), Vol.E75B, No. 2, pp. 87-91, Feb. 1992.
- [E.6-2e] T.J. Park, H.J. Eom, G.Y. Hur, W-M. Boerner and Y. Yamaguchi, TE
(P-29) Scattering from a Dielectric-Loaded Semi-Circular Trough in a Conducting Plane, Journal of Electromagnetic Waves and Applications: JEWA, Vol. 7, No. 2, pp. 235-245, Feb. 1993.

proving the utility of the relative co/cross-polarimetric phase difference expressions in polarimetric radar remote sensing from combined surface and volumetric background scatter.

However, although considerable improvement over previous conventional 'one-scattering matrix element' images are definitely obtained, resulting in the span-invariant, to become a normalization standard on a pixel-by-pixel basis; in POL-SAR image presentation, the full capabilities of true complete polarimetric vector wave imaging require the use and availability of either the 2x2 Sinclair [S] or the 4x4 Kennaugh matrix [K] for the coherent and/or partially polarized/coherent cases, respectively.

This was achieved in successive steps at JPL, ERIM and LORAL, where complete POL-SAR imaging systems were developed during the past decade which permit the recovery of [S] or [M] matrix information on a pixel-by-pixel basis as reported in

- [E.6-3a] J.J. van Zyl, H.A. Zebker, C. Elachi, Imaging Radar Polarization Signatures; Theory & Observation, (JPL) Radio Science Vol. 22, pp 529-543, 1987
(B-3)
- [E.6-3b] D.R. Sheen, E.S. Kasischke, R.A. Shuchman, and R.G. Onstott, Polarimetric Calibration and Remote Sensing Applications Using An x-C-L Band POL-SAR System, NATO-ARW, Paper III-9
(B-3)
- [E.6-3c] L.M. Novak, C.M. Burl, R.D. Chaney, G.J. Owirka, Optimal Processing Polarimetric SAR Imagery, (LORAL-Systems) The Lincoln Laboratory Journal, Vol. 3, No. 2, pp. 273-290, 1990
(B-3)

Whereas, in these papers optimal processing of POL-SAR data is accomplished by employing still rather conventional approaches such as the span-invariant and various alternative formulations of covariance matrix optimal classifiers as summarized in

- [E.6-4a] M. Walther, A.C. Segal and W-M. Boerner, Speckle Reduction in the Development of the Polarimetric Matched Image Filter (PMIF) for the Optimization of Image Discriminants in POL-SAR Image Analysis, in W-M. Boerner, et al, Direct and Inverse Methods in Radar Polarimetry, Proceedings of NATO-ARW-DIMRP'88, Bad Windsheim, FRG, 1988 Sept. 18-24, (paper No. VII-8, pp. 1497-1552) Dordrecht, NL: Kluwer Academic Publishers, 1992.
([w-34])

and further pursued with rigor in

- [E.6-4b] W-M. Boerner, M. Walther and A. Segal, The concept of the Polarimetric Matched Signal and Image Filters: Application to Radar Target Versus Clutter Optimal Discrimination in Microwave Imaging and Sensing, International Journal on Advances in Remote Sensing (IJARS), (EARSeL), Boulogne-Billancourt, France), Vol. 2, No. 1-1, pp. 219-252, Jan. 1993.
([P-31])

in order to reduce speckle and at the same time, improve on image contrast optimization, the first true approach of developing the "Polarimetric Matched Image Filter" concept is introduced in

- [E.6-5] A.B. Kostinski, B.D. James and W-M. Boerner, On the Polarimetric Matched Image Filter for Coherent Imaging, Can. Journal of Physics, Special Issue
([P-10])

However, the PMIF concept introduced in [E.6-5] is rather limited, because it is based on the three-step-procedure including conjugate antenna polarization state matching of [E.1-1] and [E.1-2], a more generalized approach is outlined in [E.6-4a/b] which requires further detailed analysis and computer-numeric evaluation.

Thus, we are currently strongly engaged in further advancing the concept of a truly PMIF by utilizing the three-frequency band NASA/JPL (P/C/X) data, sets collected primarily for the 'San Francisco Bay Area' Training Data Set, and most recently also for the 'LOCH LINNHE, Scotland, UK measurement campaigns of 1989 and 1991. Some of the computer-numerical image analyses were performed at NU-EIE/WSL at Niigata, Japan in collaboration with UIC-EECS/CSL and are presented in

[E.6-6a] Y. Yamaguchi, M. Mitsumoto, M. Sengoku, T. Abe and W-M. Boerner, (P-23) Polarimetric and Synthetic Aperture FM-CW Radar, Japan Journal for Electronics and Communications Engineering (JJECE), Vol. AP-91-60, pp. 61-68, 22 Aug. 1991;

[E.6-6b] Y. Yamaguchi, T. Nishikawa, M. Sengoku, W-M. Boerner and H-J. Eom, (P-41) Fundamental Concepts of Synthetic Aperture FM-CW Radar Polarimetry, IEICE Trans. Comm., Vol. E77B, No. 1, pp. 73-80, Jan. 1994;

[E.6-6c] Y. Yamaguchi, T. Nishikawa, M. Sengoku, H. Yamada, W-M. Boerner and H-J. (P-42) Eom, Two-dimensional and Full Polarimetric Imaging by a Synthetic Aperture FM-CW Radar, IEEE Trans. GRS, Vol. 32, summer 1994, in print;

demonstrating the utility of various polarimetric invariants derived from the correct Polarimetric Covariance Matrix formulation as presented in [E.6-4b].

Research topics I.E.6 on 'Polarimetric Doppler Radar (POL-DOP-RAD) and Imaging Radar (POL-SAR/POL-RAR/POL-SCAT/POL-ISAR)' and I.E.7 on 'Polarization Vector Tomography and Polarimetric Sensing and Imaging of Submerged Objects' is being supported by an interactive MUCIA-EAGLE international collaborative program between NU-EF/EIE and UIC-EECS/CSL as summarized in

[0.6] W-M. Boerner, Research Travel Report on 1992 September 17-29, Japan/Korea/ (T-19) Pacific Rim Travel on the 'Advancement of EWB-POL-HR RADAR/LIDAR Sensing and Imaging, Discrimination and Identification'; UIC-EECS/CSL:AOARD/MUCIA Report 1992 October 30 (93 May 15);

[0.7] W-M. Boerner, Research Travel Report on 1993 August 25-September 09, Japan (T-22) Conference Participation (IEEE-IGARSS'93, URSI-GA'93, IAGA-IWEPREP'93), UIC-EECS/CSL:AFOSR/NI&AOARD Report 1993 September 15.

I.E.7 Polarization Vector Tomography and its Application to the Sensing and Imaging of Objects Submerged/Embedded in Inhomogeneous Media or Occluded Under Semi-transparent Covers

With the advent of coherent dual polarization doppler radars (POL-DOP-RAD) operational in monostatic and bistatic (multi-static) modes of operation and also of POL-DOP-SAR within the spectral region of 300MHz to 300GHz, we will soon be able to recover essential parameters of rapidly moving, changing and whirling meteorologic and oceanographic distributed scatterers and discrete objects within such inhomogeneous media. The corresponding index of refraction (dielectric permittants ϵ) and conductivity are changing rapidly ($\vec{E} \cdot \Delta\epsilon/\epsilon \approx \lambda/L$) and/or individual ensemble scatterer

surface curvatures are very small compared to the radar operating wave length (λ), i.e. ($E \cdot \Delta\theta/\theta \approx \lambda/L$), leading to pronounced polarization state transformations of scattered and propagating waves within the medium as well as along bounding interior and exterior surfaces.

In order to obtain a better understanding of the inherent sensing and imaging mechanisms of electromagnetic vector wave interrogation with such media, it is necessary to extend scalar to vector (tensor) diffraction tomography as reviewed and attempted in the M.Sc. theses:

[E.7-1a] B.D. James, Vector Diffraction Tomography Using Radar Transform Techniques ([m-3]) in Computer Assisted Electromagnetic Imaging, M.Sc. Thesis, Graduate College, University of Illinois at Chicago, IL 1986.

[E.7-1b] N.A. Soliman, Analysis of Depolarizing Effects in Vector Diffraction Tomography - A modeling Approach, M.Sc. Thesis, Graduate College, University of Illinois at Chicago, Illinois, 1989.

and

[E.7-1c] M. Machida, Polarization Transformation Effects in Vector Diffraction Tomography - An Experimental Verification, M.Sc. Thesis, (initiated at UIC-EECS/CSL, 1989/90), Graduate Faculty, Niigata University, Niigata, Japan 1990.

It was the main objective of these projects to demonstrate the relevance of polarization state transformation effects in vector diffraction tomography and how it will affect sensing and imaging of objects within inhomogeneous dielectric media for which the characteristic parameters are compared to the wavelength of the interrogating electromagnetic vector wave.

This research is currently being further pursued in the doctoral theses of Yin, Deng-Xie and Xu, Wei, developing the analytic modeling studies initiated in [E.7-1a/b] and by Matsumoto Toshio (NU/UIC) in further perfecting the experimental microwave (2GHz - 36GHz) and millimeter wave (36GHz - 96GHz) tomographic instrumentation measurement facilities at Niigata University by utilizing novel vector electromagnetic inverse scattering schemes recently developed by Profs. Jean C. Bolomey, Christian Pichot, et al, at CNRS/ESE, Plateau de Moulon, Gif-sur-Yvette, France and by incorporating novel inversion schemes of polarimetric diffraction tomography originally explored by Prof. Karl J. Langenberg, University Kassel, FRG.

Hitherto, this research resulted in the following publications:

[E.7-2a] W-M. Boerner, 'Electromagnetic inverse Methods in its Applications to Medical Imaging - A Current-State-of-the-Art Review (INVITED)', paper No. WEAM6B.1, PP. 999-1007, Proceedings, 1989 IEEE Int'l. Symp. on Circuits & Systems, Portland Hilton, 1989 May 8-11 (Vol. 2: 89 CHZ692-2).

where a succinct overview of the entire subject matter was presented - with emphasis on the polarization state transformation and depolarization (reduction of degree of coherent polarization) in microwave/millimeterwave imaging, which was then demonstrated in

[E.7-2b] N. Soliman and W-M. Boerner, The Interpretation of Wave Depolarizing and Polarization Transformation Effects in Vector Diffraction Tomography ([C-4]) (WEAM6B.4, pp. 1012-1017), Proc. (Vol. 20), IEEE-ISCS89 May 8-11, Portland, OR.

[E.7-2c] N.A. Soliman and W-M. Boerner Interpretation of the Depolarizing Effects

([P-16]) in Vector Diffraction Tomography, Inverse Methods, Vol. 7, No. 5, 1991 (in print)

and

[E.7-2d] N.A. Soliman and W-M. Boerner, Interpretation of the Polarization State
([w-33]) Transformation Effects in Vector Diffraction Tomography, in W-M. Boerner, et al (eds) Direct and Inverse Methods in Radar Polarimetry, Proceedings of NATO-ARW-DIMRP'88, Bad Windsheim, FRG, 1988 Sept. 18-24, NATO-ASI Series C Vol. (x,y,z), Part 2, paper No. V-4, pp. 1105-1118, Dordrecht, NL: Kluwer Publishers, Jan. 1992.

The experimental verification of this research is also well progressing as demonstrated in:

[E.7-3] Y. Yamaguchi, M. Dochida, M. Sengoku, T. Abe and W-M. Boerner, Experimental Results of the Microwave Diffraction Tomographic Instrumentation System at Niigata University, Japanese IEICE Trans. Ant. & Propag., Vol. 71, pp. 46-51, June 1991.

with specific emphasis placed on the detection and imaging of objects buried in deep snow and dry sand. This transcontinental research interaction will be strongly advanced and strengthened also in collaboration with Dr. Hyo J. Eom of KAIST, Taejon-Shi, Korea.

The MUCIA-EAGLE interaction project between UIC-EECS/CSL and NI-EE.IE/WSL on high resolution polarimetric ground penetration radar was and is very successful and productive and resulted in the development of the Polarimetric FM-CW Fresnel-type SAR Imaging Radar System described in

[E.7-4a] Y. Yamaguchi, A. Kawakami, M. Mitsumoto, M. Sengoku and T. Abe, Synthetic Aperture FM-CW Radar Applied to Detection of Metallic Objects, IEICE Trans., Vol. J74-B-11, No. 7, pp. 413-420, 1991;

[E.7-4b] Y. Yamaguchi, T. Nishikawa, M. Sengoku, W-M. Boerner and H-J. Eom, On the Fundamental Study of Radar Polarimetry in FM-CW Radar, Proc. IEICE Spring Conf.'93, SB-1-4;

[E.7-4c] T. Nishikawa, T. Yamaguchi and M. Sengoku, Polarimetric and Synthetic Aperture FM-CW Radar Imaging, IEICE Technical Report, AP92-98, Nov. 1992.

The resulting polarimetric FM-CW SAR imaging system is described in

[E.7-4d] Y. Yamaguchi, T. Nishikawa, M. Sengoku, W-M. Boerner and H-J. Eom, Fundamental Concepts of Synthetic Aperture FM-CW Radar Polarimetry, IEICE Trans. Comm., Vol. E77B, No. 1, pp. 73-80, Jan. 1994;

[E.7-7e] Y. Yamaguchi, T. Nishikawa, M. Sengoku, H. Yamada, W-M. Boerner and H-J. Eom, Two-dimensional and Full Polarimetric Imaging by a Synthetic Aperture FM-CW Radar, IEEE Trans. GRS, Vol. 32, summer 1994, in print;

again demonstrating the utility of polarimetric high resolution methods to the sensing and recognition of low observable metallic and dielectric objects occluded under quasi-lossless layers of sand, soil, water, snow and ice.

I.E.8 UWB-Inflight and Multiband-Repeat-Track POL-SAR Image Interferometry

Although drastic improvements are achieved with the incorporation of complete polarization doppler utilization into electromagnetic sensing and imaging systems for the

detection of low observables well camouflaged into environmental background clutter and/or occluded under layers of soils, vegetation, water, snow, ice and clouds, high false alarm rate recognition and distinct identification still may not be possible. In order to overcome this 'last hurdle' in instantaneous detection, automated recognition, long-to-short-term identification of low observables camouflaged and occluded within multi-parameter dynamic background clutter, the overlay of successive image scenes would greatly complement the target acquisition task. With the advent of highly improved INS (Inertial Navigation Systems), SMC (Self-correcting (instantaneous) Motion Compensation), GPS (Global Positioning System) and DGPS (Differential Global Positioning System) technology, it has now become feasible to obtain highly accurate time-delayed overlays of identical geographic image scenes with precision latitude, longitude and altitude alignments. Depending on the application, two major modes of operation exist:

- (i) Instantaneous in-flight UWB-POL-SAR Image Interferometry
- (ii) Time-delayed Repeat-Track Multiband (and UWB impulse) POL-SAR Image Interferometry

and in either case, next to the precise alignment of the altitudinal, latitudinal and longitudinal vectors of consecutive image recordings also the set of orthogonal polarization base vectors (commonly (H,V) linear), need to be aligned most accurately, in order to recover the scattering matrices for detecting and precisely determining rotational in-scene motions (e.g., turning turret of a camouflaged tank occluded in vegetation clutter) next to lateral motions which may be recovered from 'amplitude-only' information.

Whereas instantaneous in-flight UWB (impulse/doppler) SAR image interferometry has been demonstrated successfully with airborne systems, repeat-track SAR image interferometry was accomplished hitherto only with the spaceborne ERS-1 amplitude-only SAR system as reported in

[E.8-1] D. Massonet, M. Rossi, G. Carmona, F. Adragna, G. Peltzer, K. Feigl and T. Rabaute, The Displacement Fields of the Landers Earthquake Mapped by Radar Interferometry, NATURE, Vol. 364, pp. 138-142, July 8, 1993.

This method, first developed in the middle 1970ies for topographic mapping, proves to be most useful also to a wide variety of sensing and imaging tasks including, for example, the 'DRI' of

- (i) the deployment of mine-fields by means of detecting the surface changes;
- (ii) the deployment of armored vehicles occluded under vegetation and various other kinds of environmental clutter;
- (iii) the detection of the gradual surface deformation caused by tectonic stress accumulation/deceleration within seismic active regions;
- (iv) surface/underburden deformation within flooded wet/dry lands;
- (v) various vibrational modes of camouflaged armored vehicles.

It is very definite that the rapid advancement of both instantaneous inflight as well as time-delayed (minutes, hours, days, weeks, months) Repeat-Track POL-SAR Image Interferometry will profoundly aid the entire target acquisition task. Therefore, major research efforts are expended in collaboration with the NAWCADWAR, Code 50C (Surveillance) and NASA/CAL-TECH/JPL (Air/Sapce-SAR) divisions on further advancing these technologies (see reports on US NAVY-ASEE-SFRP 90/91/92/93/94 programs). Certainly, such technology as 'In-flight and Repeat-track POL-RAD/SCAT/

SAR Imaging Interferometry' need also be developed rapidly for deployment on a Helicopter Platform.

I.E.9 Polarimetric Low Frequency Inversion Methods for the Detection, Localization and Identification of Nature & Man-Induced ULF/ELF/VLF Noise and Intelligible Signatures

With the advent of a highly improved ULF/ELF/VLF sensor design, based on supracooled squid technology and real-time vector signal spectral (FFT) processing, a resurgence of interest in the detection of such "Low-Frequency Signatures" of nature & man induced noise and intelligible signals has occurred. Although very considerable studies on ULF/ELF/VLF geo-electromagnetically induced signals were carried out for a long time

[E.9-1a] A.C. Fraser-Smith, R.A. Helliwell, et al, A new global survey of ELF/VLF radio noise NATO-AGARD/EPP, Effects of em noise & interference on performance of military radio communications, Lisbon/Portugal, 1987, Oct, Paper 4a (8 pages);

especially as regards to solar-terrestrial geo-electromagnetic disturbances and its effects on man-made systems, as reviewed in

[E.9-1b] W-M. Boerner, J.B. Cole, W.R. Goddard, M.Z. Tarnawacky, and L. Shafai, (P-25) Impacts of Solar and Auroral Storms on Power Line Systems, (INVITED), Space Science Reviews 35, 1983, Published by D. Reidel Publishing Co., dordrecht, Holland and Boston, U.S.A., pp. 195-205;

it is only since very recently that seismo/volcano-genic ULF/ELF/VLF emission were discovered and recorded as reported in the collection of monographs:

[E.9-2] M. Parrot and M.J. S. Johnston, eds., Seismo-electromagnetic effects, (P-25) Special Issue, Physics of the Earth and Planetary Interiors, Vol. 57 (Nos. 1-2), pp. 1-177, Oct. 1989.

Similarly, it was only since very recently that the existence of slow and fast hydromagnetic waves, excited in the ionospheric D/E and F-layers during the passage of space vehicles (shuttle, space rockets, inter-continental missiles), was observed. Specifically, it was found that in all of these cases of monitoring ULF/ELF/VLF nature (earthquake/volcano-activation, solar-terrestrial storms, etc.) and man (space vehicles, nuclear detonations, large ocean-submersibles' motion, etc.) induced signatures, great care must be taken in properly recording the three orthogonal polarization vector signal components as reported in

[E.9-3a] J.Y. Dea, E.A. Rauscher and W-M. Boerner, "Observations of ELF Signatures ([P-24]) Arising from Space Vehicle Disturbances of the Ionosphere", Can. J. Phys. Vol. 69, Nos. 8/9, pp. 959-965 Special Issue on Space Research & Aeronomy, Aug. 1991, (subm 1990 Aug., acc. 1990 Oct.), Aug./Sept. 1991.

[E.9-3b] J.Y. Dea, C.I. Richman and W-M. Boerner, "Observations of Seismo-electromagnetic Earth/Sea-Quake Precursor Signatures along Southern California Fault Lines", Recorded at the Naval Ocean Systems Center Since 1989 Oct.", Point Loma Seaside, San Diego, CA", Can. J. Phys. Vol. 69, Nos. 8/9, pp. 1138-1145, Special Issue on Space Research & Aeronomy, Aug. 1991, (subm 1990 Aug., acc. 1990 Oct.), Aug./Sept. 1991.

These very recent discoveries are of paramount importance also to land-based Army as well as US Naval Fleet Operations and if properly investigated will lead to (i) improved low-frequency Naval Ocean sea-surface/sub-sea communications; (ii) to the

safe-guarding of Naval ocean- bottom & coastal VLF communications equipment & facilities against sudden earthquakes, sea-quake induced tsunamies, etc.; and also (iii) against volcanic eruptions. For example, it has long been recognized that conventional seismic (acousto- mechanical) methods for near-term prediction of earth/sea quakes and volcanic activation are rather limited and in fact highly inadequate which has resulted in a rapid decrease of R&D funding support for those classical seismic methods. Whereas, recent discoveries such as also made at the NOSC Sea-Side Low-Frequency Observation Station, Point Loma/San Diego, CA, on detecting electromagnetic vector (polarization-State sensitive) waves well in advance of earth/sea-quakes and of volcanic eruptions do provide the long-sought physical methods of approach. Results of this research are reported in

- [E.9-4a] W-M. Boerner, J.Y. Dea, W. Van Bise, E.A. Rauscher, "Sensing of ELF Signa-
(w-60) tures Arising from Space Vehicle Disturbances of the Ionosphere", 49th AGARD-EPP Symposium on Remote Sensing of the Propagation Environment, Cesme-Izmir, Turkey, 1991 Sept. 3 - Oct. 04, Paper No. 19 (11 pages);
- [E.9-4b] W-M. Boerner, J.Y. Dea and C.I. Richman, Sensing of Seismo-Electromagnetic
(w-61) Earth/Sea-Quake Precursor Signatures along Souther California Fault Zones: Evidence of a Long Distance Precursor ULF Signals Observed Before a Moderate Southern California Earthquake Episode", 49th AGARD-EPP Symposium on Remote Sensing of the Propagation Environment, Cesme-Izmir, Turkey, 1991 Sept. 30 - Oct 04, Paper No. 20, (8 pages);
- [E.9-4c] W-M. Boerner, J.Y. Dea and P.D. Hansen, Development of Inverse Diffraction
(C-100) Model Theories for the Telemetry and Localization of ULF/ELF Noise Emission Sources, NSF Workshop on 'Low Frequency Electrical Precursors to Earthquakes: Fact or Fiction, UCR, Riverside, CA, 1992 June 14-17;
- [E.9-4d] J.Y. Dea, P.D. Hansen and W-M. Boerner, Introduction of Low Frequency
(C-101) Radio Polarimetry - Theory and Applications, NSF Workshop on 'Low Frequency Electrical Presursors to Earthquakes: Fact or Fiction, UCR, Riverside, CA, 1992 June 14-17;

are currently being further investigated as will be reported in

- [E.9-5a] J.Y. Dea, C.I. Richman and W-M. Boerner "Observations of Seismo-Electron-
(C-73) magnetic Earth/Sea-Quake Precursor Radiation Signatures along Southern California Fault Zones: Evidence of a Long Distance Precursor ULF Signals Observed Before a Moderate Southern California Earthquake Episode", 1991 24-28, Joint URSI London, Ontario/Canada: E/F + H, Session 15, Paper No. 15.3, (Full paper in preparation for Radio Science: 1992).
- [E.9-5b] J.Y. Dea, E. Rauscher and W-M. Boerner, "Observations of ELF Signatures
(C-74) Arising from Space Vehicle Disturbances of the Ionosphere", 1991 June 24-28, Joint URSI London, Ontario/Canada: E/F + H, Session 15, Paper No. 15.7 (Full paper in preparation for Radio Science: 1992).
- [E.9-5c] W-M. Boerner, J.Y. Dea, P.M. Hansen and A.W. Green, Jr., The Existence of
Regional Low Noise ULF/ELF Spectral Polarimetric Windows for Detecting Earth/Sea-Prequake Radiation Signatures of Lithospheric Stress Conditions and Tentative Modeling of Seismo-electromagnetologic Radiation Emission Cource Mechanisms, 1993 URSI-USNC National Winter Meetings, Boulder, CO, 1993 Jan. 4-8, Session URSI-H2, Paper No. 8, (1993 Jan. 06).
- [E.9-5d] J.Y. Dea, P.M. Hansen and W-M. Boerner (INVITED), Long-term ELF Background
Noise Measurements, the Existance of Regional Polarimetric Low Noise Windows and Applicationa to Earthquake Precursor Emission Studies, Journal

'Physics of the Earth and Planetary Interiors', Special Issue on 'International Decade for Natural Disaster Reduction: Electromagnetic Methods for Natural Disaster Warning' (Topic: Crust-generated electromagnetic emissions), PEPI, Vol. 77, Issue 1-2, pp. 109-125, Apr. 1993.

- [E.9-5e] J.Y. Dea, P.M. Hansen and W-M. Boerner, Direct Observation of Real-Time
(P-44) Generation of Electromagnetic Signals and a Generalized Model for Earthquake Precursor Emissions, M. Hawakawa (ed), Electromagnetic Phenomena Related to Earthquake Prediction, TERRA Publ. Co., Tokyo, 1994, in print.

Extensive analytic and computer-simulated modeling research is required for developing these novel electromagnetic vector inverse problems. Specifically, we are in the process of developing novel 'Low Frequency' Signature Inversion Schemes for: (i) the detection and localization of seismo/volcano-genic noise sources (epicenters, dykes); (ii) the precise specification of the region of impact of ascending and descending space vehicles during their exit/reentry through ionospheric D, E (and F) layers. It need be emphasized here that we are dealing here also with highly 'polarization state dependent vector inversion' problems which so far have received little attention in the literature but are becoming of very considerable interest to the Navy and its Fleet operation as well as to the Army and its Battlefield operations under severe clutter conditions. Various related inversion procedures were recently reviewed during IWEPREP'93, Sept. 5-9, as summarized in

- [0.7] W-M. Boerner, Research Travel Report on 1993 August 25-September 09, Japan
(T-22) Conference Participation (IEEE-IGARSS'93, URSI-GA'93, IAGA-IWEPREP'93), UIC-EECS/CSL:AFOSR/NI&AOARD Report 1993 September 15.

I.E.10 **Infrasonic/Near-Infrasonic High Resolution Telemetric Detection, Automated Recognition and Instantaneous-to-Long-Duration Identification of Distant Atmospheric Noise Sources**

During the pursuit of developing reliable detection, recognition and identification methods derived from extra-wideband vector electromagnetic sensing and imaging approaches, it soon became evident that in addition to active and passive electromagnetic sensing and imaging one ought to fully integrate infrasonic (below 3Hz)/near-infrasonic (3Hz - ~ 30Hz) acoustic atmospheric signatures in the 'DRI' of low observables which seem to have received undue little attention.

Atmospheric infrasonic (.1 - 10Hz) high resolution telemetric observatories were recently established at NOAA-ETL, Boulder, CO by Dr. Alfred J. Bedard, Jr. for the purpose of advancing pertinent Infrasonic Telemetric Imaging technology with applications to the detection of avalanches, mining charge detonations and other major acoustic noise sources in the nearby Rocky Mountains. Observations made during past several years include long distant detection of river boat traffic on the Mississippi, of truck traffic on distant interstates, various kinds of far-distant major detonations, tracking of electric storms across the US midwest from the Mexican Gulf to Canada, from the Rocky to the Appalachian Mountain Ranges; of earthquake related signatures during seismic events along US Pacific Coast to Idaho/Wyoming, etc. These successfully recorded atmospheric acoustic events were accomplished with the infrasonic high resolution imaging array systems at the NOAA Tower Observatory (CO-36east/I-25) operated within about .05 to 5Hz. Infrasound in this frequency range travels above the surface (not a surface wave), through the atmosphere with little attenuation and can be detected routinely hundreds of kilometers from the source and under ideal, quiet atmospheric conditions, beyond one or two thousand kilometers. The sensor array for each observatory are spread out over an area of about 100m x 100m and deployed close, but above the surface. These infrasonic atmospheric observatories are capable of detecting small scale (of the order of deca-meters: nx10m), near surface disturbances of interest to battlefield

operations, electric storm tracking, and also of surface deformations/disturbances during tectonic stress changes within fault zones up to several hundred kilometers. The information on disturbance localization in latitude, longitude and altitude so obtained are surprisingly accurate and the information content of the associated signatures is certainly very high and should complement strongly other related event signatures obtained via active and passive electromagnetic sensing and imaging.

Close interaction with Dr. Alfred J. Bedard, Jr. of NOAA-ETL at Boulder, CO was established before, during and after the pursuit of this research, resulting in rather amazing improvement on detecting, recognizing and imaging of events from co-incident passive infrasonic and passive and active electromagnetic signature recordings of natural and anthropogenic disturbances. Because of the high quality of the results, it is anticipated that infrasonic/near-infrasonic imaging methods may be conducted by DoD already on a larger scale; and if not then this technology need to be advanced and perfected more rapidly as proposed in:

- [E.10-1a] A.J. Bedard, Jr., G.E. Greene, J. Intrieri and R. Rodriguez, On the Feasibility of Detecting and Characterizing Avalanches Remotely by Monitoring Radiated Sub-Audible (near-infrasonic) Atmospheric Sound at Long Distances, Proc. of 'First Int'l. Conference on Snow Engineering, Santa Barbara, CA 1988 July, USACE-CRREL Special Rept. No. 89-6 (Feb 1989), pp. 267-275.
- [E.10-1b] A.J. Bedard, Jr., Infrasound from Natural Sources in M. Bockhoff, Proc. 1988, Int'l Conf. on Noise Control Engineering, Avignon, FR. 1988 Aug. 30 - Sept. 01, Vol. 2 (The Sources of Noise), pp. 927-930.
- [E.10-1c] A.J. Bedard, Jr., Detection of Avalanches Using Atmospheric Infrasound, Proc. Western Snow Conference, 1989.
- [E.10-1d] A.J. Bedard, Jr., Application of Atmospheric Infrasonic Observations for the Characterization and Study of Earthquake Epicenter Regions Using Multiple Sets Infrasonic Imaging Arrays, NOAA-ETL Special Report, 1994 March.

I.E.11 Extra-Wideband Multi-Platform Passive and Active Acoustic, Vector-Electromagnetic (Polarimetric) and Seismogenic Multi-Sensor Signature Fusion by Implementation of Advanced GPS/INS Technology in the 'DRI' of low observables

With the ever perfecting target camouflaging capabilities derived from rapidly advancing material technology, at the same time it becomes ever more pertinent to develop extra-wideband multi-platform passive and active acoustic high sensitivity telemetric, vector-electromagnetic (polarimetric) and seismo-electromagnetologic sensor signature fusion in order to Detect (automatically), Recognize (instantaneously) and Identify (over short-to-long space-time domains), DRI, low observables well camouflaged in dynamic multi-parameter background environments and/or occluded under dispersively opaque screens; in addition to the standard natural ambient, jammer and other anthropogenic noise sources.

With the worldwide paradigm shift on the rapid transition from nationalist military toward global environmental defense, forced upon us by virtue of the unabating population explosion, every means of safeguarding our once-and-only natural resources must be explored in every step we take, in every decision we make! Namely, the underlying studies on 'BASIC POLARIMETRIC SIGNAL/IMAGE PROCESSING' can straightforwardly be expanded to engulf this important mission (Note, a scientific UNESCO GLOBAL ENVIRONMENTAL ASSESSMENT PANEL (1994 Feb. 15-28) concluded that the world population explosion must not only be halted, but that the total global

population be reduced to below two billion by the year 2025, or else!!). Thus, the 'dual use assessment' of our research is straightforward by expanding the concept of a "target" to identify a "hostile intruder", whose mission is to endanger the terrestrial biosphere (including military personnel and facilities) and the planetary hydrospheres (soon to be misused as nuclear and extra-toxic waste dumps), and by extending at the same time "ultra-wideband" to "extra-wideband" sensing, including the entire non-invasive electromagnetic spectrum from ULF (below 1mHz) to UV (beyond 10PHz). Namely, in order to be able to automatically detect, instantaneously recognize and to identify, subject to the characteristic nature of a hostile intruder, over short (motion of armored vehicle occluded under vegetation canopy) to medium (overnight minefield deposition) to long periods (environmental changes), it has become evident that we need to implement a multi-platform approach (including in-situ close range deployed sounding buoys to remote sensors — from submerged ocean bottom to space platforms with centralized telemetric data acquisition), implementing multiple wideband (UWB and multi-spectral) polarimetric (ULF/ELF: 3-axis) sensors and POL-SAR imagers with instantaneous in-flight or time-delayed repeat-track image interferometric capabilities covering the entire 1mHz to 10PHz spectral region, and whenever necessary, complemented by infra-to-super-sonic passive and active sensors. This project is truly multi-disciplinary, multi-institutional and it addresses a wide scope of 'DRI' tasks, which though rather different in nature, do require the same set of acoustic, vector electromagnetic and seismo-electromagnetologic sensors and imagers. These concepts are described in

- [E.11-1a] W-M. Boerner and H.W. Mullaney, EPSIWASTE, Extra-Wideband Polarimetric (3-axis) Sensors and Imagers in Wide Area Surveillance of the Terrestrial Environment, ARPA (Dual Use) BAA on DRI, Jan. 1993. (UIC-EECS/CSL: Lockheed-Sanders).
- [E.11-1b] W-M. Boerner, J.Y. Dea, P.M. Hansen, A.W. Greene, Jr., W. Worthington, A.J. Bedard, Jr., J. Verdi, and J.J. van Zyl, G. Peltzer and P. Rosen, Mapping of Lithospheric Stress Displacement in Surface Deformation and Crustal Motion During Tectonic/Lithospheric Stress Accumulation Using ULF (3-axis) Electromagnetic and Infrasonic Ground Based Arrays Together with REPEAT-TRACK POL-SAR Image Interferometry - A Proposal, October 1993.
- [E.11-1c] W-M. Boerner, A.J. Bedard, Jr., W. Worthington and A.W. Greene, Jr., J.J. van Zyl and J. Verdi, Non-Conventional Seismic Signature Analyses for the National Earthquake Hazard Reduction Program, USGS (Reply to RFP) 1994 April.

The general, underlying principle deals with the utilization of the 'complete vector nature of the electromagnetic wave' over the entire non-invasive spectral domain of below 1 mHz to beyond 10 PHz dealing with wideband (multi-spectral and impulse) complete polarimetric (3-axis and/or scattering/propagation matrices) vector sensing and tensor imaging and including state-of-the-art advanced electromagnetic signal and image processing techniques such as the implementation of the 'Optimal Polarimetric Contrast Enhancement Concept (OPCEC)', the 'Polarimetric (3-axis and/or matrix) Matched Signal/Image Filter (PMSF/PMIF)', the extra-wideband 'Polarimetric Singularity Expansion Method (SEM)' for characterizing the natural eigen-resonances of a scatterer, the closely related 'Polarimetric Wavelet' and the 'Polarimetric Fractal' algorithms, highly efficient in separating useful target signal from undesirable background clutter. In addition, implementation of in-flight and repeat-track UWB (impulse and multi-spectral)-POL-SAR Image Interferometry and the fusing of all the specific 'high resolution polarimetric algorithms' will provide the required 'DRI' tools for highlighting the differential changes that occur in time and also spatially over the entire image scene. These advanced wideband polarimetric algorithms are being pursued step-by-step at UIC-EECS/CSL and the resulting identifiers will be parallellized and various separate extra-wideband

interferometric, polarimetric signatures collected on different platforms are fused to develop the 'DRI' algorithms for automatic detection, instantaneous recognition, and to short-to-long-term identification of hostile man-made and natural intruders (causes) endangering the terrestrial biosphere.

Currently, three specific sets of DRI-tasks out of a great many pertinent ones are chosen for verification:

- (A) 'Short-term DRI' of 'Isolated Intercontinental Ballistic Low Observable Missiles' by implementation of ELF-UV polarimetric together with infrasonic passive signature analyses;
- (B) 'Medium-term DRI' of the 'overnight' deployment of mine-fields (discretely distributed deployment patterns) implementing 'Repeat-Track and In-flight POL-SAR Image Interferometry; and
- (C) 'Long-term DRI' of Lithospheric/Tectonic Stress Accumulation during extended 'active seismic stress release episodes' by simultaneous implementation of (i) ULF/ELF (3-axis) with NUUV-UV polarimetric seismogenic signatures; (ii) Infra-/Near-Infra-sonic Signature Analyses; (iii) In-flight and Repeat-Track POL-SAR Image Interferometry; and (iv) Overall signatures fusion with other standard seismic signatures.

For the cases currently under investigation in collaboration with other National and International research teams, it is the prime objective to formulate and verify more reliable hazard mitigation and disaster prevention methods based on the principle of vector-electromagnetic, high-resolution infrasonic and seismogenic signatures fusion.

I.E.12 Summary

During the past twelve years, very considerable advances were made in 'Ultra-Wide-band Polarimetric Radar Target and Clutter Analysis' also within the UIC-EECS/CSL. It is the main objective of this research to further advance basic underlying principles of the related 'Direct & Inverse Electromagnetic Scattering & Diffraction Methods'. Very true, a very wide scope of acoustic high resolution imaging and electromagnetic vector inverse scattering and diffraction problem is considered which may, at times, generate the impression of being defocused. This, however, is certainly not the case; and, it should be noted that in order to keep abreast with such a truly wide scope of research programs, very considerable national/international research travel, and a tight and day-by-day highly extended fourteen(14)-to-sixteen(16) hour working day is required and being sincerely adhered to by the Principal Investigator and some of his staff.

Certainly, I and very many of my national and international colleagues will attest to the fact that the disciplines of "Electromagnetic Inverse Scattering as applied to the 'Ultrawideband Interferometric Vector-Electromagnetic Sensing & Imaging Problem and the entire Theory, Metrology, Signal/Image Processing and Technology of Radar Polarimetry' would have not enjoyed the very considerable advances those have made during the past decade, had I not served as relentless international crusader for this noble cause. Although, frowned upon by many narrow-minded, and at times, utterly misdirected (narrowly focused) piece-meal science (short-term research project) supporters, I am confident to state that this research investigation - all encompassing as it is - is well focused, is very timely; and it addresses one of the most important and major project tasks of near-future DoD Research & Technology, mainly that of "Global Environmental, Planetary Defense" in advancing wide area high resolution instantaneous land, coastal and ocean surveillance.

I.F. POLARIMETRIC MEASUREMENT DATA (MUELLER & SINCLAIR MATRIX) ACQUISITION

I.F.1 KENNAUGH/MUELLER MATRIX MEASUREMENT DATA ACQUISITION: Because we do not possess our own radar scattering matrix measurement facilities, we need to rely upon polarimetric radar measurements collected elsewhere. Specifically, we wish to acquire measurement data sets obtained with dual polarization coherent CW radar systems operating at frequencies spread throughout the 10 MHz to 300 GHz bands for the following type of precipitation and rough surface scatter for which reliable and detailed ground truth information was collected simultaneously. Specifically, we are interested in rough surface scatter data in the MMW region. To this date, we have been successful in obtaining measurement data sets in the CM-wave region from within the USA, NATO and the NW Pacific Rim; and MMW region data mainly from NATO-Europe and Japan.

(P) Precipitation Scatter: Rain and snow backscatter [41]:

- (P-1) **RADC - S Band Dual Pol. Radar (3.1 - 3.7 GHz)**
c/o Dr. Kenneth C. Stiefvater,
Michael C. Wicks, Russell D. Brown
Vincent Vannicola
RADC/OCTS, Bldg. 106, F-230
Griffis AFB, NY 13441-5700
Tel/Fax: +1(315)330-4437/3909
data sets requested,
transmittal approved
precipitation/chaff
- (P-2) **DLR - C-Band Dual Polarization Radar (5.48 - 5.85 GHz)**
c/o Dr. Wolfgang Keydel, Director
DLR-IHFT/Oberpfaffenhofen
Münchener-Str. 20, Geb. 102
D-82234 OPH/Postamt Wessling, FRG
Tel/Fax: +[49]8153-28-2306/2380/1135
data sets requested, transmittal
approved (NATO only):
precipitation/electric storms
- (P-3) **BOEING - X/Q-Band Dual Pol. Radar (8.9 and 45 GHz)**
c/o Mrs. Brenda L. Matkin
US Army Missile Command
AMSMI-RD-AS-MM/RF
Redstone Arsenal, AL 35898-5253
Tel/Fax: +1(205)876-1970/842-8479
data sets on magnetic
tape available:
precipitation/chaff
- (P-4) **UK-EECS/RSL - Multifrequency Polarimetric FM (Dual Pol.)
Radar (5.3 -10 GHz)**
c/o Prof. Richard K. Moore/Dr. S. Prasad Gogineni
RSRS Lab, University of Kansas
2291 Irving Hill Drive
Lawrence, KS 66045-2969
Tel/Fax: +1(913)864-4835/7789
data sets requested,
transmittal approved:
snow, ice, vegetated terrain
- (P-5) **NAWC.WD.CL (NWC) X/W-band Dual Pol. Radar (45/94 GHz)**
c/o Dr. Brett Borden, Rm 425
NWC - Physics Division/Michelson Lab
Naval Weapons Center (NAWCWDCL)
China Lake, CA 93555
Tel/Fax: +1(619)939-1417/1409
data sets requested,
become available in July 89:
targets and background clutter

- (P-6) CSU, Colorado State University Dual Pol. Radars
(formerly with UIUC-ISWS-CMS/CHILL)
Department of Atmospheric Sciences, Radar Meteorology Div.
Attn: Dr. Eugene A. Mueller, Chief Radar Engineer
CSU Foothills Campus, S-band (|HH|, |VV|, |HV|), X-band
Ft. Collins, CO 80523 Dual Pol. Radar (in design)
Tel/Fax: +[1](303)491-8416/8449
Radar T&F: +[1](303)356-1364
- (P-7) NOSC Dual Pol. Radars (S/C/X Bands): NCCOSC-NRaD, Code 75
Attn: Dr. Robert J. Dinger
Code 75, Radar Division data sets requested, processing
Naval Ocean Systems Center on cleared facility only: pre-
San Diego, CA 92152-5435 cipitation, targets, ocean scatter
Tel/Fax: +1(619)553-2500/1130
- (P-8) DUT-DARR Dual Polarization Dopplar Radars (12,20,30,44 and (94)GHz):
Precipitation and Environmental Remote Sensing
Attn: Dr. Leo P. Lighthart
Professor & Director
DUT Remote Sensing Laboratory Data exchanges already
Faculty of Electrical Engr. initiated via DLR and
Delft University of Technology CRL
Mekelweg 4 NL-2628CD DELFT
Tel/Fax: +[31](15)78-6292/4046
- (P-9) K-S/D-K: DND Dual Polarization Doppler Radars (2,5,10,18,30GHz; 45 and 95
GHz): Snow & Rain Precipitation Observations for Japanese Flood & Avalanche
Disaster Prevention Program.
Attn: Dr. Fumio Yoshino
Chief Scientist & Director
Hydrology Division Data exchanges negotiated between
Public Works Research Institute FWRI and Niigata University
Ministry of Construction
1 Asahi Toyoshito Machi
TSUKUBA-SHI, 305 Japan
Tel/Fax: +[81]298-64-2211/1527
- (P-10) CIS, Central Aerological Observatoroy, USSR Academy of Sciences
Attn: Dr. Shupyatskij, Arkadij Borisovich
Director General L/C/X/Ka,u Band Dual Polarization
Pervo Mayskaya 3 Radars, ground based and mounted
Dolgoprudny, Moscoss-Region on research plane (two sets)
141-700 Russia, CIS
Tel/Fax: +[7](095)408-7714/576-3327
- (P-11) USSR Academy of Sciences, A.I. Voeikov Main Geophysical Observatory
Attn: Dr. Ryzhkov, Aleksander Vasil'evich, Head, Radar Division
7 Karbyshev Str. L-K, Q, V, W Band Dual
St-Petersburg, 190-018 CIS Polarization Radars
Tel/Fax: +[75](812)247-8662/8661

- (R) Rough Surface Scatter: Rough terrain with and without vegetation; Snow and ice covered terrain
- (R-1) JPL/NASA - C-Band and P/L/C-Band POL-SAR (68cm, 24cm, 5.6cm) [14]
 c/o Dr. Charles Elachi
 Dr. Jacob J. van Zyl
 Radar Sciences Division
 CAL-TEC/JPL, MS 300-243
 4800 Oak Grove Drive
 Pasadena, CA 91109-8099
 Tel/Fax: +[1](818)354-1365/393-1891
 data sets available on magnetic tape:
 all possible combinations
- (R-2) NAWCADWAR, Code 50C (POL-SAR: L/C/X-Bands) TRI-SAR
 c/o Dr. James R. Verdi
 Radar Surveillance Division, Code 5024
 Naval Air Warfare Center
 Aircraft Division Warminster
 Street & Jacksonville Roads
 Warminster, PA 18974
 Tel/Fax: +1(215)441-1422/7281
 data sets requested, transmittal approved, become available after July 1990:
 all possible combinations of ocean and land scatter scenes
 LOCH LHINNE data
 have become available
- (R-3) MIT-LL/DARPA - LORAL/POL-SAR: (33.3 - 33.9 GHz)
 c/o Dr. Gerald Morse
 Dennis J. Blejer, V-128
 Polarimetric Radar, V-128
 Surveillance Systems Division
 MIT, Lincoln Laboratory
 P.O. Box 73, Lexington, MA 02173-9108
 Tel: +1(617)863-5500 x7472/981-3455
 Fax: +[1](617)981-0721
 data sets requested, transmittal pending
 availability of cleared facility:
 battlefield environments
- (R-4) ERIM - Radar Division - Dual Pol. Instr. Radars (X,K,Ka,V,W-Bands)
 Dr. Robert Onstott
 Dr. David R. Sheen
 ERIM - P.O. Box 8618
 3300 Plymouth Rd.
 Ann Arbor, MI 48107
 Tel: +1(313)994-1200 x25441/2414
 Fax: +[1](313)994-0944
 data sets requested, transmittal approved:
 rough surfaces, ice, snow and vegetation covered terrain (also synthesized model surfaces)
- (R-5) MI-COM LAB Dual Pol. Radar Sets (94 GHz)
 Mrs. Brenda L. Matkin
 Dr. James Mullins
 US Army MI-COM
 AMSMI-RD-AS-MM/RF
 Redstone Arsenal, AL 35898-5235
 Tel/Fax: +1(205)876-1970/842-8479
 data sets available on magnetic tape:
 ice and snow covered mountain ranges
- (R-6) U MICH Dual Pol. Instr. Radars (L(15)/C(5)/X(9-10)/35/94/140)
 c/o Prof. Fawwaz T. Ulaby, Dir.
 The University of Michigan
 Ann Arbor, MI 48109
 Tel/Fax: +1(313)764-0500/747-2106
 data sets requested, transmittal possible: indoor and outdoor scattering scenes

- (R-7) **RSRE/Radar Division Dual Pol. Radar** (79 - 81 GHz; 120 - 124 GHz)
 Attn: Drs. George N. Crisp, Keith E. Potter, Adrian Britton, Keith Ward
 Radar Division
 RSRE, St. Andrews Rd.
 Great Malvern, Worc S.
 WR 14 3PS, England UK
 Tel: +[44]684-892-733
 Fax: +[44](684)892-4540
 data sets requested and
 available: transmittal via
 DEA-MICOM/RSRE(NATO only): snow/
 ice/marine/vegetated surfaces
 with and without targets
- (R-8) **DLR-45/94/120 GHz Dual Polarization Radar**
 c/o Dr. Wolfgang J.M. Keydel
 DLR-IHFF/Oberpfaffenhofen
 Münchener St. 20, Geb. 102
 D-8031 OPH/Postamt Wessling, FRG
 Tel: +[49]8153-28-2306/2380
 Fax: +[49]8153-28-1135
 data sets requested and
 to be made available
 via a DEA (FRG-FR-USA)
- (R-9) **CELAR/BRUZ, ULTRA-WIDEBAND DUAL POLARIZATION RADAR FACILITY**
 (1GHz-240GHz: Continuous)
 c/o Dr. Oliver Crop
 CLEAR-Radar Division
 F-35170 BRUZ/RENNES
 Tel/Fax: +[33]40-74-03-34/36
 data sets requested and
 transfer under negotiation
 via a DEA (FR-FRG-USA)
- (R-10) **Univ. NIIGATA/NCDP, Snow-Ice Remote Sensing Lab** (5,10-18*, 30-36,
 40-45,94*,120 GHz), *Dual Polarization Coherent Radars
 Attn: Dr. Yoshio Yamaguchi, Assoc. Prof./NSF-JSPS Research Fellow
 Prof. Toshio Abe, Dean & Director
 Faculty of Engineering & Ministry of Transportation, National Center
 for Disaster Prevention, Snow-Ice Remote Sensing Laboratory,
 Dept. Electronic Information Engineering, Faculty of Engineering,
 University of NIIGATA
 1 Karachi 2 Nocho 850
 NIIGATA-Shi, 950-21 Japan
 Tel: +[81]25-262-7219
 Fax: +[81]25-263-3174
 data exchanges
 in progress
- (R-11) **RAS, Russian Academy of Sciences** (formerly: USSR Academy of Sciences),
 Institute of Radio Engineering & Electronics, Remote Sensing Laboratory
 Attn: Dr. Aleksander A. Chucklantsev/Dr. Neon A. Armand, Director
 Karl Marx Ave. 18 (as of 1990 Nov 01: Butcher Ave 18)
 MOSCOW GSP-3
 103-907 Russia, CIS
 Tel/Fax: +[7](095)203-4793/8414
 data exchanges via
 DLR-OPH in progress

(L/S/C*/X, Ka/Q-band POL-SAR: *currently completely polarimetric operation possible; others: |HH|, |VV|, |HV| only)

I.F.2 Computer-Numerical Measurement Data Evaluation

During the execution of this contract, major emphasis was placed on repairing our DEC-VAX 11/750 VMS operated polarimetric algorithm data files, which were assembled over the past ten years within UIC-EECS/CL, and destroyed by a definite malicious act on the day of departure of previous assistants during February, 1989. This extensive and costly multi-year repair job consisted of three major tasks:

- I.F.2-1: Coherent Sinclair Matrix Algorithms
- I.F.2-2: Kennaugh/Mueller Matrix Algorithms

I.F.2-3: Coherent [S]-matrix: Matched Polarimetric Signal/Image Filter
Algorithm Design for POL-SAR Image analysis

As a next step, the above algorithm development was further advanced:

I.F.2-4: Matched Polarimetric Signal/Image Filter Algorithms
for Kennaugh Matrix [K] and Mueller Matrix [M] Data Sets.

Our part-time computer engineers, Mr. John O'Hara and Mr. Richard W. Foster, and our graduate research assistants, Youd-Khong Dhantravan, Wei-Ling Yan, An-Qing Xi, Chuan-Li Liu, Tzung-TA Kao and Xin Zhang were all involved continuously in the development of their computer-numeric algorithms.

Use was made of data sets P-2, P-3, P-6 and R-1, R-5, R-7 and R-8, and we are in the process of receiving data tapes for P-4, P-7, R-2, R-3, R-4 and R-9. Especially, the M.Sc. thesis of Mr. Youd-Khong Dhantravan, was concerned with the computer-numeric data evaluation of measurement data sets P-3, P-7 versus P-5 and P-8 (only restricted sets currently available).

I.G. Research Continuation

The overall direction and thrust of our research will not be changed; however, major refocusing of all of our research objectives towards the development of methods of INSTANTANEOUS DETECTION, LOCALIZATION, IDENTIFICATION and SPECIFICATION OF SOURCES OF MILITARY, ENVIRONMENTAL and SOCIO-ECONOMIC POLLUTANTS via vector-electromagnetic (GHz, MMW, IR, OPT, UV), interferometric remote sensing and probing, will be strongly emphasized and advanced in context with our dedicated objective of strengthening overall "GLOBAL PLANETARY ENVIRONMENTAL DEFENSE" commitments of our 'Department of Defense'. The ongoing environmental destruction of the Gulf region caused by such "military acts of environmental vandalism" during the recent 'Mid-East' and the 'Bosnia ethnic strife' crises should serve as a serious alert of what is to be expected in the foreseeable future.

I.G-1 Analytical Methods

We are confident to carry out the definite completion of still remaining questions and, in tightening the loose ends of coherent radar polarimetry, culminating in a major research and education-tutorial text on the subject matter.

[G.1-1] W-M. Boerner, E. Lüneburg, J.J. van Zyl, Polarimetry in Remote Sensing — Basic and Applied Concepts, Chapter 14 in F. Benderson, Chief Editor, International Manual of Remote Sensing, 3rd Edition, Int'l Remote Sensing Society, 1994 (to be expanded into major research textbook together with H. Mott, Y. Yamaguchi, J. Saillard, A.I. Kozlov)

Similarly, we are confident to complete narrow-band quasi-monochromatic approaches of Kennaugh/Mueller matrix optimization and contrast enhancement for the partially polarized cases. Research on the still wide open problem of the general partially coherent case will be further pursued, and a complete answer cannot be expected soon.

Simultaneously, we are going to step up our research in ultra-wideband polarimetric transient signature and doppler analyses of dynamic scatterer ensemble motion by further pursuing the concept of time-domain polarization theory and concepts. Also, major emphasis is placed on rapidly developing POL-SAR Image Interferometry.

I.G-2 Computer-Numerical Algorithm Development for Low RCS Target Detection in Dynamic Background Clutter for the MMW Spectral Region:

The analytical model theories will be numerically tested with the existing data sets plus additional ones requested under P-1, P-4, P-5, R-1, R-2, R-4, R-4, R-6, and, hopefully, also from the University of Massachusetts at Amherst, MA. In addition, we are planning to strongly increase our Japanese research collaborators via the US-JAPANESE Scientific & Engineering Research Cooperation Act of NSF-STAJ at (i) The University of Niigata, Disaster Prevention Research Center, Division of Snow-Ice Remote Sensing and (ii) The Japan Ministry of Construction, Public Works Research Institute, Flood and Avalanche Prediction Center (P-9) at Tsukuba and Toyama, Japan (See detailed research report: 1989 August 17 to - September 13, Japan Research Travel).

Both Dr. Yoshio Yamaguchi (Assoc. Prof., Niigata University) and Dr. Fumio Yoshino (Chief Scientist, KENSETSU-SHO DOBOKU-KENKYU-SHO) have enjoyed extended stays at our UIC-EECS/CL facilities and a major NSF-STAG US-JAPANESE Research Contract is under deliberation dealing with CM,MMW and IR polarimetric scattering from snow-ice fields.

I.H. Benefits

I.H.1 Significance: Our UIC-EECS/CSL polarimetric radar vector signal and matrix image processing approach is original in that it provides new directions in radar target detection, classification, imaging and identification. Our novel polarimetric matched signal/image filter approach allows optimal information extraction of significant characteristic features of desirable targets and/or target sections with simultaneous suppression of undesirable background clutter/speckle which may be adapted to any target versus arbitrary geophysical environment.

I.H.2 Merits and Benefits: In summary, the full understanding of the electromagnetic wave/target interrogation capability, as the polarimetric doppler radar/SAR (subject to $S_{HV} = S_{VH}$ not being a design requirement) and in-flight instantaneous as well as repeat-track POL-SAR image interferometry will provide, is of paramount importance to the analysis of the complete radar wave interaction with the ground terrain, the ocean surface and/or the meteorological surface cover in that it will provide us with the essential key as to how we may maximally extract hard-to-delineate scatterer features of isolated and/or combined objects, etc. The types of analytic rough surface & vector inverse scattering studies in conjunction with the polarimetric radar/SAR data analysis currently conducted with already available data sets and proposed for the SIR-C/X-SAR analyses will be extremely helpful to all other geoscientific disciplines and in particular, for the earth sciences including geology, hydrology, glaciology, oceanography and in the biospheric, cryospheric and atmospheric remote sensing. Indeed, this highly improved understanding of microwave (P-W band) polarimetric (scattering matrix) interaction with targets and clutter will allow us to process the polarimetric radar data in a more meaningful, straightforward manner for maximal target enhancement and optimum speckle suppression without taking recourse to electromagnetically unjustified statistical (arbitrary: geo-electromagnetically) multiple parameter data adjustment games.

I.H.3 Socio-Economic Impact: In combination and complementation with other DOD/NASA/NOAA research efforts, our novel and unique polarimetric matched image filter approach will lead to:

- (i) more refined and detailed image contrast optimization for the delineation of characteristic target features (shape and material decomposition) in down and cross-range target imaging;
- (ii) more efficient surveillance, control and tracking of geophysical resources

within the very fragile terrestrial environment such as the polar/sub-polar, vegetated coastal surf zones, and tropical forestal regions;

- (iii) improved short term (immediate) and long term weather forecasting integrating space-borne high resolution polarimetric doppler SAR-imagery of localized severe electric storm/tornado and/or global dynamic cyclonic motions, respectively; also, improving on tornado/ cyclonic tracking and damage impact predictions;
- (iv) advancement of electro-optic polarimetric radar device technology with wide applications in space radar development for planetary exploration or, closer to earth, for on-board aircraft collision avoidance and more precise instantaneous electric storm/downburst (lower frequencies) prediction and tracking;
- (v) the rapid development of novel sensing technologies for the instantaneous detection, discrimination and identification of hostile intruders in a dynamic terrestrial environment (including toxic hazards).

I.H-4 Relevance to Global Planetary Defense: Globally, we are experiencing very subtle changes in the interaction of political blocks with the sweeping changes in Eastern Europe and the disintegration of the Warsaw Pact alliance and the accelerating ethnic strifes associated with it. More so, we may well expect the sudden break-up of the USSR/CIS into ethnically, racially, and religiously rearranging smaller blocks towards the borders of Asia Minor and Central Asia, freeing the Eastern European plus Western republics (Balticum, Ukraine) from the USSR/CIS. It is to be anticipated that the mission of NATO will have to change and that the forming European community of 1992 will abruptly expand to engulf in the foreseeable future the politically free floating Eastern European countries. Much sooner than one ever expected, the Persian Gulf suffered from the current Mid-East military punitive actions which, unfortunately, hence demonstrated the environmental disaster (burning oil wells, etc.) that can be inflicted on the global environment by irresponsible military acts of environmental vandalism.

As a result of all of these changes, also the priorities of defense strategies will have to change, and in consideration of the real threat of losing the grip on preserving our global environment, the attention of defense strategies must now, at this very moment of world history, be focused also strongly on "environmental protection and defense issues". No longer may we view continents and blocks separated over expansive oceans! We are all becoming more closely interwoven citizens within the same and also within distant countries. With the still unhampered global population explosion, the associated pressure for more space is dramatically growing, and with it the destruction of our global environment. Especially, our potable water resources, i.e., the terrestrial great lakes and rivers and its aquifers are seriously endangered, but so are the terrestrial oceans. Paired with the population explosion is the creation of poverty and with it also the search for and production of "agony and pain reducing agents", such as drugs, alcohol, toxic herbs, gambling of all kinds, etc., which strongly affects our socio-economic environment engulfing the poor, the middle-class, and the rich alike. There seems to be not a single country or any single group of citizens that could be singled out for not suffering from these serious problems.

In summary, the question of national defense and the protection of the individual and groups of citizens has drastically and very abruptly changed. These very evident worldwide changes must have its impact also on the Departments or Ministries of Defense worldwide, in East or West, and North or South alike. Thus, instead of viewing our "DoDs" or "MoDs" as remnants of previous "DoW/MoWs", i.e., national institutions for the preparation of war or the defense from the threat of war, we will very soon have to view our "DoD/MoDs" to become "DoD/MoDs for the Defense of the People from the People" with a globally integrated planetary defense approach

paying major attention toward these environmental issues, as was considered in our recent succinct position paper on the subject matter.

[F-18] W-M. Boerner, J.B. Cole, (invited), FROM MILITARY TO PLANETARY ENVIRONMEN-
([w-64]) TAL DEFENSE: The Challenge of the Next Century, and a Viable New Role of
the US Military in an "ENVIRONMENTAL PLANETARY DEFENSE INITIATIVE" on a
Global Scale, Proc. NSIA-DEFENSE INDUSTRY AND THE ENVIRONMENTAL AGENDA-
SYMPOSIUM'91, B. Pope, ed. Oct. 9-10, Sheraton Premier Hotel at Tyson
Corner, Vienna, VA (10 printed pages) Nov. 1991.

Our major long-term research goals are directed toward developing novel approaches for the global planetary defense problem of the:

I.H.5 "Instantaneous Ranging and Detection, Automated Recognition,
Specification and Short-to-Long-Term Identification of Sources,
Retainers, and Transmitters of Pollutants of Any Kind:
Military, Environmental and Socio-Economic",

which will require the ultimate and complete utilization of the electromagnetic vector wave interrogation capabilities, i.e., in addition to amplitude frequency and phase, also polarization information must be utilized, implementing novel DGPS and INS technology in order to realize in-flight and repeat-track POL-RAD/SCAT/SAR image interferometry, one of its most outstanding future modes of operation. In addition, wideband acoustic and seismogenic signature fusion with the extra-wideband polarimetric signatures will enable the foreseeable realization of real-time automated detection, instantaneous recognition and short-to-long-term identification of natural and man-induced catastrophic hazard mitigation and disaster prevention.

PART II: PUBLICATIONS AND PERSONNEL

- II.1 ARO PROPOSAL NO: P-26128-EL UIC-OGC-ACC NO: 2-5-30616
- II.2 PERIOD COVERED: 1989, August 01 - to - 1992, July 31,
- II.3 TITLE: BASIC POLARIMETRIC SIGNAL/IMAGE PROCESSING STUDIES
Sub-Title: Determination of Polarization States for Optimal Transmission and Reception Through Clutter
- II.4 CONTRACT NO: DAAL-03-89-K-0116
ARO-EL: Dr. James W. Mink, T/F: +[1](919)549-4240/4310
ARO-GS: Dr. Walter A. Flood, T/F: +[1](919)549-4246/4310
ARO-IP: Richard O. Ulsh, T/F: +[1](919)549-4218/4310
- II.5 INSTITUTION: UNIVERSITY OF ILLINOIS AT CHICAGO
ELECTRICAL ENGINEERING & COMPUTER SCIENCE
COMMUNICATIONS AND SENSING LABORATORY,
UIC-EECS/CL, M/C 154,
840 W. TAYLOR ST., UIC-607, SEL-4210,
CHICAGO, IL 60607-7018
Tel & Fax: +[1](312)996-5480
e-mail: boerner@parsys.eecs.uic.edu (research)
e-mail: boerner@bert.eecs.uic.edu (academic)
- II.6 AUTHOR: Dr. Wolfgang-Martin Boerner
University of Illinois Senior Scholar
Professor & Director
- II.7 PUBLICATIONS (7a to 7k)
- 7a. Dedications (D.1-3), Books (B-1 to B-9) and Monographs (M-1 to M-7) (1985-1994)
- D-1 Harold Mott, Antennas for Radar and Communications - A Polarimetric Approach, (second revised edition of H. Mott, Polarization in Antennas in Radar (1986) to which Prof. W-M. Boerner contributed profoundly), Wiley Series in Microwave and Optical Engineering (Kai Chang, Series Editor), A Wiley-Interscience Publication, John Wiley & Sons, New York, 1992.
- D-2 Robert M. Bevensee, Maximum Entropy Solution to Scientific Problems, P.T.R. Prentice Hall, Englewood Cliffs, N.J., 1993.
- D-3 Viktor Nickolaiyevich Tatarinov and Vadislav Aleksanderovich Potekhin, The Affine Polarimetric Radar Theory and Technology, Sankt-Petersburg: Gidrometizdat (in Russian: 1993), English version to be published with ARTECH-House, 1994/5.
- B-1 W-M. Boerner et al., (eds.) Inverse Methods in Electromagnetic Imaging, Parts 1 & 2, NATO ASI Series C: Mathematical & Physical Sciences, Vol. C-143, D. Reidel Publishing Co., Dordrecht/Boston/Lancaster, Jan. 1985.
- B-2 W.M. Boerner and H. Überall, SOC-MOTH(NATO), Advanced Research Short Course, Vector Inverse Methods in Radar Target/Clutter Imaging, Proceedings, ARSC, Ecole Supérieur d'Electricité, Gif-sur-Yvette, France, 1986, Sept. 1-4, Springer Verlag, Heidelberg, 1994, total pages: 428.
- B-3 W-M. Boerner, et al. (eds.) NATO, Advanced Research Workshop on Direct and Inverse Methods in Radar Polarimetry, Sept. 18-24, 1988, Proceedings, Chief Editor, 1987- 1991, (1,938 pages), NATO-ASI Series C: Math & Phys Sciences, Vol. C-350, Pts 1&2, D. Reidel Publ. Co., Kluwer Academic Publishers, Dordrecht, NC, 1992 Feb. 15.

- B-4 L.W. Root, B.L. Matkin and W-M. Boerner, (eds.) Proceedings of the Third Polarimetric Radar Technology Symposium, 1988 Aug. 12-16, Rocket Auditorium, US Army Missile Laboratory, Redstone Arsenal, AL, GACIAC, IIT-RI, Chicago, IL, August 1990.
- B-5 S.J. Anderson and W-M. Boerner, eds., Wideband Imaging and Sensing Polarimetry, WISP Workshop Proceedings, Aug. 12-14, SPRI, University of South Australia., Adelaide, Australia, Aug. 1992.
- B-6 W-M. Boerner and J. Saillard, Proceedings Radar Polarimetry, JIPR-2 92 Sept. 8-10: Contributions by W-M. Boerner, Univer. of Nantes, IRESTE-S2HF, Nantes, Sept. 1992.
- B-7 W-M. Boerner and H. Mott, eds., Radar Polarimetry, SPIE'29 Int'l Symposium, San Diego, CA, 1992 July 20-25, Radar Polarimetry Conference, SPIE, Vol. 1748, 1993.
- B-8 W-M. Boerner and F.A. Molinet, Polarimetric Radar Inverse Scattering - Determination of the Polarimetric Scattering Matrices for Simple and Complex Shapes, Springer Verlag, Heidelberg, 1994, in print.
- B-9 W-M. Boerner with S.R. Cloude, E. Lüneburg, A.I. Kozlov, H. Mott, J. Saillard, J.J. van Zyl and Y. Yamaguchi, Fundamentals of Radar Polarimetry (Vols. 1-4), Int'l Sci. Publ. House, Tokyo, London, Berlin (Vols. 1&2 in completion: Note, these set of four volumes are to appear simultaneously in English, German, French, Russian and Japanese).
- M-1 Chan, C-Y. and Boerner, W-M., (Invited Monograph), Inverse Methods in Electromagnetic Imaging, pp. 213-238, Medical Applications of Microwave Imaging, (eds. L.E. Larsen and J.H. Jacobi), IEEE Press, New York, 1986.
- M-2 W-M. Boerner, W-L. Yan, Basic Principles in Radar Polarimetry and its Applications to Target Recognition Problems - with Assessments of the Historical Development and of the Current State-of-the-Art (53 pages) in, J.K. Skwirzynski and B. de Neuman, Eds., Proceedings of the NATO-ASI on "Electromagnetic Modeling and Measurements for Analysis and Synthesis Problems, NATO-ASI, Applied Sciences Series, E, Vol. 199, Martinus Nijhoff Publishers, Kluwer Academic, Dordrecht, NL, 1991, pp. 311-363, 1991, July.
- M-3 W-M. Boerner, W-L. Yan, A-Q. Xi, and Y. Yamaguchi, Basic Principles in Radar Polarimetry, Ch. 2 (87 pages), in "Polarimetric Technology Handbook", J.W. Battles, Editor IIT-RI/GACIAC, CHICAGO, IL (Publishers), pp. 11-98, April. 1992).
- M-4 W-M. Boerner, W-L. Yan and A-Q. Xi, Basic Equations of Radar Polarimetry and Its Solutions: The Characteristic Radar Polarization States for the Coherent and Partially Coherent Cases, Invited Tutorial Monograph (65 pages), Proceedings, Paper No. 1317-29, The SPIE Int'l Conference on Polarimetry, Huntsville, AL 1990 May 13-18, pp. 16-79, 1990.
- M-5 W-M. Boerner, W-L. Yan and A-Q. Xi, "BASIC RELATIONS OF WIDEBAND RADAR POLARIMETRY: The Characteristic Radar Polarization States for the Coherent and Partially Polarized Cases" (78 pages) in J.D. Taylor, editor, Introduction to Ultra-Wideband Impulsive Radar Technology Handbook, Boca Raton, Florida: The CRC Press, Inc. 1992.
- M-6 M-W. Boerner, C-L. Liu, X. Zhang and V. Naik, Polarization dependence in ultra-wideband radar target versus clutter discrimination, Proceedings Contribution 1631-09(S1), Tutorial Introduction, The 1992 SPIE Laser and Radar Engineering

Symposium, 'Ultrawideband Radar Workshop', 1992 January 19-24, Proceedings, SPIE 1631, (25 pages), Spring 1992.

- M-7 W-M. Boerner, E. Lüneburg and J.J. van Zyl, POLARIMETRY IN REMOTE SENSING - Basic and Applied Concepts, Chapter 14 (120 printed pages) in L. Henderson, ed., Manual of Remote Sensing, Third (highly upgraded) Edition, Int'l Remote Sensing Society, London, UK, 1994.
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- C-110 W-M. Boerner, Preview of Forthcoming Radar Polarimetry Conferences, 'Workshops and Symposia' (Presentation of Dedication Volume of Proceedings/NATO-ARW-DIMRP'88 to Guest of Honor: J.R. Huynen, 1992), Sessions RPC-II-3/5.
- C-111 Y. Yamaguchi, W-M. Boerner, H-J. Eom, M. Sengoku and T. Abe, On Characteristic Polarization States in the Cross-Polarized Radar Channel, 1992 SPIE's Int'l. Symposium OE/OESE, Polarimetry Conferences, San Diego, CA, 1992 July 19-24, Session RPC-III-4.
- C-112 A.C. Segal, M. Walther, H-J. Eom and W-M. Boerner, The Polarimetric Matched Image Filter in POL-SAR Image Enhancement, 1992 SPIE's Int'l. Symposium OE/OESE, Polarimetry Conferences, San Diego, CA, 1992 July 19-24, Session RPC-IV-5.
- C-113 H-J. Eom, Y. Yamaguchi and W-M. Boerner, A Matrix Doubling Formulation of Internal Emission from a Layer with Irregular Boundaries, 1992 SPIE's Int'l. Symposium OE/OESE, Polarimetry Conferences, San Diego, CA, 1992 July 19-24, Session RPC-VI-5.
- C-114 W-M. Boerner, X. Zhang, C-L. Liu (INVITED KEYNOTE LECTURE), Evaluation of Optimization Procedures for the 2x2 Sinclair, the 3x3 Covariance and the 4x4

Mueller Matrices in Coherent Radar Polarimetry and Its Application to Radar Target versus Background Clutter Discrimination in POL-SAR Sensing and Imaging, Asia-Pacific Microwave Conference, APCM'92, Adelaide, South Australia, 1992 August 11-13.

- C-115 W-M. Boerner, Wideband Radar Polarimetry: Low Frequency Sounding - to - Optical Imaging - An Indispensable tool in 'PLANETARY ENVIRONMENTAL DEFENSE', Asia-Pacific Microwave Conference, APCM'92, Adelaide, South Australia, 1992 August 11-13, Special Workshop on 'Wideband Radar Sensing and Imaging Polarimetry', Univ. of So. Australia Campus, Friday, 1992 August 14, Session I-1.
- C-116 J.Y. Dea and P.M. Hansen, Low Frequency (ULF/ELF/VLF) Radio Polarimetry: Theory, Metrology and Applications to Seismo-electromagnetologic Telemetry in Early Earthquake Epicenter Detection, Asia-Pacific Microwave Conference, APCM'92, Adelaide, South Australia, 1992 August 11-13, Session II-3, Special Workshop on 'Wideband Radar Sensing and Imaging Polarimetry', Univ. of So. Australia Campus, Friday, 1992 August 14.
- C-117 T.J. Park, H-J. Eom, Y. Yamaguchi, W-M. Boerner and S. Kozaki, TE-Scattering from a Dielectric-loaded Simi-circular Trough in a Conducting Plane, Int'l. URSI-B/EMT Symposium, Sydney/Australia, 1992 Aug. 17-20.
- C-118 W-M. Boerner, Ultrawideband Radar Polarimetry: An Indispensable Tool in 'High Resolution Instantaneous Detection, Sensing, Specification, Imaging and identification of Global Nature and Man-Induced Environmental Threats' - An Essential Tool in 'Planetary Environmental Defense', INVITED KEYNOTE ADDRESS, JIPR-2, Normandie, France, 1992 Sept. 8-10.
- C-119 W.M. Boerner, X. Zhang, C-L. Liu and G.K. Stratis, Comparison of Optimization Procedures for the 2x2 Sinclair (Jone) $[S(A,B; B = A_1; AB = BA)]$, 3x3 Covariance $[\Sigma(A,B; B=A_1; AB=BA)]$ and 4x4 Kennaugh (Mueller $[M]$ Scattering (Propagation) Matrices, Its Lie $SU(n = 1,2,4)$ Group Expansions, and Optimization for the Symmetric (Monostatic, Reciprocal) Matrix Case, JIPR-2, Normandie, France, 1992 Sept. 8-10.
- C-120 W-M. Boerner, M. Walther and A.C. Segal, The Concept of the Polarimetric Matched Signal and Image Filters: Application to Radar Target versus Speckle Reduction & Optimal Background Clutter Discrimination in Microwave Sensing and Imaging, JIPR-2, Normandie, France, 1992 Sept. 8-10.
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- C-122 W-M. Boerner, X. Zhang, C-L. Liu, H.J. Eom, Y. Yamaguchi, M. Tanaka, Comparison of Optimization Procedures for Radar Scattering Matrices, ISAP'92, Sapporo, Hokkaido, Japan, 1992, Sept. 21-25, Special Sessions on Wideband Sensing & Imaging Polarimetry, Session A-1, No. A-1.2.
- C-123 Y. Yamaguchi, W-M. Boerner, H-J. Eom, M. Sengoku and T. Abe, An Eigenvalue Equation for the Characteristic Polarization States in the Cross-Polarized Radar Channel, ISAP'92, Sapporo, Hokkaido, Japan, 1992, Sept. 21-25, Special Sessions on Wideband Sensing & Imaging Polarimetry, Session A-1, No. A-1.3.
- C-124 H-J. Eom, Y. Yamaguchi, W-M. Boerner, A Matrix Doubling Formulation for the Calculation of Mueller Matrices of Internal Emission from a Layer with Irregular Boundaries, ISAP'92, Sapporo, Hokkaido, Japan, 1992, Sept. 21-25,

- C-125 M. Tanaka and W-M. Boerner, Optimum Antenna Polarizations for Polarimetric Contrast Enhancement, ISAP'92, Sapporo, Hokkaido, Japan, 1992, Sept. 21-25, Special Sessions on Wideband Sensing & Imaging Polarimetry, Session A-1, No. A-2.5.
- C-126 Y. Yamaguchi, M. Mochida, W-M. Boerner, M. Sengoku, T. Abe and H-J. Eom, Interpolation Technique in Polarimetric Diffraction Tomography, ISAP'92, Sapporo, Hokkaido, Japan, 1992, Sept. 21-25, Special Sessions on Wideband Sensing & Imaging Polarimetry, Session A-1, No. A-1.2.
- C-127 W-M. Boerner, H-J. Eom, Y. Yamaguchi, M. Walther and A.C. Segal, The Polarimetric Matched Image Filter in POL-SAR Image Enhancement versus Speckle Reduction, ISAP' 92, Sapporo, Hokkaido, Japan, 1992, Sept. 21-25, Special Sessions on Wideband Sensing & Imaging Polarimetry, Session A-1, No. A-1.2.
- C-128 W-M. Boerner, J.Y. Dea, P.M. Hansen and A.W. Green, Jr., The Existence of Regional Low Noise ULF/ELF Spectral Polarimetric Windows for Detecting Earth/Sea-Prefquake Radiation Signatures of Lithospheric Stress Conditions and Tentative Modeling of Seismo-electromagnetologic Radiation Emission Source Mechanisms, 1993 URSI-USNC National Winter Meetings, Boulder, CO, 1993 Jan. 4-8, Session URSI-H2, Paper No. 8, (1993 Jan. 06).
- C-129 J.Y. Das, P.M. Hansen, W-M. Boerner, An Introduction to Low Frequency (ULF/ELF/VLF) Radio Polarimetry, PIERS'93, 1A1-8, CAL-TECH/JPL, Pasadena, CA, 1993 July 12-16.
- C-130 W-M. Boerner, C-L. Liu, E. Lüneburg, M. Tanaka, Comparison of Optimization Procedures for Radar/Lidar Scattering Matrices, PIERS'93, 2A1-3, CAL-TECH/JPL, Pasadena, CA, 1993 July 12-16.
- C-131 W-M. Boerner, M. Tanaka, Y. Yamaguchi, H-J. Eom, E. Lüneburg, Development of Optimal Polairmetric Contrast Enhancement Coefficients, PIERS'93, 2A1-7, CAL-TECH/JPL, Pasadena, CA, 1993 July 12-16.
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- C-133 V.A. Sarytchev, A.I. Kozlov, A.I. Logvin and W-M. Boerner, Multispectral Wideband Polarimetric Radar Target Characteristic, PIERS'93, 2P1-8, CAL-TECH/JPL, Pasadena, CA, 1993 July 12-16.
- C-134 H-J. Eom, T.J. Park, Y. Yamaguchi and W-M. Boerner, Microwave Emission from a Dielectric-Loaded Semicircular Trough in a Conducting Plane, PIERS'93, 2P1-10, CAL-TECH/JPL, Pasadena, CA, 1993 July 12-16.
- C-135 H. Mott, W-M. Boerner, R.M. Lempkowski and Y. Yamaguchi, Comparison of Radar and Lidar Scattering Matrix Measurements, PIERS'93, 3A1-3, CAL-TECH/JPL, Pasadena, CA, 1993 July 12-16.
- C-136 Y. Yamaguchi, T. Nishikawa, M. Sengoku, H-J. Eom and W-M. Boerner, On the Fundamentals of Polarimetric Imaging by a Polarimetric FM-CW Radar, PIERS'93, 3A1-7, CAL-TECH/JPL, Pasadena, CA, 1993 July 12-16.
- C-137 Y. Yamaguchi, H-J. Eom, E. Lüneburg, J.J. van Zyl, W-M. Boerner et al, Dual

Polarization Radar/SAR Two-Channel Imagery and Its Polarimetric Contrast Enhancement, PIERS'93, 3P1-7, CAL-TECH/JPL, Pasadena, CA, 1993 July 12-16.

- C-138 A.C. Segal, M. Walther, W-M. Boerner, Development of the OPCEC Filter, PIERS'93, 3P1-10, CAL-TECH/JPL, Pasadena, CA, 1993 July 12-16.
- C-139 F.A. Molinet and W-M. Boerner, Recent Advances in Polarimetric Inverse Scattering of Complex Structured Radar Targets Using the Geometrical & Physical Optics and the Geometrical & Physical Theory of Diffraction, URSI/IGARSS'93, Session U-1, Toyko, Japan, August 18-21, 1993.
- C-140 E.A. Mueller, V. Bringi, V. Chandrasekar and W-M. Boerner, The Development of Polarimetric Contrast Enhancement Filters for Polarimetric Doppler Studies of Hydrometeoric Scatter, URSI/IGARSS'93, Session U-2, Toyko, Japan, August 18-21, 1993.
- C-141 H-J. Eom and W-M. Boerner, Matrix Doubling Procedures for the Analysis of Mueller and Covariance Matrices of Internal Emission from a Layer of Irregular Boundaries and Embedded Random Scatterers, URSI/IGARSS'93, Session U-3, Toyko, Japan, August 18-21, 1993.
- C-142 W-M. Boerner, M. Tanaka, Y. Yamaguchi, H-J. Eom and E. Lüneburg, Development of 'Optimal Polarimetric Contrast Enhancement Coefficients: OPCEC' for the Analysis of Depolarization Due to Rain, Ice and Surface Scatter Utilizing POL-RAD and POL-SAR Measurements, URSI/IGARSS'93, Session U-4, Toyko, Japan, August 18-21, 1993.
- C-143 J.Y. Dea, P.M. Hansen, A.W. Green, Jr. and W-M. Boerner, Seismo-electromagnetologic Recordings in the ULF/ELF Bands Prior/During/After Lithospheric Stress Conditions, Earthquakes and Volcano Eruptions in SW California, URSI/IGARSS'93, Session U-5, Toyko, Japan, August 18-21, 1993.
- C-144 W-M. Boerner, M. Tanaka, Y. Yamaguchi, H-J. Eom and E. Lüneburg, Development of 'Optimal Polarimetric Contrast Enhancement Coefficients: OPEC' for the Analysis of Depolarization Due to Rain, Ice and Surface Scatter Utilizing POL-RAD and POL-SAR Measurements, IGARSS'93, Session I-1, Toyko, Japan, August 18-21, 1993.
- C-145 J.Y. Dea, P.M. Hansen and W-M. Boerner, An Introduction to Low Frequency (ULF/ELF/VLF) Radio Polarimetry and Some Applications to the Interpretation of Natural and Cultural Emission Signatures, IGARSS'93, Session I-2, Toyko, Japan, August 18-21, 1993.
- C-146 W-M. Boerner, J.Y. Dea, E.A. Rauscher and W.L. van Bise, ELF Signatures Arising from Space Vehicle Disturbances of the Ionosphere, IGARSS'93, Session I-3, Toyko, Japan, August 18-21, 1993.
- C-147 W-M. Boerner, M. Walther and A.C. Segal, Development of the Polarimetric Contrast Enhancement Optimization (OPCEC-FILTER) Procedure and Its Application to Sea Surface Scatter in POL-SAR Image Analysis, IGARSS'93, Session I-4, Toyko, Japan, August 18-21, 1993.
- C-148 W-M. Boerner, C-L. Liu, E. Lüneburg and M. Tanaka, Comparison of Optimization Procedures for Radar/Lidar Scattering Matrices, IGARSS'93, Session I-5, Toyko, Japan, August 18-21, 1993.
- C-149 F.A. Molinet and W-M. Boerner, Recent Advances in Polarimetric Inverse Scattering of Complex Structured Radar Targets Using the Geometrical & Physical Optics and the Geometrical & Physical Theory of Diffraction, URSI-GA'93, Session B7, Kyoto, Japan, August 25-September 2, 1993.

- C-150 C-L. Liu, E. Lüneburg, M. Tanaka and W-M. Boerner, Comparison of Optimization Procedures for Radar/Lidar Scattering Matrices: A Unified Radar/Lidar Inversion Approach, URSI-GA'93, Session B7, Kyoto, Japan, August 25-September 2, 1993.
- C-151 H-J. Eom and W-M. Boerner, Matrix Doubling Procedures for the Analysis of Mueller and Covariance Matrices of Internal Emission from a Layer of Irregular Boundaries and Embedded Random Scatterers, URSI-GA'93, Session B9, Kyoto, Japan, August 25-September 2, 1993.
- C-152 W.L. van Bise, E.A. Rauscher, J.Y. Dea and W-M. Boerner, ELF Signatures Arising from Space Vehicle Disturbances of the Ionosphere, URSI-GA'93, Session E2, Kyoto, Japan, August 25-September 2, 1993.
- C-153 M. Mott, W-M. Boerner, R.M. Lempkowski and Y. Yamaguchi, Comparison of Radar and Lidar Scattering Matrix Measurements, URSI-GA'93, Session EA, Kyoto, Japan, August 25-September 2, 1993.
- C-154 E.A. Mueller, V. Bringi, V. Chandrasekar and W-M. Boerner, The Development of Polarimetric Contrast Enhancement Filters for Polarimetric Doppler Studies of Hydrometeor Scatter, URSI'93, Session F1, Kyoto, Japan, August 25-September 2, 1993.
- C-155 W-M. Boerner, M. Tanaka, Y. Yamaguchi, H-J. Eom and E. Lüneburg, Development of 'Optimal Polarimetric Contrast Enhancement Coefficients: OPCEC' for the Analysis of Depolarization Due to Rain, Ice and Surface Scatter Utilizing POL-RAD and POL-SAR Measurements, URSI'93, Session F6, Kyoto, Japan, August 25-Sept. 2, 1993.
- C-156 A.C. Segal, M. Walther and W-M. Boerner, Development of the Polarimetric Contrast Enhancement Optimization (OPCEC-FILTER) Procedure and Its Application to Sea Surface Scatter in POL-SAR Image Analysis, URSI'93, Session F7, Kyoto, Japan, August 25-September 2, 1993.
- C-157 J.Y. Dea, P.M. Hansen, A.W. Green, Jr. and W-M. Boerner, Seismo-electromagnetic Recordings in the ULF/ELF Bands Prior/During/After Lithospheric Stress Conditions, Earthquakes and Volcano Eruptions in SW California, URSI'93, Session HEG, Kyoto, Japan, August 25-September 2, 1993.
- C-158 J.Y. Dea, P.M. Hansen, W-M. Boerner and A.W. Green, Jr., ULF/ELF Signatures Arising from Natural and Man-Induced Emission Sources, URSI-USNC Winter Meeting, University of Colorado at Boulder, Boulder, CO, 1994 Jan. 4-7.
- C-159 W-M. Boerner, Recent Advances in Ultra-Wideband Radar Polarimetry, Second Int'l Conference on UWB Short-Pulse Electromagnetics, Weber Research Institute, Polytechnic University, Brooklyn, NY, 1994 April 5-7.
- C-160 W-M. Boerner, New Results of Radar Polarimetry, Invited Review Paper, MIKON, KSIAZ, POLAND, 1994 May 30 - June 02.
- C-161 W-M. Boerner, E. Lüneburg, Y. Yamaguchi and J.Y. Dea, Basic Formulations of Wideband Polarimetric Vector Signal Processing, 1994 IEEE-ISAP/URSI-NRSM, Seattle, WA, 1994 June 19-24.
- C-162 W-M. Boerner, A.P. Agrawal, P.P.S. Wei and G.D. Nespor, Experimental Results of Rain-Backscatter Measurements with a Wideband Polarimetric Doppler Radar in the X-band, 1994 IEEE-ISAP/URSI-NRSM, Seattle, WA, 1994 June 19-24.
- C-163 E. Krogager and W-M. Boerner, A Revisitation of Some Basic Formulations in Radar Polarimetry, 1994 IEEE-ISAP/URSI-NRMS, Seattle, WA, 1994 June 19-24.

- C-164 Y. Yamaguchi, T. Nishikawa, M. Sengoku and W-M. Boerner, Two-Dimensional Imaging by an FM-CW Radar, 1994 IEEE-ISAP/URSI-NRSM, Seattle, Wa, 1994 June 19-24.
- C-165 W-M. Boerner, J.Y. Dea and E. Lüneburg, Development of Polarimetric Vector Signal and Tensor Image Metrology in Extra-Wideband Electromagnetic Sensing and Imaging, PIERS'94, ESA-ESTEC, Noordwijk, NL, July 11-15, 1994.
- C-166 E. Lüneburg and W-M. Boerner, Optimal Polarizations in Backscatter Radar Polarimetry and Its Relevance to Polarimetric Systems Metrology and Calibration, PIERS'94, ESA-ESTEC, Noordwijk, NL, July 11-15, 1994.
- C-167 E. Krogager and W-M. Boerner, A Revisitation of Some Basic Formulations of Vector Signal/Image Processing in Radar Polarimetry, PIERS'94, ESA-ESTEC, Noordwijk, NL, July 11-15, 1994.
- C-168 W-M. Boerner, E. Lüneburg and Y. Yamaguchi, Development of Optimization Procedures of the Polarimetric Covariance and Kennaugh Radar Backscatter Power Density Matrices to Target Enhancement Versus Clutter Rejection in POL-RAD Signal Analysis, PIERS'94, ESA-ESTEC, Noordwijk, NL, July 11-15, 1994.
- C-169 W-M. Boerner, H. Mott and E. Lüneburg, Development of Polarimetric Vector Signal and Tensor Image Processing in POL-RAD/SAR Analysis, IEEE-IGARSS'94, 1994 Aug. 8-12, CAL-TECH/JPL, Pasadena, CA, 1994.
- C-170 E. Krogager and W-M. Boerner, A Revisitation of Some Basic Formulations of Vector Signal/Tensor Image Processing in Radar Polarimetry, IEEE-IGARSS'94, 1994 Aug. 8-12, CAL-TECH/JPL, Pasadena, CA, 1994.
- C-171 J.S. Verdi, S. Krasznay, F. Ilseman, J.G. Teti and W-M. Boerner, Application of the Polarimetric Matched Image Filter to the Assessment of SAR Data from the Mississippi Flood Region, IEEE-IGARSS'94, Session: POL-II, Metrology, Calibration and Analysis, 1994 Aug. 8-12, CAL-TECH/JPL, Pasadena, CA, 1994.
- C-172 W-M. Boerner, E. Lüneburg and Y. Yamaguchi, Optimization of the Mueller [M] and Kennaugh [K] Power Density and the Covariance [Σ] Matrices for Analyzing Incoherent Rough Surface Scatter, IEEE-IGARSS'94, Session: POL-II, Metrology, Calibration and Analysis, 1994 Aug. 8-12, CAL-TECH/JPL, Pasadena, CA, 1994.
- 7h. Public Forums and Hearings (attended on behalf of the University of Illinois at Chicago and as a Private Citizen Residing within the 10th Congressional District of Illinois) (F-1 to F-25).
- F-1 1989, February 25: Public Forum on Fort Sheridan, Convened by the Honorable John E. Porter, Congressman (R:10th Congressional Distr., IL): **Presentation of the Concept of Creating a "Great Lakes Environmental, Ecological Graduate Education and Research Center for the Preservation of the Great Lakes Environment within Fort Sheridan"**, by W-M. Boerner, private citizen residing within 10th Congressional District of Illinois (on Forum Records, 5 min.).
- F-2 1989, April 22: Public Forum on "Education Reform: Raising America's Grade", convened by the Honorable John E. Porter, Congressman (10th Cong. Distr., IL), **"Raising America's Grade in Education Must Start by Educating Its People on How to Preserve Its Environment"**, by W-M. Boerner, private citizen residing within 10th Congressional District of Illinois (on Forum Records: 8 minutes).
- F-3 1989, May 13: Public Forum on **"Global Warning: Too Hot to Handle"**, convened by the Honorable John E. Porter, Congressman (R: 10th Congr. Distr. of IL) **"Both Military and Industrial Expansion and the Population Explosion must be**

Controlled: No Single Nation, Large or Small, Can Any Longer Indulge in the Luxury of Waging Military, Industrial and/or Population-Explosive Warfare and Instead We Must Learn to Refunnel all Available and Newly Committed Resources to the Environmental Clean-up Problem for the Global Benefit for a "Pan-Terrestrial Community of all World Citizens", i.e., we must rapidly advance the concept of "Global Environmental Planetary Defense" to become a strong integral component of our US Department of Defense (Dr. W-M. Boerner, 10 minutes on record).

- F-4 PUBLIC HEARING OF 1989 April 24th: 1-6 PM, Ft. Sheridan, Lake County, IL, Bldg. 31, Ballroom on "The Future Re-Use and/or Recommissioning of Fort Sheridan", convened by the Honorable John E. Porter, Congressman (R: 10th Congr. Distr. of IL) on behalf of the Fort Sheridan Consortium: "RECOMMISSIONING OF A SUBSTANTIAL PART OF FORT SHERIDAN TO HOUSE A "GREAT LAKES ENVIRONMENTAL & AERONOMIC GRADUATE EDUCATION & RESEARCH CENTER" IN A MARITIME CONSERVATION AND LAKEFRONT RECREATION PARK", UIC Public Statement of 1989 April 14, presented on behalf of the UIC Vice Chancellor for Research by Dr. Wolfgang-M. Boerner, Private Citizen and UIC Professor, Residing in the 10th Congressional District of Illinois.
- F-5 PUBLIC HEARING of 1989, May 30: to discuss "THE SCOPE OF AN ENVIRONMENTAL IMPACT STATEMENT (EIS) ON THE PROPOSED CLOSURE OF FORT SHERIDAN, LAKE COUNTY, IL", convened by the Department of the Army, US Army Engineer District, Louisville Corps of Engineers, Dr. Robert G. Fuller, Acting Chief, Planning Division, Environmental Analysis Branch/Public Note #89-LD/PD-010): "RECOMMISSIONING OF A SUBSTANTIAL PART OF FORT SHERIDAN TO HOUSE A "GREAT LAKES ENVIRONMENTAL & AERONOMIC GRADUATE EDUCATION & RESEARCH CENTER" IN A MARITIME CONSERVATION AND LAKEFRONT RECREATION PARK", UIC Public Statement of 1989 April 14, presented on behalf of the UIC Vice Chancellor for Research by Dr. Wolfgang-M. Boerner, Private Citizen and UIC Professor, Residing in the 10th Congressional District of Illinois.
- F-6 PUBLIC HEARING of 1989, June 16: to discuss the responsibilities and judicial rights for the members of the "FORT SHERIDAN COMMISSION", and the incorporation of the Commission: To form a group of local, state and federal officials, as well as, private citizens, to facilitate and promote the creation of a consensus land re-use plan for the Fort Sheridan, Lake County, IL., after it converts from military to civilian use.
- F-7 PUBLIC HEARING of FORT SHERIDAN COMMISSION, 1989 October 07: Establishment of Commission Panels and Election of Panel Members (W-M. Boerner, member of EDUCATION PANEL, & PANEL OF THE ADVOCATES FOR THE PUBLIC INTEREST IN FORT SHERIDAN).
- F-8 PUBLIC FORUM, FORT SHERIDAN COMMISSION, EDUCATIONAL & ENVIRONMENTAL PANELS, 1990 December 07: Presentation of Position Paper by W-M. Boerner, on the NEED FOR THE ESTABLISHMENT OF AN INTERNATIONAL & JOINT US-CANADIAN FACILITY OF THE MIDWEST FOR EDUCATION, RESEARCH TECHNOLOGY AND PRESERVATION IN GREAT LAKES CLIMATOLOGY, ECO- SYSTEMS, COSTAL & MARINE ENVIRONMENTS AT FT. SHERIDAN, LAKE COUNTY, ILLINOIS (Submitted to FSC on 1990 January 29).
- F-10 PUBLIC FORUM, FORT SHERIDAN COMMISSION, EDUCATIONAL PANEL, 1990 February 13: Presentation of Position Paper on the "ROLE OF EDUCATION", in the future re-use of Ft. Sheridan by W-M. Boerner.
- F-11 INVITATION by the International Joint Commission, Great Lakes Science Advisory Board, Council of Great Lakes Research Managers, ELEVENTH MEETING OF THE COUNCIL OF GREAT LAKES RESEARCH MANAGERS, US EPA, Large Lakes Research Station, Grosse Ile, MI, 1990, March 8 - to - 10; COMMISSION on the ESTABLISHMENT of an

INTERNATIONAL CENTER FOR GLOBAL RESEARCH: (1) The Creation of International Science, Technology and Environmental Preservation Parks, Cities, Metropolises and Meglipoles in Japan and FR Germany; (2) "FORT SHERIDAN: Could it serve as ideal location for the Establishment of the INTERNATIONAL JOINT US-CANADIAN CENTER FOR GLOBAL ENVIRONMENTAL RESEARCH WITHIN THE GREAT LAKES".

- F-12 PUBLIC FORUM, FORT SHERIDAN COMMISSION, EDUCATIONAL & ENVIRONMENTAL PANELS, 1990 April 26, Presentation of Position Paper on "Role of Education in Global Environmental Planetary Defense", in the future re-use of Ft. Sheridan by W-M. Boerner.
- F-13 PUBLIC HEARING OF FORT SHERIDAN COMMISSION, 1990 May 31, Submission of a position paper on the "NEED FOR THE ESTABLISHMENT OF AN INTERNATIONAL & JOINT US-CANADIAN FACILITY OF THE MIDWEST FOR EDUCATION, RESEARCH TECHNOLOGY AND PRESERVATION IN GREAT LAKES CLIMATOLOGY, ECO-SYSTEMS, COASTAL & MARINE ENVIRONMENTS AT FT. SHERIDAN, LAKE COUNTY, ILLINOIS", presented to FSC.
- F-14 Elected "US NAVY ASEE (American Association for Engineering Education), SFRP (Summer Faculty Research Program), Distinguished Senior University Fellow (award) on "Ultra-wideband Electromagnetic Wide Area Environmental Surveillance of the Ocean Sea Surface and Coastal Regions, for the Instantaneous Localization, Ranging, Detection Specification and Identification of Environmental Pollutants and Naval Threats", Naval Ocean Systems Center, San Diego, CA, 1990 June 01 - Sept. 30 (in collaboration with NWC, PMTC, NADC, DTRC, NRL, NSWC, NCSC, NOARL, MI-COM, LANL and RADC): Presentation of various position papers on the urgent need for upgrading priorities on Global Planetary Defense versus National Defense issues.
- F-15 Elected Official Delegate on behalf of UIC and the Illinois State Governor's Office, for the US-USSR Environmental Preservation Program on "Save the Terrestrial Large Lakes: Save the Great Lakes Baikal/Michigan Environmental Theatre Festival", Ulan Ude and Baikal Lake, Buryato, Southeastern Siberia, USSR, 1990 Aug. 18 - Sept. 04, Presentation of Several Position Papers during Environmental Scientific Workshops and Retreats.
- F-16 INVITATION by the International Joint Commission, Great Lakes Science Advisory Board, Council of Great Lakes Research Managers, TWELFTH MEETING OF THE COUNCIL OF GREAT LAKER RESEARCH MANAGERS, ECOSYSTEMS MODEL WORKSHOP, Milwaukee, WI, 1990 Dec. 4-6; International Global Environmental Assessment Commission Panel, "The Boreal Large Lakes - Environmental/Ecological Research Exchanges: Great Lakes - Lake Baikal".
- F-17 PUBLIC TESTIMONY PRESENTED ON BEHALF OF THE UNIVERSITY OF ILLINOIS AT CHICAGO DURING THE PUBLIC HEARING ON FORT SHERIDAN, Saturday, 1991 February 23, 10:00 - to - 18:00 on the topic of:

RECOMMISSIONING A SUBSTANTIAL PART OF FORT SHERIDAN TO HOUSE AN INTERNATIONAL "GREAT LAKES CENTER" FOR ENVIRONMENTAL, ECOLOGICAL, AERONOMIC & CLIMATOLOGIC EDUCATION, RESEARCH, POLICY & ARTS IN A MARITIME CONSERVATION AND LAKEFRONT RECREATION PARK: "THE FORT SHERIDAN GREAT LAKES CENTER" in coordination with establishing all wet-bed environmental laboratories within the nearby WAUKEGAN HARBOUR site, of Lake County, Illinois; with the objective to:

REQUEST FROM THE FEDERAL GOVERNMENT THE RECOMMISSIONING BY DONATION OF THE ENTIRE FACILITY FOR SAID PURPOSE WITH SHARED STATE, FEDERAL & INTERNATIONAL SUPPORT FOR CONTINUING FUTURE OPERATION AND FACILITIES MAINTENANCE (Detailed Position Paper: 16 pages/attached to this Report).
- F-18 INVITATION TO ATTEND 'DEFENSE INDUSTRY and THE ENVIRONMENTAL AGENDA - SYMPOSIUM'91, Oct 9-10 on "Defense Technology Applications for a Cleaner Environment'

for presentation of Working Group (Defense and the Environment) exposition:
FROM MILITARY TO PLANETARY ENVIRONMENTAL DEFENSE, The National Security
 Industrial Association, NSIA-Dep EN, Suite 300, 1025 Connecticut Div. NW,
 Washington, DC 20036. (See [w-64]).

- F-19 **PUBLIC FORUM, FORT SHERIDAN COMMISSION, PANEL ON RE-USE OF HISTORICAL DISTRICT**,
 Presentation of Position Paper on: "The Establishment of 'GLICER' within the
 Ft. Sheridan, Historical District", Fall 1991, Forum, Fort Sheridan, Lake
 County, Illinois.
- F-20 **PUBLIC TESTIMONY** to be presented during forthcoming **PUBLIC HEARING ON THE FORT
 SHERIDAN, HISTORICAL DISTRICT** — Reuse Options: 'Establishment of 'GLICER'
 within the 'Historical District of Fort Sheridan', 1991 April.
- F-21 **PUBLIC FORUMS, FORT SHERIDAN COMMISSION, Panel on Reuse of HISTORICAL DISTRICT**,
 Discussions on Position Paper "CLICEREP", April/October/November 1991.
- F-22 **US ARMY CORPS OF ENGINEERS, ENVIRONMENTAL ASSESSMENT** (for the Disposal and
 Reuse of Fort Sheridan) **PUBLIC SCOPING A MEETING**, Presentation of Position
 Paper:

**REQUEST FOR INJUNCTION ON ALL CURRENT RE-USE DECISIONS
 ON FORT SHERIDAN, LAKE COUNTY, ILLINOIS
 (prepared by W-M. Boerner on 1991 December 18)**

- F-23 **US DEPARTMENT OF EDUCATION, Panel on Educational Reuse of Decommissioned
 Military Base Facilities**, April, 1992.
- F-24 **NRC Workshop on the Establishment of the National Institutes for the
 Environment**, May 1992.
- F-25 **FORT SHERIDAN REUSE COMMISSION, Quarterly Forums Public Scoping Meetings**,
 1992/1993/1994.

7i. Academy Memberships (A-1 to A-2), Honors and Citations Awarded (H-1 to H-38)

- | | | | |
|-----|--|--|------|
| A-1 | Acad. Sci.
RAS-RAT | Russian Academy of Transportation
Sciences (Communications, Remote
Sensing and Navigation) within the
Russian Academy of Sciences (RAS)
Moscow, Russia | 1993 |
| A-2 | Corresponding
Member
(ANF) | Académie Nationale Française
(Electronic Communications, Sensing
& Imaging, Navigation)
Paris, France | 1993 |
| H-1 | Alexander von Humboldt-Stiftung (FR Germany), Senior U.S. Scientist Award, the
Humboldt (Preis) Award, in recognition of past accomplishments in research and
teaching, and for the promotion of scientific cooperation between DFVLR-Oph.
(Dr. Wolfgang Keydel) and the U.S.; awarded for a nine month period, beginning
July 1, 1986 (executed: 1987, Jan. 1 - July 31; 1988 Aug. 15 - Oct. 15; 1989
April; 1989, Nov. 1-15). | | |
| H-2 | The Japan Society for the Promotion of Science, US Senior Scientist Fellow
Award, for the "Advancement in Electromagnetic Imaging and Radar Polarimetry",
August 1, 1986; renewed 1988 August (for three years). | | |
| H-3 | The Royal Society of Norway, US Senior Scientist Fellow Award, for the | | |

"Advancement of Radar Polarimetry in High Resolution Radar Imaging", Feb. 1987, Summer 1990 (3 months).

- H-4 The Chinese Academy of Science and Technology, Senior Scientist Fellow Award, May 1988 (Xian/Beijing, P.R. China) for "The Advancements of Electromagnetic Inverse Scattering".
- H-5 The Polish Academy of Science, 1988 National Award to Senior International Scientists for the "Advancement of Inverse Methods in High Resolution Radar Imagery", October 1988 (Gdansk/Warszawa, Poland).
- H-6 The USSR Academy of Science, Lenin Medal for Scientific Achievement, 1989 May 17/May 21, Moscow/Leningrad for promotion of "Direct and Inverse Methods in Radar Polarimetry".
- H-7 The University of Illinois Senior Scholar Award: 1989 - 1992, 1988 July 15, for the advancement of "Direct and Inverse Methods in Radar Polarimetry".
- H-8 Election into "Electromagnetics Academy" for contributions to "Direct and Inverse Methods in Radar Polarimetry", 1989 Dec. 15.
- H-9 Appointment to Great Lakes Science Advisory Board, Council of Great Lakes Research Managers, International Joint (US-CANADA) Commission, 1990-1993.
- H-10 The US NAVY-ASEE-SFRP-Distinguished Senior Professor Award (1990-1991), 1990 April.
- H-11 Official Delegate on behalf of UIC and the Illinois State Governor on the Illinois delegation for the "Save the Great Lakes Baikal/Michigan Environmental Theatre Festival" with Environmental Expert Retreats, Lake Baikal and Ulan Ude, Buryat, Siberia, USSR, 1990 August 17 - September 04.
- H-12 The International Information Science Foundation of Japan Senior Scientist Award on "USA-Japan Research Interaction and Exchange of Advanced Research in Information and Sensing Sciences on "Radar Polarimetry and Diffraction Tomography and on "Seismo-electromagnetology", 1990 September 07 - October 03.
- H-13 Elected and Appointed Member, Advisory Board, Baikal International Center for Ecological Research (BICER), Lystianka, Lake Baikal, East Siberia, USSR (1991-1996).
- H-14 Appointed by US Congressional Committee on US Military Base Closures for determining the "RE-USE OF THE HISTORICAL SECTION OF FORT SHERIDAN AS A GREAT LAKES INTERNATIONAL CENTER FOR ENVIRONMENTAL RESEARCH, EDUCATION & POLICY", 1991 February 28.
- H-15 The US NAVY-ASEE-SFRP-Distinguished Professor Award (1991-1992), 1991 March 15.
- H-16 The Polish Academy of Sciences, Invitation to present a major keynote address during 'Plenary Sessions of MIKON'91 with selected title of "Radar Polarimetry", Rydzyna Castle, Poland, 1991 May 22.
- H-17 Invitation by the Planning Committee of the Int'l Conference on Electromagnetics in Aerospace Applications (ICEAA'91) for organizing a SPECIAL FULL-DAY PROGRAMME WITH two Double-Sessions on "Radar Polarimetry - Theory, Metrology, Calibration, Technology, Data Processing and Applications, ICEAA'91, Torino, Italia 1991 Sept. 17-20, (Thursday, 1991 Sept. 19).
- H-18 The NATO-AGARD/EPP (Electromagnetic Propagation Panel), Invitation for the

presentation of four(4) INVITED papers at the Symposium on 'Remote Sensing of the Propagation Environment, ÇESME-İZMİR, Turkey, 1991 Sept 30 - Oct 04.

- H-19 **The Second SANKT-PETERSBURG CONFERENCE ON HIGHER EDUCATION IN EUROPE**, Research Vessel Cruise on ONEZHNSKOJE and LADOZHNSKOJE Lakes, Karelia, C.I.S., **INVITED DELEGATE & SPEAKER**, St. Petersburg, University of Science & Technology (formerly: LIAP), 1992 June 24-29.
- H-20 1992 Joint International IEEE-APS, URSI-USNC and NEMP Symposium, Chicago, Illinois, Hyatt Regency-Chicago (Lakeshore) Hotel, 1992 July 18-25, **VICE-CHAIR** (1750 participants), **Chairman Radar Polarimetry Sessions** (six non-overlapping sessions, Monday to Wednesday, 92 July 20-22).
- H-21 1992 International SPIE OE/OSE Symposium, SAN DIEGO, 1992 July 19-24 Radar Polarimetry Conference, (5400 participants), **VICE-CHAIR** (six no-overlapping double sessions, 1992 July 23-24 - 48 participants).
- H-22 1992 ASIA-PACIFIC MICROWAVE CONFERENCE (APMC'92), Adelaide, South Australia, 1992 August 10-14, **INVITED Chairman of Special Workshop on 'Wideband Polarimetric Radar Sensing and Imaging'**, 1992 August 14 (University of South Australia Campus).
- H-23 JIPR-2, 1992 (Second) International Radar Polarimetry Workshop in France, University of Nantes, **INVITED KEYNOTE SPEAKER**, member of program committee 1992 September 8-10.
- H-24 ISAP'92, Fifth International Symposium on Antennas and Propagation, Sapporo, Hokkaido, Japan, 1992 September 21-25, Senior International Correspondent and Invited Coordinator of Special Sessions on "Direct and Inverse Methods in Radar/Lidar Polarimetry.
- H-25 Academician of Transport, The Russian Federation Academy of Transport within the C.I.S. Academies of Sciences (formerly USSR Academia Nauk), Certificate No. 148, 1992 Sept. 14, for contributions to: (1) global environmental remote sensing; (2) radar polarimetry in aviation and maritime traffic control; (3) for international cooperation in transport, 1992 September.
- H-26 Corresponding Member, L'Academic Nationale Francaise, Paris, France, nominated for the advancement of radar polarimetry, 1992 September.
- H-27 AAAS Fellow Grade, Citation: for the advancement of polarimetric doppler radar theory, metrology and signal-and-image processing with application to environmental remote sensing, 1992 October.
- H-28 OSA Fellow Grade, Citation: For the Advancement of Optical (LIDAR) and Microwave Radar Polarimetry, 1993 March.
- H-29 The US NAVY-ASEE-SFRP-Distinguished Senior Professor Award (1993): Naval Air Warfare Center, 1993 April: High Resolution Polarimetric Imaging of Low RCS Objects in Rough Dynamic Ocean Sea Surface Scatter Scenarios.
- H-30 The Sankt-Petersburg Conference on Higher Education in Europe, Research Vessel 'Aleksander Ulajanov', 1993 July 04-08.
- H-31 Co-chair, Technical Papers Committee, PIERS'93, CAL-TECH, Pasadena, CA, 1993 July 12-16.
- H-32 US National Delegate, URSI General Assembly, Kyoto, Japan, 1993 August 25 - September 02.

- H-33 NSF-NCAR/ATD, Advisory Committee on Polarimetric Doppler Meteorological Radar Facilities Upgrades, 1993 Nov.
- H-34 MIKON, X. Int'l Microwave Conference, Ksiaz, Poland, 1994 May 30 - June 4.
- H-35 IEEE-APS Symposium & URSI-USNC Radio Science Conference, Technical Program Committee 1994, Seattle, WA, 1994 June 19-24.
- H-36 PIERS'94, ESA-ESTEC, TPC-member, Noordwijk, NL, 1994 July 11-15.
- H-37 IEEE-IGARSS'94, Technical Program Committee, Co-Chair, URSI-F, CAL-TECH/JPL, Pasadena, CA, 1994 Aug. 8-12.
- H-38 US NAVY-ASEE-SFRP engagement with NAWCADWAR, Code 50C, POL-SAR Image Interferometry, 1994 May 10 - Aug. 12.

7j. Grant/Contract/Prize Award Evaluation: During the past ten years in average, I was asked to review and evaluate two (2) to three (3) proposals/nominations per month and to participate in site facility evaluations about twice a year.

North America: NSF, NCR, NASA, EPA, NOAA, IEEE, APS, OSA, MacArthur.

International: NATO-SEAD, ISF, JSPS, DAAD, ESA, MOD(UK), NTNF(NO), DDRE(DK), SHAPE, IOC, EC, UNO-UNEP, IMORI, Heinrich Hertz, A. von Humboldt, Royal Society, Nobel Committee.

7k. Editorial, National and International Review Boards, (N-1 to N-18)

k.1 Member of Editorial Boards

- 1980-1986 Editorial Board of IEEE Transactions on Antenna and Propagation (2 terms).
- 1983- Editorial Board: International Institute of Physics (ICO, Bristol, UK), Inverse Methods (1983-1994), Advances in Modern Physics (1993).
- 1990- Board of Editors, International Series & Monographs on Advanced Electromagnetic Wave Theory & Applications, Science Publishers, Tokyo/London.
- 1991- Editorial Board: SPIE Proceedings on Sensing and Imaging.
- 1992- Editorial Board: International Remote Sensing Society, EARSeL, Advances in Remote Sensing.

k.2 Editorships; occurred: 10, (in progress: 3)

- E-1 IEEE, Antennas & Propagation Society, Transactions, **Associate Editor** (Inverse Methods and Imaging), January 1980 to December 1986.
- E-2 IEEE, Transactions Antennas & Propagation, Vol. 29(2), 1981 Special Issue, Inverse Methods in Electromagnetics, **Guest Editor**, 1980-1981, (417 pages).
- E-3 NATO Advanced Research Workshop on "Inverse Methods in Electromagnetic Imaging", September 18-24, 1983, Proceedings, **Chief Editor**, 1982-1984, (1400 pages), D. Reidel Publ. Co., Jan. 1985.
- E-4 Royal Society of Physics (UK), Journal of Physics, Section E, **Co-Editor** (Dec. 1983 to Dec. 1988) (new: First International) Inversion Methods in the Physical Sciences, **Associate Editor** (electromagnetic/vector), Dec. 1988 to Dec. 1994.

- E-5 W-M. Boerner, et al. (eds.) NATO, Advanced Research Workshop on Direct and Inverse Methods in Radar Polarimetry, Sept. 18-24, 1988, Proceedings, Chief Editor, 1987-1991, (1,938 pages), NATO-ASI Series C: Math & Phys Sciences, Vol. C-350, Pts 1&2, D. Reidel Publ. Co., Kluwer Academic Publishers, Dordrecht, NC 1992 Feb. 15.
- E-6 W-M. Boerner, H. Überall, (eds.), SOC-MOTH(NATO), Advanced Research Short Course, Vector Inverse Methods in Radar Target/Clutter Imaging, Co-Editor, Proceedings ARSC, Ecole Supérieur d'Electricite, Gif-sur-Yvette, France, 1986, Sept. 1-4, Springer Verlag, Heidelberg, 1992, total pages: 428.
- E-7 L.W. Root, B.L. Matkin and W-M. Boerner, (eds.) Proceedings of the Third Polarimetric Radar Technology Symposium, (3 Vol.) 1988 August 12-16, Rocket Auditorium, US Army Missile Laboratory, Redstone Arsenal, AL, GACIAC, IIT-RI, Chicago, IL, August 1990.
- E-8 S.J. Anderson and W-M. Boerner, eds., Wideband Imaging and Sensing Polarimetry, WISP Workshop Proceedings, Aug. 12-14, SPRI, University of South Australia., Adelaide, Australia, Aug. 1992.
- E-9 W-M. Boerner and J. Saillard, Proceedings Radar Polarimetry, JIPR-2 92 Sept. 8-10: Contributions by W-M. Boerner, University of Nantes, IRESTE-S2HF, Nantes, 1992 (Sept).
- E-10 H. Mott and W-M. Boerner, eds., SPIE'92 July 22-24, Radar Polarimetry Workshop, San Diego, CA, SPIE Proceedings, Vol. 1748, Feb. 1993.
- E-11 Invited Editor, Special Issue on "Theory, Metrology, Vector Signal Processing of Radar Polarimetry and its Applications", European Transactions on Telecommunications - and Related Technologies, Summer 1994 Issue (15 papers in progress).
- E-12 Invited Editor, Special Issue on "High Resolution Radar Imaging", Proceedings of the Institute of Electrical Engineering (IEE), UK, Spring 1995 (12 papers in progress).

k.3 Reviewer for (60+) International Scientific/Technical Journals

Average number of papers reviewed for last three years per month: six to eight; in addition to ongoing editorial duties. Contributions by PDFs, Visiting Scientists and Senior Post Graduate (Ph.D. level) research assistants are gratefully acknowledged.

- 1970- Archiv für Elektronik and Übertragungstechnik
- 1971- Radio Science
- 1972- IEEE Transactions on Antennas & Propagation (Assoc. Ed.: 1980-1986)
- 1973- Canadian Journal of Physics
IEEE Transactions on Microwave Theory & Techniques
- 1974- IEEE Transactions on Aerospace & Electronic Systems
IEEE Proceedings
Frequenz (FRG)
- 1975- Nachrichtentechnische Zeitung (NTZ)
Optical Engineering
Applied Physics, Springer Verlag
Institute for Scientific Information (IAI-Philadelphia, PA)

1976- Applied Optics
IEEE Transactions on Geosciences & Remote Sensing
Optica Acta
Zentralblatt für Mathematik (article/book reviews)

1977- Optics Communication
Optics Letters
J. Optical Society of America

1978- IEEE Transactions on Biomedical Engineering
IEEE Transaction on Ultrasound

1979- Utilitas Mathematica
SIAM Journal of Applied Mathematics

1980- Journal of the Franklin Institute
Mathematical Review (paper reviews)

1981- Journal of Engineering Science
IEEE Transactions on Aerospace & Electronic Systems

1982- Optik
IEEE Transactions on Oceanographic Engineering

1983- IEE Proceedings-F Communications, Radar & Signal Processing
1983- New International Journal on Inverse Methods
(Assoc. Editor: 1983-1988), Editorial Board (1989-1994)

1984- International Journal of Microwave Remote Sensing
IEEE Transactions on Communications and Information Theory

1986- Journal of Mathematical Physics

1987- Wave Propagation

1988- J. Geophysical Review
Journal of Electromagnetic Waves and Applications

1989- Physics the Earth and Planetary Interiors
Geophysical Research Letter

1990- Journal of Geomagnetic Geoscience (Japan)
Japanese Journal of Electrical & Communications Engineering

1991- Journal of Advances in Remote Sensing
Journal of Geophysics

1992- International Journal of Remote Sensing
Canadian Journal of Remote Sensing

1993- Journal of the Acoustical Society of America
Journal of Space Physics
IOC, Advances in Modern Physics (Editorial Board)

1994- AIEE Proceedings on Electronic & Electric Engineering (Australia)
IEICE (Japan) Transactions on Communications

- N-1 1989 Nov. 7-9: Institute Review, German Aerospace Research Establishment, Electromagnetic Probing and Remote Sensing Division, DFVLR-NE-HF, Oberpfaffenhofen, FRG-West Germany (Elected Member by FRG-Ministry of Science & Technology, DFG and DLR-OPH) (1989 - present: member, advisory board);
- N-2 1989 Nov. 8-present: Elected Member, Board of Planners, FRG Science & Technology Metropolitan Park Grossraum München Project, Planning Committees Meeting, Commission: Environmental Preservation, 1989 Nov. 8-10, Oberpfaffenhofen, FRG.
- N-3 1989 Nov. 15-present: Appointed Member, Board of Planners, Kansai Science City Project, Planning Board — C: Universities, Subcommittee Environmental Preservation, Kyoto, 1989 November 15-17, Kyoto, Japan.
- N-4 1990 March 01-04: US Department of Defense, Panel for Evaluating Applicants to the National Defense Science & Engineering Graduate Fellowship Program, Battelle RTP Office, 1990 March 2-4.
- N-5 1990 March 08-10: Int'l Joint Commission, Great Lakes Science Advisory Board, Panel on Education and Research, US EPA, Large Lakes Research Station, Grosse Ile, MI, Saturday, 1990 March 10.
- N-6 1990 June 01 - September 30: US Navy/DARPA Advisory Panel on Ultrawideband Impulse Radar Theory, Metrology and Technology.
- N-7 1990 December 4-6: Int'l Joint Commission, Great Lakes Science Advisory Board, Ecosystem Model Workshop, Milwaukee, WI.
- N-8 1990 December 15-present: (Standing Advisory Committee), Baikal International Center for Ecological Research, Lystianka, Lake Baikal, Irkutsk Region, RSR of Siberia.
- N-9 1991 September 24-present: FRG, Ministry of Science & Technology, Advisory Committee on the "Integration of former DDR, Akademie der Wissenschaften, Forschungs- Institute Berlin-Adlershof" into DLR-Research Centers", and the "Establishment of the DLR Institute for Terrestrial & Planetary Remote Sensing at Berlin-Adlershof".
- N-10 1991 October 8-present: Kultusministerium des Freistaates Sachsen, Advisory Committee for the Integration of all of the eight(8) major Institutes of Secondary Education of Dresden, Saxony into the "Universität Dresden", Subcommittee on the Integration of Technical Institutes (TUD and HSWV).
- N-11 1992 February 6-8: US Department of Defense, Panel for Evaluating Applicants to the National Defense Science & Engineering Graduate Fellowship Program, Battelle RTP Office, Research Triangle Park, NC, 1992 February 6-8.
- N-12 1993 January 08-10: The NSF and CSU-EE&AS/CHILL Radar Instrumentation Facilities Review for the Expansion of the CSU-EE&AS/CHILL-Radar Facility, 1993 Jan. 08-10, Ft. Collins, CO (INVITED EXPERT CONSULTANT on Polarimetric Meteorological Radar Technology) 1993 January.
- N-13 Member and Chair of 'Polarimetric Radar Meteorology Theory Panel, N-SF-NCAR/UCAR-NOAA.ERL/WPL Committee on the Upgrading of the Antenna System for the CSU-CHILL Polarimetric C-Band Doppler Radar Meteorological Instrumentation Facility at the Greely Municipal Airport of Fort Collins, CO.
- N-14 1993 February 19-21: US Department of Defense, Panel for Evaluating Applicants to the National Defense Science & Engineering Graduate Fellowship Program,

Battelle RTP Office, Research Triangle Park, NC, 1993 February 19-21.

- N-15 Member, Int'l Evaluation Committee, 10C - Panel on Extra-wideband Acoustic, Electromagnetic and Seismogenic Sensing & Imaging in Wide Area Surveillance of the Terrestrial Environment, May 1993.
- N-16 NASA/ESA:SIRC-XSAR Shuttle SAR Systems Evaluation Committee, 1994, Jan. 14-16, (NASA-JPL, Pasadena, CA).
- N-17 Member of Technical Evaluation Committee of NSF-NCAR Design Proposal for Portable POL-DOP S-Band Meteorologic Radar Facility, NCAR0Foothills Laboratory, Boulder, CO, 1994 Feb. 21-24.
- N-18 ARPA Special Committee on the Development of In-flight and Repeat-Track, Airborne and Sapce, POL-SAR Image Interferometry, Member, NAWCADWAR (50C) Team, 1994 April 12-16.
- 71. M.Sc. Theses Supervised (m-1 to m-14) C.Sc. Completed
 - m-1 X-Q. (Bill) Huang, "Lambert Mollweide and Aitoff Hammer Projections of the Polarization Sphere Mercator and its Application to Radar Polarimetry", M.S. Thesis, May 1995.
 - m-2 Huang, S-M. "Application of Kennaugh's Polarization-Corrected Inverse Scattering Identity to Radar Target Shape Reconstruction Based on Radon Transformation Theory for the Limited Angle Case", M.S. Thesis, March 1986.
 - m-3 James, B. "Vector Diffraction Tomography using Radon Transform Techniques in Computer-Assisted Electromagnetic Imaging", Jan. 1987.
 - m-4 Okeke J.O., "Polarimetric Ocean Surface Scatter Analysis in Terms of the Physical Realizability of Mueller Matrices", May 1988.
 - m-5 Soliman, N.A., "Analysis of Depolarizing Effects in Vector Diffraction Tomography", Jan. 1989.
 - m-6 Vilasouso, R., "Analysis of Polarimetric Sea-Ice Scatter Measurement Data", Spring 1990 Dhiantravon Yuadkoun, Polarimetric Analysis of Millimeter-wave Backscatter from Metamorphic Snow-Ice Packs", (Failed and Terminated: 1990 Jan. 15).
 - m-7 Yan, W-L., "Optimal Polarization States of the Stokes Reflection Matrices $[\vec{M}_p]$ and the Mueller Matrices $[M]$ ", May 1991.
 - m-8 Yuadkoun D. Dhiantravan, Polarimetric Analysis of Backscatter from Snow-Ice-Fields at MMW, (failed and terminated: 1990 Sept.).
 - m-9 Grant W. Reichard, Polarimetric Applicator (IR) for Thickness Measurements in Alloy-sheet Production, April 1992.
 - m-10 Machida, M., Polarization transformation effects in Vector Diffraction Tomography - An Experimental Identification, M.Sc. Thesis (initiated at UIC-EECS/CSL: 1989-90) Graduate, Niigata Univ., Niigata, Japan, 1990.
 - m-11 Walther, M., The Concept of the Polarimetric Matched Signal and Image Filters: Application to Radar Target Versus Speckle Reduction & Optimal Background Clutter Discrimination in Microwave Sensing and Imaging, May 1993.
 - m-12 Liu, C-L., "The Definition of the Relative and Absolute Phase Relation of the Transformation Matrices in Radar Polarimetry", Spr. 1993.

- m-13 Nishikawa, T., The Development of the Polarimetric FM-CW SAR Concept, Niigata University, Japan (M.Eng.), Aug. 1993.
- m-14 Yakayanagi, Y., The Polarimetric Enhancement of Multiple Radar Channel Imagery, Niigata University (M.Eng.), Sept. 1993.

7m. Ph.D. Theses Supervised (d-1 to d-15) Ph.D. Thesis Completed

- d-1 A.P. Agrawal, "A Model-Free Polarimetric Clutter Description Derived from Kennaugh's Target Characteristic Operator Theory Formulated in Coherency Matrix Notation", May 1987.
- d-2 B-Y. Foo, "Application of the Vector Extension of Kennaugh's Transient Target Impulsive Response Method to 3-Dimensional Target Imaging Using High Resolution Polarimetric Radar Measurement Data", Jan. 1987.
- d-3 G. Wanielik, "Vector Signal Description Models and Processing for a Polarimetric Pulse Compression Radar System", (Dr. Ing. Dissertation, Supervised in collaboration with Ord. Professor Dr. Ing. Habil Werner Wiesbeck, VHF & Microwave Electronics, Sensing & Imaging, University of Karlsruhe, FRG, June 15 1988).

Dr.Sci./Dr.-Ing. (International Co-Offender (co-supervised))

- d-4 Ernst Krogager, Aspects of Polarimetric Radar Imaging, Danish University of Technology, Lyngby-Kopenhagen Denmark, 1993 June 27 (Dr.Sci.Techn. - Denmark). Aleksander Friedland, Statistical Radar Polarimetry, Moscow State Technical University of Civil Aviation and Space Technology (MIIGA), Moscow, 1993 June 29 (Dr.Techn.Sci - Russia).
- d-5 Vladimir Ivanovich Karnyshev, Application of the Polarimetric (Affine Polarization Basis) Radar to Target Recognition, Tomsk Institute for Automatic Control and Signal Research, Tomsk State Technical University, Tomsk, W. Siberia 1993 July 02 (Dr.Techn.Sci. - Russia).
- d-6 Ichihiko Tomizawa, Ground-Based, Airborne and Space Observations of ULF/ELF/VLF Signature Generated by Electric Powerline (Harmonics) Radiation and by Seismogenic Emissions During Tectonic Stress Changes, Sugadaira Space Wave Observatory, University of Electro Communications (Denki Tsushin Daigaku), Chofu-Shi/Tokyo, Japan, 1993 Sept. (Dr.Eng.Sci. - Japan).
- d-7 Volker Ziegler, Radar polarimetrische Verfahren zur erd- und satellitengestützten Niederschlags-erkundung, Technical University of Karlsruhe, Karlsruhe, FR Germany, 1993 July (Dr.-Ing. - Germany).
- d-8 Jean François Diouris, Récepteur adaptif multicapteur pour communications radio mobiles, L'Université de Rennes I, 1993 Nov., (Dr.-Techn. - France).

Ph.D. Theses in Progress

- d-9 Soliman, N.A., "Reinterpretation of Inverse Synthetic Aperture Radar Methods in Terms of Fourier-Radon Projection Theory", 1992.
- d-10 Chan, C-Y., "Calibration Methods for Dual Polarization Radar Metrology", 1991.
- d-11 Lempkowski, R.B., "Design of Broadband Dual Polarization Radar Imaging Systems", 1993.

- d-12 Mirmira, V.K.S., "A Reassessment of the Target Eigen-Resonance Method and the Creeping Wave Concept in Electromagnetic Inverse Scattering for Target Shape Reconstruction in the Umbra REgion", (currently: Institutionalized), reinstated Sept. 1991.
- d-13 Wei-Ling, Yan, "Optimal Polarization State Theories of Isolated and Distributed Targets for the Coherent and Partially Coherent Cases", 1993.
- d-14 Xi, An-Qing, A Unified Approach for the Optimization Procedures for Radar Scattering Matrices for the Coherent and Partially Coherent Cases", 1993.
- d-15 Liu, Chuan-Li, Time-domain Analysis of Polarization State Descriptors in Transient Polarimetric Doppler Radar Sensing and Imaging, 1993.
- d-16 Kao, Tsung-Ta, Development of Graphical and Visual Methods for Polarimetric Radar Target & Clutter Signature Display, 1994.
- d-17 Xu, Wei, A Unified Approach to Bi-static Physical Optics Vector Inverse Scattering, 1994.
- d-18 Yin, Deng-Xie, The Torsional Terms in the Polarization-Extended Kennaugh Target Ramp Response P.O. Inverse Scattering, 1995.
- d-19 Zhang, Yin, A group-theoretic approach to the optimization of radar scattering matrices, 1994.
- d-20 Vivek A. Naik, Application of the Polarimetric Matched Image Filter Approach to the Optimization of Image Contrast, Speckle Reduction and Image Quality Restoration in POL-SAR Imaging.

7n. Post-Doctoral Fellows and Visiting Scientists Hosted (*Supported by Contracts to UIC-EECS/CL) (f-1 to f-16):

- f-1 Dr. Arthur K. Jordon, Adjoint Associate Professor, (Inverse Methods), US Navy, Naval Research Laboratory, Washington, D.C. (1983-1987).
- f-2 *Dr. Sujeet K. Chaudhuri, Vis. Assoc. Prof., (Inverse Scattering), University of Waterloo, Waterloo Ontario/Canada, (1984-1988).
- f-3 *Dr. Lin Shi-Ming, Visiting Assoc. Prof., (Inverse Scattering & June 19988 Radar Polarimetric), Xidian University, Xidian, Shaanxi Province, P.R. China, (1985-1986).
- f-4 *Dr. Alexander B. Kostinski, PDF, (Radar Polarimetry and Ellipsometry), UIC Physics Dept., Chicago, IL, (1985-1899).
- f-5 *Dr. David W. Carnegie, PDF, (Radar Polarimetry), UIC Physics Dept., Chicago, IL, (1985-1987).
- f-6 Dr. Eugene A. Mueller, Adjoint Professor, EECS, UIC, (Radar Meteorology), UIUC/ISWS, CHILL Radar, Champaign, IL, (1985-1990).
- f-7 *Dr. Mitsuro Tanaka, Visiting Assoc. Prof., (Inverse Scattering, Oita University, Oita, Japan, (1986-1987).
- f-8 Dr. Hollis C. Chen, Vis. Senior Professor, (Inverse Scattering and Electromagnetic Theory), Ohio University, Athens, OH, (1987).
- f-9 *Dr. Amit P. Agrawal, PDF, EECS-UIC, (Radar Polarimetry/Meteorology), Indiana Inst. of Technology, Ft. Worth, IN, (1987-1988).

- f-10 *Dr. Bing-Yuen Foo, PDF, EECS, UIC, (Electromagnetic Inverse Scattering), DePaul University, Chicago, IL, (1987-1989).
- f-11 Dr. Helmut Süss, Vis. Res. Sci., (Radar Polarimetry), DFVLR-OPH, Oberpfaffenhofen, FRG (in collaboration with CAL-TECH/JPL, Pasadena, CA, (1987-1988).
- f-12 Dr. Yoshio Yamaguchi, Visiting Assistant Professor, (Electromagnetic Deep Sounding), Niigata University, Niigata, Japan, (1988-1989)(May 1990).
- f-13 Dr. Zhang, Yi-Min, Visiting Assistant Professor, South-East China University, Nanjing & Institute of Applied Physics, Tsukuba University (Polarimetric & Ecatometric ELF/VLF, Direction Finding, Tsukuba, Japan (with TPC) (1989-1991).
- f-14 Prof. Kyohei Fujimoto (Fellow, IEEE), NSF-STA Distinguished Visiting Professor, Institute of Applied Physics, Tsukuba University, Tsukuba, Japan (Polarimetric Microstrip Antenna & Transceiver Design at VLF to Microwave Levels), (1991-1992).
- f-15 Prof. Chang B. Chu, Visiting Professor (Electromagnetic Inverse Problems & Radar Polarimetry), Kyung-Nam University Korea (1992 Jan. - 1992 Oct.).
- f-16 Dr. Zbigniew H. Czyż, Senior Antenna Engineer, Antenna Division, Polish Institute of Tele-Communications & Space Sensing, PIT, Radar Polarimetric Theory), Warsaw University of Technology, Poland, (1992 Feb. - 1993 Oct.).

8. SCIENTIFIC RESEARCH STAFF OF UIC-EECS COMMUNICATIONS LABORATORY PERSONNEL

- 8a. Principal Investigator: Dr. Wolfgang-Martin Boerner, Professor & Director
University of Illinois Senior Scholar
- 8b. Co-P.I.: Dr. Hyo Joon Eom, Associate Professor
(with UIC-EECS/CSL: 1984 Sept 15 - to - 1989 Sept
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- 8c. Vis. & Coll. Res. Sci.: Dr. Yoshio Yamaguchi, Visiting Assistant Professor
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- 8e. Post-Doct Res: Dr. Zhang, Yi-Min, (NSF-JSPS Vis-Res. Fellow)
Dr. Bing-Yuen Foo
Dr. Amit P. Agrawal
Dr. Zha, Zhong-Qing
- 8f. Comp Res Eng Mr. John O'Hara (part-time: 1989 April - 1990 Sept.)
Res Techn Asst: Mr. Richard W. Foster (part-time: 1990 Sept. --)
- 8g. Grad Res Asst: Mr. Robert M. Lempkowski, Ph.D. cand.
Mr. Grant W. Reichard, M.Sc/Ph.D. cand.
Mr. Yuadkoun D. Diantravan, M.Sc. cand.
Ms. Yan, Wei-Ling, Ph.D. cand. (M.Sc.: 91 May 13)
Mr. Xi, An-Qing, Ph.D. cand. (M.Sc.: 91 April 15)
Mr. Liu, Chuan-Li Ph.D. cand. (M.Sc.: 92 April 15)
Mr. Matthias Walther, Ph.D. cand. (M.Sc.: 93 Oct. 15)
Mr. Kao, Tzung-Ta, Ph.D. cand.
Mr. Xu, Wei, Ph.D. cand.
Mr. Yin, Deng-Xie, Ph.D. cand.
Ms. Zhang, Xin, Ph.D. cand.
Mr. Wong, Si-Dart, Ph.D. candidate
- 8h. Techn Secr Ass: Ms. Helen Chao-Hui Tuan (terminated: April 1991)
Admin. Secr. : Ms. Mirian R. Mailey (terminated: November 1992)
Techn. Asst. : Mr. Richard W. Foster

9. NATIONAL/INTERNATIONAL INTERACTIONS: (Detailed List)

9a. US Department of Defense

1. Interaction with US Army Laboratory Personnel:

- (01) ARO-GS/EL: Dr. Walter A. Flood and Dr. James W. Mink;

- (02) US Army MI-COM: Mrs. Brenda L. Matkin, Lloyd W. Root, Jim Mullins, and Ray Smith;
- (03) US ACE/WES: Dr. Daniel Cress, Dr. John D. Curtis, Dr. Tony Bombich, Dr. James C. Campbell;
- (04) US Army BRDEC: Dr. Karl Steinbach, Donald Franklin, et al;
- (05) US Army CRELL: Dr. Daniel Fisk, Dr. Samuel Colbeck, et al;

2. Interaction with US Naval Laboratory Personnel:

- (06) US Navy NWC
China Lake, CA Dr. Bob Dinger, Dr. Brett Borden, Dr. Michael Mumford;
Dr. David Shriner
- (07) US Navy NADC:
Warminster, PA Dr. Otto Kessler, Ray Dalton, Frank Plonsky, Andrew
Ochadlick, Gregory Catrambone;
- (08) US Navy NRL:
Washington, DC Dr. Merrill Skolnik, Dr. Dennis Trizna, Dr. Jim Hansen,
Dr. Lothar Ruhnke, Dr. Lewis Wetzel, Dr. Edward Althouse
- (09) US Navy NOSC:
San Diego, CA Dr. George M. Dillard, Mr. Donald R. Wehner, Dr. Thomas E.
Tice, Dr. Jürgen Richter and Dr. John E. Griffin; Dr.
David W. Brock, Dr. Jack Y. Dea, Mr. Charles I. Richman,
Mr. Paul A. Singer, Dr. James W. Bond;
- (10) US Navy DTRC:
Adelphi, MD Mr. William Schuette, Dr. Kenneth Nicolas, and Dr. David
Johnson;
- (11) US Navy PMTC
Point Mugu, CA Dr. Dean J. Mensa, Dr. Terry E. Battalino;
- (12) US Navy, NCSC
Panama City, IL Dr. Elan Moritz, Dr. Edward C. Linsenmeyer, Dr. Gerald
Dobek, Dr. Michael Wynn;
- (13) US Navy, NOARL
Stennis/Bay Dr. Peter M. Smith, Dr. Albert Pressmann, Dr. Edward C.
St. Louis, MS Mozley, Dr. Lee Estep, Mr. Will E. Avera;

3. Interaction with US Air Force Laboratory Reviewed:

- (14) US Air Force RADC/Rome: Dr. Mike Wicks, Dr. Vincent Vannicola, Dr. Kenneth C.
Rome, N.Y. Stiefvater, and Mr. Gerald Ginello;
- (15) US Air Force RADC/East: Dr. John B. Schindler, Dr. Francis Zucker, and
MA, Bedford, Mr. Phil Blacksmith;
- (16) US Air Force WPAFB/
AFWAL: OH, Dayton Dr. John Earles, Mr. Mehdi Shirazi, Richard Koesel
and Dr. Jesse C. Ryles;
- (17) US Air Force KAFB:
Albuquerque Dr. Carl E. Baum; Dr. Jürgen Nitsch.

9b. US National Laboratory Personnel:

- (18) NASA-GSFC: DR. David Atlas;
Greenbelt, MD
- (19) NASA-LDRC: Dr. Curtis P. Rinsland;
Langley, VI
- (20) NASA/CAL-TEC-JPL: Dr. Jakob J. Von Zyl, Dr. Charles Elachi, Dr. Dianne
Pasadena, CA Evans, Dr. Michael Kolbrick, Mme. Pascale Dubois, Mr.
Walter M. Brown, Jr.
- (21) ERIM-RO: Dr. William R. Brown, Dr. S. Robinson, Dr. I.J. La Haie,
Ann Arbor, MI Dr. D. Herrick, Dr. Politis, Dr. I. Cyndrich;
- (22) MIT-LL: Dr. Richard M. Barnes, Dr. Lesley M. Novack, Dr. Carl
Lexington, MA E. Muehe, Dr. Russell O'Donnald
- (23) GIT-RAIL: Dr. William R. Holm, Dr. Eckehardt Rausch, Mr. Jerry
Atlanta, GA Eaves;
- (24) OSU-ESL: Dr. Jonathan D. Young, Dr. Eric Walton, Dr. David L.
Columbus, OH Moffatt
- (25) U PENN-VFRC: Dr. Bernard D. Steinberg, Dr. Milton Berkowitz
Philadelphia, PA

- (26) JHU-APL: Dr. John Apel, Dr. Mathew Feinstein, Dr. James Farrell.
Laurel, MD
- (27) IDA, Alexandria, VA Dr. Irvin W. Kay (Systems Techn. Div)

9c. NATO & European R & D Centers:

- (28) DLR-OPH: Dr. Wolfgang Keydel, Dr. Helmut Suess, Dr. Ernst
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FRG Mr. Rainer Weppner;
- (29) FGAN-WW: Bonn, FRG Dr. P. Egon Baars, Dr. Helmut Schimpf, Dr. Klaus
Magura, Dr. Karl-Heinz Krücker;
- (30) SHAPE-TC: Ir. André J. Poelman, Dr. Leo Lighthart
Scheveningen, NL (DUT: Pol. Doppler Radar Facilities);
- (31) NATO-Hgts: Dr. Craig Sinclair, Dr. Tilo Kester, Dr. Giorgio A.
Brussels, BU Venturi, Dr. Paul Rambaut
- (32) ONR-Europ. Dipl.Ing. Hans Dolezalek, Dr. John Andrews;
Branch Office:
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- (33) USARDSG Dr. Karl H. Steinbach, Chief Scientist & Director
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- (34) USAFOSR Dr. Robert J. Côté, Chief Scientist
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- (35) ONR-FAR-EAST Branch Dr. George B. Wright, Dr. Sachio Yamamoto
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Tokyo, Japan
- (36) RSRE: Dr. Adrian Britton, Dr. Ian Anderson, Dr. Keith D. Ward
Great Malvern, UK
- (37) NTNF-ERS: Norway Dr. Jens Hjelmstadt, Dr. Dag T. Gjessing, Kjeller,
Dr. Fan-Nian Kong; Dipl.-Ing. Hans Döderlein
- (38) ONERA: Dr. Jaques Dorais, Dr. Frédéric A. Molinet, Dr. Jean-
Chattillon-France Paul Marcellin;
- (39) CELAR: Dr. S. Assailly, Dr. Oliver Crop, Dr. Pierre Gaudon,
Rennes, France Dr. Denis Raguin
- (40) IRESTE: Dr. Joseph Saillard, Dr. Eric Pottier
Nantes, France
- (41) TNO-FEL, Scheveningen Dr. A. de Loor, Dr. Jan de Groot
The Hague, Netherlands
- (42) JRC/EARSEL Dr. Giovanni Nesti, Dr. Alois J. Sieber, Dr. M. Hohmann
ISPRA, Lago Maggiore
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10. ATTACHMENTS (for original copy only)

Copies of reports and papers may be obtained upon written request; but are not attached to the twenty(20) copies of this report.

- 10.1 7a. Books/Mongraphs: B-4
- 7b. Papers Published: P-3, P-5, P-10, P-11
- 7c. Papers in Review Cycle/in Print: p-7, p-8, p-9, p-15, p-16
- 7d. Refereed Workshop Contributions: w-37, w-38
- 7e. Technical Reports: R-6
- 7f. Travel Interaction Reports: T-1, T-2, T-3, T-4, T-5, T-6, T-7 (Final: 90
December 15), T-8 (Final: 90 December 15)