The European Microwave Signature Laboratory

Alois S. Sieber

Advanced Tecniques
Institute for Remote Sensing Applications
Joint Research Centre, Ispra Establishement
Commission of the European Communities

The paper is a well-written documentation of the EMSL; nevertheless, I wonder if it would not be useful for potential readers if reference would be made to similar facilities like the one at HARC. In addition, to my taste, the Introduction is a little bit too philosophical; it could be somewhat more concise. Some minor corrections have been made in the text.

ABSTRACT

The **Institute for Remote Sensing Applications (IRSA)** of the **Joint Research Centre (JRC)** of the **Commission of the European Communities (CEC)** developed a new and unique facility to conduct research in radar wave / target interaction, the **European Microwave Signature Laboratory (EMSL) which** has been constructed at Ispra, Italy and which has been inaugurated in April 1992. This document provides an overview of the objectives of the EMSL Installation, a technical description of both the anechoic chamber and of the basic measurement systems, the typical radar measurement modes and of the potential field of applications.

INTRODUCTION

The sense of urgency which is clearly felt by human society in the examination of such questions as climatic warming, ozone depletion, food production, tropical deforestation and desertifications is mainly due to the recognition that these are global issues potentially affecting everyone.
To reach the overall goal of protecting this system earth art its different scales, objective and actual information at different geographical scales about the ecosystem, the environment, the impact of human activities on it and the impact of climatic changes are required. Throughout the last twenty years it has become evident that remote sensing techniques can provide unique facts in a synoptic, frequent and economic way.
The community of environmental engineers making use of remotely sensed data of the "system earth" has progressively recognized the need for having access to data free of prevailing weather and illumination conditions. Microwave sensors have this inherent capability. With the successfull launch of the first European remote sensing satellite ERS-1, by the European Space Agency (ESA) in July 1991 and the successful start of the L-band SAR image data collection of the Japanese ERS-1 early 1992, it can be stated that microwave remote sensing of the earth's surface from space will become of increasing importance due to:
- its inherent capability of operating independently of the visibility conditions and the weather situation. Microwave sensors provide data and target parameters at times and situations when visible and infrared sensors are restricted in their operation or even fail.
- its potential for providing object characterizing information which cannot be derived from any other remote sensing data source in either the visible or the infrared region of the electromagnetic spectrum.
- ESA committed a continuation of this programme by committing a launch of the ERS-2 in 1994, which will be complemented in 1995 by the Canadian RADARSAT.

The natural illumination independence and all-weather capability of such sensors has been known for a long time and have also been proven by theory and experiment. However, in spite of many years of research, especially in the USA and Europe, knowledge concerning the information content of microwave backscattering and forward scattering is still just in its early stages. There exists an urgent need to investigate and improve the knowledge of the interaction of radar waves with natural targets as a function of measurement and object parameters.
At workshops and expert meetings in Europe, users and researchs have requested the start of coordinated activities in the field of microwave signature research to support and accompany ERS-1 and follow-on projects. Such a pro-

gramme would encourage interested groups to continue work in the field, to cooperate with others, and to promote a quantitative approach to remote sensing. It became evident that this task was very large and would exceed the capabilities of individual research groups. Therefore, the JRC has taken the initiative to design and develop a microwave signature laboratory which will be open for use to research and commercial customers. This new and unique European facility will complement air-and spaceborne measurements by providing stable and reproducible environmental conditions and operational modest for highly controlled experiments.
The design for the laboratory was based on the following requirements:

- it has to be large enough to measure real natural targets, e.g. trees,
- it should provide experimental capabilities over a wide range of measurement parameters,
- it should provide operational modes similar to those used by airborne and spaceborne sensors,
- it should provide backscatter and any required bistatic measurement geometry,
- it should operate automatically,
- it should provide the opportunity to use, simultaneously, other sensors in the optical and infrared region, and
- the measurement data should be processed and analysed in real time.

Using these requirements as a frame of reference the Microwave Team of the JRC constructed the overall concept for such a facility. Under contract to the JRC and industrial consortium undertook a feasibility study using the JRC design as an input. The overall laboratory concept was also presented by the Microwave Team (MWT) of the JRC to an international group of experts in October 1988. These advisers gave a very positive evaluation and recommended that the project should proceed as proposed.
Based on the results of the industrial feasibility study in JRC split the laboratory design and construction into three parts:

- electronics and HF measurement system,
- data recording and signal processing facility, and
- mechanical and electro-mechanical components.

The first two parts namely the electronic measurement system and the data recording and processing system were designed and constructed by the Microwave Team itself. For the remainder, a contract has been issued to the SIEMENS company which was signed in November 1989.
The installation is now complete as well as the Commissioning phase. The inauguration of this facility took place in April of 1992. The JRC launched, at this time, the first Call for Research Proposals to invite the international expert community to make use of this facility. This Call for Proposals will be repeated at opportune times in the future.

Laboratory Overview

The European Microwave Signature Laboratory consists of a large installation which provides the environment and the facilities to perform mono- and bistatic polarimetric radar measurement in a stable, controlled and reproducible way. The installation is placed inside an air-conditioned building. The measurement system can be remotely controlled and monitored from a control room where a direct link to the signal processing facility is also available. A schematic overview of the installation is shown in Fig. 1 (exploded view) and a description of the major elements of the laboratory is given below.

Structure and electro-mechanical components

The overall shape of the anechoic chamber results from the conjunction of a hemispherical dome and a cylinrical part, both with a radius of 10 m. The floor of the chamber is at a level of 5 m below the centre of the sphere. Along the gap between the two parts a circular arch is mounted that supports a rail system where two sleds can move independently. Each sled carries a transmit/receive module pointing at the centre of the arch where the target is located (the focal point in Fig. 2).
A target positioner, mounted on a linear rail system, is used to transport the target inside the chamber through the main door (5 m wide, 8 m high). The same system also permits the accurate positioning of the target inside the chamber for both the rotation and linear movement as depicted in Fig. 3. The specifications concerning the mechanical aspects of the radar/target positioners are listed in Tab. 1. All the movements are remotely controlled either manually or via computer. Motion parameters (aiming position, acceleration, speed, safety limits etc.) can be set by the operator via software. The rotation movement can also run continuously at a constant speed. Depending on the size of the target, suitable adapters may be mounted on the target positioner platform to reach the level of the focal point. If necessary, the target mounted on the positioner can also be accessed inside the chamber by means of an additional platform moving on the same linear rail system.
In addition to the receiving/transmitting antennae mounted on the sleds, a set of 37 fixed receiving antennae pointing to the focal point are distributed over one half of the dome. On the other half, 30 unused positions are available for placing additional antennas or other sensors. The inner surface of the chamber, as well as all the mechanical parts which are visible to the transmitting and receiving antennae, are covered by microwave absorbing material (-40 dB max normal incidence reflectivity at 1 GHz).

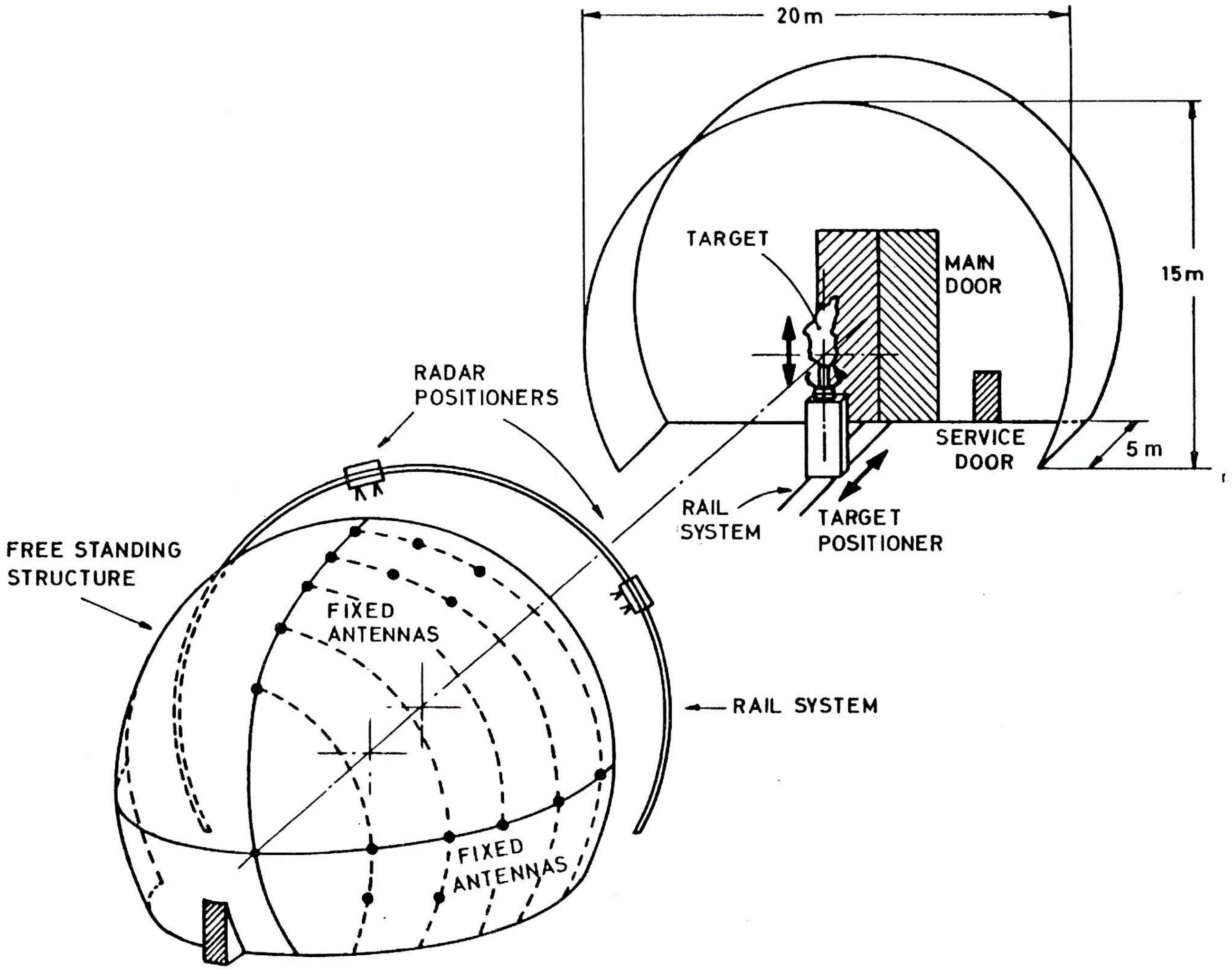

Fig. 1 - Overview to the Microwave Signature Laboratory (exploded view).

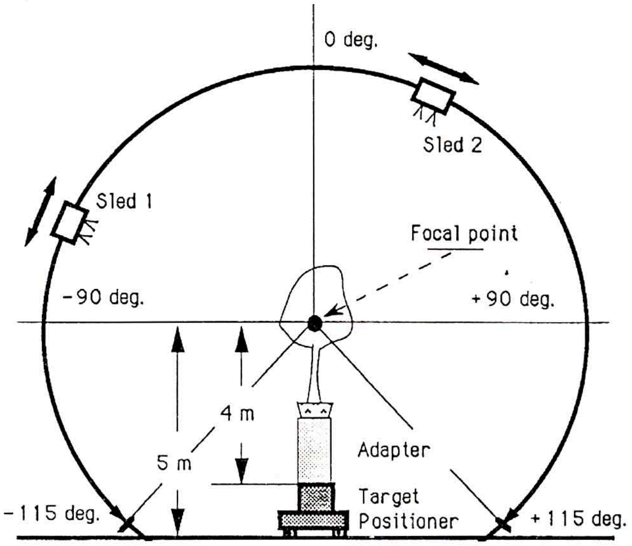

Fig. 2 - Diagramme of the focal plane describing the illumination positions of the two radar sleds.

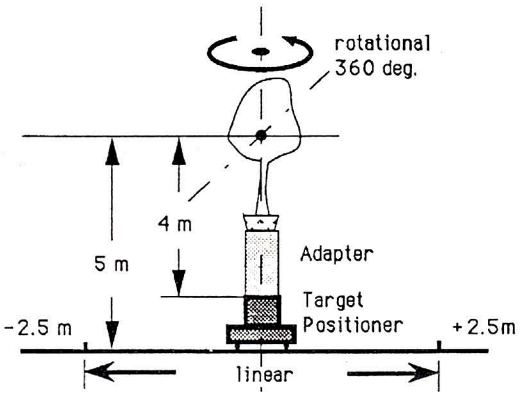

Fig. 3 - Target Positioner movements and range.

An illumination level (about 1000 lux) sufficient for maintaining plants in normal physiological conditions is guarantied by a set of 5 lamps mounted in a semi-recessed position on top of the cylindrical part. The illumination level can be modulated (e.g. to simulated diurnal illumination variations) by switching the lamps on or off either manually or via software. The air inside the chamber can be exchanged depending on the requested environmental conditions.

Measurement System

A schematic diagram of the measurement system is depicted in figs. 4-6. It is based on a vector network analyser (NA) with a synthesizer as the signal source and three external frequency converters (test sets) which receive the radio frequency (RF) signal from the antennae and convert it to an intermediate frequency (IF) before detection. The step mode operation (each frequency point phase-loced) is used in order to have consistent and accurate polarimetric measurements. One test set is dedicated to the receivers located on the two sleds and the other two are shared by the channels of the 37 fixed antennae. All the antennae are dual polarised. The transmitting and receiving paths are selected by means of RF switches while IF switching between the three test sets is performed automatically by the NA.
The specifications of the measurement system are listed in Tab. 2. the system is currently operational in the frequency range 2-26 GHz; the extension to the whole range is planned for the near future. The spatial resolution (range and cross range) depends on the measurement parameters and on the subsequent data processing. Further details are given in the next section.
The control of all the measurement equipment is performed via an HP-IB bus. The main controller is connected to the NA which, in turn, directly controls the synthesizer, the three test sets and, optionally, other peripherals via a separate bus. The on-going measured raw data can be visualised on the screen of the NA and on the monitor of the main controller. At the same time this data, recorded in an interim Mass Storage, is available for access by quasi real time pre-processing software which performs a preliminary calibration, analysis and evaluation. Data is stored in a standard format which includes additional information on the measurement configuration, parameters, target type, environmental conditions, etc. in order to give the maximum support for the efficient use of the data and to simplify the automatic documentation and archiving of the measurements.
Complementary information about the target (e.g. physical and physiological parameters) will be acquired by dedicated instruments depending on the specific type of experiments. TV cameras are installed on each sled to permit visual control of the target and comparison between optical image and microwave response. Two small lasers laigned with the antennae boresight are also available on the sleds to help the proper positioning and orientation of the targets, both for the calibration and the experiments.

Measurement Objectives and Typical Modes

The Microwave Signature Laboratory is designed to serve researchers an users in the field of land oriented remote sensing tasks as a central facility and tool. However, since the laboratory is very flexible in the various measurement modes it offers, it will, therefore, be used for other purposes, particularly industrial applications.
The interaction of radar waves with targets depens on the prime measurement parameters of wavelength, polarisation and illumination geometry and on two sets of target characteristics, namely the two-or three-dimensional geometry of the target and it's dielectric characteristics. The term geometry also includes, in the case of surface scatterers, the surface roughness. For complex volume targets, the term geometry comprises not only the shape, size and orientation of the individual scatterers but also the three dimensional distribution.
The prime objective of the signature laboratory is the identification of dominant scatterers and their description as a function of changing measurement parameters. The design of the laboratory permits monostatic and bistatic far field measurements of large targets such as rough soil surfaces, agricultural plants and trees as well as of man made targets. In the case of plants, it is planned to identify not only the dominant scattering centres at a given growth stage, but also the diurnal changes and the changes in the scattering behaviour due to the growing process (artificially enhanced).
The empirical investigation of existing high and low resolution SAR data indicates that the spatial resolution provided by the sensor (system bandwidth) imposes severe limitations on what can be deduced about the radar signature of targets. It is not possible to investigate this aspect under controlled, reproducible conditions by means of air-and spaceborne sensors. The signature laboratory, however, will provide many different measurement modes such that the limitations imposed by the measurement process on the resulting signatures can be quantitatively investigated.
A second group of measurement objectives, especially dedicated to industrial users, can be described in general terms as radar cross section measurements of different

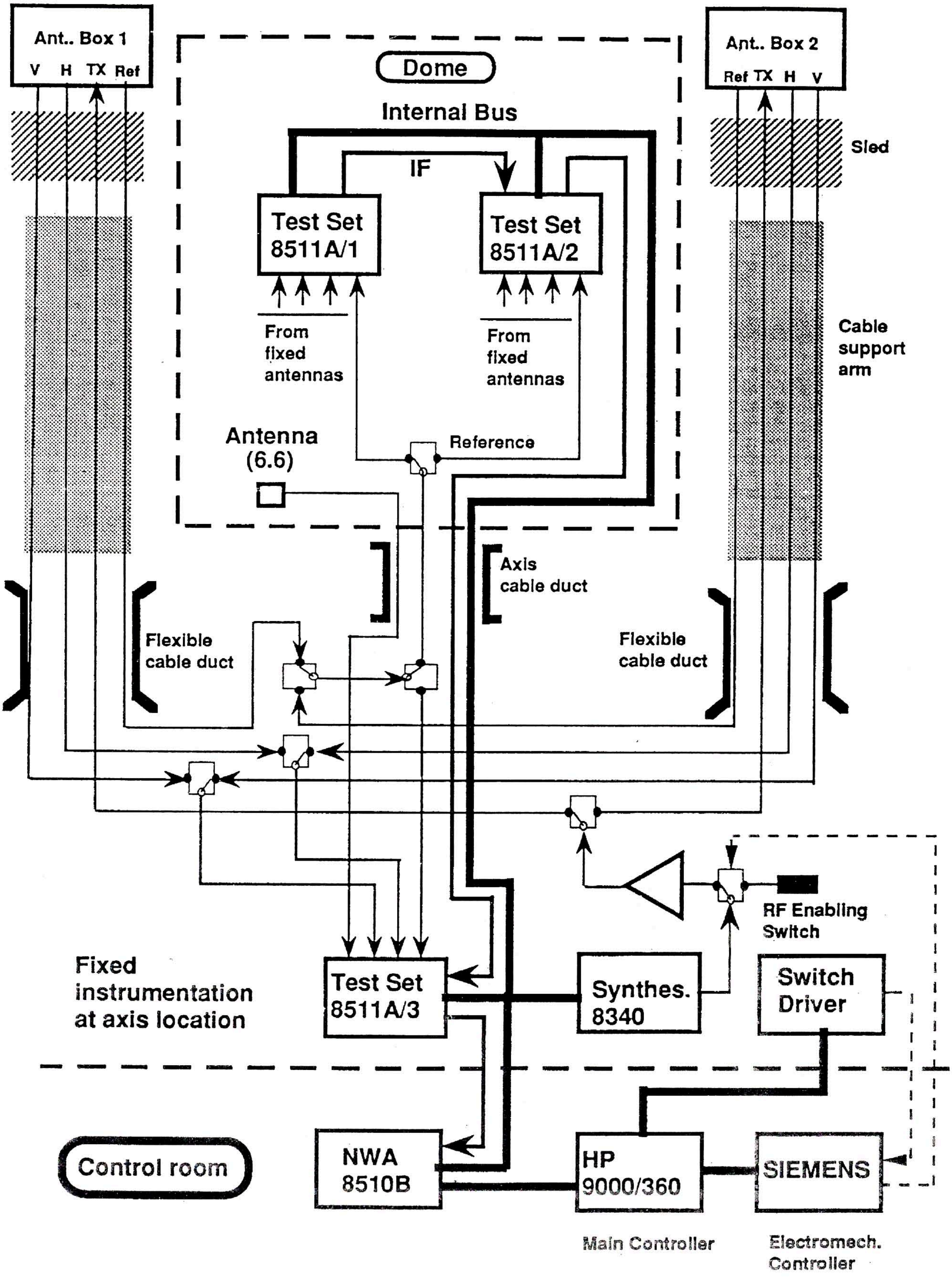

Fig. 4- Microwave Measurement System.

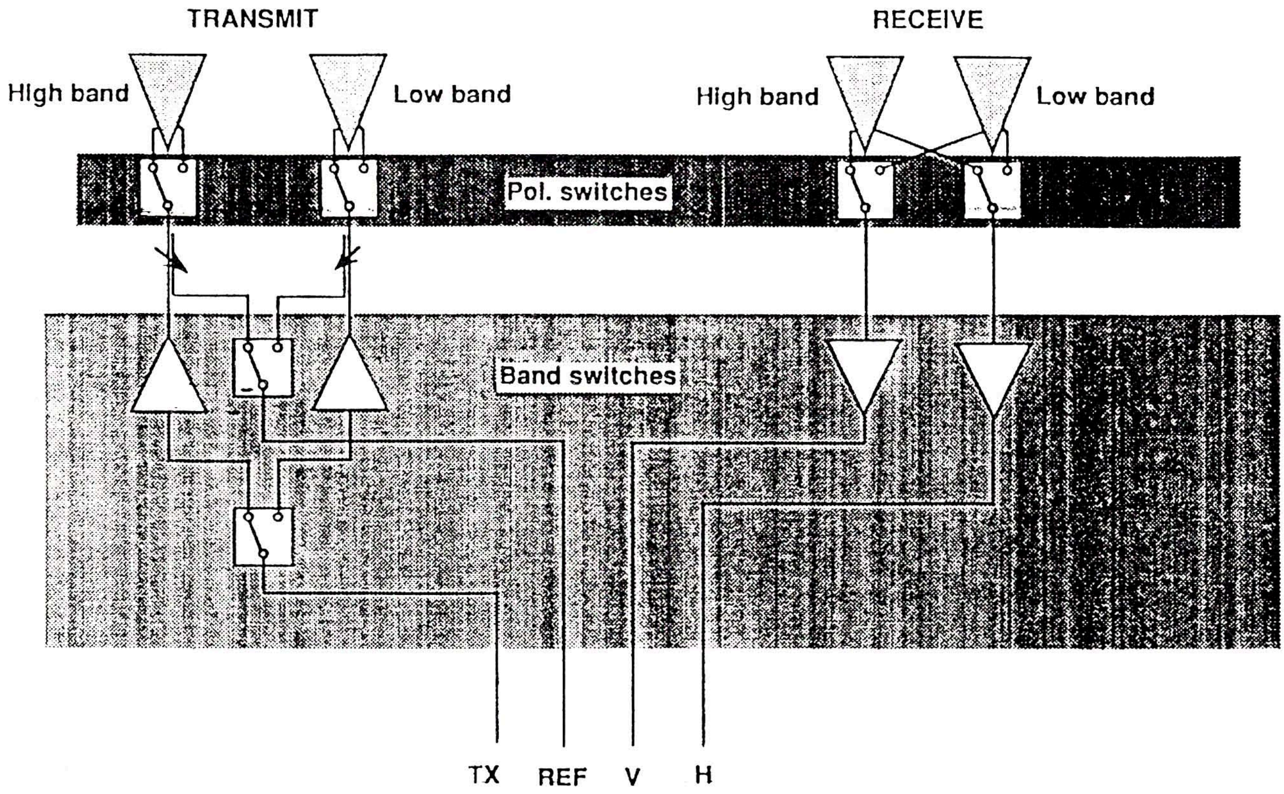

Fig. 5 - Antenna Box Layout.

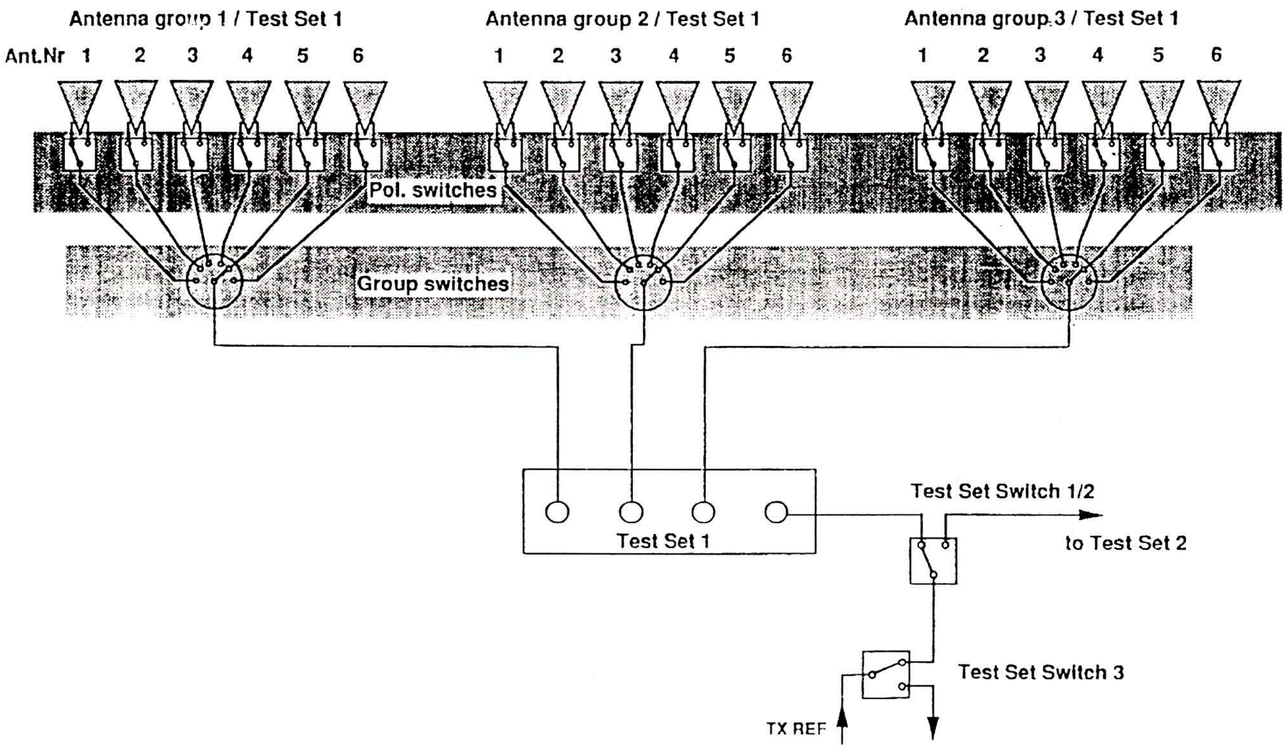

Fig. 6 - Fixed Antennae Configuration.

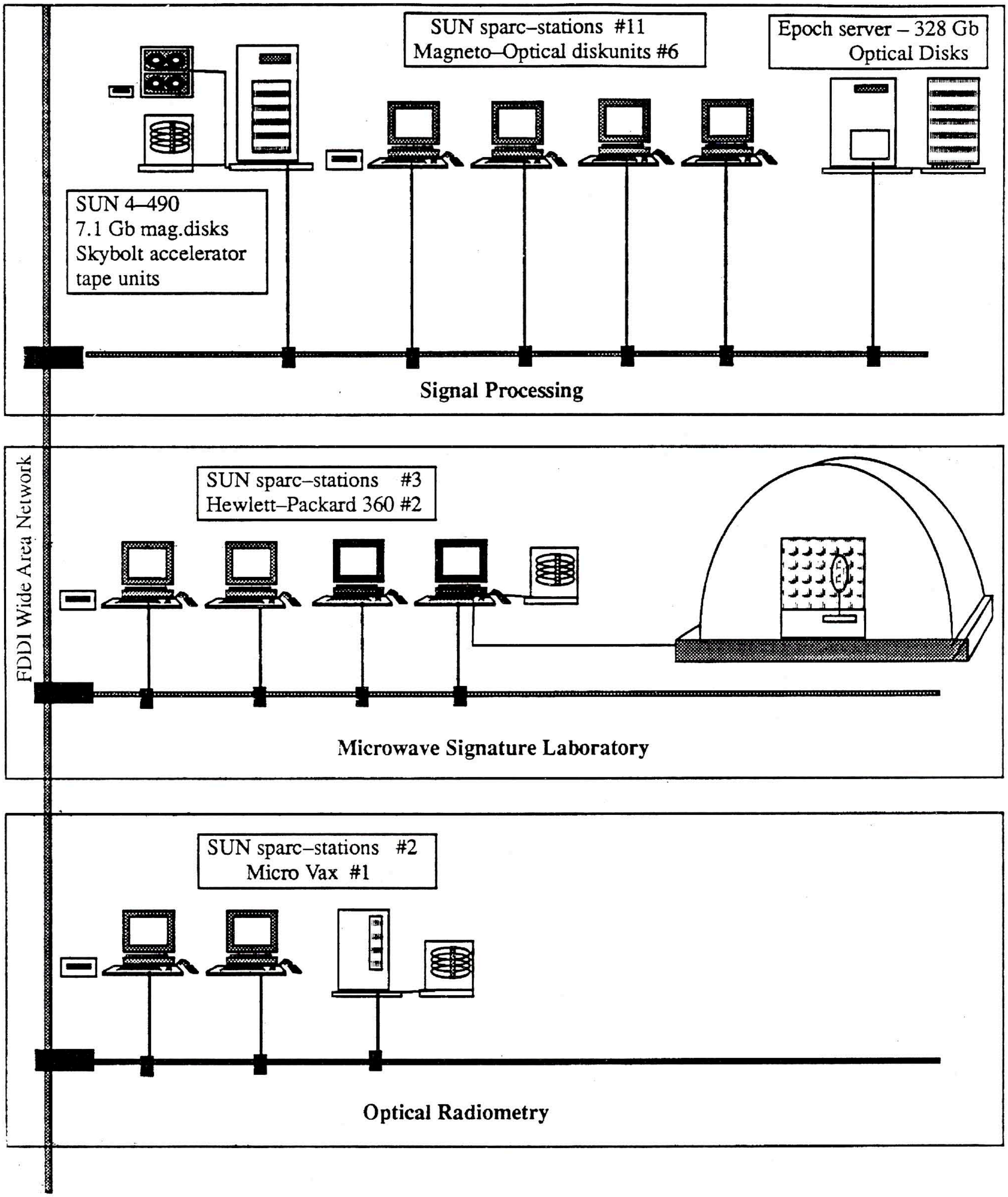

Fig. 7 - The AT Unit Data Processing System.

materials; antenna and related radiation measurements; EMC measurements; and the determination of material properties.

The laboratory layout permits backscatter measurements as well as bistatic measurements for any desirable illumination geometry with regard to the targets. This means that, amongst other tasks, the entire energy balance for complex scattering processes can be investigated.

For all desirable illumination geometries, one-dimensional range measurements and two-and three-dimensional imaging techniques can be selected. In all cases, the range measurements are based on the selection of the signal bandwidth and the subsequent time delay sorting.

The cross-range resolution in the case of *one dimensional scatterometer* measurements is determined by the antenna beam widths of the transmit and receive antenna. The illumination geometry can be choosen such that the transmitting and receiving antennae are located at any illumination angle from positions beneath the target to the zenith point. The target itself can be moved successively through the illumination pattern. If the transmit and receive antenna are located in the zenith above the target this mode can be used to simulate the performance of a *radar altimeter*.

The cross range resolution is detemined in the *real aperture* 2-D mode again by the beam widths of the selected antennae. The *incoherent* real aperture imaging process is simulated by a linear displacement of the targets through the illuminated pattern. Any improvement in cross-range will be gained by making use of *diffraction* phenomena. This approach permits laboratory simulation of special modes ike the *SAR mode* (sinthetic aperture radar), the *spot-like mode*, the *topographic mode*, the same side *stereo mode* as well as the apposite side stereo mode. All these modes can be achieved for different cuts through the three dimensional target by selecting the appropriate illumination geometry, and the appropriate target movement (linear, circular). All these imaging approaches could be called *two-dimensional*.

In addition to movement of the targets, the two radar transmitters/receivers can be moved on a circle around the targets. In repeating the two dimensional imaging techniques for each of the radar positions, complete *three dimensional tomograms* of the targets of interest can be effected.

It should be kept in mind that all of these imaging modes are available for any backscattering and bistatic geometry, the complete frequency range and, in addition, that they are always coherent ad fully polarimetric.

System Calibration

A polarimetric calibration procedure is implemented in the frequency domain in order a set of correction factors (calibration data set) characterising the transfer function of the whole measurement system (end-to-end calibration). The response of the empty room is measured separately and subtracted at raw data level from all the measurements. Different calibration targets can be used depending on the specific measurement configuration. These objects are normally placed in the focal point of the chamber. Special holders with low reflectivity are used in order to minimise the interaction of the measured object with the surrounding environment. The calibration can be extrapolated to the whole region of interest by applying additional corrections which take into account the three-dimensional polarimetric antenna pattern.

If the system is maintained in reasonably stable conditions, the calibration can hold for several days and only the empty room response needs to be re-measured following every change in the arrangement of the chamber.

The original calibration measurement set is saved and archived so that different correction factors can be derived and applied off line to the measured data, corresponding to the specific user requirements.

Table 1: Mechanical Specifications

Positioning	**Range**	
Repeatibility		
Radar	- 115/+115 deg	+/-0.005 deg
Target (linear)	-2.5/+2.5 m	+/-0.05 mm
Target (rotation)	0/360 deg	+/-0.05 deg
Anechoic chamber diameter	20 m	
Antennae-focal point distance	10 m	
Target Movement type	Step Mode	

Table 2: Specifications for the Basic Measurement System

Measurement geometry	mono/bistatic
Frequency range	1 - 40 GHz
Polarisation	HH, VV, HV, VH, coherently (polarimetric)
Sensitivity	-60 dB (sm)
Dynamic range	100 dB
Range resolution	10 m - 1 cm (bandwidth dependent)
Cross-range resolution	10 m - 1 cm (mode dependent)

Data Processing Facility
Hardware

The data processing system of the Advanced Techniques unit consists of a server-client based network of workstations (see Fig. 7). The system is distributed both in the geographical and logical sense: it is distributed geographically because stations are physically residing in different rooms and buildings; in the logical sense because resources, like data files and peripherals, are shared. The connectivity of the shared resources is assured by a tree of local area networks (LANs) within a building (the LANs are compliant at the physical and link with the IEEE 802.3 standard, commonly referred to as "Ethernet") and by a wide area network (WAN) over the JRC campus.
The heart of the system is a SUN4/490 which acts as a data file server for 14 SUN SPARC stations, 2 SUN4/260, 2 HP9000/360 and 3 Macintosh II. The server is equipped with 6.9 Gigabytes of magnetic disk storage and 10 gigabytes of Write Once, Read Multiple (WORM) times optical disk storage; files are shared through the SUN's NFS (Networked File System) protocol. The operating system is SUN OS, which is a variant of the Unix operating system.
A second file server dedicated to an optical jukebox system provides 28 Gigabytes of real-time accessible filing space. Peripherals inclue black and white laser printers, a thermal colour printer, a document scanner and a digitizing tablet, two tape units and a Exabyte cartridge reader and a CD ROM drive.
Each workstation is equipped with a high resolution (1150x900), 8 bit deep bitmapped terminal capable of running windowing and graphical applications both in Sunview and in X11/News environments. In addition, the two SUN4/260 stations host an application accelerator, TAAC1, which achieves a peak performance of 12 MFLOPS using parallel processors and has a 32 bit deep frame buffer for image display.
For even higher computationally intensive applications (e.g. raw SAR data processing) another VME based accelerator, code named SKYBOLT, has been installed on the server and provides a peak performance of 80 MFLOPS in single-precision.

Software

Since the activities of the Advanced Techniques Unit are directed to both basic research and operational data processing and analysis, a wide variety of development and application software has been installed. Part of the software has been procured, and many tools have been developed in house. In the following, a summary of the available software is provided.

Commercially available software

Program development
optimizing compilers for C, Fortran and Pascal
symbolic window-based debuggers
network programming libraries (RPC, sockets)
graphical libraries (Phigs+)
numerical analysis libraries (NAG, Numerical Recipes)

Analysis and visualization
image visualisation tools (PV_WAVE and IDL)
statistical analysis software (NEW-S)
symbolic manipulation tools (Mathematica)

Database management system
Sybase

Geographical information systems
GRASS3.1.

Software Tools Developed by JRC

Visualization and analysis
DISTOOL - general purpose interactive visualization and analysis tool with data structure indepenent IO library (handles of any type of file organization);

Polarimetry
POLTOOL - analysis and visualization tool for 4 look Stokes matrix data; includes: power synthesis, signature calculation, HH/VV phase difference, amplitude ratio images, image processing, covariance matrix calculation, phase calibration,
Huynen theory parameters, Bayes classifier, remote procedure services.
S SMTOOL - analysis and visualization tool for 1 look scattering matrix data; includes the functionally of POLTOOL plus:
characteristic polarization states statistics (CPS); CPS based specle filter.
POLLIB - polarimetric analysis routines library
LAUNCHER - environment for batch processing

Calibration
CALTOOL - interactive polarimetric, radiometric calibration and point target analysis

Radar Imaging
SIMSAR - generation of two and three and three-dimensional radar images using the time domain backpropagation technique

Laboratory
Data Acquisition Measurement Control and Calibration

APPENDIX C

The EMSL provides a variable measurement facility which is useful for many application areas outside the field of remote sensing. In the following a list of different application fields is provided.

C. Potential Fields of Applications

REMOTE-SENSING

Geophysical Calibration of R/S Measurements.
Characterisation of EM Wave/Target Interaction by Physically Relevant Models at all Scales.
Verification of Models and Experiments.

TRAFFIC CONTROL

Test of new, non-scalar air-traffic surveillance methods.
Verification of Advanced Methods for Ship Traffic Control.
Development of Advanced Approaches for All-Weather Helicopter Guidance.
Investigation of new Approaches for Ground Traffic Control and Guidance.
Autonomous Vehicle Control.

ROBOTICS IN INDUSTRY

Development of Methods of Pattern Recognition for Positioning.
Development of Methods for Parts Counting.
Development of Methods for Quality Control.
Development of Methods for the Guidance of Moving Parts.
Development of Methods for Measurement of the Filling Levels of Containers (Fluids and Solid Controls).

MATERIAL PROPERTIES

Radar Cross Section Measurements of Construction Materials.
Radar Cross Section Measurements of Natural and Man-Made Targets.
Radar Cross Section Measurements of Atmospheric Components.
Radar Cross Section Measurements of Absorbing materials.

ANTENNA AND RADIATION MEASUREMENTS

Measurements of Antennae Characteristics (e.g. Gain, Polarimetric Gain, Gain Bandwidth, Efficiency).
2 - and 3 - Dimensional Antenna Diagram Measurements.
Measurements of the Characteristics of Passive and Active Antennae.
Antenna Near-and Far-Field Measurements.

COMMUNICATION TECHNIQUES

Characteristics of Telecommand and Telecommunication Antennae.
Investigation of Telecommunication Paths Including Multipath Effects.
Propagation Measurements of Realistic 3-Dimensional Models.

ELECTROMAGNETIC COMPATIBILITY (EMC)

Determination of Radiation from Equipment.
Measurement of Leaage from Equipment.
Determination of sensitivy of Equipment to Radiation.

D. Potential Customers

National and International Remote Sensing Establishments and Agencies
Aircraft Industries
Airport Authorities
Radar Companies
System Houses
Governmental Research Institutes
Industrial and other Private Research Institutes
Suppliers of Relevant Components
Automobile Industry
Engine Builders
Control Manufacturers
Aerospace Industries
Communication Industries
Computer Industries and Suppliers of Components
Producers of Building Materials, Structural Material and Absorbing Materials
Material Research Institutes.