Microwave remote sensing techniques (active and passive) are nowadays accepted as being powerful tools, not only complementing the infrared and visible portions of the electromagnetic spectrum, but offering unique solutions to known problems. Although the scenario and expectancy of the research/user community is extremely positive, recognizing this potential, it must be said that most of the research regarding applications was/is being undertaken in the northern hemisphere. Extremely few work has been done in the tropical world, a research that is urgently needed in order to understand and validate microwave remote sensing of targets from tropical areas. In this context the Institute of Space Research (INPE) and the Institute for Radiofrequency Technology (HF) of the German Aerospace Research Establishment (DLR) organized a project of cooperation in microwave remote sensing. The aim of this project is to develop and verify methodologies in microwave radiometry and Radar imaging of natural targets, especially soils (high iron oxide content) and vegetation (including the Amazon region) and the ocean surface (including pollution), using laboratory, field and airborne systems (line-scanners, SAR and SAI). Cooperation and further development in radiometer and imaging Radar technology and processing is also included. This paper presents the activities within the scope of the project and also presents some of the relevant results already obtained in joint activities during 1988/89.

KEY WORDS: Microwaves, Radiometry, Radar, INPE, DLR, Cooperation.

1. INTRODUCTION

The penetration of microwaves through clouds and in soils and vegetation and the quasi all weather day and night operation of these sensor systems are some of the advantages of using microwaves, especially in Brasil where cloud coverage jeopardizes many applications related to environmental monitoring when using visible and infrared sensor systems. Applications in Cartography, Agriculture, Oceanography, Meteorology and others are rapidly becoming operational. The ERS-1, SIR-C/X-SAR, J-ERS, and RARDSAT (to mention some of these) are spaceborne programmes/missions carrying microwave sensor systems to explore the potential of microwave remote sensing in the 90's.

The applications that are possible with microwaves are also dependent on the target characteristics. In this sense the peculiarities of brazilian soils, vegetation and even of the South Atlantic Ocean (continental shelf) must be carefully investigated to allow for effective applications and an adequate benefit/cost relation.
2. WORK PROGRAMME

2.1 Laboratory Activities

These activities are concentrated on the comparison of electrical constants (complex permittivity and permeability) of soil, water and different types of oil (water pollution) samples, measured with radiometers, network analyzers and Time Domain Reflectometry (TDR) techniques. The main purpose of this effort is the understanding of the energy-matter interaction mechanisms under controlled conditions, especially soil samples from tropical areas (Palme, 1987), in the frequency range of 1-10 GHz and oil samples in the 32/90 GHz region. These measurements are also intended to give support to results from field and airborne missions.

The TDR system was developed at the Department of Electrical Engineering of the Escola de Engenharia Maua/Instituto Maua de Tecnologia-Sao Paulo. This system provides reliable results for liquid and porous materials for frequencies up to 12 GHz.

In Germany, besides the use of a Vector Network Analyzer which will be further implemented in the near future with the use of proper sample holders, a 32/90 GHz reflectance measurement system was developed during joint activities in Germany in 1988/89.

Some results already obtained with these systems will be presented further on.

2.2 Field Radiometry

The planned actions are directed to repetitive stationary measurement campaigns with the 1.4 GHz radiometer from DLR, for applications in Agriculture / Agrometeorology and Oceanography.

In Agriculture / Agrometeorology, the possibility of monitoring the spatial distribution of soil moisture on a regional basis with microwave radiometers (airborne systems) is not far from becoming operational, at least on those areas where soils are essentially dielectrics (Jackson, 1987; Reutov and Shutko, 1986). For Brazil, where the occurrence of soils with high iron oxide contents and even peculiar magnetic characteristics is predominant (Ferralsols and Oxisols) in most of the important agricultural areas, the possibility of monitoring soil moisture (and also soil salinity) needs to be carefully investigated especially at frequencies lower than 4 GHz (Palme, 1988).

In this context measurement campaigns over ten representative brazilian soils with different polarization, viewing angles and soil conditions (soil moisture, iron oxide content, texture and salinity) are planned.

In relation to Oceanography measurement campaigns over the Brazilian northeast and southeast continental shelf with different polarization, viewing angles and sea state are scheduled. There is an evident interest in the possibility of investigating sea temperature and salinity.

During the last two years the joint activities in field radiometry were carried out in Germany, with emphasis not on the target and applications, but essentially on the calibration, stability measurements and signal statistics of the 1.4 GHz radiometer. Besides stationary measurements, this system was also installed and operated in the DO-228 D-CALM in calibration flights (fixed mode and sweep mode - 1.350 to 1.500 GHz with 31 channels).

Some results from these campaigns are presented later on.

2.3 Imaging Radar

In this subject the following topics are being / will be covered:

- Development of an X-Band SLAR system (to be installed in INPEs aircraft) with support of existing subsystems of DLR. INPE supports DLR in the development of new Radar subsystems.
According to the schedule of the project, the DLR subsystems are already in Brazil. INPE's team is at the moment concentrating efforts on the development of the SLAR, in order to install and implement this system already this year (Phase A). There is a great interest and necessity of images produced by this airborne system, not only for the research and user community of INPE, but also for governmental organizations / agencies, as for example CETESB - Companhia de Tecnologia de Saneamento Ambiental - where the main interest is to participate in flight campaigns together with INPE (Laboratory for Atmospheric and Geophysical Research) for the detection of sea surface pollution caused by the spilling of different oils by ships, a problem that unfortunately is becoming very common along the coast of the State of Sao Paulo, causing great damages to marine ecology and local economy. Oil spill detection is an application where this airborne system, together with a cryogenic 90 GHz line-scanner, has proved to be extremely efficient (Gruener, Schreiber and Witte, 1988; Witte, 1986).

Other applications for the X-Band SLAR are:

- imaging and monitoring of flooded areas that cannot be mapped by optical sensors due to the presence of clouds and/or at night;
- imaging of the areas which are almost permanently clouded, both on land and ocean test sites (Amazon Region);
- imaging of bedform signatures on the ocean surface over the continental shelf;
- soil moisture and irrigation efficiency mapping (Krupenio, 1986) on agricultural lands where water resources are critical, in order to achieve optimal use of irrigation water (as in some areas of the State of Sao Paulo where the urban v.s. irrigation water conflict is increasing);
- behaviour of soils from tropical areas (Latosols);
- imaging of the test sites selected for the X-Band Shuttle Imaging Radar (X-SAR).

As a preparation for the planned flight campaign of the DLR/INPE microwave remote sensing systems in 1993 and possibly for ERS-1 remote sensing satellite, INPE intends to build up a SAR processor to generate high resolution and high quality radar imagery. Since 1988 DLR operates an experimental C-Band SAR (Synthetic Aperture Radar) system that produces high resolution and high quality radar images and will also be implemented in the DLR/INPE joint flight campaign.

The development of an off-line SAR processor by INPE has already begun. It must be said that the Department of Image Processing (DPI) of INPE has experience in post-processing of radar images, especially speckle reduction and segmentation.

2.4 Radiometer Technology

Development of microwave radiometers in Brazil under consultance of the DLR for field and airborne missions (probably L-Band for soil moisture, soil salinity and/or a cryogenic 90 GHz system for pollution of the sea surface).

2.5 Airborne Campaigns

Joint airborne measurement campaigns with the DLR/INPE microwave systems (passive/active) are planned to occur in Brazil in 1993 over areas still to be defined. Some airborne campaigns were carried out during joint activities in Germany in 1988/89 with passive (1.4 GHz) and active (SLAR and scatterometer) systems. These missions were also essentially devoted to the calibration of the systems, and to soil moisture detection together with the Technische Universitaet Braunschweig.

3. SOME RESULTS FROM JOINT ACTIVITIES DURING 1988/89

3.1 Laboratory Activities

Figure 1 presents results obtained with the TDR system for dry soil samples with varying iron oxide content. These results are shown in the time domain and not in the frequency domain as would be expected, because it has
been extremely difficult to model the sample holder for this kind of target. As there are strong evidences that the permeability of these soils is different from that of free space, the modeling of the sample holder needs to be not only capacitive but also inductive (complex permeability may affect complex permittivity) in order to allow the measurement of $\varepsilon^*$ and $\mu^*$. Furthermore there is a possibility that these soils behave anisotropically. The only sample that is a pure dielectric is the one with 0% iron oxide (iron oxide extracted chemically). A comparison between the three curves shows that the reflected signals differ markedly, and that these differences for sure will influence results in the frequency domain. Intensive research on this subject is being done in the Microwave Laboratory of the Department of Electrical Engineering of IMT.

Figure 2 shows a scheme of the 32/90 GHz reflectance measurement system. It allows measurements of liquids (water, oils, alcohols, etc), porous materials (soils, etc) and even of vegetation under controlled conditions, in function of incidence angle (15-70 degree), polarization and frequency. Figure 3 presents the result of a water sample measured at 32 GHz. $T_1$ stands for the temperature of the reference (blackbody) and $T_2$ for the water temperature. $S=17$ mV/K represents the calibration of the system. The dispersion of data can also be clearly seen. These results for water fit very well to Fresnel equations. The great advantage of this system is the possibility of measurements under controlled conditions in this frequency range.

3.2 Field Radiometry

As stated before, the emphasis given to measurements in the field with the 1.4 GHz radiometer was on the calibration, radiometer stability and signal statistics. Figure 4 shows one of a series of longterm measurements over a bare soil area with an

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Fig. 1 - TDR Measurement results (Time Domain) for Oxisols with different iron oxide contents - dry soil samples.

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32/90 GHz REFLECTANCE MEASUREMENT SYSTEM

Fig. 2 - 32/90 GHz Reflectance Measurement System.

32 GHz RADIOMETER \( \sim 100 \text{ ms} - 0.5 \text{ K} \)
SAMPLE: WATER
\( T_1 = 330 \text{ K} \) \( S = 17 \text{ mV/K} \) \( T_2 = 290.5 \text{ K} \)

Fig. 3 - Results for a water sample at 32 GHz.
1.4 GHz RADIOMETER
STATIONARY MEASUREMENT CAMPAIGNS-MI1-13/14; 1.0.88
TESTSITE OBERPFaffen HOFen—BARE SOIL
f=1.410 GHz (SSB) fc+10 Hz t±68 ms B+10 MHz ΔT=4K

Fig. 4 - Results of a longterm measurement campaign with the 1.4 GHz radiometer and associated signal statistics.
incidence angle of 30 degrees. During the whole measurement period (24 hours) no significant climatic change was observed. Presented are the first four statistical moments (mean-value, standard deviation, skewness and kurtosis) and also the associated basic statistic (in this computation kurtosis was expected to be 0) and histogram of each moment respectively. For every block of 500 values of raw data one mean, standard deviation, skewness and kurtosis was calculated by the data acquisition system. During the 24 hours 960 values for the four moments were obtained. In order to test the hypothesis of normal distribution of the data the Kolmogorov-Smirnov normality test (goodness of fit) was applied to each set of data, with a significance level of 0.010. For the mean-value data are not normally distributed probably because of some signature / effect present. Standard deviation and skewness showed very good overall results being also normally distributed. The good statistics related to the standard deviation is a clear indicator of the radiometer stability. Nevertheless the positive values for kurtosis indicate that some phenomena is present. The altered histogram is the confirmation. This effect could be associated with the mean-value data. The third and fourth moments are in fact extremely sensitive to hardware instability and also to external interferences which, by the way, were very often observed in L-Band. Skewness and kurtosis can contain important hints not only about signature analysis but also about the kind of interference, etc. Unfortunately there are few studies about how skewness and kurtosis are affected, what their altered states do really represent, and what important information is hidden, regarding specific applications. This is a subject that must and will be further investigated, to provide secure and effective interpretation of radiometric data.

3.3 Airborne Campaigns

The same 1.4 GHz radiometer was installed in the DLR 228 D CALM research aircraft of the DLR, so as to allow for calibration flights and airborne missions. When airborne, this radiometer operates in a profiling mode (depression angle of 90 degrees), and in the frequency range of 1.350-1.500 GHz permits the selection of a fixed frequency (fixed mode) or the operation in sweep mode (31 channels). One of these calibration flights was performed near Oberpfaffenhofen over the Ammersee lake, in fixed mode (1.410 GHz) and also in sweep mode (a 20 MHz deviation was observed so that in fact the 31 channels covered the frequency range of 1.330-1.480 GHz). Figure 5 presents the results obtained for f=1.410 GHz and the statistics of the forest-lake-forest segments. The emissivity values found for lake (0.36) and forest (0.84) agree well to literature. The histograms show excellent results and the Kolmogorov-Smirnov normality test confirms that the distributions are Gaussian.

In sweep mode however, Figure 6, two distinct interferences are observed. One in the vicinity of 1.375 GHz and the other extending from about 1.420 to 1.465 GHz. This is a very good example to show how sensitive L-Band measurements are and how destructive interferences can be. The interference near 1.370 GHz is narrow banded and a strong correlation between 1.370, 1.375 and 1.380 GHz can be observed. The destructiveness of the second interference is of a different kind and broad band. The origin of these interferences remained unknown. In the next flight campaigns the use of a spectrum analyzer was suggested so that clean channels or frequency ranges can be selected, allowing the use of higher integration times and therefore achieving better resolution.

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7. References


Fig. 5 - Results from a calibration flight with the 1.4 GHz radiometer operating in fixed mode and associated signal statistics.

