DESIGN OF THE GROUND BASED ARRAY FOR THE TROPISCAT EXPERIMENT

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ABSTRACT

A ground-based Radar long wavelength design for imaging the vertical structure of the vegetation layer is proposed. In this system design, there is a fundamental constraint for minimum distance between nearby antennas required to avoid coupling effects. This leads to the height ambiguity appearing as a serious problem. In this paper, we discuss a multi-static configuration design which solves the minimum distance between antennas problem based on the concept of a virtual array.

Key words: TropiScat, virtual array.

1. INTRODUCTION

The BIOMASS mission, a candidate for the next Earth Explorer Core mission, is proposed to meet a pressing need for information on the carbon sinks and sources in the forests globally, which will be of essential value for climate modelling and policy adaptation [1], [2]. It is essential that BIOMASS could measure the tropical forest biomass, in order to estimate with accuracy this large component of the terrestrial carbon pool and the carbon sources generated by deforestation in the tropics. To this aim, the TropiSAR experiment has been performed in August 2009 in French Guiana [3]. Preliminary results show that it is possible to detect biomass level higher than 300 t/ha when using P-band intensity, however with low accuracy. It is expected that the tomgraphic vertical structure of forest areas will improve the retrievals of such high biomass values [4], [5]. Moreover, the tomgraphic interpretation has indicated that the scattering mechanisms may significantly differ from the mechanisms observed in temperate and boreal forests [4]. To improve our understanding of the scattering mechanisms, necessary for the development of robust retrieval algorithms, a ground based experiment TropiScat is proposed. Such experiment over a selected site in tropical forest would complete significantly airborne experiments by providing detailed and continuous datasets for various seasonal and weather conditions, providing a comprehensive dataset which will be used to refine the BIOMASS retrieval algorithms.

The Guyaflux tower (55m) has been selected to support

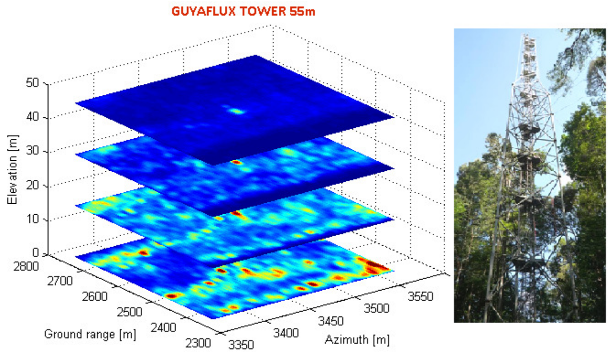

Figure 1. The ground based radar system will be installed on the top of Guyaflux tower in the tropical rain forest Paracou, French Guiana for TropiScat experiment. On the left panel, the metalic Guyaflux tower 55m, completely surrounded by trees whose canopy is on average 30m high, can be seen through 3D SAR Tomography technique. The right panel shows a picture of the Guyaflux tower.

this experiment and antennas will be placed on the top of the tower to radiate P to L band signals to the forest below as shown in Figure 1. A preliminary test was carried out in October 2010 using a Vector Network Analyser (VNA) with 2 P band antenna instruments [6]. The vertical aperture for tomographical imaging was formed by progressively moving downwards the couple of antennas. The first successful test results are the inputs for a stable configuration designed to ensure the quality of the results of the experiments to dure more than one year. This paper will discuss the design of an antenna array to be deployed on the top of the Guyaflux tower in the frame of the TropiScat experiment.

This paper is organized as follows: in section 2 the problem statement is presented, in section 3 the array design is discussed, in section 4 the tomographic performance is shown and in section 5 conclusions are drawn.

2. PROBLEM STATEMENT

The system is to be realized by connecting a VNA to multiple antennas through a switchbox, which allows to use

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any of them either as transmitter or receiver. The system will be designed to accomplish three requirements:

1. provide fully polarimetric vertical resolution capabilities, while ensuring unambiguous imaging of the whole vegetation layer;
2. gather data continuously for about a year with a conveniently short time, so as to study both the short term temporal coherence and its seasonal variations;
3. provide a sufficient number of looks to allow reliable coherence evaluation at every fixed height by averaging independent and homogeneous samples.

The requirement 1 resutls in a sufficient aperture requirement along the vertical direction. On the other hand, the antennas have to be closely spaced along the vertical direction to ensure unambiguous imaging. Requirement 2 entails the system is capable to acquire data of the same scene for an extended period of time. Requirement 3 can be fulfilled by using a large bandwidth system and/or by exploiting time averages. As an alternative, Requirement 3 could also be fulfilled by forming a further aperture along the azimuth direction. This option, however, would entail the usage of a either very large number of antennas or the capability to move the array horizontally, and hence it has been discarded. Finally, the system has to be able to operate at wavelengths compatible with those commonly used for investigations of vegetated scenarios through space borne SAR's, namely P-Band and L-Band. However, studying temporal decorrelation at P-Band seems to be the most urgent task to be accomplished, in order to provide input for the quantitative assessment of Tomographic and PolInSAR results achievable through the exploitation of multi-pass BIOMASS surveys on tropical forests.

The following constraints have been established by POLIMI, ONERA and CESBIO/CNES:

1. Employment of 20 antennas;
2. Each antenna has to be operated either as transmitter or a receiver;
3. The physical separation between any two antennas has to be equal or larger than $0.8m$.

Constraint 1 is intended to limit experiment costs. Constraint 2 allows to simplify system installation and improve the overall SNR by operating a simpler RF switchbox. Constraint 3 has been established in order to minimize electromagnetic coupling effects due to the interaction among different antennas. The value of $0.8m$ has been deemed to be a sufficiently safe distance to operate the equipment correctly, as resulted from field trial experiments in October 2010 [6], [7].

However, at the vertical sampling of Constraint 3, the height ambiguity appears as a serious problem. Since the vertical sampling requirement to have a safe height of ambiguity, i.e: a half of P band wavelength, is broken if we place antennas in 1D vertical direction.

A trivial solution to fulfill Constraint 3 while granting a large height of ambiguity could be pursued by employing a 2D array, i.e: by separating any 2 nearby antennas horizontally. It is important to keep in mind that the horizontal distance also should be greater a wavelength to avoid coupling effects. This would entail correlation loss between signals at different antennas, since each of them would sense the imaged volume with different horizontal wavenumbers. In other words, moving to horizontal direction is still not a solution.

In the remainder, we propose a multi-static configuration design which solves the minimum distance between antennas problem based on the concept of a virtual array.

3. ARRAY DESIGN

To conjugate requirements and constraints above the array design has been based on the concept of a virtual array. Roughly speaking, the virtual array is the array relating to the center positions between any transmitter and receiver positions. The design is obtained by placing a transmitting and receiving antennas in such positions as to illuminate, at least theoretically, the same wavenumbers of the investigated object as a single monostatic antenna placed in the middle.

By employing multiple transmitting-receiving pairs we thus achieve the same imaging performance as a vertical array constituted by closely spaced antennas, even though the physical separation is actually consistent with Constraint 3.

The most promising design so far encompasses one vertical array of 5 antennas for each polarization (i.e: horizontal or vertical) and for each operating mode (i.e.: transmit or receive). This simplifies not only the switch boxes but also the system operation.

This design has been optimized for a central frequency of $500MHz$. However, the system is expected to provide imaging capabilities at $700MHz$ and $900MHz$, so as to cover all cases to be investigated within TropiScat, if need be. The virtual arrays for HH and VV are found at the same positions, whereas the virtual arrays for HV and VH are $0.8m$ apart. This is expected to result in the possibility to preserve HHVV coherence, whereas the HV and VH are expected to be totally uncorrelated because of the separation between the corresponding virtual arrays.

System main figures are summarized as follows: overall horizontal extent: $< 2.5m$; overall vertical extent: $< 4.5m$; minimum distance between antennas: $0.8m$. The antenna positions are shown in Figure 2.

The position of each virtual antenna along the vertical direction is the same in all cases. This entails the same

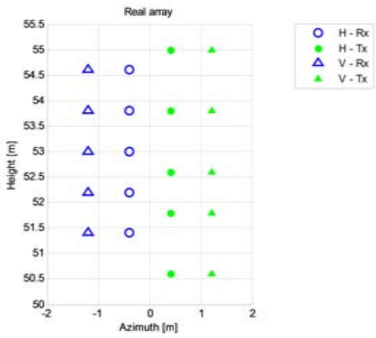

Figure 2. Antenna positions for tomographic measurements

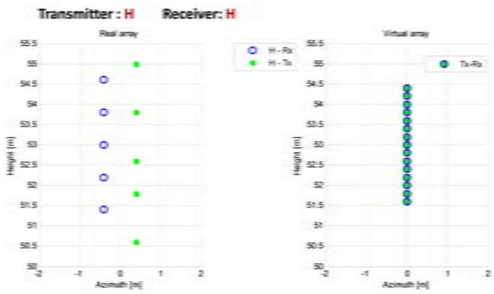

Figure 3. The real and virtual array for HH mode

imaging properties in all four polarizations. In particular, the resulting virtual array aperture and spacing are, respectively: $Az = 2.8m$; $dz = 0.2m$. Figure 3 shows an example virtual array of H-transmitter H-receiver mode.

Figure 4 reports the 3D Impulse Response Function at $500MHz$ for a target at $20m$ above the ground of HH configuration. The figure has been obtained by considering the antenna pattern in both the elevation and horizontal planes of antenna LP Satimo 400 [8], allowing to appreciate the actual shape of the 3D resolution cell.

As a first approximation the vertical resolution can be assessed as:

$$\rho_z = \frac{\lambda}{2A_z} r \quad (1)$$

Where λ is the carrier wavelength and r is the distance from the antenna to the target. For example, vertical resolution at $r = 70m$ is readily obtained as: $\rho_z = 7.5m$ at $500MHz$; $\rho_z = 5.3m$ at $700MHz$; $\rho_z = 4.1m$ at $900MHz$.

Ambiguities can arise depending on the vertical spacing between two nearby positions along the array, dz. Again as a first approximation, the height of ambiguity can be assessed as:

$$z_{amb} = \frac{\lambda}{2d_z} r \quad (2)$$

Which turns out to be higher than $40m$ for $r > 50m$ even at $900MHz$.

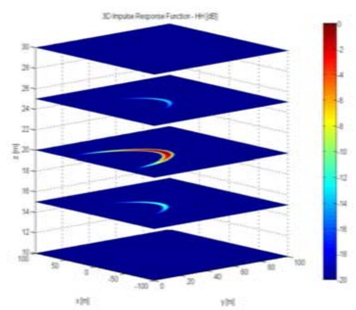

Figure 4. 3D Impulse Response Function for a target at 20m above the ground. $F_c = 500MHz, \theta = 40^0$.

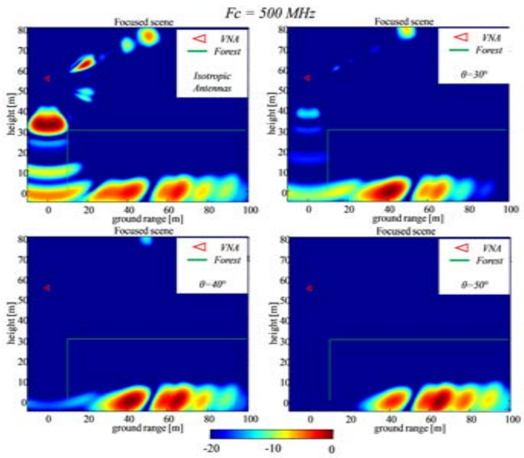

Figure 5. Imaging at 500 MHz - numerical simulation

4. TOMOGRAPHIC IMAGING PERFORMANCE

4.1. Tomographic performance

We simulate random scatterers on the tower and at the ground layer in such a way as the backscattered power from the tower scattering is 10 times greater than from the ground scattering. Scattering from the forest has intentionally not being included, so as to allow evaluation of ambiguous contributions within the vegetation layer. The simulation uses the diagram of antenna LP Satimo 400 [8]. 4 scenarios are considered with isotropic antenna and antenna diagrams with look angle $\theta = 30^0, 40^0, 50^0$ respectively. Detailed information about the tomographic imaging performance are displayed in Figure 5.

The best imaging quality is found at $500MHz$. In this case the array ensures rejection of spurious contributions well beyond 20 dB. The situation is clearly im-

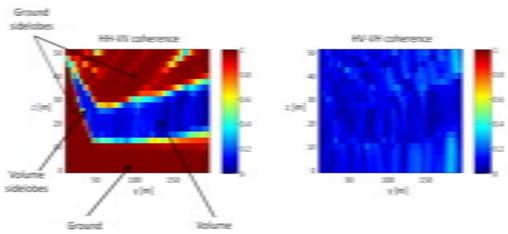

Figure 6. Coherence magnitude for HH-VV and HV-VH

proved by accounting for the elevation antenna pattern. At $700MHz$, and especially at $900MHz$, spurious contributions appear that might jeopardize the overall imaging quality at near ranges, where ambiguities from the tower and terrain are likely to appear within the forest.

4.2. Polarimetric coherence

Coherence evaluation has been carried out by simulating a two layer scenario representing ground and volume scattering in such a way as the Ground HH-VV coherence equals 1 while the Volume HH-VV coherence at $20m$ above the ground is zero. The estimated polarimetric coherence are shown in Figure 6.

HH-VV coherence is characterized by four regions. At the ground level the observed coherence is very close to 1, consistently with the value simulated for ground scattering. At about $20m$ the coherence is observed to drop down towards 0, as a consequence of the fact that this region is occupied by volume scattering. Almost all the rest of the picture is dominated by sidelobes from ground scattering, which yield the same polarimetric coherence as the one observed at the ground level. Finally, near range areas with very low coherence are observed, as a result of the presence of spurious contributions from volume scattering. It is important to remark that ground sidelobes do not affect coherence measurements for the volume, despite the fact that the backscattered power from ground scattering had been set to 10 times that from volume scattering. Polarimetric coherence between HV and VH is approximately 0, as a consequence of the separation between corresponding virtual arrays.

5. CONCLUSION

We proposed an array design which is well suited to study the vertical distribution of forest parameters. The tomographic array is intended to provide fully polarimetric 2D (ground range-height) resolution capabilities through the coherent combination of the signal from 20 different antennas. This is approximately equivalent to a 1D vertical array having a $20cm$ spacing for each polarization. This spacing, at P band, yields an ambiguous return appearing at an angle close to 135^0 from the target, well distinguished from the forest. The system can work from $500MHz$ to $900MHz$. The vertical resolution in far range $70m$ is about $7.5m$ in P-Band and proportionally higher at higher frequencies. The co-polar HH-VV coherence is preservesd as their virtual arrays coincide. The VH and HV virtual arrays are separate and allow to double the available number of cross polar looks. Each antenna belongs to either the receiver or the transmitter groups, simplifying the hardware switch boxes implemetation. In future, the design performance assessment will be based on a measurement data in term of polarimetric tomographic and temporal polarimetric coherence with respect to forest heights.

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