Forest bistatic scatttering at low frequencies: simulations and indoor measurements

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Abstract

We are interested in the bistatic scattering of a forest area at VHF-UHF band for FOPEN applications. A modelling tool is used to simulate different configurations and we present in this communication comparisons between simulated and real bistatic data collected by ONERA in one of their anechoic chambers. Two cases are namely analysed: first a single dielectric cylinder and then a group of vertical dielectric cylinders.

1. Context and configurations

As matters stand, it is not possible to establish the relevancy of bistatic observations. Obviously, there is a clear advantage for a military point of view: a passive radar can be used as a delocalized receiver and an improvement in the detection of stealth target is expected. However, this research area is still in a nascent stage. There are still problems to solve to build a bistatic image and to calibrate bistatic data. Furthermore, we have to make our usual processing tools evolve from the monostatic to the bistatic case, and we might expect that this is not trivial, like for polarimetry. In the particular frame of forested areas observation, bistatic configurations are expected to improve biomass retrieval [1]. For FOliage PENetration (FOPEN) studies, bistatic observations could decrease the forest contribution, which is so high in the monostatic case, and therefore enhance the detection capabilities. Due to the few amount of available bistatic data, it appeared that the use of scattering models is crucial to make these studies progress. Few models have been developed, which can handle these configurations. In this new situation, only descriptive models can be considered, as they do not rely on any *a priori* knowledge either on the quantities to derive (like for analytical models) or on past observations (like for empirical models). In terms of coherent modelling (which means that we consider both the amplitude and the phase of the scattered fields), our COherent Scattering MOdel (COSMO) is one of the very few bistatic models available and in addition, one of the very few models which has been widely tested in the monostatic case (See [2] for further details). Previous studies [3,4] have strengthen the reliability in the bistatic results delivered by COSMO, but measurements still remain essential to validate our simulating tool. In this communication, we present comparisons between simulated and real bistatic data collected by ONERA in one of their anechoic chambers. Two cases are analysed: first with a single dielectric cylinder and then with a group of vertical dielectric cylinders.

For almost all the results presented here, we consider a single or a group of three dielectric cylinders whose height is 9m and whose diameter is 30 cm. The radar configuration is described in Fig. 1. We consider an incident monochromatic plane wave $\mathbf{E}_i$ with a frequency f and either V- or H- polarized. The incident direction is described by the aspect angle θ_i and the azimuth angle $\phi_i = 0$. In our bistatic study, the emitter is located at a constant place and only the receiver is moving. As a consequence, the scattering aspect and azimuth angles are varying respectively in $[0°, 80°]$ and in $[0°, 180°[$. The scattered electric field $\mathbf{E}_s$ is simulated for all polarizations. The monostatic configuration is simulated for $\theta_s = \theta_i$ and $\phi_s = \pi$, the specular configuration is achieved for $\theta_s = \theta_i$ and $\phi_s = 0$. Measurements have been conducted in an anechoic chamber with a scale of $1/30$. The cylinders of the experimentation have a height of 30cm and a diameter of 1cm. The *scaled* permittivity of these cylinders in the UHF-VHF band is provided by the manufacturer. When the cylinders are lying over a metallic plate, the calibration process has been made in such a way that the direct response of the plate is substracted. Therefore, in this case, we have to consider the contribution of the scatterer and of its interactions with the plate, but not the direct contribution of the plate. Because of the configuration of the anechoic chamber, the pure monostatic case could not be achieved and consequently no measurement has been collected. In addition, for the pure specular case, the measurements are cluttered by the strong response of the transmitter, as it is aligned with the receiver. The reader has also to note that for the real data, the monostatic

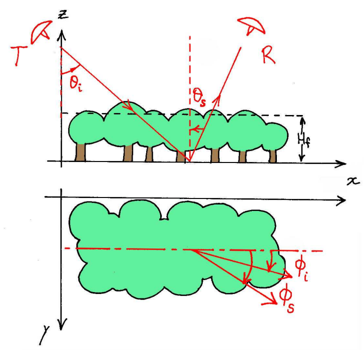

Figure 1: Bistatic radar configuration: side view (top) and top view (bottom). T refers to the transmitter, which is located at a constant place. The incidence angles θ_i and ϕ_i are then constant. R is the receiver, which is moving all around the scene, with θ_s varying in $[0, \pi/2]$ and ϕ_s in $[0, \pi]$. H_f is the mean height of the scene under study.

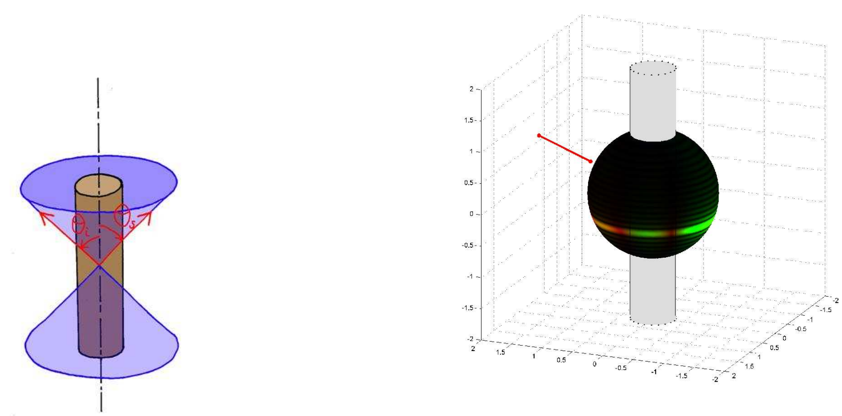

Figure 2: **a (left)**: Representation of the scattering directions which maximize σ_{qp} for a constant incident direction. **b (right)**: Projection on a sphere of σ_{qp} of a vertical dielectric cylinder in free space. The arrow indicates the direction of the incident wave ($\theta_i = 60°$, $\phi_i = 0$ and $f = 300$MHz). The receiver has moved all around the cylinder. The Pauli basis is applied.

configuration is obtained for $\theta_s = \theta_i$ and $\phi_s = 0$ and the specular configuration is achieved for $\theta_s = \theta_i$ and $\phi_s = \pi$. When measured and simulated data are compared, appropriate changes have been made and the configuration of the real data has been retained. Different presentations have been adopted along this paper, in order to better illustrate the bistatic variations of the scattering coefficients σ_{qp} defined as $\sigma_{qp} = 10\log_{10}\left(4\pi\frac{\langle|\hat{\mathbf{q}}.\mathbf{E}_s|^2\rangle}{|\hat{\mathbf{p}}.\mathbf{E}_i|^2}\right)$ with $\hat{\mathbf{q}}, \hat{\mathbf{p}} = \hat{\mathbf{v}}, \hat{\mathbf{h}}$ defining the receive/transmit polarization vectors. When θ_s and ϕ_s vary, σ_{qp} is projected on a sphere. In this case we have used the Pauli basis which shows the polarimetric behavior: $HH - VV$ in green represents the double-bounce scattering, $HH + VV$ in red, the single scattering, and $2HV$ in blue, the volume scattering. These interpretations are known to be *valid* for monostatic configurations. When θ_s (resp. ϕ_s) varies, we plot the variations for all the polarizations of σ_{qp} with respect to θ_s (resp. ϕ_s). Finally, when both f and ϕ_s vary, we plot the hologram of σ_{qp} in the Pauli basis.

2. Case of a single dielectric cylinder

The scattering directions which lead to the strongest scattering coefficients are drawn in Fig. 2a. They describe the surface of a cone defined by $\theta_s = \theta_i$ (upper part of the cone) and $\theta_s = \pi - \theta_i$ (lower part of the cone, which actually contains the maximal response for $\phi_s = \phi_i$, i.e. in the forward direction). Consequently, we expect to obtain high values of the scattering coefficients on the ring determining the lower part of the scattering cone.

We have plotted in Fig. 2b the variations of the simulated bistatic scattering coefficients of a vertical dielectric cylinder with θ_s and ϕ_s for $\theta_i = 60°$, $\phi_i = 0$ and $f = 300$MHz. As predicted, we obtain the strongest responses on a ring

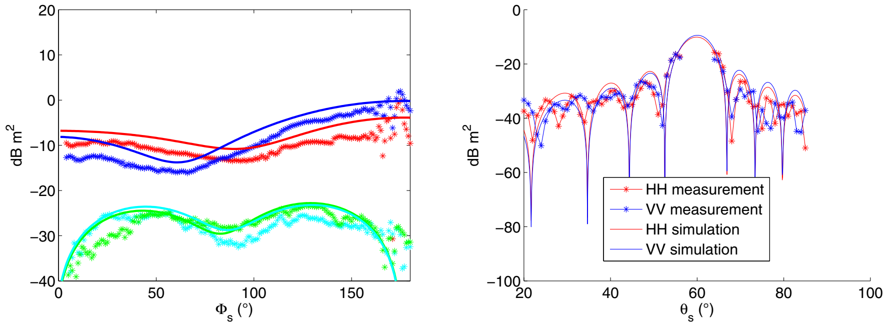

Figure 3: **a (left)**: Comparison between the variations of the measured (full line with dots) and simulated (full line) bistatic scattering coefficients of a dielectric cylinder w.r.t. ϕ_s. The four polarizations are plotted : VV (dark blue), VH (green), HV (light blue) and HH (red). Frequency is of $300MHz$, $\theta_i = \theta_s = 70°$. For the measured data, $\phi_s = 180$ is obtained in the specular direction and $\phi_s = 0$ corresponds to the classic monostatic configuration.**b (right)**: Comparison between the variations of the measured (full line with stars) and simulated (full line) bistatic scattering coefficients of a dielectric cylinder w.r.t. θ_s in the monostatic region. The co-polarizations are plotted : VV (blue), and HH (red). Frequency is of 300 MHz, $\theta_i = 60°$, $\phi = 0°$.

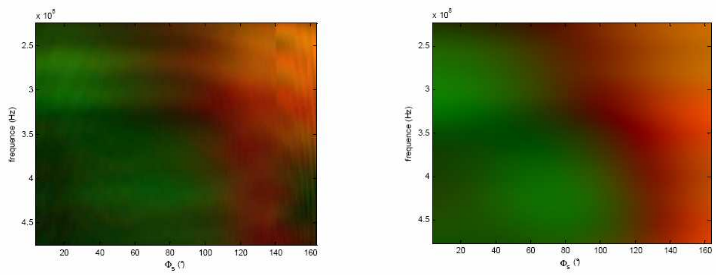

Figure 4: Variation of the polarimetric behavior of a vertical dielectric cylinder lying over a perfectly conducting plane w.r.t. frequency and ϕ_s: measurements (left) and simulations (right). The Pauli basis is applied: $HH - VV$ is in green, $HH + VV$ is in red and $2HV$ is in blue.

located in the lower part of the cylinder. We consider a section of this scattering pattern and focus on the variation of the scattering coefficient with ϕ_s. The incidence angle is slightly different (now $\theta_i = 70°$) and we consider the case $\theta_s = \theta_i$. Fig. 3a represents the comparison between simulated and measured data for all polarizations. The error between the measurements and the simulation can reach 3 dB for co-polarizations and 5 dB for the cross-polarizations. These results are very encouraging knowing first that the uncertainty on the measurements can be important and considering then that the amplitude of the measurements are very small but well reproduced by the simulations. Fig. 3b represents now the comparison between simulated and measured data for all polarizations in the case where only θ_s is varying. We obtain a very good agreement for the first two lobes around the main lobe (which corresponds to the monostatic case). Elsewhere, we observe a faster variation of the measurements, which could be linked to the size of the plate. The polarimetric behavior of a cylinder lying over a metallic surface is plotted in Fig. 4 with respect to f varying in $[225, 475]$ MHz and ϕ_s in $[10°, 160°]$. First we observe that the polarimetric behavior is very well simulated and there again, this result is very encouraging. Then, it confirms a result we obtained in a previous study [3], where we concluded that the polarimetric behavior of a dielectric cylinder over a ground depends on the scattering azimuth angle ϕ_s. We observe here that this behavior depends also on frequency. This result is very important, as it has a strong impact on the interpretation. Fig. 4 confirms that*Monostatic* polarimetry is expected to fail for bistatic observations and efforts have to be made to solve this difficulty but these new developments have to include the impact of frequency.

3. Case of a set of vertical dielectric cylinders

Three dielectric cylinders are located over a metallic surface. Their positions correspond to the edges of an equilateral triangle with a side of 3.5cm, i.e. a *scaled* distance of 1.05m at VHF-UHF band. This distance is actually a very

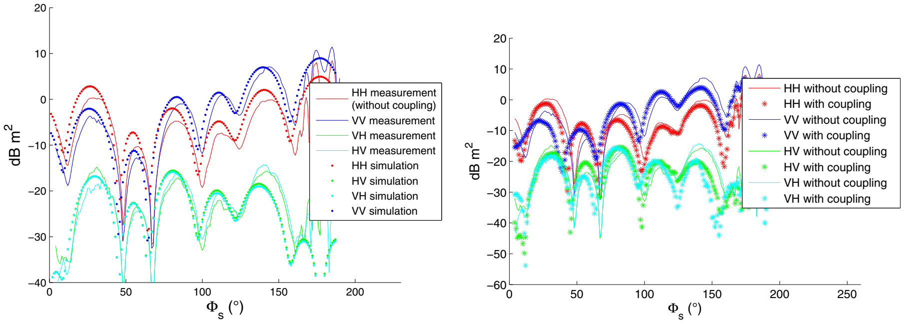

Figure 5: Comparison between the variations of the measured (full line with dots) and simulated (full line) bistatic scattering coefficients of a group of dielectric cylinders w.r.t. ϕ_s. The four polarizations are plotted : VV (dark blue), VH (green), HV (light blue) and HH (red). Either the interactions are considered in the measurements (left) or they have been suppressed by superimposing the duplicated response of a single cylinder, whose phase has been shifted w.r.t. the location of each cylinders in the group. Frequency is of 275 MHz, $\theta_i = \theta_s = 70°$. For the measured data, $\phi_s = 180$ is obtained in the specular direction and $\phi_s = 0$ corresponds to the classic monostatic configuration.

short one and is not really representative of the mean distance separating two trunks. The variations of the bistatic scattering coefficients of the group of cylinders are measured for different ϕ_s. The same configuration is simulated, but mutual interactions are not taken into account. Two comparisons are made: first we directly compare the measured and the simulated data. Then we duplicate the response of a single cylinder and we shift the phase of its scattered field accordingly to the location of each of the three cylinders. We compare this result with the same simulated data, as the ones quoted just above. These comparisons are represented in Fig.5. We can deduce from these two figures that the bistatic scattering amplitude of a group of cylinders is well simulated, provided that mutual interactions can be neglected. In realistic FOPEN configurations, the distance between two adjacent trunks is generally larger than the one considered for this study, and we can conclude that COSMO simulates quite well the bistatic behavior of a group of trunks at UHF-VHF band, when ϕ_s varies.

4. Conclusion and perspectives

We have presented in this communication, the very first bistatic measurements over a single or a group of dielectric cylinders collected by ONERA in one of their anechoic chambers. These data have been satisfactorily compared to simulated ones, obtained with a modelling tool at frequencies in UHF-VHF band. These results allow to validate a little more COSMO and to strengthen past observations we made, namely for polarimetric analysis. We are now more confident to use this tool, for example to determine the most relevant configurations for FOPEN studies. Since the forest contribution is very strong in the monostatic and in the *specular* regions, we could conclude that these two configurations have to be avoided. Nevertheless, we have to go further and study the variation of the attenuation for different bistatic configurations to confirm this result.

5. References

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