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Nicole de Beaucoudrey, François Poulain, Laurent Davoust, Jean-Marc Rousset, Félicien Bonnefoy. Microwave scattering experiment on a wave tank: bistatic setup. 6th European Conference on Antennas and Propagation, Mar 2012, Prague, Czech Republic. 10.1109/EuCAP.2012.6206230 . hal-00663559

HAL Id: hal-00663559

<https://hal.science/hal-00663559>

Submitted on 12 Mar 2020

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Microwave Scattering Experiment on a Wave Tank: Bistatic Setup

N. de Beauhoudrey¹, F. Poulain¹, L. Davoust², J.M. Rousset², F. Bonnefoy²

¹ IETR UMR 6164, CNRS, Université de Nantes, Lunam Université, Nantes, France

² LMF UMR 6598, CNRS, Ecole Centrale de Nantes, Nantes, France

Abstract—To validate models of electromagnetic wave scattering by rough surfaces, a laboratory experimental setup of microwave scattering by a water surface is implemented above a wave tank. This wave tank facility allows to produce controlled waves and, therefore, to acquire signals with known conditions. The previous configuration was monostatic, i.e. with both antennas (the transmitter and the receiver) in the same location, and it therefore enabled to record only the signal backscattered after reflection from the water surface. Very recently, we extended the experimental setup to get a bistatic configuration, with the two antennas in different locations. Measurements are acquired for several angles of incidence and observation and for various conditions of waves. The analysis of measurements permits to study the effect of electromagnetic parameters (frequency, angles of antennas, ...) and hydrodynamic parameters (wave type, height and wavelength, ...).

Keywords—electromagnetic scattering, rough surfaces

I. INTRODUCTION

The study of electromagnetic scattering by natural rough surfaces has many applications, for example in remote sensing of the ocean, to detect targets on the sea (ships, drifting objects, ...) or to extract environmental parameters (ocean state, salinity, oil spills, ...). In order to evaluate the electromagnetic scattering of rough surfaces such as the sea, scattering models have been developed for many years [1-2]. To validate the reliability of results calculated by scattering models, it is useful to compare them with experimental results. It is difficult not only to have at our disposal such measurements in real conditions, but even more to know precisely the geophysical parameters in such cases (sea state, ...). A laboratory experimental setup is therefore an optimal tool to acquire measurements with known conditions. For this, we use the wave tank of the Laboratoire de Mécanique des Fluides (LMF) of Ecole Centrale de Nantes. The experiment in a wave tank permits to control the shape of produced waves. The goal is to get the values of the hyperfrequency reflectivity of a water surface as a function of its roughness, for different directions of observation.

In a first stage, we realized a setup on the wave tank for a monostatic configuration, i.e. with both antennas (the transmitter and the receiver) in the same location [3]. This simple setup allowed to record only the signal backscattered after reflection from the water surface.

Very recently, we extended the experimental setup to get a bistatic configuration, with the two antennas in different locations. Measurements can now be acquired for different angles of incidence and observation. We present the experimental setup and the measurements carried out very recently (september 2011).

II. BISTATIC EXPERIMENTAL SET-UP

The wave tank is a rectangular pool (length 50m, width 30m, depth 5m) of fresh water. 48 paddles are located on one side of the basin and a wave absorber on the opposite side. A specialized software controls these paddles for generating three-dimensional waves. Fig. 1 gives a general view of the microwave apparatus installed above the wave tank. The transmitter antenna is fixed on a deck while the receiver antenna is installed below a platform hunged under a handling crane.

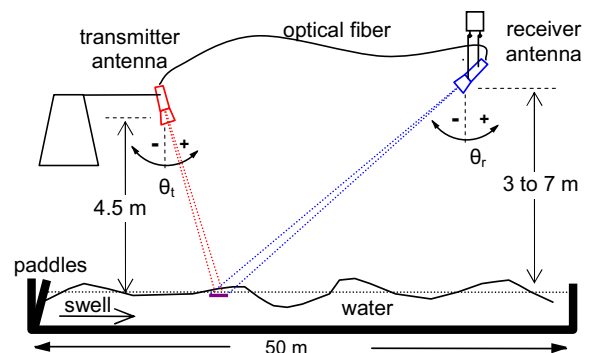


Figure 1. General view of the experimental bistatic setup.

funded by the french Region Pays de la Loire through the DIMBAHO project (Diffusiomètre Micro-Ondes sur BAssin de HOule).

Each antenna is held in a rotating frame (Fig. 2). A vector network analyzer (Agilent PNA 8364) is positioned near the receiver antenna and connected to the transmitter antenna by an optical fiber. A computer, located at ground level, remotely controls the microwave apparatus: it steers the antennas in the chosen directions, it drives the analyzer and performs acquisition of measurements.



Figure 2. Transmitter (a) and receiver (b) antennas.

The pyramidal horn antennas are linearly polarized and can be positioned in either vertical or horizontal orientation (i.e. with the electric field constrained in either V or H plane). The transmitter altitude over the mean water surface is fixed at 4.5 m while the receiver altitude varies from 3 m to 7 m.

III. MEASUREMENTS

A. Microwave parameters

We operate in X band (8-12 GHz). For this campaign, we chose VV configuration. The antennas devices can be rotated in the vertical plane defined by the swell direction (along the length of the basin), with 0.2° angular step. The acquisition frequency is 20 Hz (sampling time of measurements 0.05 s), thus allowing to follow temporal variations of the swell.

B. Hydrodynamic parameters

Experiments have been conducted either above a still water surface or above two-dimensional waves, propagating in one direction (along the basin length). In order to do this, the 48 paddles move in conjunction. Generated waves are either regular (Stokes waves) or irregular (random waves, with a Bretschneider spectral distribution). The wave height (defined respectively as the peak-to-trough distance for regular waves or as the significant wave height for irregular waves) is ranging from 5 cm to 35 cm. The wave frequency is equal to 0.5 Hz or 0.7 Hz, thus corresponding to a period T of 2 s or 1.43 s and a wavelength, $L=g/(2\pi f^2)$, nearly equal to 6 m or 3 m.

C. Experiments

Experiments were carried out with various conditions during the measurement campaign. The altitude of the the receiver antenna was chosen equal to the transmitter, i.e. 4.5 m. Horizontal distance between the antennas can vary: we realized measurement for 2 distances, 'long' 14 m and 'short' 5.4 m.

For a given horizontal distance, the orientations of both antennas have to match so that they illuminate the same part of the water surface. Fig. 3 shows the bistatic geometry with θ_t the angle of the transmitter beam axis, θ_r the angle of the receiver beam axis, and the internal angle bisector of these 2 beams.

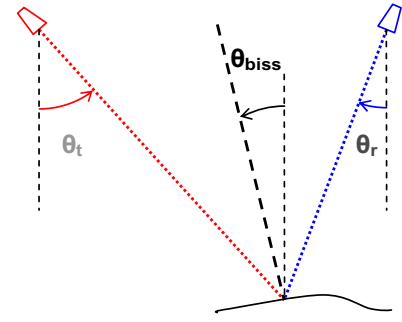


Figure 3. Geometry of antennas axes, with their bisector.

Table I gives the orientations we carried out, $\{\theta_t, \theta_r\}$, measured relatively to the vertical, in the counterclockwise direction. θ_{biss} is the angle of the bisector. For the case with $\theta_t = -\theta_r$, the bisector is vertical, corresponding to the specular case for a still water surface (horizontal).

TABLE I.

	Antennas orientation		Bisector angle
	transmitter	receiver	
'long' antennas distance = 14 m (in bold, specular case)	56°	-56°	0°
	61°	-55°	3°
	61°	-50°	5.5°
	67°	-40°	13.5°
'short' antennas distance = 5.4 m (in bold, specular case)	31°	-31°	0°
	51°	0°	25.8°
	40°	-22°	8.5°
	36°	-27°	4.9°
	44°	-15°	15°
	14°	-45°	-15°

Fig. 4 presents some examples of acquired raw data as a function of time. Each curve plots the modulus of the ratio of the received electric field to the transmitted one. The microwave frequency is 8.1 GHz. The antennas configuration is for 'short' distance, in specular case $\{31^\circ, -31^\circ\}$, with waves of height $H = 10$ cm.

- Fig. 4(a) is for regular waves 0.5 Hz.
- Fig. 4(b) is for regular waves 0.7 Hz.
- Fig. 4(c) is for irregular waves 0.5 Hz.
- Fig. 4(d) is for irregular waves 0.7 Hz.

Fig. 5 shows a set of experiments, for regular waves of frequency equal to 0.7 Hz, with height $H = 25$ cm. Fig. 5(a) plots the swell amplitude, measured with a swell probe at a fixed distance, as a function of time. We acquired the electromagnetic signal, at microwave frequency 8.1 GHz, for 'short' antennas distance 5.4 m, for 3 configurations $\{\theta_t, \theta_r\}$.

- Fig. 5(b) plots the signal at $\{\theta_t = 31^\circ, \theta_r = -31^\circ\}$ $\theta_{biss} = 0^\circ$.
- Fig. 5(c) plots the signal at $\{\theta_t = 36^\circ, \theta_r = -27^\circ\}$ $\theta_{biss} = 4.9^\circ$.
- Fig. 5(d) plots the signal at $\{\theta_t = 40^\circ, \theta_r = -22^\circ\}$ $\theta_{biss} = 8.5^\circ$.

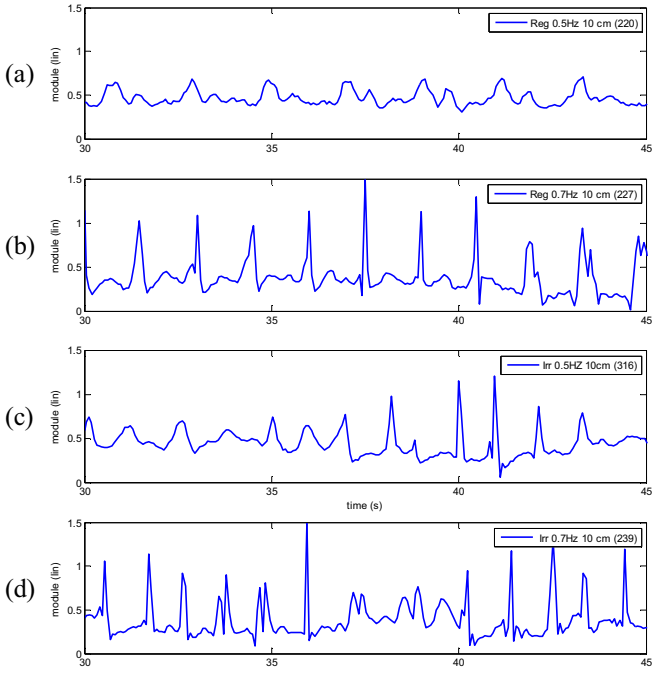


Figure 4. Measures as a function of time in specular case, with waves of height $H = 10$ cm.

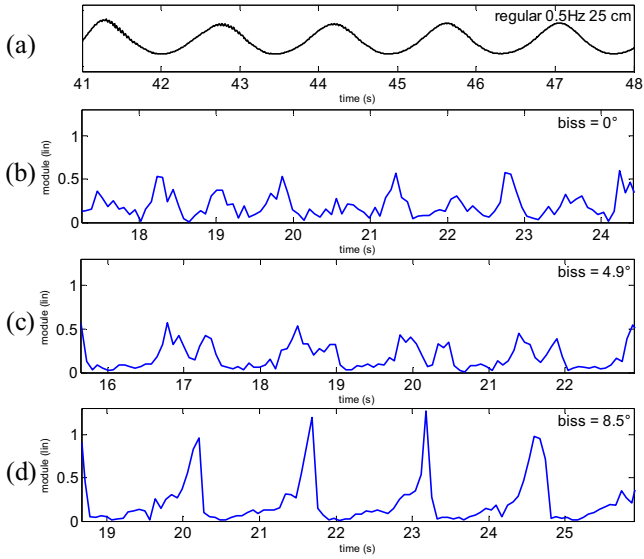


Figure 5. Measures as a function of time for different angular configurations.

Each angular configuration of antennas enhances the signal reflected by different parts of the surface, such that slopes are equal to $\tan(\theta_{\text{biss}})$. Fig. 6 explains in details this phenomenon, with simulations of 2D gravity wave propagation in the wave tank [4-5]. Fig. 6(a) plots the surface height as a function of time for a given distance, $x = 3$ m, as a function of time. Fig. 6(b-f) show the surface height as a function of distance, x , for a fixed time. For each time, t_1 to t_5 , we represent the antenna axes as well as their bisector, put in the position where the slope of the surface is equal to $\tan(\theta_{\text{biss}})$.

- First, Fig. 6(b) shows that the configuration $\theta_{\text{biss}} = 0^\circ$ will give a high level of signal when the illuminated part of the surface is in the trough of the wave, corresponding to time t_1 , or $t_1 + nT$.
 - Next, Fig. 6(c) shows that the configuration $\theta_{\text{biss}} = 0^\circ$ will also give a high level of signal when the illuminated part of the surface is in the peak of the wave, corresponding to time t_2 , or $t_2 + nT$.

Indeed, Fig. 5(b) has such peaks, higher for troughs because a concave surface focusses the antenna beam, while peaks are convex and make the beam diverges.

- Fig. 6(d) with the antennas configuration $\theta_{\text{biss}} = 8.5^\circ$ gives a high signal at time t_3 , when the illuminated part of the surface has highest slopes. This configuration is for Fig. 5(d), with $\theta_{\text{biss}} = 8.5^\circ$.

- Fig. 6(e) and Fig. 6(f), with the configuration $\theta_{\text{biss}} = 4.9^\circ$, gives a high signal at times t_4 and t_5 . This corresponds to Fig. 5(c), where we can see two peaks, before and after the highest slope respectively (Fig. 5d).

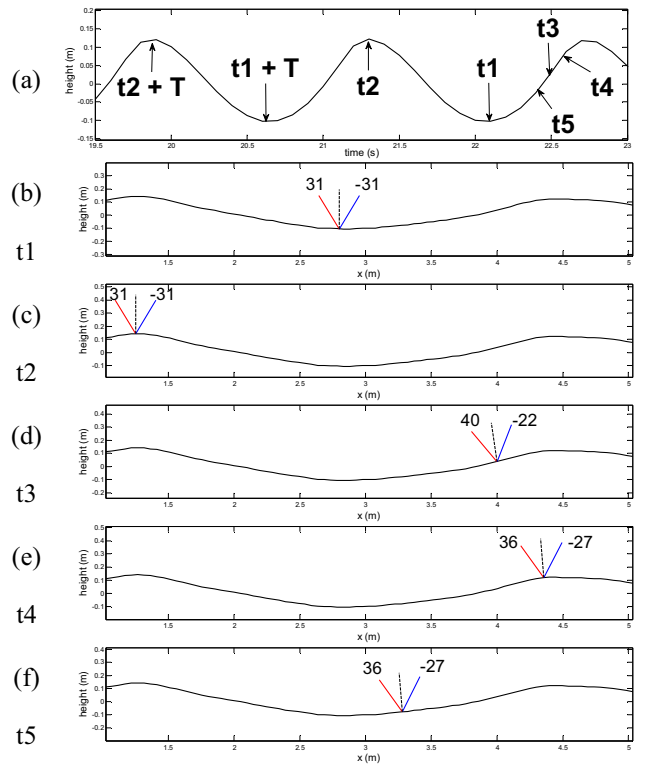


Figure 6. Effect of the the angle of the bisector.

IV. CONCLUSION

This experimental setup of microwave scattering by a water surface has been implemented above a wave tank, in a bistatic configuration, with the two antennas in different locations.

Measurements acquired for various hydrodynamic and electromagnetic conditions of waves can be used as a database for further analysis. Here, we have studied the effect of the bisector angle of antennas axes on the results.

These experiments will be compared to simulation results obtained from electromagnetic models [6].

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