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Preliminary study of 0.14 THz water surface clutter reflectivity at near vertical incidence angle

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Abstract：As the development of radar systems developed for the terahertz and higher millimeter region continues to grow, the interest in the water surface and land clutter at terahertz and higher millimeter frequencies continues to increase. An empirical model of sea clutter reflectivity is described firstly, which is valid at near vertical incidence and has small average absolute deviation compared to other empirical models. Simulated results of 0.14 THz sea clutter at near vertical incidence with this model are shown. An indoor test-bed is constructed in order to measure 0.14 THz water surface clutter reflectivity and an experiment is carried out. Initial experimental results are presented and compared to the simulation results, which partially verifies that the empirical sea clutter model still works at 0.14 THz.

Keywords：water surface clutter reflectivity；VGH model；terahertz radiometer

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1　Introduction

The understanding of back scattering feature of water and ground at terahertz and higher millimeter frequencies becomes more and more important as the radar systems working at these frequencies continue to evolve[1-2]. Most attention is paid to the scattering properties of different types of ground and water at microwave frequencies[3-4]. At terahertz frequencies, a representative work has been done by the Submillimeter-wave Technology Laboratory(STL) about back scattering coefficient of sand, gravel, topsoil with various moisture content, roofing shingles, and brushed and unbrushed concrete at 100 GHz and 240 GHz[5]. The results of the scattering properties of water at terahertz frequency still have been rarely reported.

In order to study the scattering properties of water, there are two issues need to be resolved. First, there is very little data which can be used. Most of the data that has been published are in the microwave and lower millimeter-wave region. Second, few model has been verified at terahertz frequency. All the empirical models of water clutter reflectivity are based on the existing experimental database and whether or not they can still work at terahertz frequency needs to be tested.

Both of the two problems will be discussed in this article. A millimeter-wave empirical model for Radar Sea clutter reflectivity called Naval Research Laboratory(NRL) is introduced first and a simulation result is shown for the model at 0.14 THz. In order to verify the validity of the model, an indoor test-bed is constructed based on a 0.14 THz single frequency radiometer and a preliminary experiment is carried out. The reflectivity of water is measured at near vertical incidence using a relative measurement method and the result is presented and compared to the simulation result of NRL model.

2　Introduction of VGH Model

There are several popular empirical models that have been published in the past years[6-7]. Most of these models are based on the Nathanson's database which represent the de facto standard for sea clutter reflectivity as a function of frequency, grazing angle, sea state, and polarization[8]. One typical model, named NRL model, which was published by

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researchers from NRL has received a lot of attentions[4]. The form of the empirical model was chosen in order to make the average absolute deviation between the model and the experimental data minimized.

The form of the NRL model is

$$\sigma_{\mathrm{H,V}} = c_1 + c_2 \lg_{10}(\sin\alpha) + \frac{(27.5 + c_3\alpha)\log_{10} f}{(1+0.95a)} + c_4(1+SS)^{1/(2+0.085a+0.033SS)} + c_5 a^2 (\mathrm{dB}) \tag{1}$$

In which α is the grazing angle(°), SS is the sea state, and f is the radar frequency. The constants c_1–c_5 are optimized to make the average absolute deviation between the model and experimental results in Nathanson's book minimized. For horizontal polarization, the constants are listed in table 1.

Table1 Constants in the VGH model

constants	polarization	
	horizontal	vertical
c_1	–73.000 0	-50.790 00
c_2	20.780 0	25.930 00
c_3	7.351 0	0.709 30
c_4	25.650 0	21.580 00
c_5	0.005 4	0.002 11

Compared with other models, the NRL model shows a better agreement with the measured data. The model can be applied at grazing angles from 0.1° to 60° and radar frequencies from 0.5 GHz to 35 GHz.

When the radar frequency is 0.14 THz and the polarization is horizontal, using the NRL model, the sea clutter reflectivity of different sea states at near vertical incidence is shown in Fig.1. The simulation result shows that the sea clutter reflectivity at vertical grazing angle is 13.49 dB.

3 Experimental Results Measurement of 0.14 THz Surface Clutter Reflectivity

3.1 Measuring Principle

Based on the radar equation

$$P_{\mathrm{r}} = \frac{P_{\mathrm{t}} G_{\mathrm{t}} G_{\mathrm{r}} \lambda^2 \sigma}{(4\pi)^3 R^4} \tag{2}$$

The Radar Cross-Section(RCS) of the water is

$$\sigma = \frac{P_{\mathrm{r}} (4\pi)^3 R^4}{P_{\mathrm{t}} G_{\mathrm{t}} G_{\mathrm{r}} \lambda^2} \tag{3}$$

σ is the RCS of the target, P_{r} is radar received power, R is the range of the target, P_{t} is radar transmitted power, G_{t} is the gain of transmitted antenna, G_{r} is the gain of received antenna, λ is radar carrier wavelength.

In order to measure the reflectivity of water, a scaler has to be used and the RCS of the scaler σ_{s} can be calculated theoretically. Using the scaler, the RCS of water σ_{W} can be obtained by

$$\sigma_{\mathrm{W}} = \frac{P_{\mathrm{rW}}}{P_{\mathrm{rS}}} \left(\frac{R_{\mathrm{W}}}{R_{\mathrm{S}}} \right)^4 \sigma_{\mathrm{S}} \tag{4}$$

P_{rW} and P_{rS} are the radar echo intensities of water and scaler; R_{W} and R_{S} are the ranges of water and scaler form water respectively. σ_{S} is the theoretical value of the scaler[9].

A metallic sphere is chosen as the scaler and the RCS is

$$\sigma_{\mathrm{S}} = \pi r^2 \tag{5}$$

in which r is the radius of the sphere. The sphere is with the diameter of 55 mm, and the σ_{S} is −26.2 dBsm[10].

The water surface clutter reflectivity is defined as

$$\sigma_0 = \sigma_{\mathrm{W}} (BR)^2 / 4\cos\psi \tag{6}$$

in which B is the Half Power Beam Width(HPBW) of the scatterometer, R is the distance between the scatterometer and water surface, and ψ is the grazing angle[10].

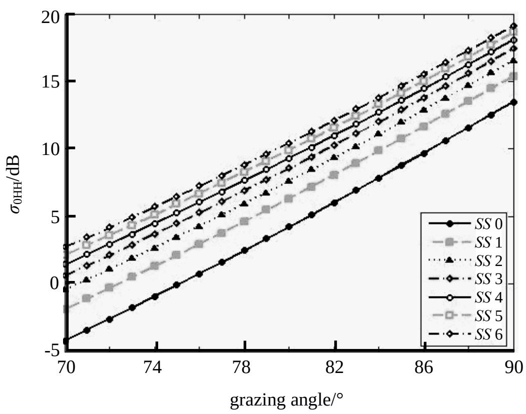
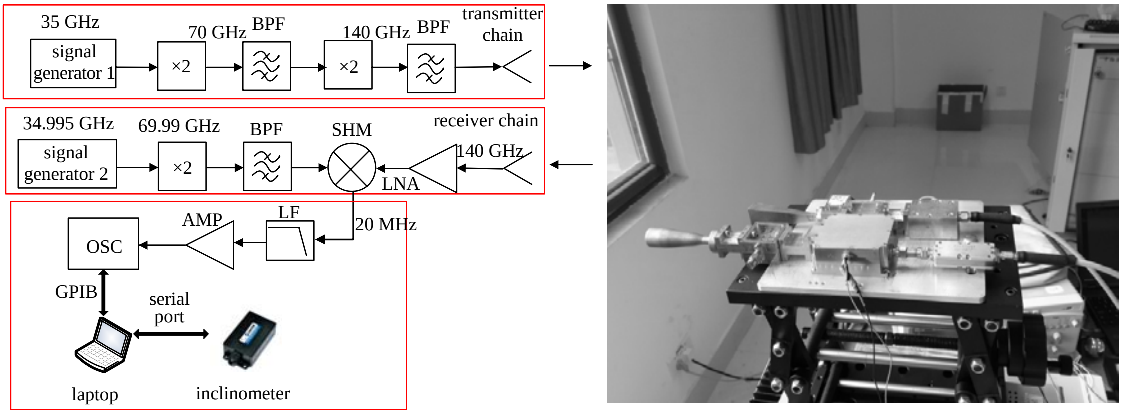


Fig.1 Simulation results of 0.14 THz sea clutter reflectivity at near vertical incidence

3.2 Introduction of the 0.14 THz Water Surface Reflectivity Measurement Test-Bed

In order to verify the availability of NRL model working at 0.14 THz, a test-bed is constructed for measuring the water surface clutter reflectivity.

The main part of the test-bed is a 0.14 THz radar scatterometer. The structure of the scatterometer is shown in Fig.2(a), and a photo is shown in Fig.2(b). In the transmitter chain, a 35 GHz single frequency signal is generated and up converted to 0.14 THz by two doublers. In the receiver chain, the received signal is down converted to intermediate frequency by a Sub-Harmonic Mixer(SHM). The radar echo intensity is sampled by an oscilloscope. An inclinometer is utilized to detect and sample the grazing angle. In order to synchronize the oscilloscope and the inclinometer, a LabVIEW interface is developed and run on a personal computer. The computer is connected to the oscilloscope and the inclinometer through GPIB and serial port respectively.



(a) structure chart　　(b) photograph of 0.14 THz multiplier chain

Fig.2 Structure and photograph of 0.14 THz multiplier chain

3.3 Measurement Results

Using the 0.14 THz radar scatterometer, an experiment of measuring the 0.14 THz water surface clutter reflectivity at near vertical incidence is designed. As is shown in Fig.3, the scatterometer is hanged over a small pool full of water and the antennas point to the water vertically. After the starting of measurement, the scatterometer transmits and receives signals continually and the grazing angle is changed manually. The radar echo and grazing angle are sampled synchronously by the oscilloscope and the inclinometer respectively and uploaded to the computer for further processing. Limited to the exiting test-bed conditions, only the simulation results at the condition of SS_0 and horizontal polarization can be examined.

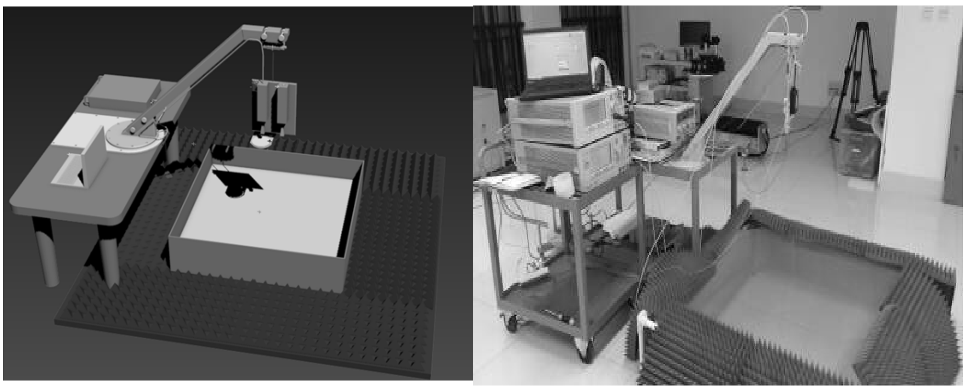


Fig.3 0.14 THz water surface clutter reflectivity measurement test-bed

The test platform operating parameters are shown in Table 2. The echo is received by the receiver and down converted to 20 MHz of which the square of the amplitude is proportional to the RCS of the object. Put relevant results in to equation (4) and equation (6). Then the water surface clutter reflectivity at near vertical incidence can be obtained.

Table2 Measurement parameters of water surface clutter reflectivity

frequency/THz	HPBW/(°)	transmitting power/mW	polarization	waveform	grazing angle range/(°)	distance/m	scaler	scalar RCS/(dBsm)
0.14	7	0.11	horizontal	CW	70–90	0.82	metallic sphere	–26.2

The comparison of the VGH model and measurement results at the condition of SS_0 and horizontal polarization are shown in Fig.4. The measurement results show that the prediction values gained by VGH model are consistent with the measured ones at vertical grazing angle and the difference between them is less than 1 dB. Compared to the calculated results, the changing trends of the measured results are gentler between 85° and 90°. When the grazing angle is between 85° and 76°, both the measured results decline rapidly and the speed of the decline of measured data is faster than the predicted ones. At grazing angles smaller than 75°, the measured results are affected by the reflected wave of the edge of the pool and ground which make the changing trends of the measured data become slower. The maximum difference between the measured data and predicted data is about 10.5 dB at 76°.

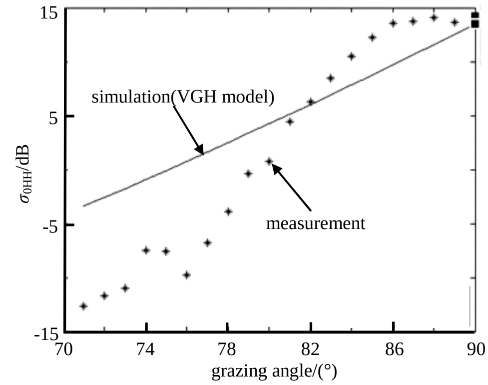


Fig.4 Simulation and measurement results of the relation between the grazing angle and reflectivity

4 Conclusion

In this paper, a preliminary discussion is made in this article about the scatter features about 0.14 THz water surface clutter reflectivity at near vertical incidence. The VGH model is introduced firstly for its good agreement with the experimental data. Based on the VGH model, the simulation results of 0.14 THz water surface clutter reflectivity at near vertical incidence can be obtained. In order to validate the simulation results, a 0.14 THz test-bed is constructed and a single frequency continuous wave scatterometer is designed. Using the 0.14 THz test-bed, the still water surface clutter reflectivity at high grazing angles is measured. Although big difference appears at lower grazing angle, measurement results show a good match with the simulation results and the difference between them is less than 1 dB at vertical grazing angle. Although the preliminary study shows that exiting empirical models at lower frequency still have reference value at 0.14 THz, a lot of research needs to be done including both theoretical and experimental sides.

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