LABORATORY STUDY ON MICROWAVE REMOTE SENSING OF GROUND TRUTH*

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Received July 20, 1990

ABSTRACT

In order to improve the interpretation of the earth system microwave remote sensing, the research of microwave spectrum characteristics of the ground truth (earth objects) was carried out in laboratory. A laboratory for microwave remote sensing of the earth objects has been constructed to improve the remote sensing level, the laboratory consists of four parts: the measuring system of dielectric constants, the microwave emissivity meter, the microwave reflectometer and the microwave remote sensing simulation experiment in field. In this paper, the principle of measurement, the correction of near field process, the structure of instrument, the calibration method and the measurement of the earth substances, including soil, water and oil, are discussed. The laboratory may supply the condition for measuring the parameters of the earth substance remote sensing and help to interpret the remote sensing data.

Key words: microwave remote sensing, ground truth, microwave reflectivity, microwave emissivity, microwave dielectric constant

I. INTRODUCTION

Microwave reflectivity,emissivity and dielectric constant of the earth substance are important parameters of microwave spectroscopy of the ground object.These parameters are widely used in satellite meteorology, radar meteorology and remote sensing of the ground truth. For improvement of the earth system remote sensing, it is necessary to study the microwave properties of the earth substances. For this purpose, a laboratory was built to study the ground truth microwave remote sensing. It includes the measuring system of dielectric constant, the microwave emissivity meter, the reflectometer and the microwave remote sensing simulation experiment. The stress was put on studying the remote sensing of oil slick on water surface, and soil moisture. The laboratory may supply conditions for measuring the parameters of the earth substance remote sensing and facilitate the image interpretation of the earth system remote sensing.

II. MICROWAVE REFLECTIVITY

1. *Mirror Microwave Reflectivity*

By Fresnel theory, the microwave reflectivity is

$$R_{\parallel} = \left| \frac{\cos\theta - \sqrt{\varepsilon' - j\varepsilon'' - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon' - j\varepsilon'' - \sin^2\theta}} \right|^2 , \tag{1}$$

* Supported by National Natural Science Foundation of China

$$R_{\perp}=\left|\frac{(\varepsilon'-j\varepsilon'')\cos\theta-\sqrt{\varepsilon'-j\varepsilon''-\sin^2\theta}}{(\varepsilon'-j\varepsilon'')\cos\theta+\sqrt{\varepsilon'-j\varepsilon''-\sin^2\theta}}\right|^2, \qquad (2)$$

where $\varepsilon_r=\varepsilon'-j\varepsilon''$ is dielectric constant, θ is incident angle, $R_{\parallel}$, $R_{\perp}$ are horizontal and vertical polarizations, respectively.

The microwave reflectivity is a function of the dielectric constant. For example, the dielectric constant of water ε_w is

$$\varepsilon_w=\varepsilon_\infty+\frac{\varepsilon_S-\varepsilon_\infty}{1+(\lambda_S/\lambda)^2}-j\frac{\lambda_S}{\lambda}\frac{\varepsilon_S-\varepsilon_\infty}{1+(\lambda_S/\lambda)^2}, \qquad (3)$$

where ε_∞, ε_S, λ_S are parameters.

2. *Measurement of the Dielectric Constant*

The microwave dielectric constants of the earth substances are very important parameters of the earth system remote sensing. However, for remote sensing, only large samples of the earth substance are useful. And some of earth substances are in liquid state. Therefore the resonance cavity micro-disturbance method is inapplicable to the earth system remote sensing. We measured the dielectric constants of the substances on the earth surface, such as water, sand, diesel oil etc., by using the short-circuited line method. Experiments prove that this method is applicable and convenient. The device of the short-circuited line method is shown in Fig.1. It is used for comparing the shapes of standing waves in the waveguide filled with air before and after the sample was put in and for measuring the displacement of a node of the standing wave. The processes are:

(1) Calculating the normalized input impedance from the standing wave ratio and the position of a node of standing wave with minimum ratio;

(2) Calculating the propagation constant in the waveguide filled with the sample from the normalized input impedance, the thickness of the sample and the wavelength in the waveguide filled with air;

(3) Calculating the dielectric constant of the sample from the propagation constant in the waveguide filled with the sample, the wavelength of the TEM (transverse electromagnetic) wave in free space and the cutoff wavelengrh of the waveguide. In order to make the measured results exact and more reliable, some experimental techniques and skills are used. The measured results are consistent with the theoretical data and those obtained from other methods. For example, $\lambda=3.2$cm, $t=30°$C, the dielectric constant of water, measured with short-circuited line method, $\varepsilon_w=66.7-j25.0$ and that derived from formula (3), $\varepsilon_w=65.61-j25.77$. The difference between them is 2—3%.

III. MICROWAVE REFLECTOMETER

The microwave reflectivity instrument was developed in our laboratory. Its structure is shown in Fig.2. The microwave signal transmitted from antenna T is reflected by the surface which is to be measured. Then it is received by antenna R and finally detected. In order to measure the variation of the reflectivity with different incident angles,we changed the incident angle from 5° to 60°.

1. *Non-Reflecting Absorption Background*

When the reflectivity of the background is small enough that may be neglected, it may be considered that the received reflective power comes from the sample surface to be measured. In order to make the reflectance of the background less than 1% of that of sample surface to be measured, it requires the reflectivity of the background to be smaller than 0.001. The background size should be large enough so as to fill the main lobe of the antenna, when oblique incident takes place. In the experiment, the incident angle$\leqslant 60°$, the arm length $L=1605$mm, the wavelength $\lambda=3.2$cm and the main lobe of the antenna $\phi_0=19°$,then the size of the non-reflecting absorption background is filled with sharp absorbers, arranged in square array. The disk with the sample to be measured is located at the center of non-reflecting absorption background.

2. *Antenna*

The antenna is required to possess the features of small side lobe, large gain and light weight.

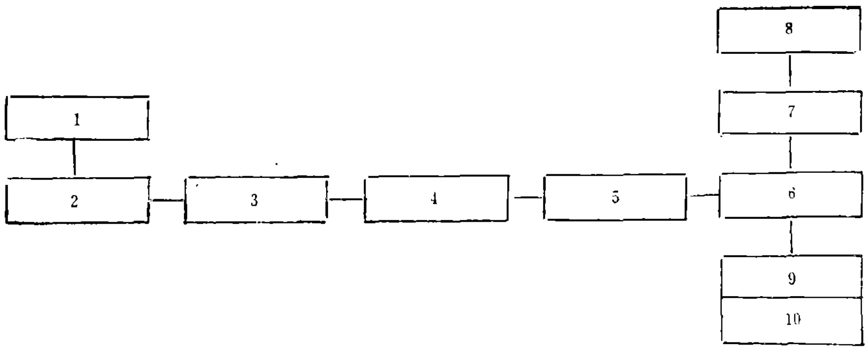


Fig. 1. The short-circuited line method of measuring dielectric constant.
1. oscillator; 2. attenuator; 3. isolator; 4. attenuator; 5. wavemeter; 6. slotted line; 7.crystal detector; 8. amplifier and indicator;9. sample; 10. short circuiting plate.

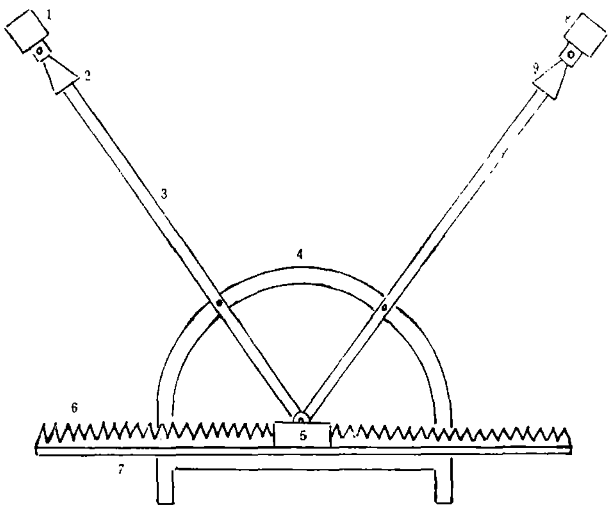


Fig. 2. The structure of the microwave reflectometer.
1. microwave generator; 2. transmmitting antenna; 3. arm; 4. arched slide; 5. sample; 6. non-reflective background; 7. base; 8. receiver; 9. receiving antenna.

3. *Microwave Signal Generator*

It is fixed on the top end of the arm. The power of the transmitter should be much larger than the heat radiation. By the Rayleigh-Jeans formula, the power of the heat radiation p is

$$p=\frac{2\pi kT}{\lambda^2}\Delta f \ , \tag{4}$$

where k is Boltzmann constant, T is absolute temperature, and Δf is bandwidth. Let $T=300$K, $\Delta f=100$ MHz. Then

$$p=2.5\times 10^{-13}\mathrm{W cm^{-2}}. \tag{5}$$

Supposing that the transmitted energy is homogeneously distributed in the main lobe of the antenna. Under the condition that the reflective power is 1000 times the heat radiation, then we have

$$p_t R/\pi(L\mathrm{tg}\phi_0)^2 > 1000p. \tag{6}$$

Let reflectivity $R=0.1$, the length of the arm $L=1605$mm, and the main lobe $\phi_0=19°$. Then the transmitted energy P_t is

$$P_t > 0.24\mathrm{mW}. \tag{7}$$

So it can satisfy the needs that the power of the generator is in the mW level, and the heat radiation may be neglected.

4. *Arm Length*

It should meet the requirement of the far field. By the condition of path difference $\leqslant\lambda/16$, we have the minimum length of the arm L_{min}

$$L_{min}=2D^2/\lambda, \tag{8}$$

where D is the diameter of the antenna, for the horn antenna $D=\sqrt{A^2+B^2}$, $\lambda=3.2$cm, $A=13.5$ cm, $B=9.0$ cm, then $L_{min}=1645$ mm. Owing to the mechanical limitation, we set the arm length $L_1=1605$ mm.

5. *Diameter of the Sample Disk*

When perpendicular incidence occurs, the phase difference between the path from the phase center of the transmitting antenna to the center of the sample disk and the path from the phase center of the transmitting antenna to the side of the sample disk is δ_0, i.e.,

$$\delta_0=\pi d_c^2/(2L\lambda). \tag{9}$$

When $\delta_0=\pi$, we have the maximal gain, the diameter of the disk d_c becomes d_{max}:

$$d_{max}=\sqrt{2L\lambda}. \tag{10}$$

Letting $L=1605$ mm, $\lambda=3.2$ cm, then $d_{max}=32$ cm. In order to avoid the wave distortion caused by slanting incidence, we take d_c to be smaller than d_{max}, i.e., $d_c=28.6$cm.

IV. MEASUREMENT OF MICROWAVE REFLECTIVITY

i. *Measurement of Microwave Reflectivity in the Near Field*

The microwave reflectivity was measured with the microwave reflectometer in laboratory. Two methods were used: direct-method and comparative method. The direct method was used to directly measure the sample's reflectance and the reflectivity was derived from the microwave radiative equation.

The reflectivity measured directly by following formula

$$R_\xi = \frac{p_{\xi r}}{p_0 \eta_\xi(\theta)\cos^2\theta}, \tag{11}$$

where ξ represents the horizontal or vertical polarization; $p_{\xi r}$ is the received reflective power which is the reflected transmitting power by sample surface; p_0 is received reflective power which is the reflected transmitting power of the perpendicular incidence by the ideal reflective surface; and $\eta_\xi(\theta)$ is the angle correction of the slant incidence. We have

$$p_0 = \frac{p_t G_t \pi d_c^4 AB}{64 L^2 L_1^2 \lambda^2} \psi_\xi(0), \tag{12}$$

$$\eta_\xi(\theta) = \psi_\xi(\theta)/\psi_\xi(0), \tag{13}$$

where p_t is transmitting power, G_t gain of the transmitting antenna, d_c diameter of the sample to be measured, A, B the size of the receiving horn antenna, L the distance from the phase center of the transmitting antenna to the center of the sample disk to be measured, L_1 the distance from the center of the sample disk to be measured to the center of the receiving horn antenna, and $\psi_\xi(\theta)$ the correction coefficient at incident angle θ, for the gain decrease caused by the phase difference of irradiation of the reflective surface. The $\psi_\xi(\theta)$ and $\eta_\xi(\theta)$ against incident angle θ are shown in Fig.3.

For the reflectivity measured by the comparative method, the following formula is used

$$R_\xi = R_0 \frac{p_{\xi r}}{p_{r0}}, \tag{14}$$

where R_0 is reflectivity of the known body surface, p_{r0} is the received power, reflected by the known body surface, and $p_{\xi r}$ is the received power, reflected by the measured sample surface.

Usually, the well conductive metal plate is taken as the ideal reflective surface, $R_0 = 1$. In measurement, the direct-method and the comparative method are used and cross corrected with their results so as to obtain the accurate result of the experiment.

2. *Calibration of Microwave Reflectometer*

(1) The ideal reflective surface is a smooth Aluminium-plate (Al-plate). With the experimental conditions: $\lambda = 3.2$ cm, $\theta = 10°$, the reflectivity measured with reflectometer is $R_\parallel = 0.94$, or $R_\perp = 1.02$, the theoretical value should be $R_\parallel = R_\perp = 1.00$.

(2) The reflectivity is measured with the comparative method to check the near field correction. In microwave band, the Al-plate reflectivity in both polarizations equals 1.00 at any angle.

With the reflectometer measurement, the microwave reflective power $p_{\xi r}$ and the reflectivity $R_\xi(\theta)$ are shown in Fig.4. The accuracy of correction depends on the deviation of Al-plate reflectivity $R_\xi(\theta)$ from 1.00. The mean departure of $R_\xi(\theta)$ from 1.00 should be smaller than 5%.

Through calibration with the comparative method, the effects of some unknown factors may be eliminated. Therefore the accuracy level of the comparative method is usually higher than that of the direct method.

(3) The near field measurement is carried out in laboratory.The interference effects cannot be neglected in near field.In experiment,we found that the result would be better with the following procedures: The reflective information would be increased,when an absorptive screen with an open hole at the center, which likes a diaphragm, was put upon the disk to be

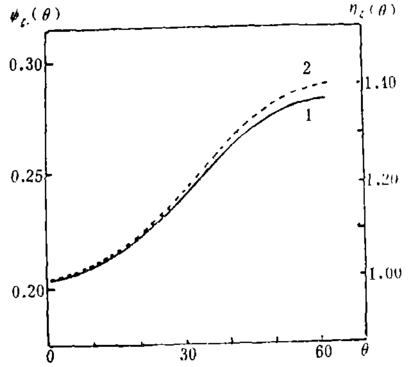
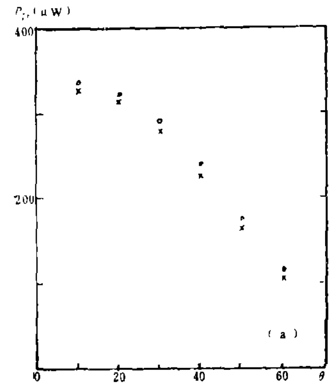


Fig. 3. $\psi_\xi(\theta)$ and $\eta_\xi(\theta)$ against incident angle θ.
$\lambda=3.2$cm, $p_t=34$mW, G=80, A=13.5cm, B=9.0cm, $d_c=28.6$ cm, L=1605mm, $L_1=1545$mm
1. parallel polarization;
2. perpendicular polarization.



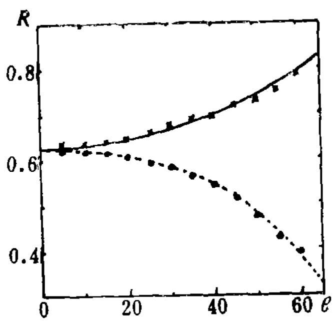


Fig. 5. Reflectivity of water surface against incident angle θ.
$\lambda=3.2$cm, $t=20$°C, $\varepsilon_w=61.65-j32.24$, parallel polarization.

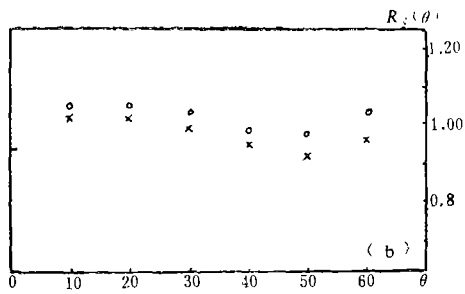


Fig. 4. Reflective power $p_{\xi r}$ in(a) and reflectivity R_ξ in (b) of aluminium plate against incident angle θ.
$\lambda=3.2$cm, $A=13.5$cm, $B=9.0$cm, $L=1605$mm, $L_1=1545$mm, $d_c=28.6$cm.

Solid (dashed) lines indicate theoretical value for parallel (perpendicular) polarization and crosses (circles) the corresponding experimental values hereafter.

measured. For example, $\lambda=3.2$cm, the diameter of sample disk to be measured is $d_c=28.6$cm, the diameter of the diaphragm is 25cm,then the reflective power received would be increased by one time.

3. *Microwave Reflectivity of the Earth Substances*

To study the characteristics of water, soil, and oil slick on water surface, some experiments were carried out with $\lambda=3.2$cm and $\lambda=8.5$mm wavebands. At the same time, the dielectric constant was also measured. Theoretical calculation of the microwave reflectivity with Fresnel theory was carried out for comparison. For example, reflectivities of water surface and dry sand versus incident angle as well as that of oil slick on water surface versus incident angle and thickness are given in Figs. 5—8, respectively.

V. MICROWAVE EMISSIVITY METER

Under natural conditions, the measurement of emissivity is always disturbed by various external factors. Therefore an instrument isolating the influence from outside is needed to study the effect on emissivity of different factors.

1. *Structure of the Microwave Emissivity Meter*

The microwave emissivity meter consists of three parts: microwave radiometer, microwave chamber and sample box (see Figs.9 and 10).

(1) *The microwave radiometer*

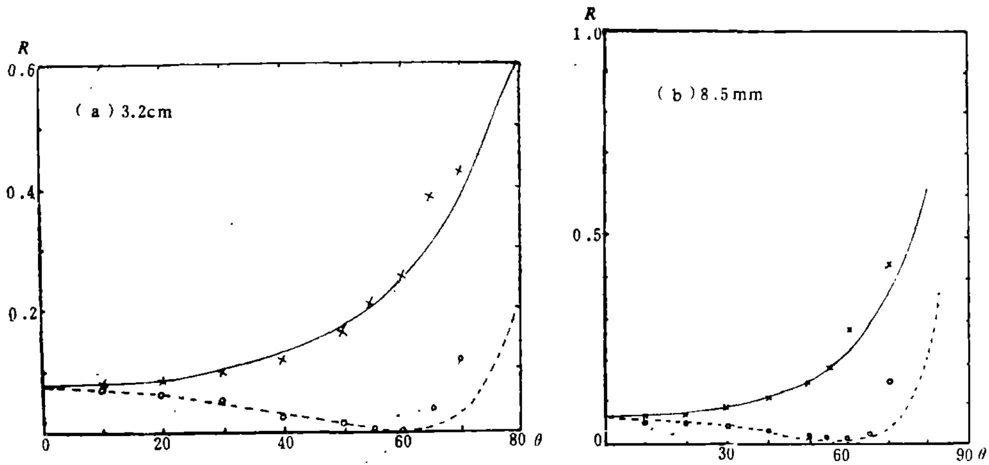


Fig. 6. Reflectivity (R) of dry sand surface versus incident angle θ for (a) $\varepsilon_s=3.04-j0.58$, $\lambda=3.2$cm and $\varepsilon_s=2.79-j0.051$, $\lambda=8.5$mm.

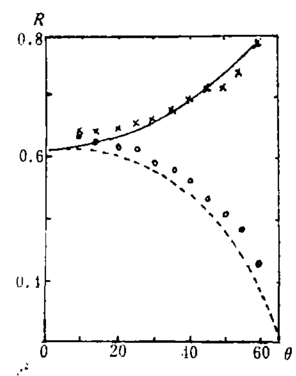


Fig. 7. Reflectivity of oilslick on water surface against incident angle, thickness of oil slick $d=0.9$mm, $\lambda=3.2$cm, $t=20$°C.

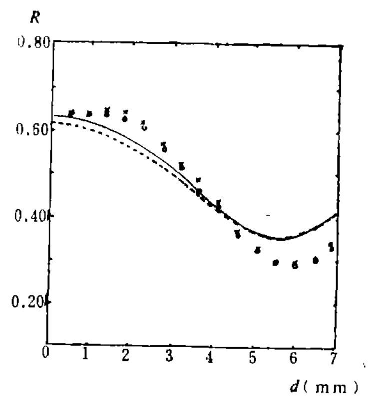


Fig. 8. Reflectivity of oil slick on water surface against thickness of oil slick, $t=20$°C, $\theta=10$°, $\lambda=3.2$cm.

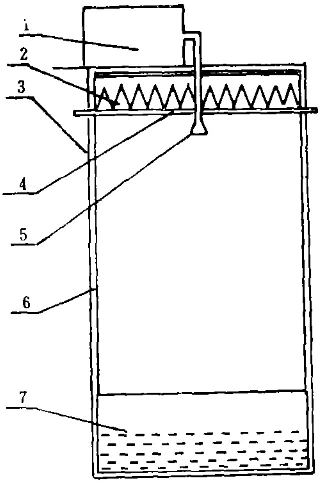


Fig. 9. The structure of the microwave emissivity meter.
1. microwave radiometer,
2. absorber whose temperature can be changed,
3. outer wall, 4. reflector,
5. horn antenna, 6. inner wall reflector, 7. sample box.

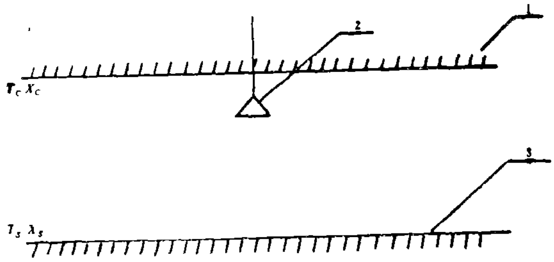


Fig. 10. Sample model of the microwave emissivity meter. 1. ceiling, 2. horn antenna, 3. sample surface.

Two microwave radiometers are alternatively adopted, their bands are 8.5mm and 3.2cm respectively. The former is a compensatory style and the latter the Dicke's style. The horn antenna of microwave radiometer stretches into the microwave emission chamber to feed the emission of the earth objects into the microwave radiometer.

(2) *The microwave emission chamber*

The ceiling board of the microwave emission chamber can be changed as a totally reflective plate (an aluminium plate with 1 mm thickness) or a blackbody under high temperature (up to 120°C). The blackbody is made of corrugated sheet copper and equipped with electrothermal plates to raise temperature. Its surface is pasted with carbon powder. The walls of the microwave emission chamber are totally reflective aluminium plates. According to the principle of mirror-image, the emission of the microwave emission chamber is equivalent to the emission between an upper board and the sample plate both stretching infinitely. The receiving range of the main lobe of the horn antenna and the sample surface should be long enough to satisfy the far-field condition.

(3) *The sample box*

The sample box is a metal container ($80\times80\times40cm^3$) which can be moved freely in order to change the sample conveniently. In measurements, the sample box and the microwave emission chamber form a closed system.

2. *Measuring Principle for the Microwave Emissivity Meter*

The principle of measurement is as follows:

The inner walls of the microwave emission chamber are smooth aluminium plates, wihch can be considered totally reflective. The microwave radiative transfer in the microwave emissivity meter is equivalent to the emission between a ceiling and the sample plate, both stretching infinitely because their size is far larger than the emission wavelength. Its ceiling is a totally reflective object or a high temperature blackbody. The horn antenna receives the emission of the sample plate and the ceiling radiation reflected by the sample plate. The brightness temperature $T_b^{(1)}$ received by the horn antenna is

$$T_b^{(1)} = X_S T_S + X_C T_C (1 - X_S), \tag{15}$$

where T_S is sample temperature, X_S sample emissivity, T_C ceiling temperature, and X_C ceiling emissivity.

The brightness temperature $T_b^{(2)}$ of second reflection by the ceiling and sample plates is

$$T_b^{(2)} = T_b^{(1)} (1 - X_C)(1 - X_S).$$

Similarly, the brightness temperature $T_b^{(n)}$ of nth reflection is

$$T_b^{(n)} = T_b^{(n-1)} (1 - X_C)^{n-1} (1 - X_S)^{n-1}.$$

The brightness temperature T_b received by the horn antenna is

$$\begin{aligned} T_b &= T_b^{(1)} + T_b^{(2)} + T_b^{(3)} + \cdots \\ &= T_b^{(1)} [1 + (1 - X_C)(1 - X_S) + (1 - X_C)^2 (1 - X_S)^2 + \cdots]. \end{aligned} \tag{16}$$

Then

$$T_b = \frac{X_S T_S + X_C \cdot T_C \cdot (1 - X_S)}{1 - (1 - X_C) \cdot (1 - X_S)}. \tag{17}$$

By taking two mesurements with the ceiling board of totally reflective body or blackbody, from Eq.(17), the sample emissivity X_S is obtained

$$X_S = 1 - \frac{T_{b1} - T_{b2}}{[(X_1 T_{C1} - X_2 T_{C2}) + (1 - X_{C1}) T_{b1} - (1 - X_{C2}) T_{b2}]}, \tag{18}$$

where T_{b1}, T_{C1} and X_{C1} are the brightness temperature mesaured by radiometer when the ceiling is a reference body, the ceiling temperature and the ceiling emissivity, respectively. T_{b2}, T_{C2} and X_{C2} are variates same as T_{b1}, T_{C1} and X_{C1}, except that the ceiling is an absolutely reflective body. When the ceiling is an absolute reflective body, $X_{C2} = 0, T_{b2} = T_S$.

VI. MEASUREMENT OF THE MICROWAVE EMISSIVITY METER

1. *Calibration and Scaling*

The instrument isolates the influences from outside. Its ceiling is a heated reference body and its bottom is an aluminium plate. Owing to $X_S = 0$, the brightness temperature T_b received by the horn antenna is

$$T_b = T_{C1}, \tag{19}$$

i.e., the brightness temperature equal to the ceiling temperature is independent of the ceiling material or its emissivity.

(1) *The influence of the aluminium plate emission on the emissivity measurement*

The conductivity of aluminium $\sigma = 3.43 \times 10^{-7} \Omega^{-1} \text{m}^{-1}$ and the relative dielectric constant $\varepsilon_r = \varepsilon' - j\varepsilon''$, $\varepsilon'' = \sigma\lambda / (\pi c \varepsilon_0)$ where $\varepsilon_0 = 8.85419 \times 10^{-12} \text{CV}^{-1} \text{m}^{-1}$, $c = 3 \times 10^8$m/s and $\varepsilon' = 1$

for metal. By Fresnel formulae (1) and (2), when $\theta=0°$, the reflectivity of underlying surface R is

$$R=\frac{(p-1)^2+q^2}{(p+1)^2+q^2}, \tag{20}$$

where

$$p=\left\{\frac{1}{2}\left[(\varepsilon'^2+\varepsilon''^2)^{\frac{1}{2}}+\varepsilon'\right]\right\}^{\frac{1}{2}}, \quad q=\left\{\frac{1}{2}\left[(\varepsilon'^2+\varepsilon''^2)^{\frac{1}{2}}-\varepsilon'\right]\right\}^{\frac{1}{2}}.$$

Using the relation of emissivity X and reflectivity R

$$X=1-R,$$

we have the emissivity of aluminium plate

$X=6.76\times10^{-4}$ for $\lambda=8.5$mm,

$X=3.48\times10^{-4}$ for $\lambda=3.2$cm.

The deviations of brightness temperature, caused by the emissivity of the aluminium plate departing from zero, are shown in Table 1.

Table 1. The Error of Brightness Temperature, Caused by the Emissivity of Aluminium Plate Departing from Zero ($T_s=290$K)

Wavelength	Ceiling Temp. T_c(K)	300	320	340	360	380	400
8.5mm	ΔT_b(K)	−0.0075	−0.0225	−0.0376	−0.0526	−0.0676	−0.0826
3.2cm	ΔT_b(K)	−0.0086	−0.0146	−0.0206	−0.0386	−0.0626	−0.0746

From Table 1, it is shown that the error may be neglected, it is thus assumed that the aluminium reflectivity is equal to 1.00.

(2) *Measurement of the ceiling emissivity of the reference body*

In order to measure the sample emissivity, the emissivity of the reference body X_{C1} should be given. The emissivities of the aluminium ($X_S=0$) and the water adopted as the given quantities. The emission of water surface was measured with the microwave emissivity meter, its ceiling being absolutely reflective body (aluminium plate) or reference body.
Then

$$X_S=1-\frac{T_{b1}-T_{b2}}{X_{C1}T_{C1}+(1-X_{C1})T_{b1}-T_{b2}}, \tag{22}$$

i.e.,

$$X_{C1}=\frac{X_S}{1-X_S}\times\frac{T_{b1}-T_{b2}}{T_{C1}-T_{b1}}, \tag{23}$$

or

$$Y=\frac{1}{A}X_{C1}Z, \tag{24}$$

where

$$A=X_S/(1-X_S), \quad Y=T_{b1}-T_{b2}, \quad Z=T_{C1}-T_{b1}.$$

The coefficient X_{C1} could be derived from a set of experimental data of Y and Z. The experimental data show that the emissivity of the high temperature reference body is independent of its temperature within the range of its temperature change. In our microwave emissivity meter, the emissivities of the reference body are

$$X_{C1}=0.90 \quad \text{for} \quad 8.5\text{mm},$$
$$X_{C2}=0.61 \quad \text{for} \quad 3.2\text{cm}.$$

(3) *Measurement of the slow change of the radiometer gain*

When measurement takes longer time, the measurement result will be affected because of the slow change of the radiometer gain. Here we will discuss how to remove the effect and improve the measuring accuracy.

First, the calibration is carried out. A line is plotted to represent the relation between the brightness temperature T_b and the output voltage V_b, i.e.

$$T_b=kV_b+b, \tag{25}$$

where k and b are constants.

When the ceiling is the absolutely reflective body, then $X_{C2}=0$, $T_{b2}=T_S$. When the ceiling is the reference body ,we have the relation $T_{b1}=kV_{b1}+b$ and

$$X_S=1-\frac{kV_b+b-T_S}{X_{C1}T_{C1}+(1-X_{C1})(kV_{b1}+b)-T_S}, \tag{26}$$

where T_{C1}, X_{C1} are the ceiling temperature and emissivity, T_S is sample temperature obtained from other measurement, for example, thermometer measurement, its accuracy is 0.1°C. The change of k represents the change of gain. The calibrations of 8.5mm and 3.2cm radiometers are shown in Tables 2 and 3. The correlation coefficient of the experimental data fits γ (0.9979–0.9999). The gain fluctuation is 3—4%. So the calibration should be done before and after every experiment in order to eliminate the error caused by the gain fluctuation.

Table 2. 8.5mm Radiometer Calibration ($T_b=kV_b+b$)

No.	1	2	3	4	5	6	7	8	9	10
Gain k(K/mV)	1.23	1.24	1.23	1.27	1.25	1.32	1.30	1.28	1.33	1.27
γ	0.9998	0.9999	0.9985	0.9992	0.9999	0.9997	0.9996	0.9979	0.9995	0.9998

γ: correlation coefficient.

Table 3. 3.2cm Radiometer Calibration ($T_b=kV_b+b$)

No	1	2	3	4	5	6	7	8	9	10
Gain k(K/mV)	0.084	0.0928	0.0876	0.0899	0.0872	0.0831	0.0835	0.0921	0.0818	0.0883
γ	0.9999	0.9999	0.9998	0.9997	0.9996	0.9985	0.9995	0.9996	0.9999	0.9991

2. *Measurement of the Microwave Emissivity*

(1) *Emissivity of water surface*

The emissivities of water with different temperature were measured. The comparison between the measured values by the microwave emissivity meter and the theoretical values is shown in Fig.11. The experimental values coincide with theoretical ones.

(2) *Emissivity of soil*

The emissivities of soil with different moisture were measured with the microwave emissivity meter. The relation between the soil dielectric constant and the moisture was measured with the short-circuited line method. The microwave emissivity of the soil decreases with the increase of soil humidity. The dielectric constant, both real and image parts, increases with the increase of soil humidity. The examples of measurement results are shown in Fig.12.

(3) *Emissivity of oil slick on water surface*

The emissivity of oil slick with different thickness on water was measured with the microwave emissivity meter. The examples of measurement results are shown in Fig.13.

(4) *Open-air simulated experiments constructed to verify the results of the microwave remote sensing*

The container was a box($180\times180\times40cm^3$) filled with fresh water covered with oil slicks in different thickness. The microwave radiometer of 8.5mm wavelength was used to detect the emission of the oil slicks on the water surface. The experiment spot was selected on an open terrace on the top of a building, on a clear and breezy day. The brightness temperature and both the horizontal and vertical polarizations were observed at zenith angle $\theta=45°$. In the meantime the brighrness temperature of the sky background emission was observed. The emissivity of the oil slick changing with the thickness is shown in Fig.14. It coincides with the theoretical prediction.

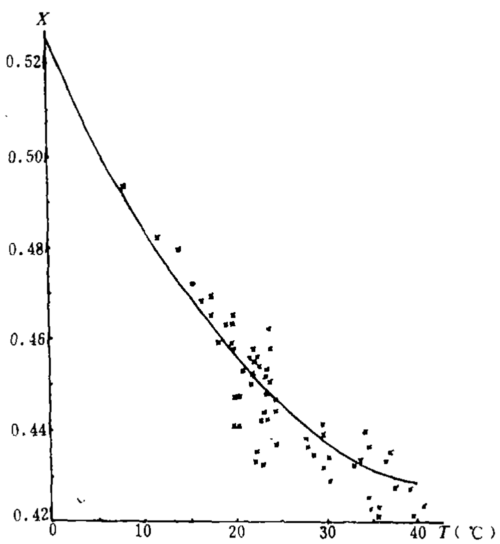


Fig. 11. Emissivity X of water surface against temperature. ($\lambda=8.5$mm)

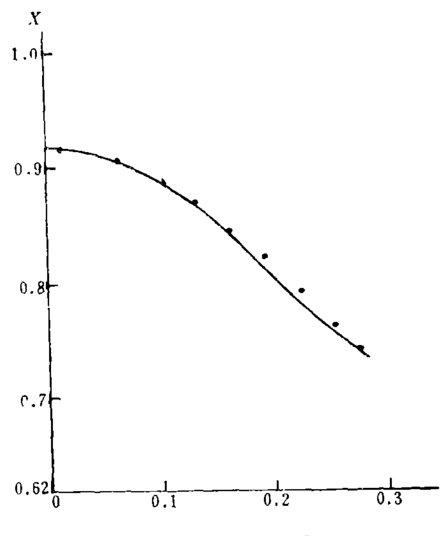


Fig. 12. Emissivity X of sand surface against soil moisture. ($\lambda=3.2$cm)

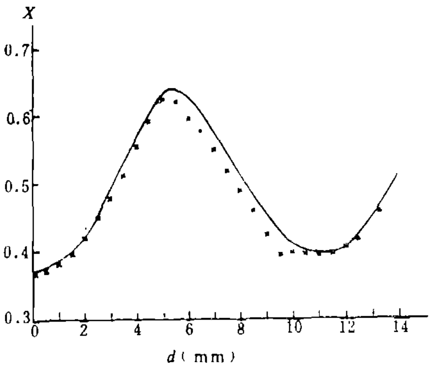


Fig. 13. Emissivity of oil slick on water surface against thickness of oil slick. ($\lambda=3.2$cm, $\theta=0$, $t=20°C$)

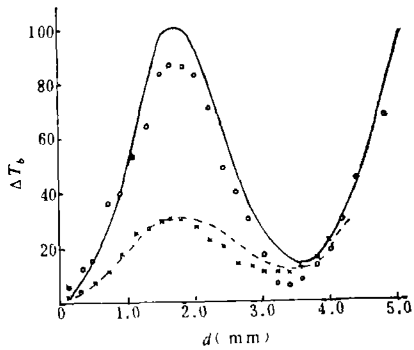


Fig. 14. Microwave brightness temperature difference between the water and the oil slick as function of thickness of the oil slick. ($\lambda=8.5$mm, $\theta=45°C$)

VII. CONCLUSIONS

(1) The laboratory may provide conditions for measuring the dielectric constant, reflectivity and emissivity of the earth substances (such as soil, water, oil, etc.) in microwave band. In laboratory the remote sensing for the earth substance parameters may be studied with the isolation of the influence from outside.

(2) The experimental data of the microwave reflectivity and the emissivity coincide with the theoretical values derived from Fresnel theory.

(3) In the measurement, the experimental data of many times may be averaged to improve the accuracy. The error of the emissivity measured with microwave emissivity meter is less than 4%. The error of the reflectivity measured with the microwave reflectometer is less than or equal to 5%.

(4) The reflectivity at various, except zero, incident angles may be measured with the microwave reflectometer. And the emissivity in perpendicular direction ($\theta=0°$) may be measured with microwave emissivity meter. Combining the reflectometer and the emissivity meter, the spectral properties of the microwave of the earth substances in all directions may be obtained.

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