PAPER

Method for the Measurement of Scattering Coefficients Using a Metal-Plate Reflector in the Microwave Region

Ryoichi UENO† *and* Toshio KAMIJO†, *Regular Members*

SUMMARY A new method for measuring the scattering coefficient using a metal-plate reflector was developed in order to provide a non-destructive way for the assessment of microwave materials in free space. By displacing the position of the metal-plate reflector on the specimen to be tested, the incident wave and the scattered wave from the measured area were determined without the influence of extraneous waves such as the direct coupling between transmitting and receiving antennas and scattered waves from background objects. Because the behavior of a metal-plate reflector is similar to that of an optical shutter in optics, our new scattering measurement system enables us to measure both backward- and forward-scattering coefficients of small regions of the specimen for various types of materials in a non-destructive manner. Our study examined the metal-plate size dependence of the complex reflection and transmission coefficients of some dielectric sheet samples. The measured data indicated that the reflection and transmission coefficients of a Bakelite flat plate and Styrofoam sheet were constant for various sizes of metal plates at the X-band.

key words: *scattering coefficient, reflection coefficient, transmission coefficient, non-destructive measurement*

1. Introduction

In order to gain some insight into the capability of a specimen, the electric and magnetic parameters of materials in the microwave region need to be determined, and various measurement methods must be used in various situations as well. For measurements of complex permittivity and complex permeability in closed spaces, the cavity resonator method and the standing wave method are available [1], [2]. We developed the perturbation method using a compact cavity resonator without sample insertion hole [3], with which we could determine complex permittivity and permeability separately using a small specimen cleaved from raw material. These data were used to develop new microwave devices such as radio-wave scatter suppressors or absorbers. But in order to assess the actually designed absorbers, it is necessary to provide the experimental data of scattering coefficient in the light of the actual situation usage [4], [5].

In recent years, the need to develop a scattering-coefficient measurement method has increased in the fields of electromagnetic compatibility, microwave remote sensing, local-area telecommunications, and non-contact or non-destructive measurements of the human body, earth, and buried objects. When measuring scattering coefficients in free spaces, it is difficult to eliminate extraneous direct waves in the measurement field, such as direct coupling between transmitting and receiving antennas and scattered waves from surrounding objects. Although the measurement is conducted in an open space, direct coupling and scattered waves from the sample outside the measured area can be observed, as illustrated in Fig. 1.

In the conventional reflection-coefficient measurement method, which has no separation technique, the measurement error due to direct waves, determined by the ratio of intensity of extraneous direct waves to the total received waves of the receiving horn, would be very large in the case of measurement for incident angles below 10 degrees and above 45 degrees [6]. Therefore, we must separate the direct-wave component from the received signal. In order to cancel this extraneous direct-wave, non-destructive separation methods using time-gate technique have been proposed, such as the short-pulse method [7], [8] and the time-domain method [9], [10]. However, these methods cannot be applied to specimens that have scatter objects near the measurement region [2], such as support materials and the specimen itself, or to materials that have frequency-dispersive permittivity and permeability. In addition, we cannot determine the location of the measurement area of the objects to be tested accurately.

In our early scattering-coefficient measurement method for movable specimens [4], [5], [11], [12], which was applied to the assessment of metal-backed radio-wave scatter suppressors in order to eliminate ghosts or false targets due to the bridge on the X-band ship radar, the extraneous direct-wave components were separated by slightly raising and lowering the vertical positions of both the specimen and the reference metal flat plate. In this case, the specimen to be tested can be

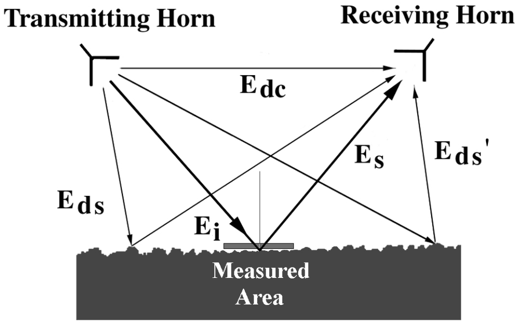

Fig. 1 Direct waves in an open-space scattering-coefficient measurement system.

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† The authors are with the Graduate School of Engineering, Tokyo Metropolitan University, Hachiohji-shi, 192-0397 Japan.

manufactured or cleaved from raw material, the cross-sectional size of which is the same as that of the metal-plate reflector. Although we need not to move the specimen, the advantage is that we can make the phase of the incident wave for the specimen and that of the metal-plate reflector coincide.

Because the specimen to be tested is unmovable in a non-destructive arrangement, we could not apply our early method to fixed objects or specimens. New non-destructive scattering-coefficient measurement method suitable for unmovable object have been proposed [13]–[15]. In this paper, we explain the principle of the separation technique of our measurement method, in which the extraneous direct wave is separated by displacing the position of only the metal flat plate on the specimen to be tested. This separation method enabled us to carry out experiments of scattering coefficients of fixed samples and also forward-scattering measurements of materials, which scatter incident waves in all directions. Because the behavior of the metal-plate reflector is similar to that of an optical shutter in optics, we could also determine the measured area of the object. In addition, this paper shows the metal size dependence of the complex reflection and transmission coefficients of a few dielectric sheet samples at the X-band frequency.

2. Principle of Complex Scattering-Coefficient Measurement Method Using a Metal-Plate Reflector

2.1 Separation Technique of the Non-destructive Scattering-Coefficient Measurement Method Suitable for Unmovable Objects or Specimens [13]–[15]

In order for the information on the scattering field obtained from the specimen to be of practical significance, the scattering measurement must be conducted non-destructively.

We propose a new non-destructive scattering-coefficient measurement method which is suitable for unmovable samples. Using the new method, it is also possible to conduct forward-scattering or transmission-coefficient measurements without the influence of extraneous direct waves.

Figure 2 shows the various direct-wave component in a general scattering-coefficient measurement. Figure 3 shows the arrangement of the sample and metal plates in the new measurement method.

The total direct wave E_d is determined by slightly displacing only the metal plate on the sample; the sample, on the other hand, remains fixed. The measurements are made in two steps. The first step consists of measuring the received signals by slightly displacing the position of the metal plate on the sample in order to determine the incident wave field. After the metal plate is removed, the received signal, which is the sum of the scattered signals from the sample and the fixed direct wave, is measured in the second step.

The metal-plate reflector is used to determine not only the incident wave but also the measured area of the specimen, or shadow region. The uniform incident-plane wave from the transmitting antenna is illuminated on two regions: one where the metal plate exists on the sample, and the other one, where only the sample exists. The direct waves are determined by displacing the reference metal plate slightly. The radiation patterns of the metal plate are those of a uniformly illuminated aperture [10]. The behavior of the metal plate is similar to that of an optical shutter in optics. Thus the incident wave E_i in the measurement area is determined from the reflected wave for the metal flat plate reflector. Because the scattered wave from the sample outside the measured area does not change upon displacing the metal plate, it is added to the component of the direct wave. Furthermore, extraneous scattering waves from the support mechanism and the underground signals also become components of the direct wave E_d .

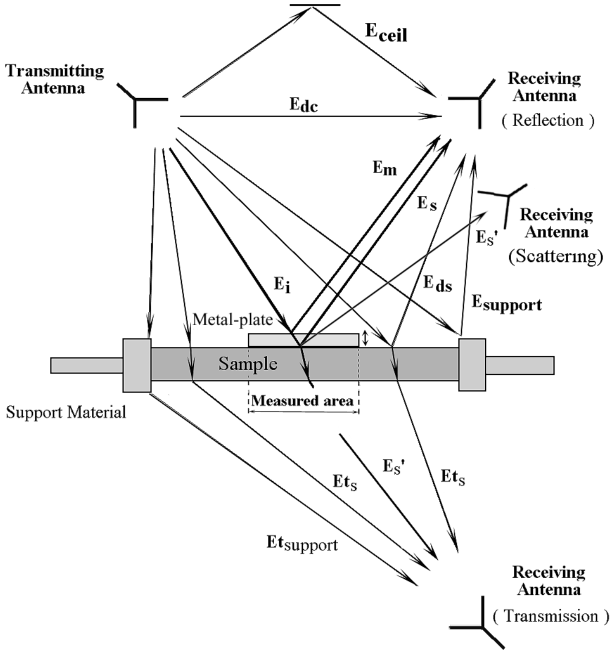


Fig. 2 Direct-wave component in a non-destructive scattering-coefficient measurement.

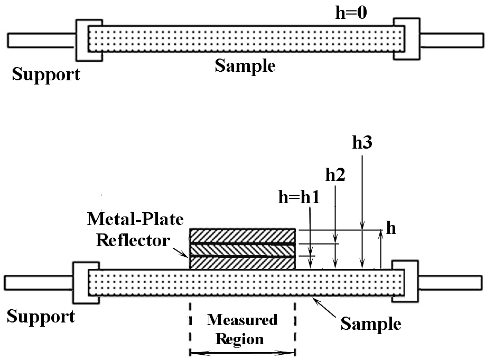


Fig. 3 Arrangement of sample and metal plates in the scattering-coefficient measurement method.

The scattered wave E_s from the sample in the measurement area is separated from the direct wave, which had been determined in the first step. Thus, the scattering coefficient

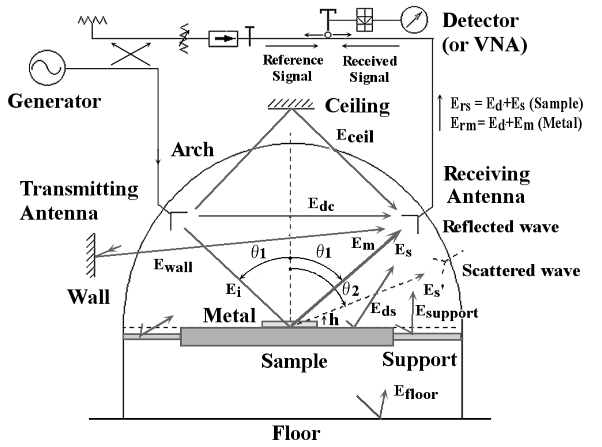


Fig. 4 Various direct-wave components in the non-destructive scattering-coefficient measurement method.

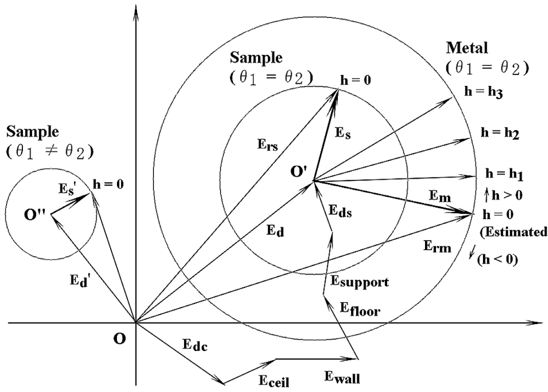


Fig. 5 Vector diagram of the received signals in the non-destructive scattering-coefficient measurement method.

is obtained non-destructively. This process also ensures that the measurement area of the sample equals that of the reference metal plate, a condition required in our early scattering-coefficient measurement method using movable specimens as well [4], [5], [11], [12].

The principle of our separation technique is as follows. Figure 4 shows details of various direct-wave components in a free-space scattering-coefficient measurement arrangement in an ordinary laboratory.

In a bistatic scattering-coefficient measurement arrangement, the specimen is located in the far field of the transmitting and receiving antennas so that it is illuminated by a uniform plane wave.

The linearly polarized incident-plane wave, focused on the specimen at an incident angle θ_1, is scattered in all directions by the specimen to be tested. In general, the angle of reflection θ_2 and the polarization of the scattered wave are not equal to that of the incident wave. For simplicity, however, we consider the specimen to be a flat plate; thus, the angle of reflection θ_2 is equal to the angle of incidence defined in the incident plane.

In Fig. 4, extraneous direct coupling E_{dc} due to side-lobe radiation of the antenna exists between the transmitting and receiving horns, with the extent climbing markedly as the angle of incidence θ_1 reaches 45 degrees or more [6]. The scattering-coefficient measurement techniques have been degraded by extraneous direct waves such as the above-mentioned direct coupling, as well as by underground signals scattered from the floors, ceilings, side walls, support materials, and the sample itself outside the measured area.

These extraneous direct-wave components of the received signal are easily separated by slightly raising the vertical positions of the metal flat plate reflector on the specimen.

Figure 5 shows a detailed vector diagram of received signals. The scattering- or reflection-coefficient is obtained by the procedure shown in Fig. 5.

The received wave signal E_{rs} for the sample, which is detected by the receiving horn, is the sum of the reflected signal E_s from the specimen and the unwanted direct wave E_d. We separate the direct wave into six components, E_{dc}, E_{ceil}, E_{wall}, E_{floor}, $E_{support}$, and E_{ds} which are caused by direct coupling, scattered waves from the ceiling, scattered waves from the walls, scattered waves from the floor, and scattered waves from the sample support mechanisms, and the sample itself outside the measured area respectively.

$$E_{rs}=E_s+E_d \tag{1}$$

$$E_d=E_{dc}+E_{ceil}+E_{wall}+E_{floor}+E_{support}+E_{ds} \tag{2}$$

The measurements for flat metal plates give us the estimated received signal E_{rm} at $h = 0$ required to determine the incident wave E_i, or E_m.

$$E_{rm} = E_m + E_d \tag{3}$$

The scattering coefficient s, or the ratio of the scattered wave to the incident wave E_i on the scattering surface, is equivalent to the ratio of the scattered wave E_s from the sample to the reflected wave E_m from the metal plate at the same distance from the scattering point. In other words,

$$s = \frac{E_s}{E_m} \ . \tag{4}$$

The received signal E_{rs} is represented by the phaser summation indicated below:

$$E_{rs} = |E_s|e^{j\Phi_s} + |E_d|e^{j\Phi_d} \tag{5}$$

$$\begin{aligned} E_{rs} = {} & |E_s|e^{j\Phi_s} \\ & + |E_{ceil}|e^{j\Phi_{ceil}} + |E_{wall}|e^{j\Phi_{wall}} + |E_{floor}|e^{j\Phi_{floor}} \\ & + |E_{support}|e^{j\Phi_{support}} + |E_{ds}|e^{j\Phi_{ds}} \ , \end{aligned} \tag{6}$$

where the time-dependent factor $e^{j\omega t}$ is abbreviated in these phaser equations.

The equation of E_{rm} for the metal plate is similarly derived:

$$E_{rm} = |E_m|e^{j\Phi_m} + |E_d|e^{j\Phi_d} \ . \tag{7}$$

It is noted that the direct-wave component is constant for both Eqs. (5) and (7).

Usually, the real wave signals are expressed in a time-dependent cosine function form, for example,

$$E\cos(\omega t-\phi)\ . \tag{8}$$

Thus, the summation of signals having various values of amplitude and phase is expressed in a form such as

$$\sum_{n=1}^{N} E_n\ \cos\,(\omega t-\phi_n)\ . \tag{9}$$

We expressed these waves in a complex function such as

$$\sum_{n=1}^{N}\ \{\boldsymbol{E}_n\} = \sum_{n=1}^{N}\{E_n e^{j\,(\omega t-\phi_n)}\ \}$$
$$= \sum_{n=1}^{N}\{E_n\cos(\omega t-\phi_n) + \boldsymbol{j}E_n\sin(\omega t-\phi_n)\}\ . \tag{10}$$

Therefore, the real wave function for the summation of the waves through multiple paths is obtained from the real part of these complex functions, i.e.,

$$\mathrm{Re}\,[\sum_{n=1}^{N}\{E_n\cos(\omega t-\phi_n) + \boldsymbol{j}E_n\sin(\omega t-\phi_n)\}]$$
$$= \sum_{n=1}^{N}\{E_n\cos(\omega t-\phi_n)\ \}\ . \tag{11}$$

This is the projection of vector E_m to the abscissa in a complex plane diagram.

Both the amplitude and phase of this received signal relative to the reference signal are measured by a slotted-line standing wave detector, or Vector Network Analyzer, connected to the receiving horn antenna. Therefore, we can display these components vectorially in the complex plane diagram, as shown in Fig. 5.

In order to separate the direct-wave components, we slightly raise the position of the metal plate reflector on the specimen. The sample displacement h has to be so small that no amplitude change of scattered waves occurs and only the phase changes. The phase change ϕ for the displacement h is

$$\phi = \frac{2\pi}{\lambda}2h\cos\,(\theta_1)\ , \tag{12}$$

where λ is the free-space wavelength. This condition is necessary for the amplitude of the radiation field to be in inverse proportion to the distance between the horn and the sample. Thus, the locus of the vector of the received signal, due to the displacement of the metal reflector, draws the circle of radius $\left|E_m\right|$, with the center O' corresponding to the vector of the direct wave E_d.

Because the position of the specimen is fixed, the received signal is the sum of the direct wave and the reflected wave from the specimen at $h=0$. If the specimen is movable as in the case of our early scattering-coefficient method, due to the displacement of the specimen, the circle of radius $\left|E_s\right| = \left|s\ E_m\right|$ is drawn, establishing the center O' corresponding to the vector of direct wave E_d. In the general case of a scattering-coefficient measurement, the direct wave for the metal plate is different from that of the sample, and we thus rename the direct wave $E_d{}'$.

Consequently, the direct wave is separated from the received signal vectorially, and then the amplitude of the scattering coefficient s is determined from the ratio of these two radii. In addition, the phase of s is determined from the phase difference between two vectors E_s, and E_m. If the scattering angle θ_2 is equal to the incident angle θ_1, the direct wave for the sample $E_d{}'$ is coincident with that of the metal plate E_d, as are the two centers, O' and O''.

2.2 Complex Scattering-Coefficient Measurement Method Suitable for Movable Specimens [4], [5], [11], [12]

Because our early scattering-coefficient measurement method was developed for the assessment of metal-backed radio-wave scatter suppressors, it was suitable for materials that predominantly scatter the incident waves backwards. Moreover, the specimens to be measured were easily obtained from raw materials. Although this method is not applied to non-destructive arrangements, it has two advantages. The first advantage is that it ensures that the measurement area of the sample equals that of the reference metal-plate reflector automatically. Although we do not need to move the specimen to get

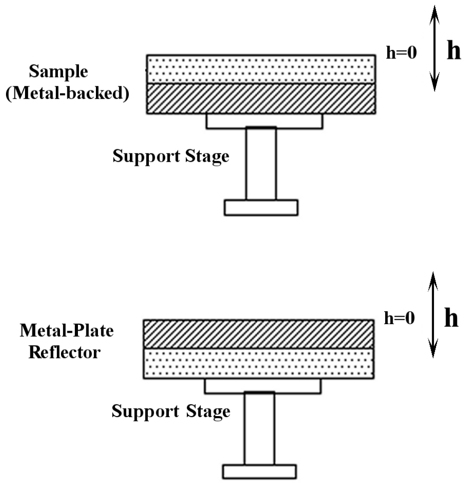


Fig. 6 Arrangement of sample and metal plates in the scattering-coefficient measurement method using a movable specimen.

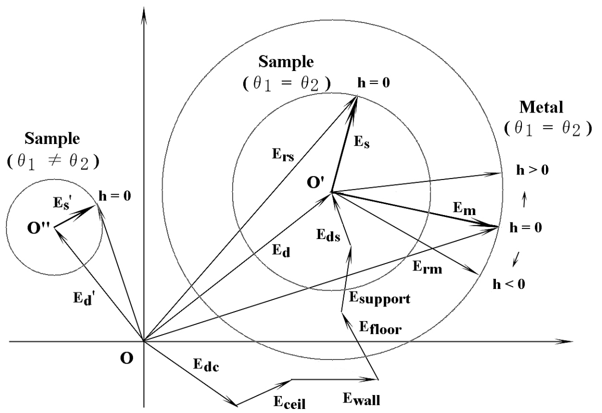


Fig. 7 Vector diagrams of received wave signals in scattering-coefficient measurement systems using a movable specimen.

the data of scattering coefficient, we can set the vertical position h of the metal-plate reflector to zero, which leads to the second advantage, that we can make the phase of the incident wave for the specimen and that of the metal-plate reflector coincide.

Figure 6 shows the arrangement of the sample and metal plates in the measurement method using movable specimens. A vector diagram of received signals is shown in Fig. 7.

2.3 Advanced Scattering-Coefficient Measurement Method Suitable for Transmission Measurements Using a Metal-Backed Absorber

In the case of measuring forward scattering, such as the transmission-coefficient measurement of a dielectric sheet sample, we must decrease the influence of scattering from the edges of the metal plate, as shown in Fig. 8. If this influence is much smaller than those of other direct-wave and scattered-wave components, the forward-scattering coefficient can be measured by the method described in the preceding section. However, if the field intensity of the scattered wave is very weak, this effect must be taken into consideration.

In order to decrease the edge-scattering effect, we can use a curved-edge reflector coated with an absorber [17]. In this case, however, it is not necessary to use a metal plate to determine the direct wave. We propose an advanced measurement method using a metal-backed flat absorber to determine the direct wave. The separation process has two stages. First, the incident wave is determined using the metal plate on the sample in the reflection arrangement. It is not necessary to move the metal plate. Next, the direct waves for both reflection and transmitting arrangements are determined by displacing the metal-backed absorber subjected to weak influences of scattering from the edges and surface of the metal plate. If the scattering coefficient of the absorber is close to the ideal zero, it is not necessary to move it because the direct-wave component of the metal plate equals that of the metal-backed absorber in the same measurement area so that the two centers of the circles coincide, as indicated in Fig. 5.

Therefore, this method makes it easy to measure forward-scattering coefficients. It is noted that reradiation from the back surface of the metal plate is also reduced. In this case, the absorber should be attached or coated to the back surface of the metal-plate reflector, as mentioned above [17].

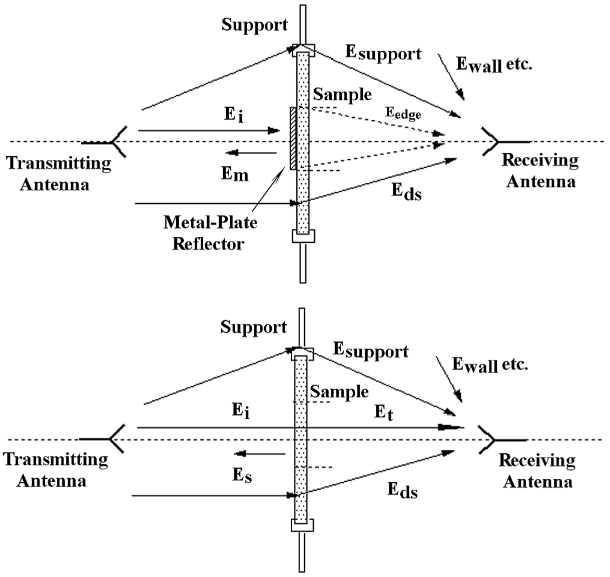


Fig. 8 Direct waves for measuring reflection and transmission coefficients.

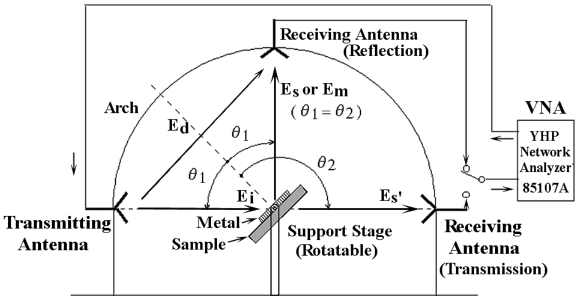


Fig. 9 New non-destructive scattering-coefficient measurement equipment.

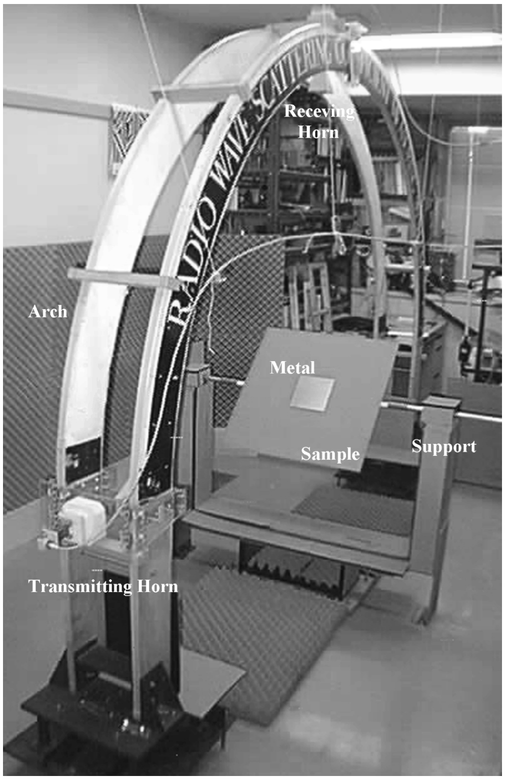


Fig. 10 Photograph of the new scattering-coefficient measurement equipment in the X-band region. The arch diameter is 2.6 m, and the aperture dimensions of the horn antenna are 93 mm × 68 mm. The measured sample is a flat Bakelite sheet with a size of 600 mm × 600 mm × 3.2 mm. The size of the metal plate reflector was varied, but it is 150 mm × 150 mm in this photograph.

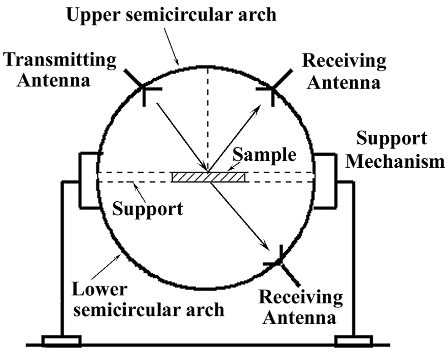


Fig. 11 Ideal arrangement of the scattering-coefficient measurement equipment.

3. Measurement Setup of the New Scattering-Coefficient Measurement Method

Figure 9 shows the experimental setup of the X-band scattering-coefficient measurement system. Transmitting and receiving antennas are attached to a semicircular arch with a diameter of 2600 mm. The aperture of the horn is 97 mm × 68 mm. The measurement frequency is 9.4-9.5 GHz (X-band). The vector components of the received signals are easily measured by a Vector Network Analyzer (YHP 85107A). The samples are mounted on a rotatable support stage so that the scattering measurements are made on a variety of configurations for oblique incidence, and the horns attached to the arch are movable so as to vary the angles of scattering and the polarization.

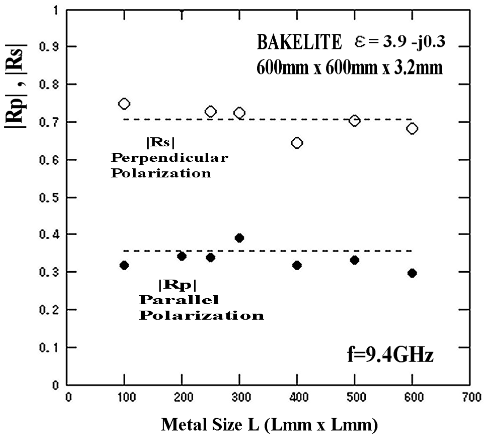
Figure 10 shows the actual scattering-measurement setup in an ordinary experimental room without an echoic chamber.

The present horizontal setup does not afford the ease of sample displacement and reduction of scattering from the support material and floor provided by the vertical setup arrangement in our previous measurement method, as indicated in Fig. 4. Therefore, the ideal scattering measurement setup should be the vertical arrangement shown in Fig. 11.

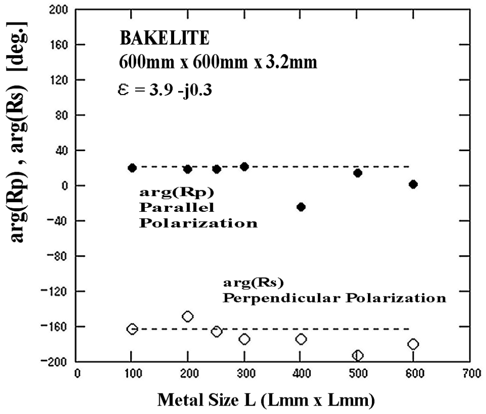
4. Examples of the Measurement of Reflection and Transmission Coefficients of a Few Dielectric Sheet Samples

4.1 The Measurement of Reflection and Scattering Coefficients of Scatter Suppressor or Absorbers Using Movable Specimens [4], [5], [11], [12]

The measurement of low reflection materials such as absorbers is very effective by our separation method. Measurement of the reflection coefficient of metal-backed magnetite-impregnated plastics serving as radio-wave scatter suppressors and metal-backed plane microwave absorbers on the market were conducted using movable samples. In addition, the scattering coefficients of metal-backed ferrite-impregnated plastic sheets with slightly unflattened surface were measured.



(a) Amplitudes of Rp and Rs



(b) Phases of Rp and Rs

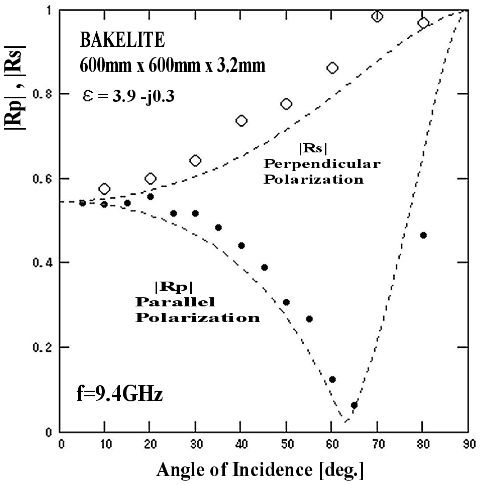
Fig. 12 Reflection coefficients of a dielectric sheet sample as a function of the metal-plate size. Metal-plate size ranged from (100 mm × 100 mm) to (600 mm × 600 mm); the incident angle was 45 degrees.

To obtain these measured data, see references [4], [5], [11], [12].

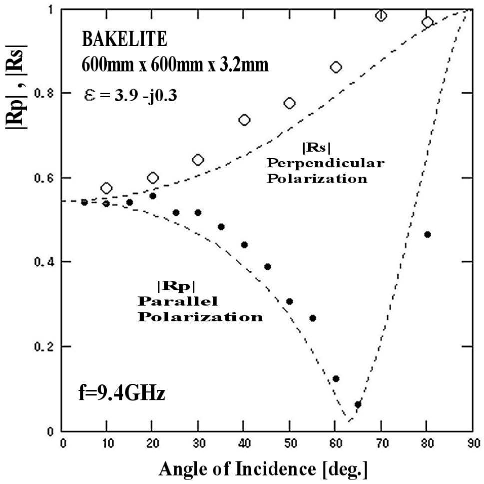
4.2 The Measurement of Reflection Coefficients of a Dielectric Sheet Sample [13], [14]

In order to assess the non-destructive measurement method, the reflection coefficients of a commercially available dielectric sheet sample were measured. The experimental conditions, namely whether or not the direct waves are well separated, are always checked by the vector diagram of the field from the reference metal-plate reflector.

Figure 12 shows the reflection coefficients of dielectric sheet samples as a function of the size of a square metal plate, ranging from (100 mm × 100 mm) to (600 mm × 600 mm), where the incident angle is 45 degrees [13]. The complex dielectric constant of the Bakelite sample was measured by a perturbed TE107 rectangular cavity resonator [3]. The measured complex permittivity was 3.9-j0.3 at 9.4 GHz using a cleaved specimen from raw material; its size was 1 mm × 1 mm × 10.2 mm. The measured data of reflection coefficients in Fig. 12 are almost constant for various sizes of metal plates



(a) Amplitudes of Rp and Rs



(b) Phases of Rp and Rs

Fig. 13 Reflection coefficient of a dielectric sheet sample as a function of the angle of incidence.

and also coincide with the calculated reflection constant from the measured complex permittivity within 10%. In Fig. 12, the measurement error becomes large when the sample size is 400 mm × 400 mm. This was due to the poor flatness of the large sample and the unhomogeneousness of the sample thickness.

Figure 13 shows an example of the reflection coefficient of the same Bakelite sheet sample as a function of the angle of incidence. It is noted that our measurement method enabled us to obtain both the amplitude and phase data of the reflection coefficients. When the angle of incidence is below 60 degrees, the measured data coincide with the calculated value of complex reflection coefficient illustrated as the dotted line in Fig. 13. There is a marked increase of error for the data of phase at near quasi-Brewster Angle for parallel polarization, which is due to the decrease of phase measurement accuracy for a weak received signal. For above 70 degrees for parallel polarization, which is the error due to the effect of edge coupling to the dielectric guideline becomes large. Other reflection coefficient measurement methods also have the same problems due to this effect.

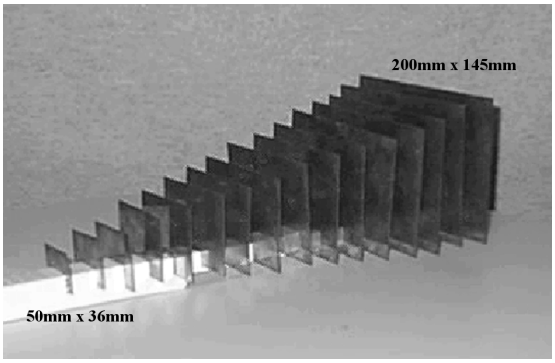
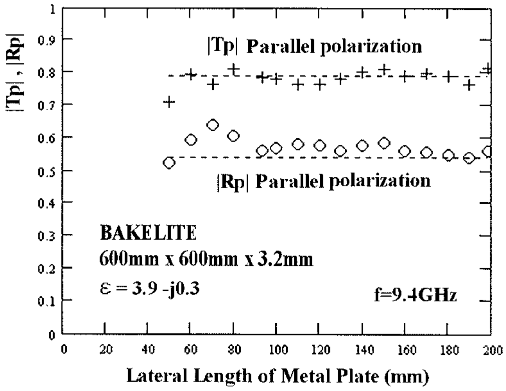
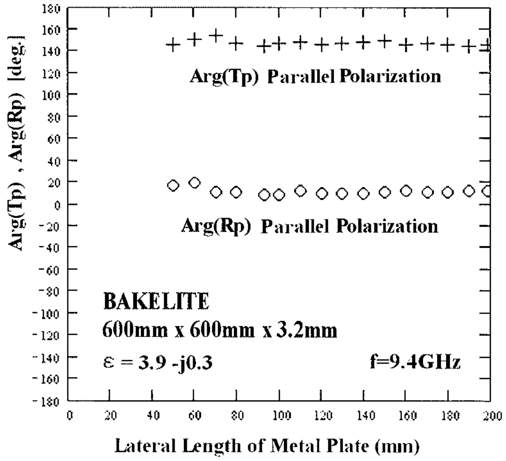


Fig. 14 Photograph of rectangular metal-plate reflectors. Their lateral length ranges from 50 mm to 200 mm.

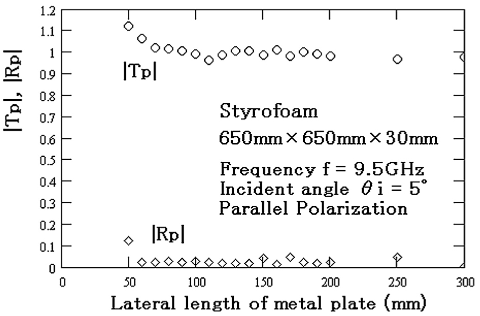


(a) Amplitudes of Tp and Rp

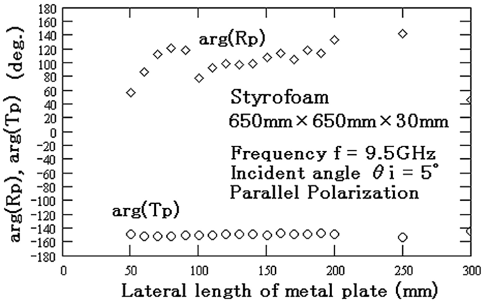


(b) Phases of Tp and Rp

Fig. 15 Complex transmission and reflection coefficients of a Bakelite sheet sample as a function of the lateral length of the rectangular metal-plate reflector. The lateral length ranged from 50 mm to 200 mm; the incident angle was 5 degrees for parallel polarization.



(a) Amplitudes of Tp and Rp



(b) Phases of Tp and Rp

Fig. 16 Complex transmission and reflection coefficients of a Styrofoam sheet sample as a function of the lateral length of the rectangular metal-plate reflector. The lateral length ranged from 50 mm to 200 mm; the incident angle was 5 degrees for parallel polarization.

4.3 Measurement of the Reflection and Transmission Coefficients of a Dielectric Sheet Sample [7], [8]

Rectangular metal plates, whose sizes were in direct proportion to the aperture dimensions of the horn antenna, were also manufactured in the workshop of our university. Figure 14 shows the rectangular metal-plate reflectors.

Figure 15 shows an example of complex transmission- and reflection-coefficient measurements of a dielectric sample as a function of the lateral length of the rectangular metal plate, which ranges from 50 mm to 200 mm. The measured data indicate that the complex reflection and transmission coefficients of a Bakelite plate were constant for above 100 mm of lateral length of the metal plates at 9.4 GHz.

In order to demonstrate that the intensity of the reflected wave from the reference metal plate equals that of the transmitted wave without a specimen, the transmission and reflection coefficients of a Styrofoam sheet sample were measured [13], [14]. The dielectric constant of these foam materials is nearly 1 (measured complex permittivity was $1.06\text{-}j8\times10^{-4}$ by perturbed cavity resonator at 9.5GHz), so that the transmission is also nearly 1. Figure 16 shows complex transmission and reflection coefficients of a Styrofoam sheet sample as a function of the lateral length of the rectangular metal plate. The lateral length ranged from 50mm to 200mm, and the incident angle was 5 degrees for parallel polarization. The measured data indicated that the transmission coefficients of the Styrofoam sheet were nearly 1 for above 100 mm of lateral length of the metal plate at 9.5 GHz. Therefore, we can determine the incident wave field using the data of reflection from the reference metal-plate reflector. The large measurement error for the data of phase for the reflection coefficient in Fig. 16(b) is also due to the decrease of phase measurement accuracy for a weak received signal.

Data for the scattering coefficients of scattered objects are not available at this point because the measurement system was first assessed using dielectric-plane sheet samples, for which material information is easily predicted.

5. Conclusion

Our scattering-coefficient measuring method has been designed to overcome the difficulties arising from the existence of extraneous direct waves. In free-space measurement, these direct waves always exist even if the experiment is conducted in the conventional radio-wave anechoic chamber or open space. In our new scattering-coefficient measurement method, the extraneous direct waves are easily separated by displacing only the metal plate on the sample to be tested so that non-destructive assessments of any material with a variety of shapes can be performed in terms of both forward- and backward-scattering coefficients. Therefore, our method could be applied in an ordinary laboratory as well as in an anechoic chamber.

In addition, because the measured area was determined from the size of the reference metal-plate reflector on the sample, measurements of complex scattering coefficients for small regions of the sample were possible. The behavior of the metal-plate reflector is similar to that of an optical shutter in optics. Thus, this method could be applied to the non-destructive assessment of uniform and non-uniform microwave materials or scattered objects and to research on underground or hidden objects.

Although the present measurements were conducted in the X-band region, our method could be applied to other lower- and higher-frequency regions of electromagnetic waves. Future studies will allow us to report on the frequency limitations of this measurement method, the size limitations of the metal-plate reflectors, and practical measurements of scattering coefficients from objects.

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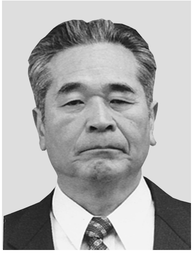

Ryoichi Ueno received his B.E. and M. E. degrees in electrical engineering from Keio Gijyuku University, Tokyo, Japan, in 1961 and 1963, respectively. In 1963, he joined the Department of Electrical Engineering, Tokyo Metropolitan University, as a Research Associate, and he retired in March, 2000. His research interests include the separate measurement of complex permittivity and permeability of magnetic materials and methods for the measurement of complex scattering coefficients in the microwave region.

Toshio Kamijo received his B.E. and M.E. degrees in electrical engineering from Tokyo Metropolitan University, Tokyo, Japan, in 1976 and 1978, respectively. In 1978, he joined the Department of Electrical Engineering, Tokyo Metropolitan University, as a Research Associate. His research interests include the measurement of complex refractive index of materials at the microwave and optical regions and applications of microwave- and optical-magnetic materials.