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Study on The Scattering Characteristics of Electromagnetic Wave with Dielectric Band

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Abstract: When electromagnetic signal penetrates medium, its signal intensity will decrease and even change the polarity of electromagnetic wave due to the scattering of electromagnetic wave. Electromagnetic wave signal propagation in rainy days, fog days, dust and another medium electromagnetic signal attenuation phenomenon. Since raindrops, haze particles, dust particles and other media have different degrees of electric quantity, in order to measure the effect of charge itself on electromagnetic wave attenuation, this paper involves the attenuation experiment of electromagnetic wave with dielectric plates. PP board, PVC board and PMMA board are selected to conduct experimental research on the influence of electromagnetic signal attenuation.

Keywords: Electromagnetic wave; Charged; Attenuation; Dielectric plate.

1. The conductivity of the dielectric plate and its influence on electromagnetic wave propagation

The electrons in the dielectric, also known as insulators, are bound around the nucleus to which they belong, so few free electrons inside the material can only make microscopic displacement even if they are affected by external electric field, and most of the charged particles in the molecules can only make macroscopic migration like the free electrons in the conductor [1].

Conductivity is a measure of a substance's ability to carry current, defined by Ohm's law as the ratio of current density to electric field strength. The relative dielectric constant is a physical parameter that characterizes the dielectric property or polarization property of a material, whose value is equal to the ratio of the capacitance of a capacitor of the same size made of vacuum medium to the predicted dielectric material [2-4].

The relationship between the dielectric constant and the conductivity is $\varepsilon_e = \varepsilon(1 - j\kappa / \omega\varepsilon)$

ε_e : Dielectric constant j : maginary unit κ : The conductivity of the medium ω : The angular frequency of an electromagnetic wave ε : The dielectric constant of an ideal medium. It follows that, when $\varepsilon_e = \varepsilon$, the conductivity is zero and the surface conductivity is zero. When the charge is 0, the conductivity is 0, and when the charge is not 0, the conductivity is not 0.

The conductivity of a substance is not only related to its condensed state and composition, but also related to the external electric field conditions in which the substance is located. For substances in a strong field, the magnitude of molecular electric dipole moment, the arrangement and distribution of molecules, the thermal vibration of crystalline lattice, etc., may all change greatly, thus changing the electrical conductivity of substances [5].

There is a surface conduction current through the surface of a solid medium $I_S = G_S U$, Where G_S is the surface conductance of solid medium, unit S. If two parallel plate electrodes are added on the surface of solid medium, the distance between electrodes is D, and the electrode length is L, then $G_S = \gamma_s \dfrac{l}{d}$ In the formula, the proportional coefficient γ_s is the surface conductivity of the medium, which has the same unit as the dielectric conductance, and is also Siemens., It can also be written as surface current density $J_S = \dfrac{I_S}{l} = \gamma_s \dfrac{U}{d} = \gamma_s E$ Where, J_S is the surface current density, whose unit is Am-1.

The value of the surface conductivity γ_s (or surface resistivity ρ_s) of the medium is not only related to the nature of the medium, but also affected by the humidity, temperature, surface structure and contamination of the surrounding environment [6].

When the dielectric is positive relative to the conductor, the discharge area generated on the dielectric is uniform and round, the discharge area is relatively small, and the energy released is also relatively small. When the dielectric is negative potential relative to the conductor, the discharge area generated on the dielectric is an irregular star-shaped area with a large area and more energy released [7].

Different electrical conductivity of the medium scattering of electromagnetic waves, the conductivity of the smaller conductor medium, the medium can produce scattering and absorption of electromagnetic waves, lead to the electromagnetic wave energy attenuation, the conductivity larger conductive medium, electric conductivity after the incident to the surface, can produce skin effect, electromagnetic wave propagation in the medium surface scattering, and decay, not the incident to the depths of the medium, degree of attenuation is greater than the low conductivity of medium (8-9).

2. Interaction between dielectric and electromagnetic wave

The influence of band dielectric on the propagation of electromagnetic wave is studied based on the interaction between electromagnetic wave and medium. The study of electromagnetic wave propagation characteristics mainly studies the reflection and transmission characteristics of electromagnetic wave, which are affected by the electromagnetic parameters of materials. The electrification of the medium will change these parameters and then affect the propagation characteristics of electromagnetic waves.

Reflection, transmission and absorption and other phenomena occur when electromagnetic waves are perpendicular to the interface of two media, as shown in Fig1.

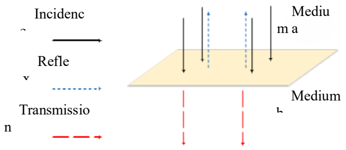

Fig .1 Incident, reflection and transmission of electromagnetic wave at the boundary of medium

Assuming that a beam of electromagnetic wave is incident from medium A to medium B in the z direction, and the electric field direction of incident wave, reflected wave and transmitted wave is X direction, the electric field Ei and magnetic field Hi of incident wave can be expressed as:

$$\begin{cases} E_i = E_{im} e^{-jk_a} e_x \\ H_i = \dfrac{E_{im}}{\eta_a} e^{-jk_a} e_y \end{cases} \tag{1}$$

Whereex and ey are unit vectors in x andy directions perpendicular to each other and also to the propagation direction z, and Eim is the magnetic induction intensity of the incident wave; k is the propagation coefficient, $k = \omega\sqrt{\mu\varepsilon}$, andη is the intrinsic impedance. The impedance can be expressed by the following equation:

For ferromagnetic materials such as metals:

$$\eta = \sqrt{\mu / \left(\varepsilon - j\frac{\sigma}{\omega} \right)} \tag{2}$$

For non-metallic materials with good insulation:

$$\eta = \sqrt{\mu / \varepsilon} \tag{3}$$

Among them, ε and μ are dielectric constant and permeability, σ is conductivity, ω is the angular frequency of electromagnetic wave. Similarly, the electric and magnetic fields of reflected and transmitted electromagnetic waves can be expressed as:

$$\begin{cases} E_r = E_{rm} e^{jk_a} e_x \\ H_r = -\dfrac{E_{rm}}{\eta_a} e^{jk_a} e_y \end{cases} \tag{4}$$

$$\begin{cases} E_t = E_{tm} e^{-jk_b} e_x \\ H_t = \dfrac{E_{tm}}{\eta_b} e^{-jk_b} e_y \end{cases} \tag{5}$$

Where Erand Et are the electric fields of reflected and transmitted waves respectively, Hr and Ht are the magnetic fields of reflected and transmitted waves respectively, and Erm and Etm are the electric fields of reflected and transmitted waves respectively.

The reflection coefficient in transmission line theory can quantitatively describe the absorption performance of electromagnetic waves of materials and reflect the degree of reflection attenuation of dielectric materials to incident electromagnetic waves [10].

3. Experimental design of electromagnetic wave attenuation with dielectric plate

The high voltage source is used to make the dielectric plate electrify. After the dielectric plate is electrified, after careful elimination treatment, then carry out the electrification experiment behind, because the object's electrification history or electrification state, directly affects the object's electrostatic starting electric quantity and the object's electrification symbol. Originally, the measurement results of electrification in the first contact and separation between uncharged objects can reflect the actual electrification properties of objects [11].

Experimental materials selection: according to the laws of the object surface charge dissipates, through a series of static leakage testing, finally selected experimental dielectric materials for acrylic (60 cm long, 60 cm wide, the thickness of 4 mm, 15 mm, 30 mm), PVC board (60 cm long, 60 cm wide, the thickness of 3 mm, 15 mm, 30 mm), PP board (60 cm long, 60 cm wide, the thickness of 3 mm, 15 mm, 30 mm).

Experimental instruments: signal source SML01(9KHz-1.1ghz), signal source SMR 20 (1G HZ-20ghz), two double-cone antennas, two log-periodic antenna ETS3142E(26MHZ-6ghz), horn antenna BBHA9120D (1201), spectrum analyzer AgilentE4440A(3HZ-26.5GHz), positive high voltage source, negative high voltage source, consumer.

Experimental frequency selection: generally, no less than 3 frequency points are selected within every 10 octaves. In order to better study the electromagnetic wave attenuation law under different frequencies, frequency point density is increased. Finally, frequency point is selected as follows:1GHz, 1.2Ghz, 1.4Ghz, 1.5Ghz, 1.6Ghz, 1.7Ghz, 1.8Ghz, 1.7Ghz, 1.8Ghz, 1.9Ghz, 2.2Ghz, 2.1Ghz, 2.2Ghz, 2.4Ghz, 3Ghz, 5Ghz, 6Ghz, 8Ghz, 9Ghz, 12Ghz, 15Ghz, 17Ghz. During the experiment, the distance between the antenna and the shielding material was strictly carried out in accordance with the standard, and the ground was marked to ensure the repeatability of the experiment. Anti-static clothing was worn during the whole operation.

The experimental construction system block diagram is shown in Figure 2 below:

The experimental steps are as follows:

(1) Connect the experimental instruments, adjust the vertical polarization of the antennas, and output power of the signal source is 10dBm;

(2). Record the received power of each frequency point after passing through the air;

(3). Ensure that the experimental conditions remain unchanged, install the measured medium plate in the window of the shielding room, use the non-contact meter to measure the voltage of the medium plate, and record the received power at each frequency point under the basic voltage;

(4) The surface charge amount of the dielectric plate is increased by using the jet method to record the receiving

power at various frequency points under high voltage.

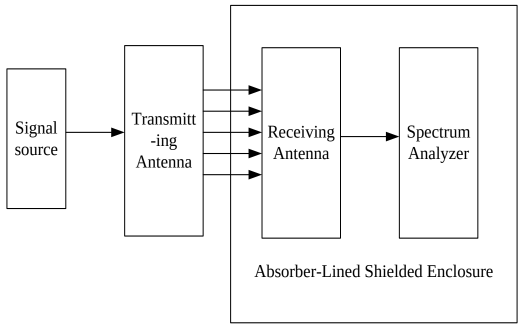

Fig.2 Block diagram of the experimental system for measuring the shielding effectiveness of the dielectric plate

4. Analysis of experimental data

Taking 3mmPP board as an example, the data is presented in the form of THREE-DIMENSIONAL diagram, the X coordinate is Voltage/V, the Y coordinate is Frequency/GHz, and the Z coordinate is Received Power/dBm. The data is as follows See Fig. 3.

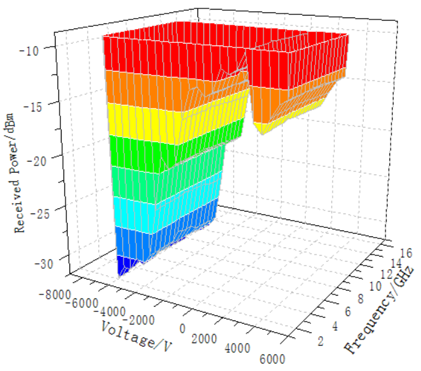

Fig.3 Schematic diagram of received power of 3mmPP board at different voltages and frequencies

As can be seen from the figure, with the increase of electric charge, the receiving power becomes smaller and smaller, indicating that the dielectric plate is electrified, which increases the attenuation of electromagnetic wave. After the statistical collation of data, it is found that the experimental media have this trend. It shows that the charge has an effect on the attenuation of electromagnetic wave in the dielectric plate.

Taking the 2GHz 3mmPP board as an example, the received power and fitting curve under different voltages are shown in Fig4.

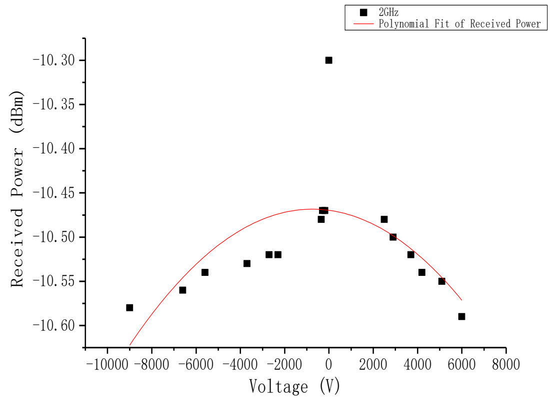

Fig.4 Receiving power of 3mmPP board at 2GHz

It directly reflects that the receiving power reaches its maximum at the voltage of 0. With the increase of electric quantity, the receiving power decreases obviously, and the receiving power of acrylic and PVC plates also has this rule. Experiments have verified that the electrification of medium plates has certain influence on the attenuation of electromagnetic waves.

The attenuation maximum value statistics of various materials are shown in Table 1 below.

Tab.1 Statistical table of the maximum value of power attenuation of each material

Dielectric plate material	Maximum power attenuation at positive voltage /dB	Minimum power attenuation at positive voltage /dB	Maximum power attenuation at negative voltage /dB	Minimum power attenuation at negative voltage /dB
3mmPP plate	0.89	0.08	0.72	0.13
15mmPP plate	0.37	0.02	1.1	0.05
30mmPP plate	0.69	0.05	0.8	0.05
3mmPVC plate	1.04	0.04	0.65	0.09
15mmPVC plate	0.47	0.05	0.39	0.07
30mmPVC plate	1.63	0.04	1.64	0.06
4mmPMMA plate	1.89	0.04	2.53	0.08
15mmPMMA plate	0.85	0.03	0.97	0.06
30mmPMMA plate	0.42	0.04	0.51	0.08

Influences of various factors on electromagnetic wave attenuation of dielectric plates:

(1). Influence of different thickness on electromagnetic wave attenuation of dielectric plate.

As shown in Fig5., the thickness of dielectric plates with dielectric plates is not proportional to electromagnetic wave attenuation according to the experimental data results.

(2). The influence of different frequencies on electromagnetic wave attenuation of dielectric plates

As shown in figure 6, with the increase of frequency, the attenuation of electromagnetic wave increase trend on the whole, analyze in PP board, for example, 3 MMPP plate as the frequency increases, the electromagnetic wave attenuation increases monotonously, 15 MMPP look under voltage increases monotonously with the increase of frequency electromagnetic wave attenuation, 15 MMPP plate under the negative voltage and 30 MMPP plate with increased frequency of electromagnetic wave attenuation increases after the first decreases, and the overall trend of flat.

(3). Influence of different materials on electromagnetic wave attenuation of dielectric plates.

As shown in Fig. 7, the influence of dielectric plates with three kinds of materials on electromagnetic wave attenuation is shown in fig. 7. The influence trend of electromagnetic wave attenuation under different thickness and voltage of the same material is the same.

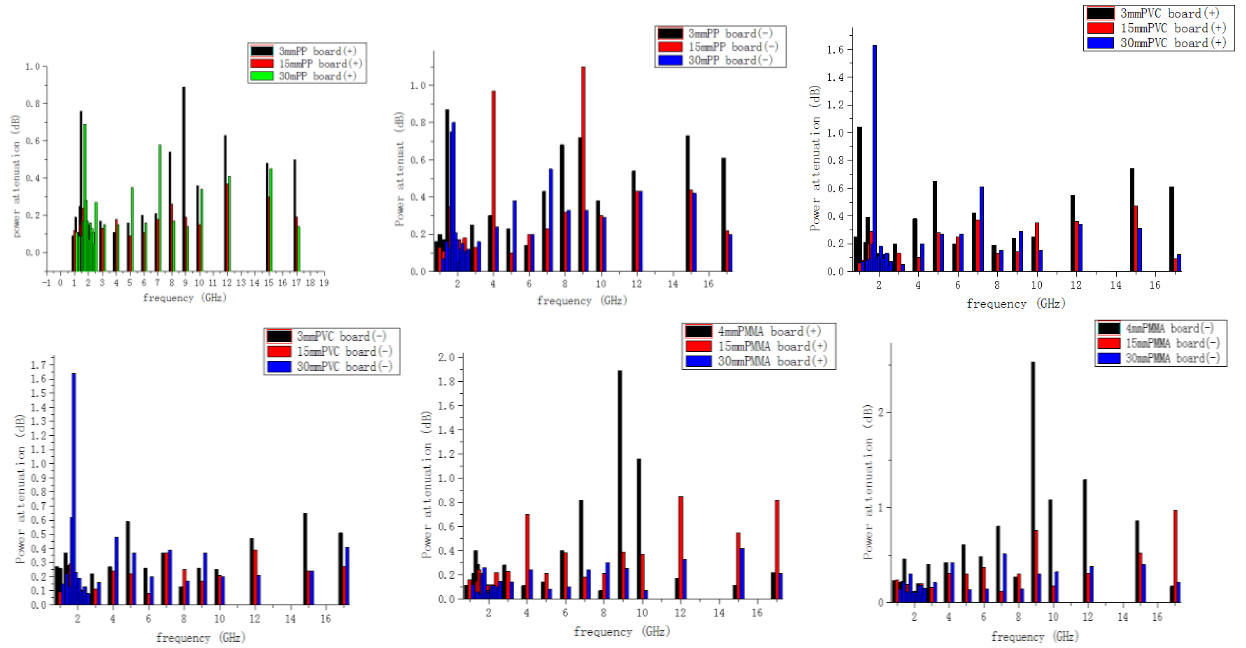

Fig.5 Electromagnetic wave attenuation of dielectric plates with different thickness

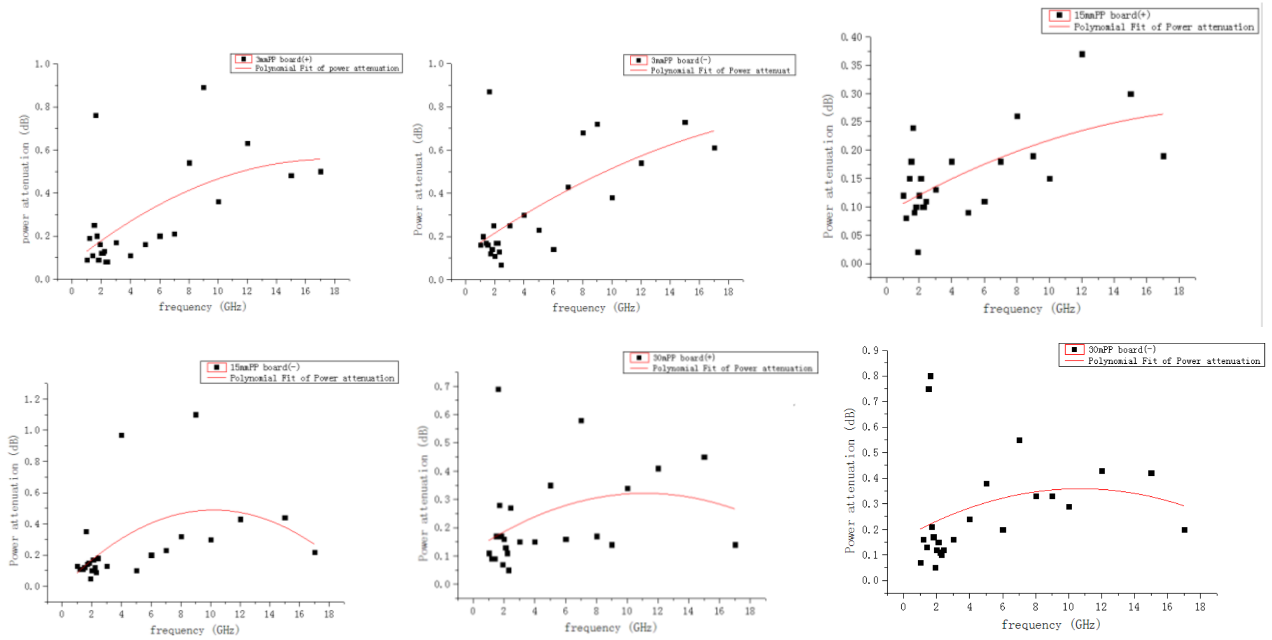

Fig.6 Electromagnetic wave attenuation of PP plate at different frequencies

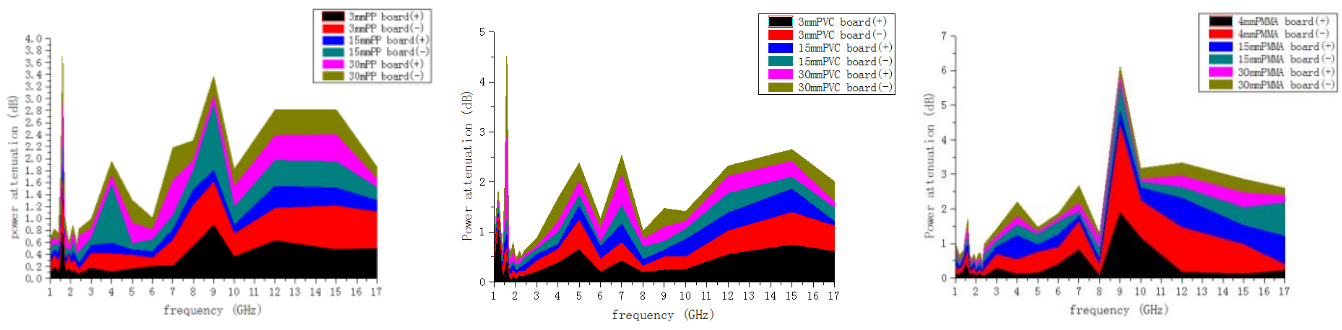

Fig.7 Electromagnetic wave attenuation of dielectric plates with different materials

5. Conclusion

Various obstacles will be encountered in the process of electromagnetic wave propagation. Due to the different shape, size and material properties of obstacles, different forms of electromagnetic wave scattering will be caused, and the received electromagnetic wave energy will be somewhat attenuated. When electromagnetic wave encounter obstacles with electrostatic, because the free electrons forced vibration occurred in the electromagnetic field, forced the free electrons to be seen as electric dipole, outward scattering of electromagnetic wave, causing the scattering field increases, at the same time, the vibration of the free electrons consumes transmission of electromagnetic energy, causing the energy loss in the process of electromagnetic wave propagation [12, 13].The experiment of electromagnetic wave attenuation on dielectric plate proves that the influence of electric charge on electromagnetic wave propagation is enhanced, and the attenuation of electromagnetic wave increases with the increase of electric charge.

References

[1] Xie Li, Wu Mudan. Experimental study on cross polarization of 1.2ghz Electromagnetic Wave with local band dielectric, CSTAM2013-A31-1999.

[2] Perry F. Wilson, M.T.Ma.Fields Radiated by Electrostatic discharges. IEEE Transactions on Electromagnetic compatibility, 1991, vol.33(1) :10-18.

[3] Liu Yakui, Xie Li. Study on dielectric permittivity of surface dielectric under Electromagnetic radiation, 2016 National Symposium on Environmental Mechanics, Suzhou, China.

[4] Xu Lanyun ., pan Liuxian. Charge surface densities of several typical charged conductors [J]. Journal of Lingling University, 2003, 24(2):45-47.

[5] An Zhenlian, Chen Qingru, zhang Xinxi. Discussion on collision electrification mechanism of powder [J]. 1997, 26 (2):71-74.

[6] Tang Kai, Hou Jialin, WANG Zhen, WANG Junfeng. Lightning protection principle and Experiment based on changing surface charge density of objects [J]. Journal of the Academy of Equipment Command&Technology, 2010, 21(1) :118-121.

[7] Wang Xiue. Research on the surface charge distribution of electrostatic balanced conductors [J]. Journal of Beijing Technology and Business University9(Natural Science Edition), 2003, 21(3):59-60.

[8] Dong Qunfeng, LI Yingle, LI Junjie, ZHANG Hui. Study on microwave attenuation characteristics of charged dust medium based on Mie theory[J]. EQUIPMENT ENVIRONMENTAL ENGINEERING, 15(6): 99-102.

[9] Lausang Pincuo. Some Applications of Higher Mathematics in Electrostatics. Mathematical, physicochemical research [J].2016, (10):297-298.

[10] Song Xinhua, YAN Honghao, MA Zhengzheng, WANG Yang, XU Bin. Orthogonal Analysis of Electromagnetic Wave Reflection Coefficient based on transmission Line Theory [J]. Science, Technology and Engineering, 2012,18 (12): 137-141.

[11] Zhang zijia, pan qi, Chen haixiu. Rayleigh scattering of charged particles [J]. Acta optica sinica, 2015,35 (5).

[12] Liu Shanghe, Wei Guanghui, Liu Zhicheng et al. Electrostatic theory and protection. Beijing: Ordnance Industry Press, 1999.1.

[13] Falin, Castagna John p., dong hefeng. A fast and accurate algorithm for calculating reflection/transmission coefficients [J]. Science in China series G: physics, mechanics and astronomy, 2008,38 (7): 873-895.