Journal of Applied Mathematics and Physics, 2021, 9, 3094-3101
https://www.scirp.org/journal/jamp
ISSN Online: 2327-4379
ISSN Print: 2327-4352

Electrical Properties of Dead Sea Water

Maen Ishtaiwi*, Muna Hajjyahya*, Shahd Habbash

Department of Physics, An-Najah National University, Nablus, Palestine
Email: *m.ishtaiwi@najah.edu, *m.hajjyahya@najah.edu, shahdhabbash118@gmail.com

How to cite this paper: Ishtaiwi, M., Hajjyahya, M. and Habbash, S. (2021) Electrical Properties of Dead Sea Water. *Journal of Applied Mathematics and Physics*, **9**, 3094-3101.
https://doi.org/10.4236/jamp.2021.912201

Received: November 13, 2021
Accepted: December 19, 2021
Published: December 22, 2021

Abstract

In this paper, dielectric measurements were carried out to obtain conductivity, permittivity (real and imaginary parts) and loss tangent of Dead Sea water. These dielectric properties were measured using two different methods: Vector Network Analyzer "VNA" (Dielectric Assessment Kit "DAK") and Four Probe method, all measurements taken at room temperature (25˚C). The collected data has been analyzed in the frequency range (200 MHz - 9 GHz), by making a comparison between the measured data for Dead Sea water and distilled water, the results have shown that a huge difference in dielectric properties for the two samples. The conductivity of Dead Sea water is much larger than the conductivity of distilled water, which has been expected because of the fact of the high salinity of Dead Sea water.

Keywords

Permittivity, Conductivity, Salinity, Dead Sea, Vector Network Analyzer (VNA)

1. Introduction

The Dead Sea is a landlocked hypersaline lake located in the deepest part of the Dead Sea Jordan Rift Valley. About 80 km long and 13 km wide, its water level, currently at −407 m below mean sea level, makes it the lowermost surface on the face of the earth [1]. The soaring hot and dry conditions of this region mean that large quantities of water are evaporated. This leads to the salt and other minerals becoming more and more concentrated. The water of the Dead Sea is characterized by very high salinity; it has 345 grams of mineral per liter (34.5% or 34.5 g/100 mL). This salt concentration is about 7 to 10 times that of the oceans [2]. The composition of minerals in the Dead Sea is particularly renowned for its healing and anti-aging effects on the skin. This is not merely a beauty fad. Through the years, modern medicine and science have clinically proven the skin benefits of Dead Sea elements. In fact, many dermatological patients from all over the world are sent to the Dead Sea by their treating doctors. The secret of the Dead Sea effect is in the naturally pure, intensive and powerful minerals absorbed by the skin every time it comes into contact with Dead Sea mud, water and salts [3]. The great benefits of Dead Sea water, which were caused by the high salinity rate, have made it interesting for us to study its dielectric properties. The concentration of salts in water affects its microwave dielectric properties, which can be seen by comparing these properties with that of distilled water at various frequencies. It has been observed by [4]; that over the frequency range (200 MHz - 1.4 GHz), the dielectric constant of pure water remains constant, whereas that of saline water decreases slowly with increase in frequency. It is also observed that the dielectric loss of pure water increases with increase in frequency whereas in the case of saline water it is found to decrease with increase in frequency. A previous study showed that at frequencies between 3 and 10 GHz, there is a significant difference between the permittivity's of natural seawater and an aqueous NaCl solution of the same salinity and, on the other hand, there is no significant difference between the permittivity's of natural and synthetic seawater for frequencies greater than 3 GHz [5]. A comparison between theoretical models which describe the concentrations dependence of the conductivity of electrolyte solution and experimental results shows a good agreement between them [6]. According to the mentioned studies, we expect to get a similar behavior for the dielectric properties of Dead Sea water with that for high salinity water in the low-frequency range.

This work is a step towards this goal. Therefore, we study the dielectric properties (conductivity, permittivity—real and imaginary parts and loss tangent) of Dead Sea water at 25˚C by using two different methods: Vector Network Analyzer (200 MHz - 9 GHz) and Four Probe Method. We also make a comparison with the dielectric properties of Distilled water to make a clear picture of the unique properties of seawater from distilled water.

2. Methodology

The experimental measurements of the Dead Sea water samples have been obtained, water samples from the Dead Sea surface have been collected on September 17, 2021 and then have been analyzed in Material Research Lab at An-Najah National University. The sample density has been measured to be 1.2254 g/cm^3.

2.1. Vector Network Analyzer (VNA)

The objectives of this research are to study the electrical properties of Dead Sea water. The permittivity and conductivity results have been measured as a function of frequency by using a Vector Network Analyzer (VNA). The VNA works in a wide range of frequency (200 MHz - 14 GHz). However, in this research work, the analysis of the samples was in the frequency range (200 MHz - 9 GHz), with typical selections of 200 points.

SPEAG's Dielectric Assessment Kit (DAK) product line offers high-precision dielectric parameter measurements (permittivity, conductivity, loss tangent) over the very broad frequency range (4 MHz - 67 GHz) for various applications in the electronic, chemical, food, and medical industries. The probe is connected to a VNA for measurement of the complex reflection coefficient (S_{11}) at the probe end. The measured S_{11} is then converted into the complex permittivity of the material under test using the DAK software [7]. A personal computer has been connected to receive the pairs of data (conductivity, real and imaginary parts of permittivity and loss tangent) for the given frequency range as shown in **Figure 1**. Precise measurements are dependent on precise calibration of the setup. The calibration is sensitive to cable movement and temperature (it must be stabilized for the sample and ambient before start measurements). The sample must be homogeneous, isotropic and free of impurities that could affect the dielectric measurements. In addition, the good electrical contact between the sample and the probe means removing bubbles from the solution. Also, the sample volume must be sufficient to ensure that reflected signals at the boundaries of the sample are kept low so as to not significantly influence the measurements.

It, therefore, seems that laboratory measurements of the conductivity and permittivity are necessary in order that the effect of Dead Sea water on the propagation of waves may be accurately determined over the whole range of frequencies in practical use.

2.2. Four Probe Method

The experimental setup consists of probe arrangement; sample (Dead Sea water and Distilled water), power supply, digital voltmeter and ammeter.

Four probe apparatus is one of the standards and most widely used apparatus for the measurement of resistivity of semiconductors and can be used for other samples. This method is employed when the sample is in the form of a thin wafer. The sample is a millimeter in size and has a thickness (w) [8]. It consists of four probes arranged linearly in a straight line at equal distance s; (s = 2 mm)

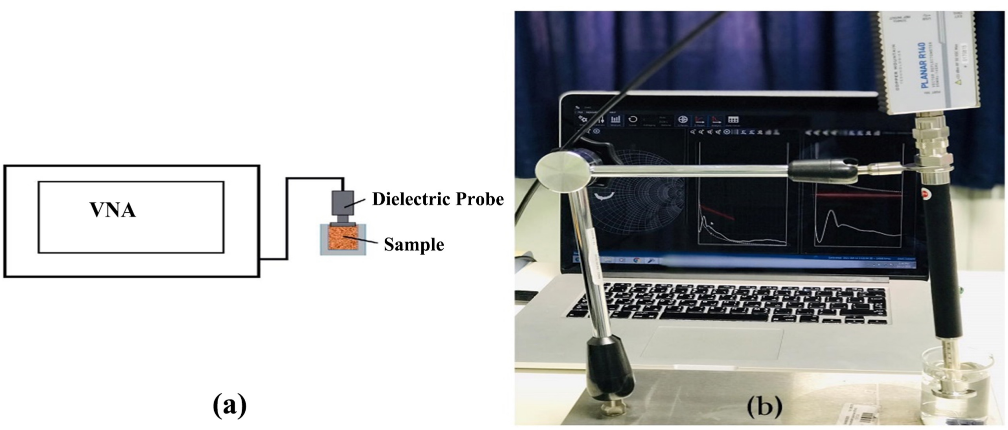


Figure 1. (a) Schematic diagram of VNA (b) Sample measurement set-up consisting of a vector network analyzer (VNA) and coaxial line dielectric probe (DAK-12 Probe) inserted into the sample.

from each other. A given current is passed through the two probes and the potential drop (V) across the middle two probes is measured for each value of the current as shown in Figure 2.

3. Results and Discussion

3.1. The Conductivity Data for Dead Sea Water and Distilled Water

3.1.1. Vector Network Analyzer Method Calculations

The conductivity is a measure of the ability of a certain material to conduct electrical currents. The conductivity of Seawater is a function of frequency, temperature and salinity. We denote it as $\sigma(f, t, s)$, [5]. For the two samples (Dead Sea water and Distilled water) under investigation, we have a constant salinity and temperature. The total dissolved solids (TDS), which we indicate as the salinity of the collected dead seawater is computed in the Chemistry Department at An-Najah National University. "TDS refers to any salts, minerals, metals, cations, or anions dissolved in a soil saturation extract, composed primarily of inorganic salts consisting of the major cations (*i.e.*, Na^+, K^+, Ca^{2+} and Mg^{2+}), major anions (*i.e.*, Cl^-, NO_3^-, HCO_3^-, CO_3^{2-}, and SO_4^{2-}), and small amounts of organic matter that are dissolved in water [9], and its value is 60.1 g/L. Our intention is to study the behavior of the electrical conductivity through frequency range (200 MHz - 9 GHz).

Figure 3 shows that for Dead Sea water, the significant increase in conductivity occurs at frequencies less than 2 GHz and then completes the increase slightly. On the other hand, the conductivity increases linearly in the whole frequency range for Distilled water. For both (Dead Sea water and Distilled water) reach close values of conductivity as the frequency increases.

3.1.2. Four-Probe Method Calculations

The Conductivity is calculated from the values of voltage (mV) and current (mA) which pass through the four probes which are equally spaced with distance, s =2 mm. The thickness w of the two samples is 2 mm. Using Equation (1) for resistivity ρ (Ω·m) then taking the reciprocal for conductivity σ (S/m)

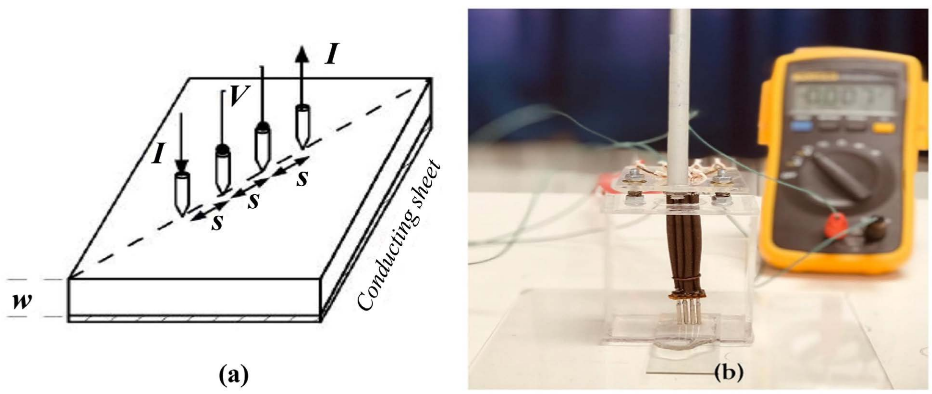


Figure 2. (a) Schematic diagram (b) measurements set-up of four probe method.

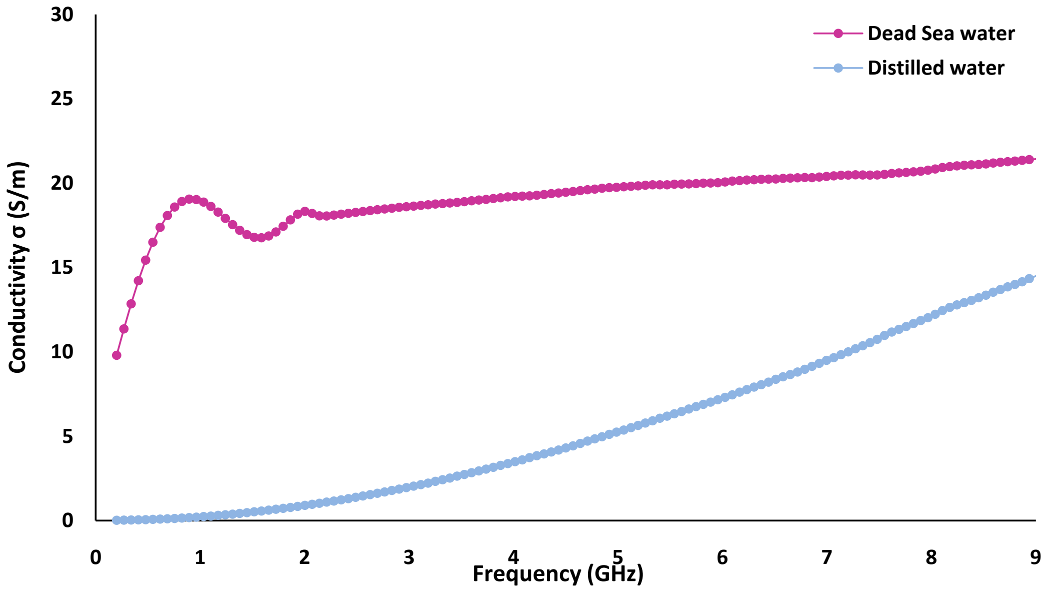


Figure 3. Measured conductivity for Dead Sea water and distilled water at temperature 25˚C, in the range of 200 MHz - 9 GHz.

$$\rho = \left(\frac{V}{I}\right) w\pi \Bigg/ \ln\left(\frac{\sinh\left(\frac{w}{s}\right)}{\sinh\left(w/2s\right)}\right) \tag{1}$$

The measured data for currents and voltages are tabulated in Table 1. It is clear that the conductivity of Dead Sea water is 3 - 4 order of magnitude larger than that for distilled water.

3.2. The Permittivity Data for Dead Sea Water and Distilled Water

Permittivity is a quantity used to describe dielectric properties that influence reflection of electromagnetic waves at interfaces and the attenuation of wave energy within materials. In frequency domain, the complex relative permittivity ε^* of a material to that of free space can be expressed in the following form of Equation (2):

$$\varepsilon^* = \varepsilon' + i\varepsilon'' \tag{2}$$

The real part ε' is referred to as the dielectric constant and represents stored energy when the material is exposed to an electric field, while the dielectric loss factor ε'', which is the imaginary part, influences energy absorption and attenuation, and $i = \sqrt{-1}$.

By using VNA, we have measured the values of ε' and ε'' in the range of 200 MHz - 9 GHz. All measurements are taken at a temperature of 25˚C.

It has been observed, that the dielectric constant ε' has larger values in distilled water than Dead Sea water in the whole range of frequencies. It is also clear that the dielectric constant is a decreasing function of frequency. In the low-frequency range (below 2 GHz) the values for Dead Sea water are decreasing dramatically, while distilled water is slightly changed (approximately constant), as shown in Figure 4(a).

It has been observed, that the imaginary part of permittivity ε'' decreases exponentially for the Dead Sea water and starts from a very high value which is approximately 1000. While its value for the distilled water is very small and goes to zero in the whole range of frequency, as shown in Figure 4(b).

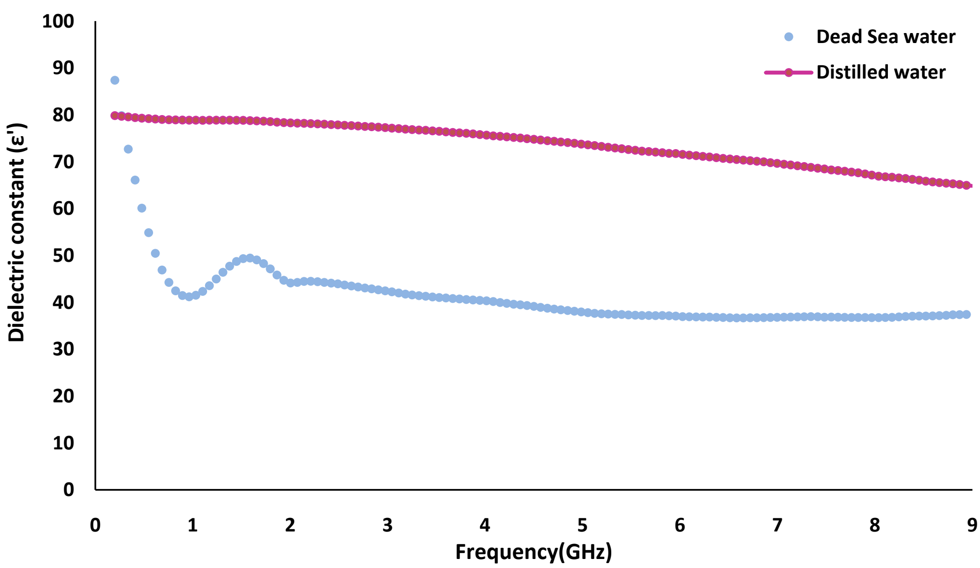
3.3. The loss factor Data for Dead Sea Water and Distilled Water

The electric loss tangent of a material is defined in Equation (3):

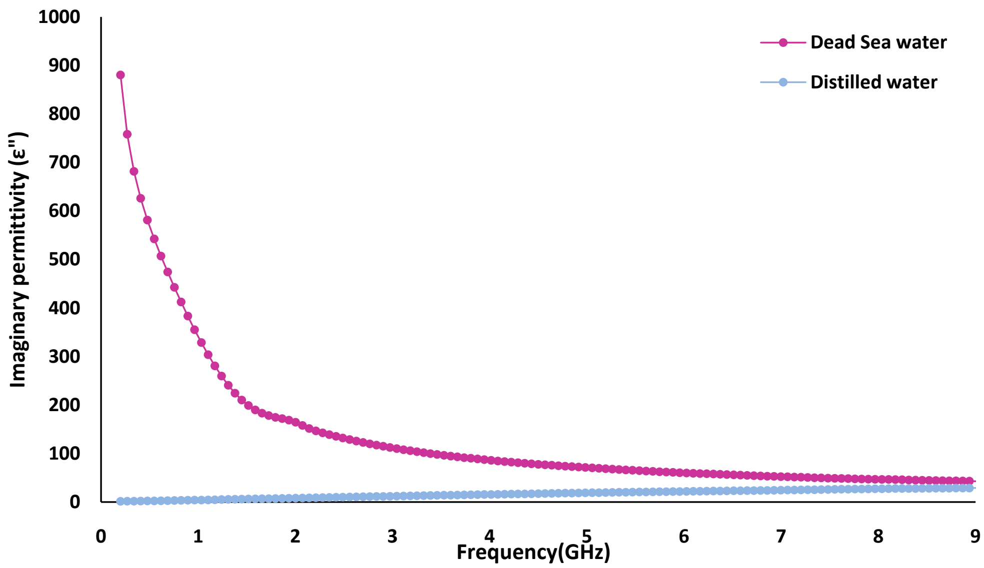
$$\tan(\delta) = \varepsilon''/\varepsilon' \tag{3}$$

Table 1. Voltage and current measurements for Dead Sea water and distilled water.

Type of Sample			
Dead Sea Water		Distilled Water	
Voltage (mV)	Current (mA)	Voltage (mV)	Current (mA)
43	0.05	30	1.68
66	0.52	70	2.85
80	1.38	110	4.07
101	2.92	160	5.30
116	3.65	230	6.88
168	4.84	320	8.34
222	5.80	410	9.61
340	10.7	530	11.53
Conductivity (S/m)			
4.608		0.0067	



(a)



(b)

Figure 4. (a) Measured real part of complex permittivity ε' for Dead Sea water and Distilled water, at temperature 25˚C in the range of 200 MHz - 9 GHz. (b) Measured imaginary part of complex permittivity ε'' for Dead Sea water and Distilled water, at temperature 25˚C in the range of 200 MHz - 9 GHz.

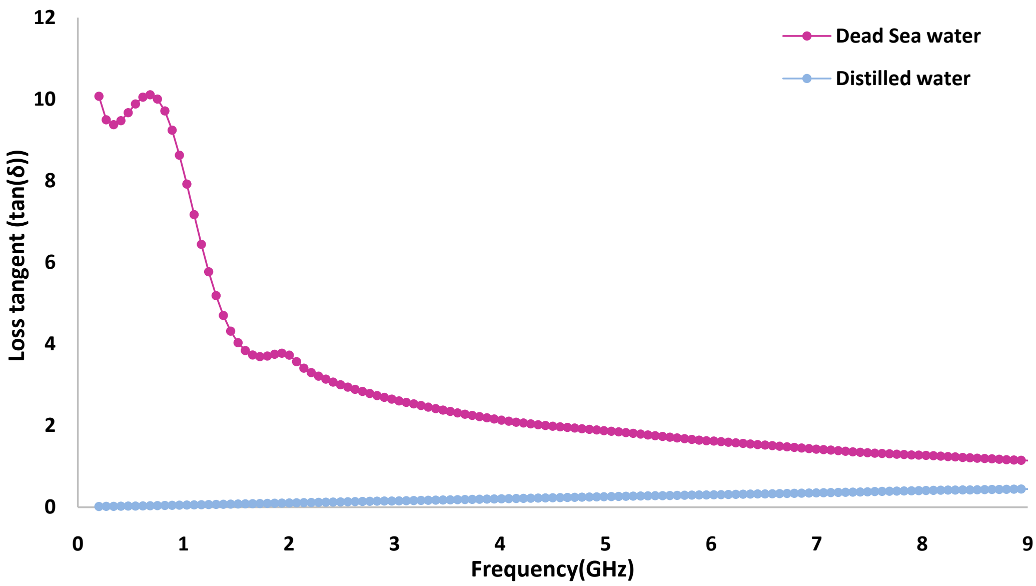


Figure 5. Dielectric loss tangent tan(δ) for Dead Sea water and distilled water, at temperature of 25˚C in the range of 200 MHz - 9 GHz.

The greater the loss tangent of the material, the greater the attenuation as the wave travels through the material. It is related to the capability of the material for absorbing energy from the electric field [10].

Figure 5 shows that for the Dead Sea water, the dielectric loss tangent has an exponentially decreasing tendency with an increase in frequency. While it increases slightly for distilled water as the frequency increases.

4. Conclusion

In this work, we conclude that the conductivity of Dead Sea water is much larger than the conductivity of distilled water over the frequency range (200 MHz - 9 GHz), according to two different used methods (VNA and Four Probe). The large difference between them is caused by the high concentration of salts in the Dead Sea water (high salinity). This is expected by the fact of the direct proportionality between the number of free ions, which is large in the high salinity medium and the electrical conductivity of that medium. So Dead Sea water can be used efficiently in low-frequency applications that need a high dielectric conductive medium. In future work, an advanced design of electrical capacitor with high capacitance using the Dead Sea water as a dielectric material.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Nissenbaum, A. (1993) The Dead Sea—An Economic Resource for 10 000 Years. *Hydrobiologia*, **267**, 127-141. https://doi.org/10.1007/BF00018795

[2] Katz, U., Shoenfeld, Y., Zakin, V., Sherer, Y. and Sukenik, S. (2012) Scientific Evidence of the Therapeutic Effects of Dead Sea Treatments: A Systematic Review. *Seminars in Arthritis and Rheumatism*, **42**, 186-200. https://doi.org/10.1016/j.semarthrit.2012.02.006

[3] Baumann, L.S. (2009) Dead Sea Minerals. *Skin & Allergy News*, **40**, 27. https://www.researchgate.net/publication/244860928_Dead_Sea_Minerals

[4] Gadani, D.H., Rana, V.A., Bhatnagar, S.P., Prajapati, A.N. and Vyas, A.D. (2012) Effect of Salinity on the Dielectric Properties of Water. *Indian Journal of Pure and Applied Physics*, **50**, 405-410.

[5] Ellison, W., Balana, A., Delbos, G., Lamkaouchi, K., Eymard, L., Guillou, C. and Prigent, C. (1998) New Permittivity Measurements of Seawater. *Radio Science*, **33**, 639-648. https://doi.org/10.1029/97RS02223

[6] Zhang, W.T., Chen, X., Wang, Y., Wu, L.Y. and Hu, Y.D. (2020) Experimental and Modeling of Conductivity for Electrolyte Solution Systems. *ACS Omega*, **5**, 22465-22474. https://doi.org/10.1021/acsomega.0c03013

[7] DAK—Dielectric Assessment Kit Product Line: Overview. https://speag.swiss/products/dak/overview/

[8] Smits, F.M. (1958) Measurement of Sheet Resistivities with the Four-Point Probe. *Bell System Technical Journal*, **34**, 711-718. https://doi.org/10.1002/j.1538-7305.1958.tb03883.x

[9] Corwin, D.L. and Yemoto, K. (2020) Salinity: Electrical Conductivity and Total Dissolved Solids. *Soil Science Society of America Journal*, **84**, 1442-1461. https://doi.org/10.1002/saj2.20154

[10] Kotsuka, Y. (2019) Electromagnetic Wave Absorbers: Detailed Theories and Applications. John Wiley & Sons, Inc., New York. https://doi.org/10.1002/9781119564430