[1] Imadeldin Elsayed

[2] Mohamad Shaiful

[3] Izzeldin Ibrahim

[4] Khalid Bilal

[5] Mohamed Hassan

A Revised Model of Salinity Surface Reflection Coefficient at A range of Frequencies

Journal of Electrical Systems

Abstract: **-** The frequency of the incident signal wave can affect how salinity influences the seawater's reflection coefficient. The impact of salinity on the electromagnetic characteristics of seawater is generally more pronounced at multiple frequencies. This paper investigates a wide range of frequencies such as 100 MHz up to 1 THz under the 30 ppt salinity level, angle is 30-degree, distance traveled up to 100 meter, and sweater dielectric 81 to offer distinct attention that should respect each salinity value individually when designing the wireless coastal connection. Due to an undeniable disagreement among scholars regarding the relationship between salinity and frequency, the study provides a method to predict the reflection coefficient in different ranges of frequencies using derivation equations. Nevertheless, the distinct outcomes show under the 30 ppt salinity the reflection coefficient hit 0.015 dB at frequencies from 100 MHz up to 500 MHz and then growing up to reach 0.03 dB at 1 GHz, whereas under the same salinity level and from 100 GHz to 500 GHz achieved 0.2 up to 0.4 dB, and increase to hit 0.9 dB at 1 THz. The significance of the result would open the way to accommodate the salinity levels under the specific frequency and hence the accuracy of the link budget. Overall, the fluctuation in coastal link parameters such as frequency, power transmitted, and salinity level produces peculiar signal behavior that should be estimated in the coastline budget.

Keywords: Reflection coefficient; Salinity; Marine communications; Electric properties

I. INTRODUCTION

Wireless communication has witnessed immense growth in the past decades, thus giving a paramount role to telecommunications companies for implementing designs and planning in different environments, particularly across seawater that covers more than 70% of the Earth [1][2]. In this information era, high data rates are inevitable in modernization, where signal behavior contributes to the revolutionizing digitalization. To assess the wavelength phenomenon electromagnetically in an open water environment that covers about two-thirds of the Earth, saltwater is the perfect candidate [2].

Seawater has a relatively high salinity compared to fresh water. The average salinity of seawater is around 35 parts per thousand (ppt), although the salinity can vary depending on the environment, activities, and seasons [3].

From the signal behavior point of view, Signal reflection is the process of a signal bouncing back when it encounters an obstacle or barrier [5]. When an electromagnetic signal, like a radio or light wave, encounters a reflecting surface or interface, reflection occurs. A signal's reflection can be influenced by a number of factors, the type of surface or interface that the signal interacts with is one of the most crucial variables, while the frequency of the signal and the angle at which it reaches the surface affect the reflectance qualities of various materials. In addition, the impedance of the surface is a significant factor that can affect how a signal is reflected, it measures the resistance of a surface or medium present to an electromagnetic signal's transmission [5][6]. Signal reflects back to the source when the interface's impedance differs from the medium it travels through [7].

Signal reflection can significantly impact signal transmission and reception in various communication systems. In order to ensure that messages are transmitted and received reliably in the upcoming technology revolution era that need insatiable data rate demand, signal reflection must frequently be taken into consideration from various mediums such as building, foliage and assessing communication systems. Whereas at the seawater, dielectric constant elements such as salinity, and signal frequency affect how electromagnetic waves are reflected from sea surface, due to salty water is considered a conductor of electricity, the reflection of electromagnetic signals from it remarkably with absorption in some cases [8][9].

[1] *Imadeldin Elsayed Elmutasim: University Malaysia Pahang UMP

2 Mohamad Shaiful/ University Malaysia Pahang UMP

3 Izzeldin Ibrahim / University of Suhar, Oman

4Khalid Bilal / University of Science and Technology, Sudan

5 Mohamed Hassan / Lovely Professional University, India

Simply said, as the salinity of the seawater affects its electrical conductivity, notably an impact would be accommodating on how an electromagnetic signal reflects off of it and offer clear correlation that reflection of an electromagnetic signal increases with seawater salinity. However, it's crucial to keep in mind that there are other elements that can alter how electromagnetic signals travel through water in addition to seawater's ability to reflect some of them. The propagation of electromagnetic signals can also be influenced by other variables, such as seawater temperature and density [10]–[12].

Accurate propagation should be determined for each specific environment to tackle various parameters, including path loss and fading, which affect the coverage area and improve receiver sensitivity, respectively. Despite the unique ecosystems and varying salinity levels in regions like the Gulf area, Red Sea, and Dead Sea, previous studies have not thoroughly explored the gradient of seawater salinity, especially in wireless models [13][14]. This scenario is ideal for investigating and modeling signal behavior as it reflects diffusely from seawater in multiple directions. However, when look to comparing the strength of the reflected signal with the incident signal, the reflection of an electromagnetic signal may be expressed as a ratio or as a percentage. This ratio, which can also be written in decibels (dB), is known as the reflection coefficient [15]. According to this definition, the reflection coefficient is a logarithmic ratio, typically measured in decibels (dB). For instance, would be -6 dB if it were 0.5 (or 50%). In some cases, it may also be expressed as a phase angle which represents the phase shift between the incident and reflected signals and typically measured in degrees or radians. Addition to earlier, the intensity of the reflected signal depends on the signal type and measurement, with the unit varying accordingly.

For example, watts per square meter (W/m2) may be used to measure the strength of a reflected radio frequency (RF) signal [16][17]. Nevertheless, important to keep in mind that the measure and methods for regulating the reflection of an electromagnetic signal will vary depending on the particular application and the signal's properties. Our study aims to analyze electromagnetic wave reflection by modeling the saline seawater surface at various frequencies to prepare for the upcoming technological revolution with high data rate demands. While the contributions of this study are summarized as follows:

- Salinity's impact on wireless link budget in challenging environments.
- Differentiating outcomes based on similar salinity levels at different frequencies.
- The model demonstrates how to differentiate between frequencies at similar salinity degree would lead to distinct outcomes.
- Distinguishing regions based on varying salinity levels.
- Assessing the impact of frequency on wireless link design and electromagnetic signal behavior.

II. RELATED WORK

Several studies have explored electromagnetic signal reflection in seawater. For example, [18] developed UWB antenna was utilized to sensor salt saltwater samples and perform quality tests utilizing the antenna's return loss characteristics when immersed in the water sample, and the research findings were in good agreement with the simulated results. In [19] focused on analyzing radar cross-section and scattering characteristics at high grazing angles to understand their variations with different wind speeds and wave heights. Also [20] analyzed the reflection of electromagnetic waves from the sea surface at low grazing angles, with a focus on understanding how the reflection varies with the frequency and polarization of the incident wave. Moreover, the author at [21] developed a model for predicting the reflection of electromagnetic waves from the sea surface using the small perturbation method, and tested the model using measurements taken in the coastal waters.

Continuously, salinity influence was analyzed at [22] on the reflection of electromagnetic waves from the sea surface, with a focus on understanding how the reflection varies with the salinity, frequency, and polarization of the incident wave. Another study discussed the correlation between the salinity of seawater and its reflection coefficient at microwave frequencies in [23]. The authors measured the reflection coefficient of seawater samples with varying salinity levels and found the relation between the reflection coefficient, salinity, and dielectric constant. They also achieved the correlation between the reflection coefficient and salinity was frequency dependent. Crucial study has been conducted of the microwave reflection coefficient of seawater at L-band using Debye model in [24] for predicting the reflection coefficient of seawater at (1-2 GHz) frequencies based on the physical properties of the water such as temperature, salinity, and pressure. The authors validated the model using measurement data and found good agreement between the predicted and measured reflection coefficients.

Additionally, another remarkable outcome has been obtained in [25] which measured the reflection coefficient of seawater samples with different salinity levels and found that the reflection coefficient decreased with increasing salinity. They also found that the relationship between the reflection coefficient and salinity based on the frequency used and the effect of salinity on the reflection coefficient was more pronounced at lower frequencies. Nevertheless, the author at [26] investigated the effect of salinity on the microwave backscattering coefficient of seawater and sea ice and the result obtained the coefficient increased with increasing salinity. They also agree with [27] via found that the relationship between the backscattering coefficient and salinity was frequency dependent. In the same context, the reflection coefficient had been estimated using a range of bands including Ku-band (12-18 GHz) frequencies based on the physical properties of the water such as temperature, salinity, and pressure in [28]. Another paper [29] demonstrated low-loss propagating electromagnetic wave between two lossy conductive mediums and offer the results that according to surface wave type might be steered by a seafloor-seawater interface and utilized for underwater radio transmission and imaging.

The study validated the model using measurement data and found positive agreement between the predicted and measured reflection coefficients. Accordingly, the [30] has been demonstrated the relationship between the salinity of seawater and active radar cross section using microstrip antennas, the measurement tool had taken seawater samples with varying salinity levels and found that the scattering coefficient increased with increasing salinity. They also found that the relationship between the backscattering coefficient and salinity was frequency-based on.

The two types of reflection Diffuse and specular need to underpin in various communication systems, and should be accommodated through different techniques to offer a flawless system that would reflect on the entire performance and service quality [31]. Transitioning to our next focal point, the mode paves the way to think about several strategies to manage how an electromagnetic signal reflects off of a surface when estimating accurately allowing us to accommodate the phenomenal in wireless link design.

III. MODEL APPROACH

In this study we proposed Imad-Shaiful model (Ima-Sha) to analysis the salinity surface refection coefficient and produce an accurate outcome that could serve a wide range of wireless coast link designers as well as maritime communication through gives a full respect to the seawater salinity levels. The megahertz followed by gigahertz frequencies until 1 THz have been applied on a selective salinity level which is 30 ppt seawater salinity, an incident angle of 30. The model has been simulated using the MATLAB program and could expanded to changeable salinity levels which would show remarkable findings.

The model calculates the reflection coefficient in specific coastline parameters and the results obtained that according to the distinct frequencies under salinity seawater surface level would lead to different outputs. For example, under the same circumstances, the 10 MHz offers a different finding from the 1GHz, 500GHz, and 1 THz and offers attention that each frequency should be fully respected from the seawater specifications perspective

The significant parameters when considering seawater are conductivity, salinity, and permittivity. The first two parameters (conductivity and salinity) can be determined using equation (1) based on the ITU standard to consider the approach working at present in the telecommunication domain, while the third parameter (permittivity) describes the dielectric properties that influence electromagnetic waves. Hence, the model begins by identifying the link between conductivity and salinity, as expressed in the following:

$$\sigma = i\,\phi \tag{1}$$

Where i is correlation coefficient, σ is the conductivity in seawater and ϕ is the salinity level. Hence;

$$i = \sigma/\phi \tag{2}$$

The standard values in ITU for seawater are $\sigma = 4$ and $\phi = 35\ ppt$, thus:

$$i = 0.114 \tag{3}$$

$$\sigma = 0.1142\,\phi \tag{4}$$

Whereas when the wave strikes a conducting medium, such as salt saltwater, part of it is reflected back while the other goes into the medium, which is referred to as the depth of penetration. Hence, during that a strong correlation between the Depth penetration that is reduces the phase angle with the increasing distance.

$$\delta = 1/\beta \tag{5}$$

In a good conductor medium $\beta = \sqrt{\frac{\omega\mu\sigma}{2}}$

Then

$$\delta = 1/\sqrt{\frac{\omega\mu\sigma}{2}} = \sqrt{\frac{2}{\omega\mu\sigma}} \tag{6}$$

$$= 1/\sqrt{\pi f \mu\sigma} \tag{7}$$

Where f frequency, μ permeability, σ conductivity, and β is phase factor.

Considering the physics of wave reflection, which depicts the distance traveled by the wave from the incident medium to the reflecting barrier and then reflects back to ensure proper decay.

$$R = e^{-2d/\delta} \tag{8}$$

Where R reflection coefficient, d is distance, and δ penetration depth

Substituting

$$R = e^{-2d\sqrt{\pi f \mu \sigma}/\varepsilon_r \cos(\theta)} \tag{9}$$

Where ε_r is dielectric constant of the salt seawater which is 81 [21] and $\cos(\theta)$ is the reflected angle.

The model considered wide range of frequencies that cover maritime radar uses VHF, S-band, X-band, until beyond E band.

IV. RESULTS AND DISCUSSION

The results of our model show phenomenal that the reflection coefficient in seawater is strongly dependent on the signal frequency, and salinity level in the water, and that agreed with other review studies.

The study found at the first frequency group at the 100 MHz up to 500 MHz the reflection factor reached to 0.015 dB and then move up until reach to 0.03 at 1 GHz as shown in fig. 1. However, at another frequency group which is from 100 GHz to 500 GHz the reflection factor hit 0.2 up to 0.4 dB at continues raise to get 0.9 dB at 1 THz as shown in fig. 2.

Generally, the salinity could impact the reflection coefficient with respect to the frequency which could also appear that some part of the signal could absorb. This is consistent with previous studies that have shown a similar trend for reflection coefficients with care of salinity level, frequency, and medium dielectric constant.

These results have important implications for marine communication systems, which rely on the efficient transmission of signals through seawater. By understanding the factors that affect reflection coefficients in seawater, we can design more effective communication systems that take into account the properties of the medium through which they are operating.

The next figures explicit the notion reflection coefficient in dB at the frequencies mentioned. Figure 1 demonstrated the 30 ppt salinity degree analysis under a range of frequencies in 100 meter distance from 100 MHz up to 1 GHz proves the result.

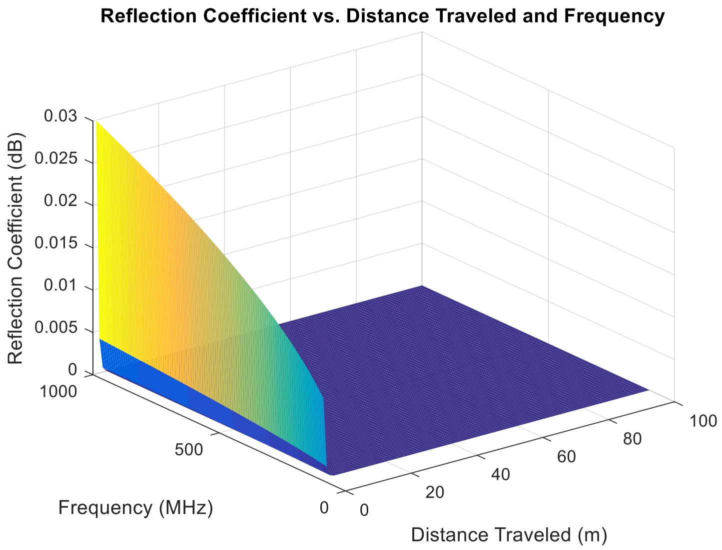

Figure 1. Reflection coefficient at 30 ppt salinity level from 100 MHz to 1 GHz

While at the upcoming fig. 2 shows the reflection coefficient in dB using the 30 ppt salinity level at frequencies from 100 GHz up to 1 THz with the same distance.

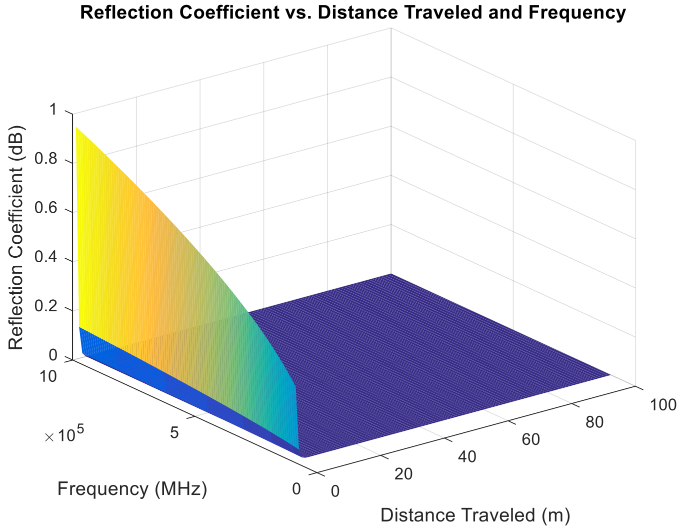

Figure 2 . Reflection coefficient at 30 ppt salinity level from 100 GHz to 1 THz

V. MODEL VALIDATION

Model validation is a crucial step in the development and assessment of the study. However, a low-cost measurement system to check the salinity has been developed in [32] based on electromagnetic reflection using salinity levels up to 25%. The same parameters, such as salinity and frequencies, have been calculated for validation to obtain the reflection coefficient and shown in Fig. 3.

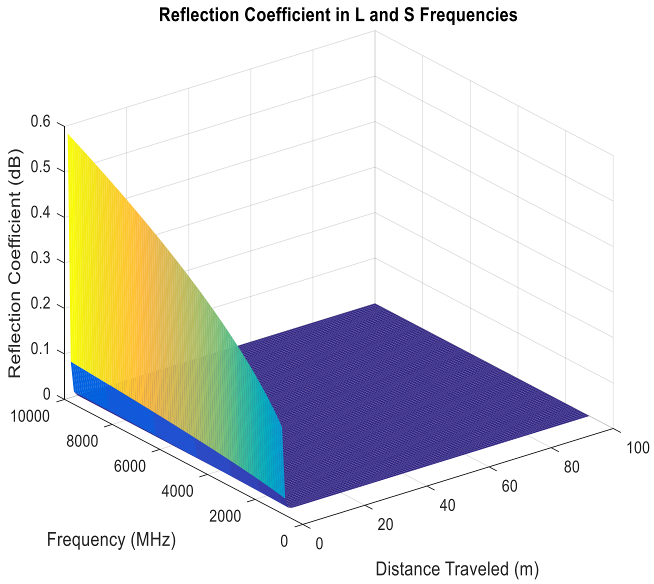

Figure 3 . Reflection coefficient at 25 ppt salinity level from 1 to 10 GHz

While the benchmarking explicit a remarkable agreement between models through regression line analysis. Table 1 followed by Figure 4 demonstrated the two model comparisons.

Table 1. Reflection Coefficient Models Comparison

Frequency GHz	Reflection Coefficient in low-cost measurement Salinity Model	Reflection Coefficient in Our Model
1.4	0.28	0.246
1.7	0.30	0.287
2.6	0.27	0.271
2.8	0.25	0.276

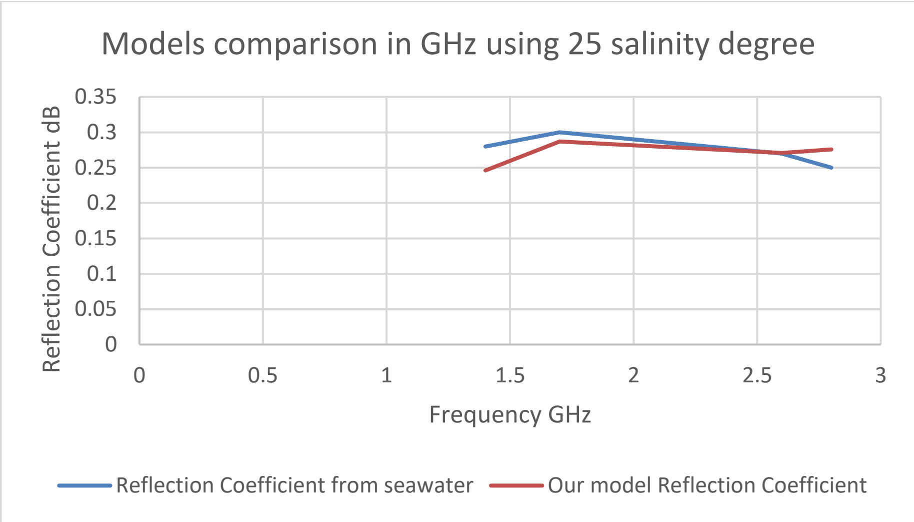

Figure 4. Comparison between low-cost measurement salinity model and our model.

VI. CONCLUSION

Seawater electric properties are crucial as they hold the water composition characterization chemically that could accommodate electromagnetically, while salinity is a significant contributor to water quality concerns across the globe. However, certain seawater conditions can be beneficial for service providers when other materials are unavailable. The work considers reflection coefficient in various frequencies from 100 MHz until 1 THz under the 30 ppt salinity to offer a robust predication result when think about wireless coast line communications and ensure the signal behaviour in marine environment that can provide proper data rate demanded in the technology revolution era. The result showed that Im-Iz model would offer distinct outcomes under the 30 ppt salinity when the reflection coefficient hit 0.015 dB at frequencies from 100 MHz up to 500 MHz and then growing up to reach 0.03 dB at 1 GHz, whereas from 100 GHz to 500 GHz achieved 0.2 up to 0.4 dB, and increase to hit 0.9 dB at 1 THz under the same salinity level. The comparison with low-cost measurement salinity model has been done and the validation demonstrated a notable agreement between two models. The future work will investigate the seawater dielectric constant contribution in Intelligent Reflection Surface IRS.

ACKNOWLEDGMENT

We gratefully acknowledge the University of Suhar in Oman for their support and resources that facilitated the completion of this research. We thank University Malaysia Pahang for providing valuable resources during the study writing. Special thanks to Dr. Mohamed Shaiful and Dr. Izzeldin Mohamed for their insightful guidance and feedback. We are indebted to the participants who generously volunteered their time and expertise for this research.

REFERENCES

[1] L. Cao et al., “Review Article Nutrient Detection Sensors in Seawater Based on ISI Web of Science Database,” 2022, doi: 10.1155/2022/5754751.

[2] Soteris A. Kalogirou, "Seawater desalination using renewable energy sources", Progress in Energy and Combustion Science, Volume 31, Issue 3, 2005, Pages 242-281, ISSN 0360-1285, https://doi.org/10.1016/j.pecs.2005.03.001.

[3] S. Kim, S. Y. Chun, D. H. Lee, K. S. Lee, and K. S. Nam, “Mineral-enriched deep-sea water inhibits the metastatic potential of human breast cancer cell lines,” Int J Oncol, vol. 43, no. 5, pp. 1691–1700, Nov. 2013, doi: 10.3892/IJO.2013.2089.

[4] C. W. Hou et al., “Deep Ocean mineral water accelerates recovery from physical fatigue,” J Int Soc Sports Nutr, vol. 10, Feb. 2013, doi: 10.1186/1550-2783-10-7.

[5] T. Wu, J. Chen, and P. F. Wu, “Multi-Mode High-Gain Antenna Array Loaded with High Impedance Surface,” IEEE Access, vol. 8, 2020, doi: 10.1109/ACCESS.2020.3015758.

[6] Y. I. Ashyap et al., “Fully Fabric High Impedance Surface-Enabled Antenna for Wearable Medical Applications,” IEEE Access, vol. 9, 2021, doi: 10.1109/ACCESS.2021.3049491.

[7] P. K. Panda and D. Ghosh, “Wideband and high gain tuning fork shaped monopole antenna using high impedance surface,” undefined, vol. 111, Nov. 2019, doi: 10.1016/J.AEUE.2019.152920.

[8] N. Sakai, K. Noguchi, and K. Itoh, “A 5.8-GHz Band Highly Efficient 1-W Rectenna with Short-Stub-Connected High-Impedance Dipole Antenna,” IEEE Trans Microw Theory Tech, vol. 69, no. 7, 2021, doi: 10.1109/TMTT.2021.3074592.
[9] T. Jaroslav, Výborný & Anton, “Determinationt of Thermal Conductivity,” in Chapter 16 . Determination of Thermal Conductivity, 2012.
[10] S. Constable, “Conductivity, Ocean Floor Measurements,” Encyclopedia of Geomagnetism and Paleomagnetism, pp. 71–73, Jul. 2007, doi: 10.1007/978-1-4020-4423-6_30.
[11] Yang and J. G. Peng, “A study on the effect of water conductivity in the underwater active electrolocation,” 2013 IEEE International Conference on Applied Superconductivity and Electromagnetic Devices, ASEMD 2013, pp. 34–37, 2013, doi: 10.1109/ASEMD.2013.6780702.
[12] Irrgang, J. Saynisch, and M. Thomas, “Impact of variable seawater conductivity on motional induction simulated with an ocean general circulation model,” Ocean Science, vol. 12, no. 1, 2016, doi: 10.5194/os-12-129-2016.
[13] Ash-Mor, A., et al. "Shelf inhabiting foraminifera as a tool for understanding late quaternary mass transport processes in the Northern Gulf of Eilat/Aqaba, Red Sea." Marine Geology 456 (2023): 106988.
[14] Raz, Eli. "The Future of the Dead Sea: is the Red Sea—Dead Sea Conduit the Right Solution?." The Jordan River and Dead Sea Basin. Springer Netherlands, 2009.
[15] Kannadhasan, S., and R. Nagarajan. "Design and development of T-Shaped antenna structure for wireless communication." Waves in Random and Complex Media (2022): 1-15.
[16] Q. Ding, “A mathematical model for reflection of electromagnetic wave,” in Journal of Physics: Conference Series, Jun. 2019, vol. 1213, no. 4. doi: 10.1088/1742-6596/1213/4/042077.
[17] G. Yu et al., “A Novel Phase Difference Measurement Method for Coriolis Mass Flowmeter Based on Correlation Theory,” 2022, doi: 10.3390/en15103710.
[18] Jeyagobi Logeswaran, and Rajasekar Boopathi Rani, "UWB Antenna as a Sensor for the Analysis of Dissolved Particles and Water Quality," Progress In Electromagnetics Research Letters, Vol. 106, 31-39, 2022. doi:10.2528/PIERL22062901
[19] Xia, Xiaoyun, et al. "RCS Measurement and Characteristic Analysis of a Sea Surface Small Target with a Shore-Based UHF-Band Radar." Electronics 11.16 (2022): 2573.
[20] Nilsson, Månz. "Radio-wave propagation modelling over rough sea surfaces and inhomogeneous atmosphere." (2021).
[21] Permyakov, Valery A., Mikhail S. Mikhailov, and Elena S. Malevich. "Analysis of propagation of electromagnetic waves in difficult conditions by the parabolic equation method." IEEE Transactions on Antennas and Propagation 67.4 (2019): 2167-2175.
[22] H. El-Sallabi, A. Albadr, and A. Aldosari, “UAV propagation channel characteristics in SHF band,” https://doi.org/10.1117/12.2518854, vol. 11021, pp. 108–115, May 2019, doi: 10.1117/12.2518854.
[23] Mathur, Parul, et al. "A novel non-invasive microwave technique for monitoring salinity in water." TENCON 2019-2019 IEEE Region 10 Conference (TENCON). IEEE, 2019.
[24] Zhou, Yiwen, et al. "Seawater debye model function at L-band and its impact on salinity retrieval from aquarius satellite data." IEEE Transactions on Geoscience and Remote Sensing 59.10 (2021): 8103-8116.
[25] Phan, Duy Tung, and Chang Won Jung. "Multilayered salt water with high optical transparency for EMI shielding applications." Scientific Reports 10.1 (2020): 21549.
[26] J. Roesler, Y. J. Morton, Y. Wang, and R. S. Nerem, “Coherent GNSS-Reflections Characterization Over Ocean and Sea Ice Based on Spire Global CubeSat Data,” IEEE Transactions on Geoscience and Remote Sensing, vol. 60, 2022, doi: 10.1109/TGRS.2021.3129999.
[27] N. Reul et al., “Sea surface salinity estimates from spaceborne L-band radiometers: An overview of the first decade of observation (2010–2019),” Remote Sens Environ, vol. 242, Jun. 2020, doi: 10.1016/j.rse.2020.111769.
[28] Kaya, Yunus. "Cheaper, Wide-Band, Ultra-Thin, and Multi-Purpose Single-Layer Metasurface Polarization Converter Design for C-, X-, and Ku-Band Applications." Symmetry 15.2 (2023): 442.
[29] Igor I. Smolyaninov, "Surface Electromagnetic Waves at Gradual Interfaces Between Lossy Media," Progress In Electromagnetics Research, Vol. 170, 177-186, 2021.doi:10.2528/PIER21043006
[30] S. Sengupta, H. Council, D. R. Jackson, and D. Onofrei, “Active Radar Cross Section Reduction of an Object Using Microstrip Antennas,” Radio Sci, vol. 55, no. 2, 2020, doi: 10.1029/2019RS006939.
[31] Ebihara, Akinori F., Kazuyuki Sakurai, and Hitoshi Imaoka. "Specular-and Diffuse-reflection-based Face Spoofing Detection for Mobile Devices." 2020 IEEE International Joint Conference on Biometrics (IJCB). IEEE, 2020.
[32] Meng, Cheng & AbdulMalek, MohamedFareq & Afendi, Mohd & Shing Fhan, Khor & Mohd Nasir, Nashrul & Tan, Wei & Md Noorpi, Nur & Mohd Mukhtar, Nurhakimah & Othman, Mohd Azlishah. (2014). Development of Low Cost Microwave Detection System for Salinity and Sugar Detection. International Journal of Mechanical and Mechatronics Engineering. 14.