Toward Extension of Undersea EM Field Propagation Distance

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ABSTRACT: The present paper shows that one could realize the effective power delivery to the sailing ships on the sea by shielding the power transferring electrodes properly. In addition, it is trying to clarify the origin of transmission loss of EM field in the seawater based on the general kQ theory. The theory can predict the wave transmission efficiency in the seawater directly from the measured S parameters, irrespective of non-propagating (near) field or propagating (far) field. Thus, it would predict that there could be some low loss frequency band in the seawater.

KEY WORDS: wireless power transfer, wireless communication, under sea, electrode shielding, movement of ions

1. INTRODUCTION

It has long been understood in human society that electromagnetic waves suffer great losses in seawater due to transmission losses caused by ionic currents, making wireless communications very difficult, and even today, the ITU Recommendation rigorously shows in its graph that the conductivity of seawater does not decrease with frequency, being proportional to its density in the water [1]. The authors ,nevertheless, questioned whether Na+ and Cl- ions, which have a much larger volume and weight than electrons, should gradually become unresponsive to higher frequencies. They have always felt that it is physically unnatural that the definition of the conduction current in Maxwell's equations uses the same expression for ionic currents [2]~[5] as for the conduction currents generated by electrons in solids

Recently, however, it has turned out that the ITU recommendation is not meant for the propagation of the electromagnetic waves inside the sea water, but for the wave transmission over the earth surface. It was clarified by asking directly ITU Japan Office. According to their answer, the sea is chosen only as one of the candidates that work as the reflecting medium. Considering the big permittivity of water compared with the air, the wave propagation is not affected too much from the loss factor of the sea water. Another point is that the recommendation is not backed by the experimental result but derived from the Debye model [2]. Now that we can forget about ITU recommendation as the evidence for the high transmission loss in the sea、we will switch the strategy to experimentally demonstrating the effectiveness of structures that may interfere with or suppress the ion current, based on the fact that many people have misunderstood the meaning of ITU recommendation.

The first trial is based on the simple principle of applying an insulator that covers the surface of metallic transmitting electrodes or wires and suppresses the conduction current by preventing the exchange of electrons that occurs there. This method has been used for some time to prevent electrode corrosion, but it has never been clearly taken as a method to suppress the conduction current. We would like, in addition, to optimize the electrical properties, shape, and dimensions of electrode covering materials with this very purpose in mind. As a first step toward this goal, we have already seen the possibility of obtaining higher efficiency from experimental results than from electromagnetic field simulation results [6], and we intend to show the results of gradual improvement of the characteristics in the future.

We then began, however, to think that the electrode covering might be effective only in the vicinity of the electrode. If the exchange of electrons at the electrode is forbidden by the covering, ions in the vicinity of the electrode will be unable to disappear from the water and will become overcrowded, making it difficult for them to move. But this effect seems to diminish as one moves away from the electrode. In other words, when the electromagnetic field is divided into a far field (propagating field) and near field (non-propagating field), the covering seems to be effective for the near field but not for the far field. In other words, the covering may be effective for power transmission over short distances, but may be ineffective for wireless communication over long distances.

Thus, considering what can be done to improve the latter efficiency of wireless communication in seawater, we have no choice but to return to our original physical insight that the higher the frequency, the less mobile the ions should be. As counterarguments, articles have already been reported [7]~[13] where several experiments in the MHz to GHz range have shown that the conductivity remains unchanged, maintaining the high values shown in Ref. 1. We have no choice but to search for flaws in those experimental methods, but we think it would be more efficient and constructive to show a decrease in conductivity by our own experiment, and have planned the following experiment. We will divide our research into the following two categories, depending on the purpose of the use of electromagnetic waves.

(1) Wireless power transfer - Comparison of experiments with and without electrode covering

(2) Wireless communication - Experiments using broader frequency waves in seawater. Search of radio window for maritime communication

2. TRANSMISSION BETWEEN TWO SQUARE ELECTRODES

2.1 Experiment

Figure 2.1 shows 2 square metal electrodes facing each other inside a rectangular water tank. We measure the complex admittance between the electrodes as a function of frequency for two salt density, and with or without electrode cover. We have to be careful about the electrodes not to be coupled with the resonance of water itself. In other words, we are supposed not to make the exciting frequency too high.

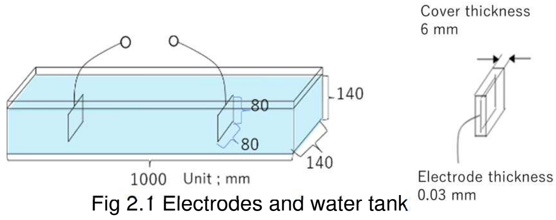


Fig 2.1 Electrodes and water tank

2.1.1 Electrodes without cover in tap water

Figure 2.2 shows the experimental result for the tap water as the reference for the results under seawater, where the imaginary part of the admittance is expressed by the capacitance dividing the susceptance by jω for easier understanding. The measurement frequency range will be from 0.1~120MHz. These principles will be completely repeated hereafter. The numbers in the figure give the distance between electrodes in mm.

The resonance at around 10 MHz is due to the series resonance by the electrode capacitance and its lead wire. Both capacitance and conductance are almost constant and inversely proportional to the electrode distance irrespective of the frequency under the resonance, which looks adequate.

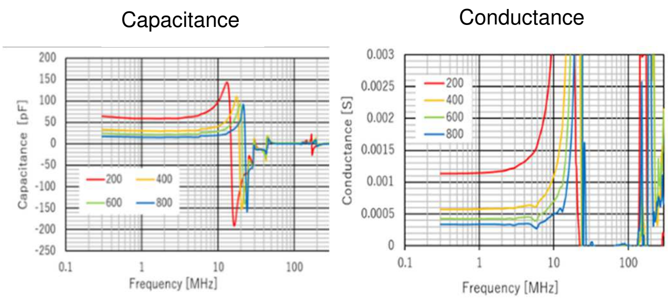


Fig.2.2 Admittance of electrodes without cover in tap water

2.1.2 Electrodes with cover in tap water

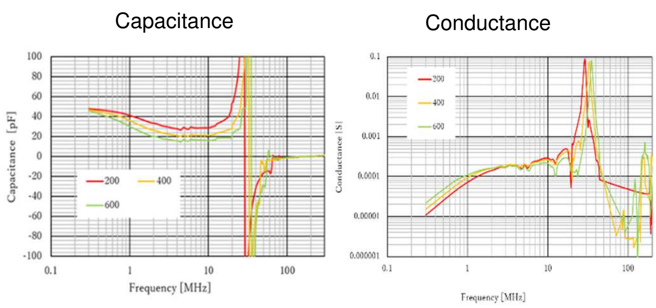


Fig2,3 Admittance of electrodes with cover in tap water

The electrode cover makes capacitance in series, and hence, both the capacitance and conductance of electrodes decrease as shown in Fig 2.3. Since the characteristics of the electrodes in tap water so far are simple and no wonder, we will leave them as the starting point and move on to the case for the sea water

2.1.3 Electrodes without cover in sea water

Conduction current naturally flows in this case, and thus, magnitude of inductance exceeds the susceptance, resulting in negative capacitance as shown in Fig. 2.4. The reason why the conductance converges to zero rapidly with frequency can also be Conduction current naturally flows in this case, and thus, explained by the increase of inductance in Fig 2.4. We can also imagine that the water becomes a good conductor that has zero impedance for any frequency above 20 MHz.

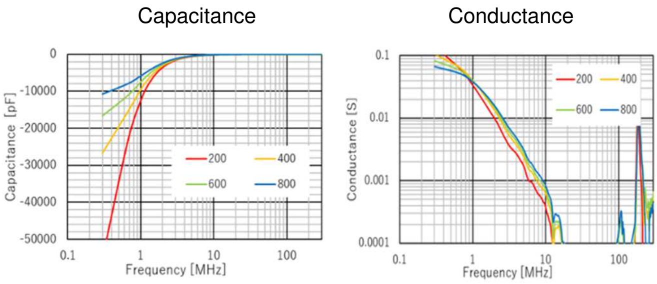


Fig2.4 Admittance of electrodes without cover in sea water

2.1.4 Electrode with cover in sea water

By covering the electrodes, capacitance is recovered, but the conductance is not, fortunately. It is suppressed to be below 0.001S under the self-resonant frequency around 10MHz. Though the result is quite favorable, we need to find the reason.

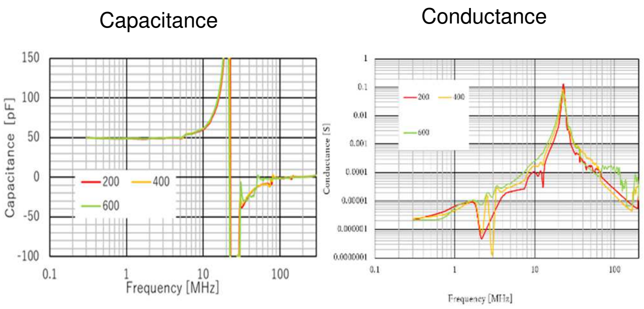


Fig2.5 Admittance of electrodes with cover in sea water

In any EM simulation software, the conduction current is assumed to be proportionate to the salt density having constant value with respect to the frequency. Since we think this assumption is the biggest reason for the stagnation of the undersea communication technology, we want to show its error by showing the difference between the simulation and experiment for the transmission in the sea.

2.2 Simulation

2.2.1 Electrodes without cover in sea water

The tendency on the frequency in Fig2.6 is almost the same as the experimental result in Fig 2.4 for both capacitance and conductance. Their magnitude decreases monotonously according to the frequency.

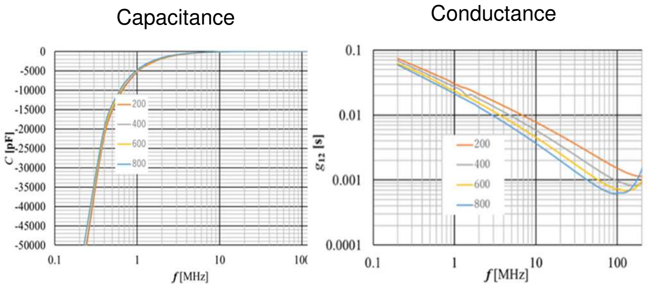


Fig. 2.6 Admittance of electrodes without cover in sea water

The tendency on the frequency in Fig2.6 is almost the same as the experimental result in Fig 2.4 for both capacitance and conductance. Their magnitude decreases monotonously according to the frequency.

2.2.2 Electrodes with cover in sea water

When we cover the electrode, the capacitance changes in the same way as the experimental result, but the conductance slope with the frequency is far steeper than the experiment. It means the conductance value in the simulation software is assumed too big than reality.

Another fact we must recognize is the importance of electrode shields. It has been elucidated that the loss induced by conduction currents extremely reduced by the shielding both theoretically and experimentally. The reason could be the restriction of ions movement around small distance apart from the shielded electrodes. But this effect will become weaker far apart from the electrodes, and thus it may not be effective for the radiation field

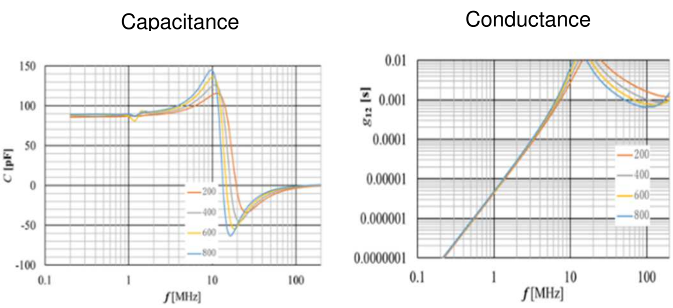
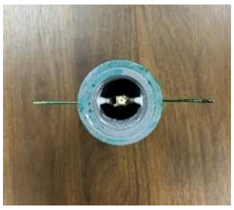


Fig 2.7 Admittance of electrodes with cover in sea water

3. TRANSMISSION BETWEEN TWO DIPOLE ANTENNAS

3.1 Preliminary loss measurement between two antennas in air

We have prepared a simple measurement structure that might resist the water and wind flow under and over sea surface, respectively. Fabricating 2 dipole antennas totally covered with vinyl chloride as shown in Fig.3.1, we have measured the transmission characteristics in air. The picture for the experimentation is shown in Fig.3.2 where the antennas distance is changed from 0.5 to 3m.



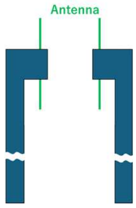


Fig 3.1 Prepared dipole antenna   Fig3.2 Measurement in air

The experimental results of S parameters for different antenna distances are shown in Fig.3.3 and the corresponding frequency characteristics of the maximum transfer efficiency are in Fig.3.4, which is calculated based on kQ theory [14]. It is applicable irrespective of non-propagating or propagating mode, that is, near field or far field. Therefore, it can deal with both the wireless power transfer system and wireless communication system. The results in Fig. 3.4 are quite reasonable.

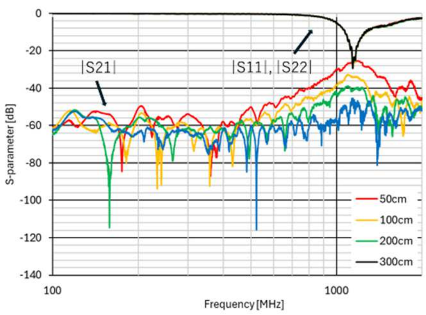


Fig. 3.3 Measured S parameters for several antenna distances in air

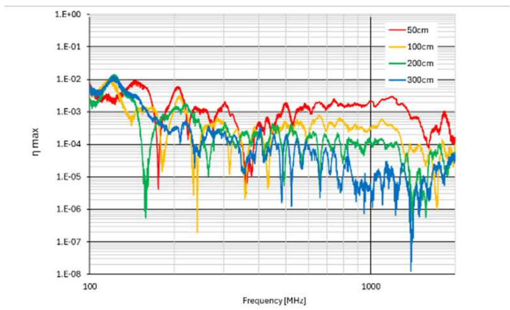


Fig. 3.4 Calculated max power transfer efficiency from the data above

3.2 Loss Measurement between two antennas under sea

We understand our system is only a minimum preparation that can be narrowly used for undersea experiments. But we have measured the propagation efficiency between the same dipole antennas as in the last section, trying to suppress the unwanted modes such as the lateral wave and the reflection wave at the sea surface by an aluminum plate.

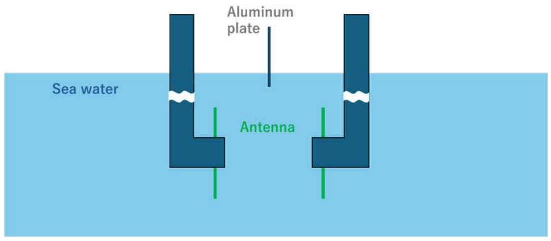


Fig 3.5 Measurement setup under sea

But unfortunately, the system did not work due to the invasion of seawater into the antenna shielding space. The necessity of calibrations of the observing point insists the screwing end of the antenna supporting pipes, which makes the weak points for the water shield. We have to devise the remedy seriously for the successful underwater experiment.

4. SUMMARY.

Though two topics shown in the introduction show the possibilities to improve the energy and signal transfer efficiency in the sea, respectively, they have not been clarified in the real system yet. As is well known, maritime experiments need large-scale and deliberate preparation, and thus we are now planning for that. We hope the expectations come true.

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