Research article Available online www.ijsrr.org ISSN: 2279–0543

International Journal of Scientific Research and Reviews

Variation of Complex Permittivity of Water and Saline water solutions over Microwave frequency range from 1 GHz to 20 GHz

Foram M. Modi[*1], Hemalkumar P. Vankar[2], Tanmay R. Pandit[3], Vipin A. Rana[4], Amardatta D.Vyas[5] and Deepak H. Gadani[6*]

[1-6]Department of Physics, School of Sciences, Gujarat University, Ahmedabad-380009, Gujarat, India.

E mail: modiforam1234@gmail.com[1], *dhgadani@yahoo.com*[6*]

ABSTRACT

Dielectric measurements were carried out to obtain complex permittivity ε* = ε'- j ε'' of distilled water and saline water solutions of concentration varying from 10,000 ppm to 40,000 ppm. The complex permittivity of different samples was measured carried out by using Anritsu Shockline Vector Network Analyzer (model-MS46322A) operating in the frequency range from 1GHz to 20 GHz, at 20 °C. The variation in dielectric constant and dielectric loss with salinity of water and frequency of measurement is compared with values calculated using Stogryn equations and results are found to be in good agreement with corresponding values. This study provides useful data for remote sensing applications of oceans and salinity estimation in water reservoirs.

KEY WORDS:

Complex permittivity, Saline water, Microwave frequency, Vector Network Analyzer

***Corresponding author**

Dr. Deepak H Gadani,

Associate Professor,Department of Physics,

University School of Sciences, Gujarat University,Ahmedabad 380 009,

E-mail:dhgadani@yahoo.com,

Mo. No.: 9879005755

INTRODUCTION

Salinity of water is very crucial in determining the quality of our environment and for residential purpose. Salinity represents to the quantity of salt in water which affects the acidity. Disturbance of acidity of water may cause inconvenience to human race, flora and fauna[1].Gadani *et al*[2]measured dielectric constant of distilled water and NaCl solutions for concentrations varying from 5000 to 35000 ppm in the frequency range from 200 MHz to 1.4 GHz using a Vector Network Analyzer (VNA).

R P Singh*et al*.[3]calculated the dielectric constant and dielectric loss of saline water solutions of salinity varying from 0 to 40.0 parts per thousand. Further the variation of dielectric constant and dielectric loss of river and sea water with variation of frequency from 0.5 GHz to 10.0 GHz have been compared. It has been observed that for estimation of salinity the frequency range from 0.5 GHz to 4.0 GHz is best suited[3].

Ho and Hall[4] measured dielectric constant and dielectric loss of sea water samples collected from different oceans as well as for NaCl solutions with concentrations varying from 0.3 N to 0.7 Nat 2.65 GHz, over the temperature range from 5.5 °C to 24 °C. It has been observed[4] that at this frequency, the dielectric properties of sea water depends only on its chlorinity, and not geographical location.

Stogryn equations[5] represent the dielectric constant of saline water as a function of temperature in °C and normality, in Debye form. Ellison *et al.*[6] have measured the permittivity of representative samples of natural seawater, synthetic sea water and aqueous NaCl solutions at 3-20 GHz in 0.1-GHz steps and over the temperature range -2°C to 30°C in 1°C steps, in order to construct more reliable model and concluded that for a frequencies between 3 and 10 GHz there is a significant difference between the permittivities of natural sea water and aqueous NaCl solution of the same salinity. On the other hand, there is no significant difference between the permittivity of natural and synthetic sea water for frequencies greater than 3 GHz.

EXPERIMENTAL TECHNIQUE:

The saline water solutions of different salinity varying from 10,000 ppm to 40,000 ppm were prepared with an addition of NaCl (AR grade, procured from Finar Limited) in distilled water. Further sea water samples were collected from Diu and Dwarka seabed.

Dielectric measurements of prepared samples were carried out over a frequency range of 1 GHz to 20 GHZ at the temperature of 20 °C using Anritsu Shockline Vector Network Analyzer

(VNA, model no. MS46322A). To eliminate the systematic measurement error; calibration has been done using two load materials (water and methanol). Dielectric Assessment kit provided from SPEAG along with DAK-3.5 probe have been utilized to carry out these measurements.

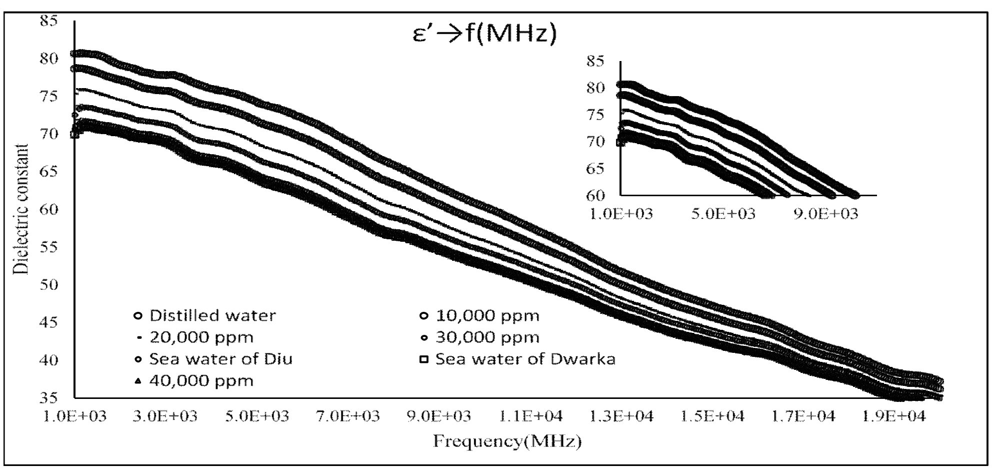
Fig (1) –Anritsu shockline Vector Network Analyzer (Model-MS46322A)

After the calibration, the measurements were carried out to estimate complex permittivity of pure and saline water solutions over the frequency range from 1 GHz to 20 GHz. Themeasured values of complex permittivity of saline water have been compared with the values calculated using Stogryn equations[5] as follows:

$$\varepsilon = \varepsilon_\infty + \frac{\varepsilon_0 - \varepsilon_\infty}{1 - i2\pi\tau f} + \frac{i\sigma}{2\pi\varepsilon_0^* f} \quad \text{…............ (1)}$$

RESULTS AND DISCUSSION

Fig(2) shows variationof dielectric constant and dielectric loss of pure water and saline solutions,using Anritsu Vector Network Analzer,over the frequency range of measurements. For distilled water and saline water solutions, ε' decreases with increase in salinity. Further it can be observed that the dielectric constant of distilled water and saline water solutions decreases with increase in frequency.



Fig(2) Variation of Dielectric constant over frequency for various water solutions

When sodium chloride (NaCl) is dissolved in water, water molecules bind with the molecule of NaCl to form hydrogen bonding[1]. It increases the inertia of molecules. Subsequently, the mobility of water molecules is degraded and so polarization. The mobility of these molecules is constraint for polarization and hence causes the descending of ε' when salinity increases. Higher salinity implies less free water molecules. Hence, ε' decreases with increase in salinity of water.The rate of decrease in dielectric constant is found to increase with increase in salinity. In contrast (Fig (3)), ε'' increases with increase in salinity of water at lower microwave frequency range. As frequency rises, experimental value of ε'' of pure water rises up to about 10 GHz after which itbecomes constant.

The variation of dielectric loss with frequencydepends on ionic conductivity which represents the motion of ions in an electrolyte solution at the high frequency[2]. The ionic conductivity of electrolyte solution increases due to dynamic effect of relaxation of an ion atmosphere on the motion of an ion, which in turn increases dielectric loss.

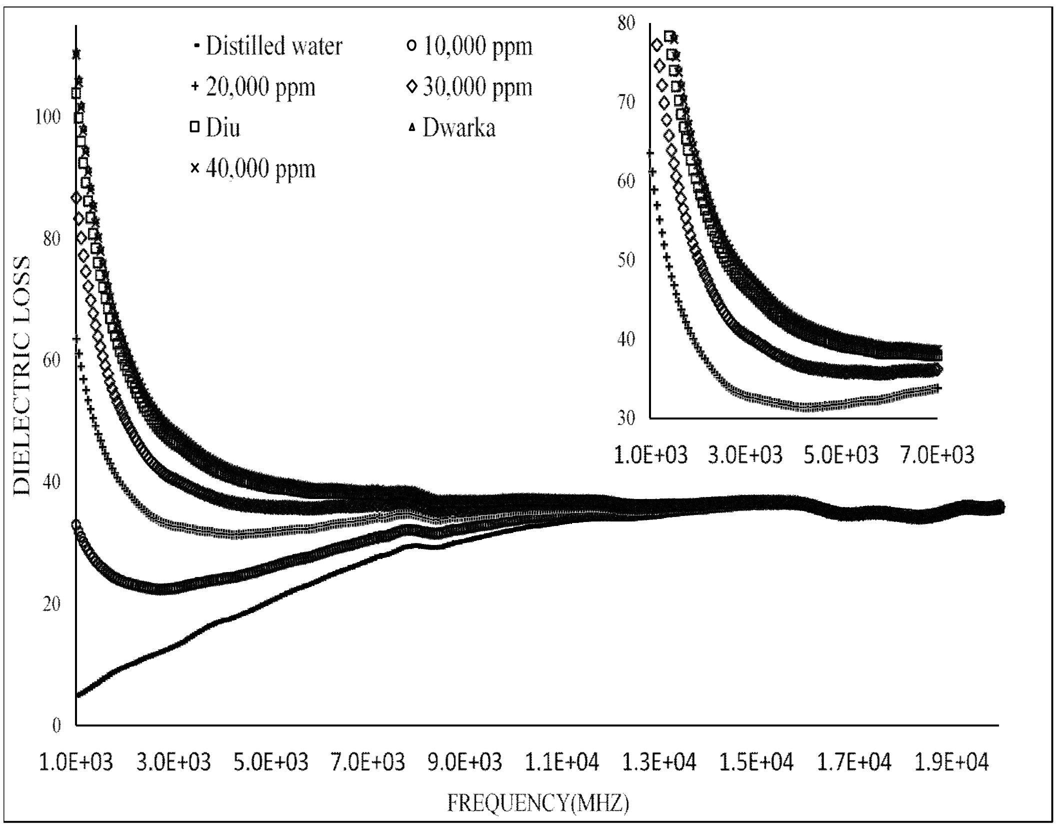


Fig (3) Variation in Dielectric loss with frequency for various water solutions

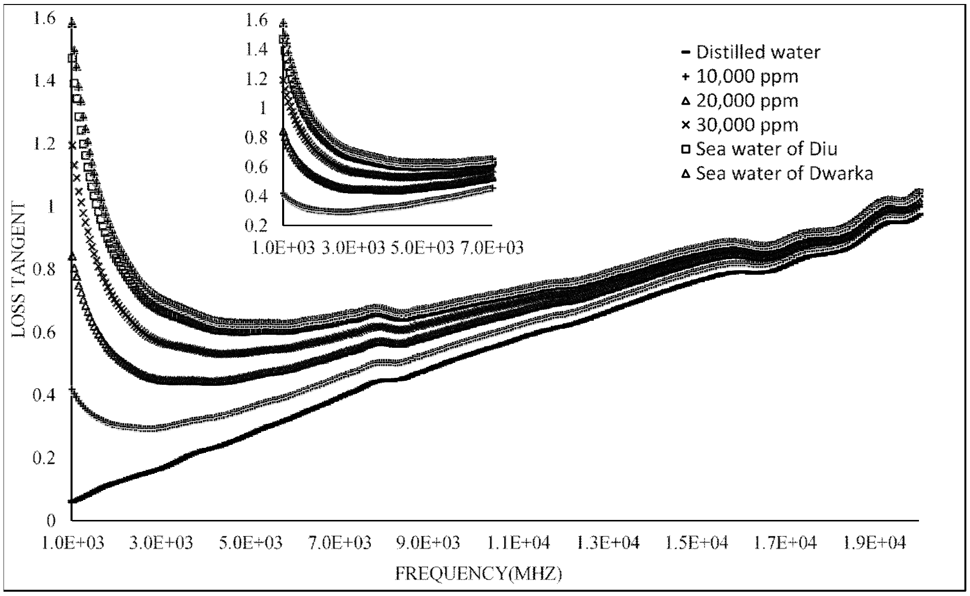


Fig (4) Variation in tanδ with frequency for various water solutions

Fig (4) shows variation of loss tangent with frequency, for distilled water and saline water solutions. It can be observed from figure that tanδ increases with increase in salinity. Over the given frequency range tanδ of distilled water increases with increase in frequency. For saline water of different salinity, as frequency increases loss tangent decreases rapidly up to certain frequency having a deep and there after it start to increase slowly. The deep in tanδ is found to shift towards higher frequency, with increase in salinity, as seen from the box in the graph.

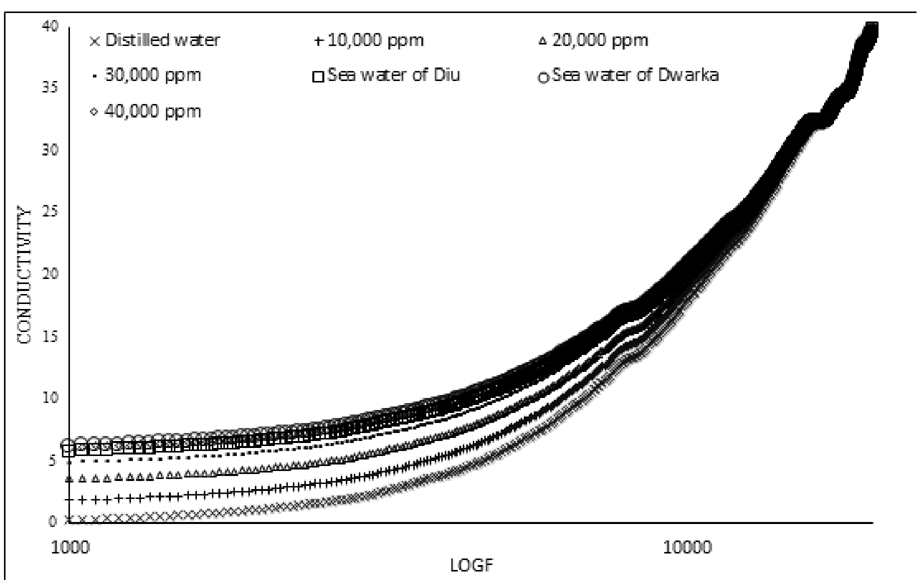
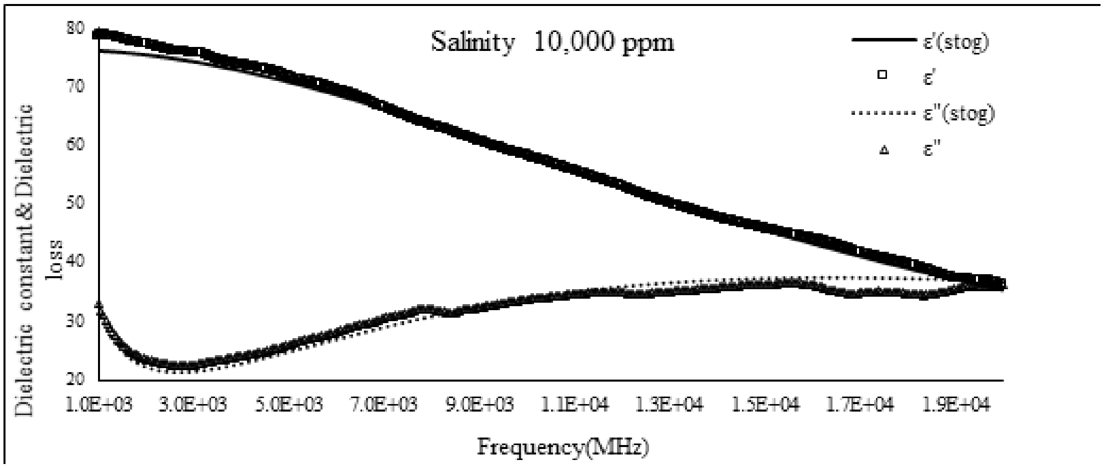


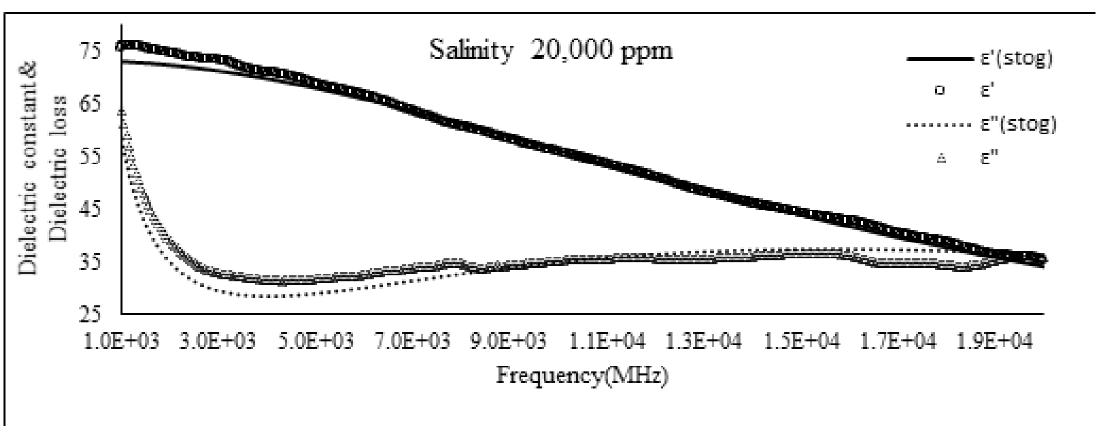
Fig (5) Variation in conductivity with frequency for different saline solutions.

Fig (5) shows variation of conductivity with frequency, for distilled water and saline water solutions. The conductivity of distilled water is lower than saline water solutions, it increases with increase in frequency. As salinity increases, conductivity of water solution also increases. Conductivity is a capability of water to allow electrical current to flow, which is directly related to conductive ions such as chlorides and inorganic materials (alkalis, chlorides, sulfides and carbonate compounds) present in the water[7].



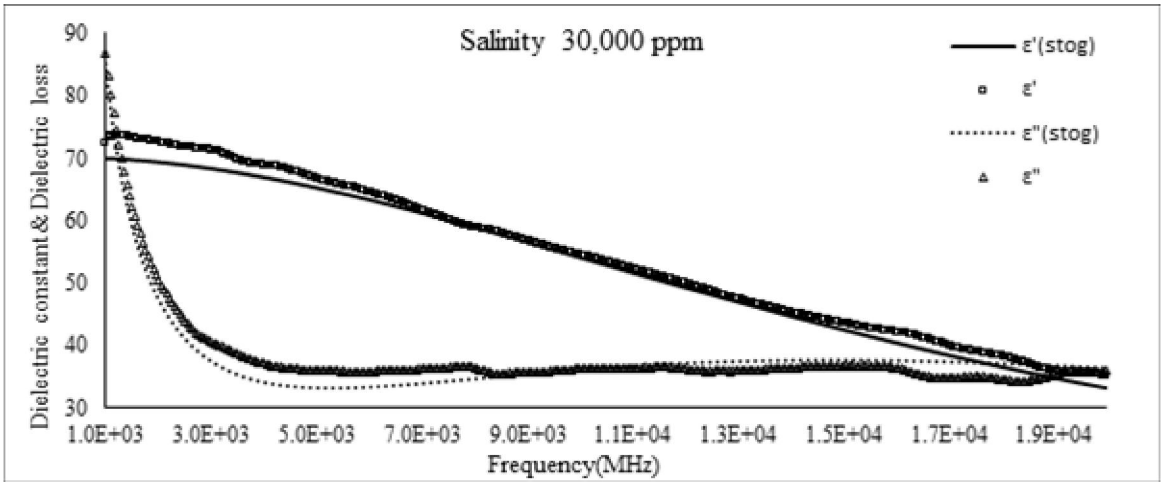
Fig(6) Comparison of complex permittivity of 10,000 ppm saline water with Stogryn model

Comparison of complex permittivity of water with Stogryn equations is shown in fig (6). It can be observed that experimental values of dielecric constant anddielectric loss are higher than calculated values from Stogryn equations upto about 3 GHz, afterwhich these values are in good agreement with Stogryn equations.



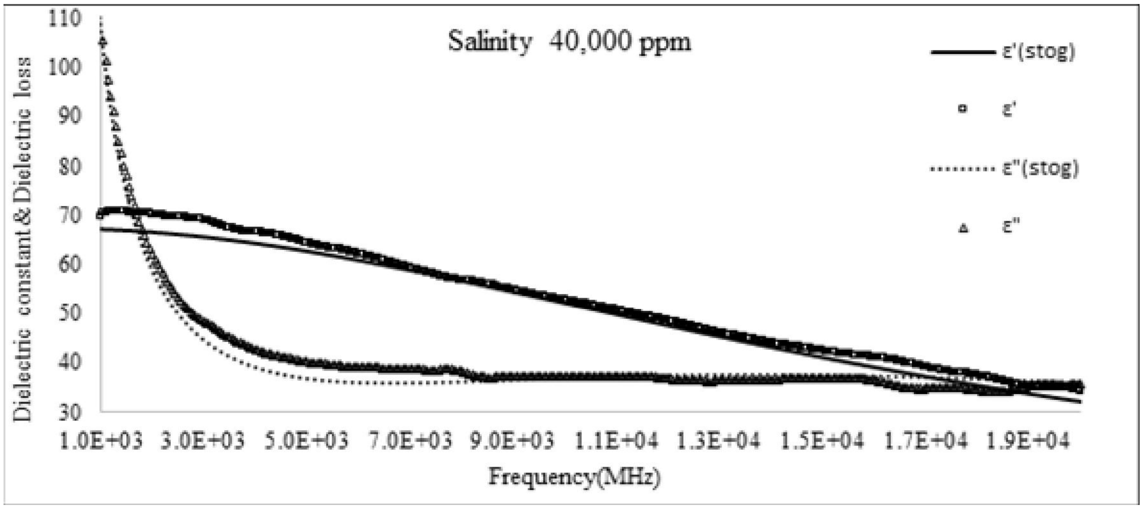
Fig(7) Comparison of complex permittivity of 20,000 ppm saline water with Stogryn model

From fig (7), it can be observed that experimental values of dielecric constant are higher than calculated values from Stogryn model uptoabout 3.2 GHz and dielectric loss is higher than calculated from Stogryn model uptoabout 8.3 GHz, after which these results are good in agreement with values calculated from Stogryn equations.



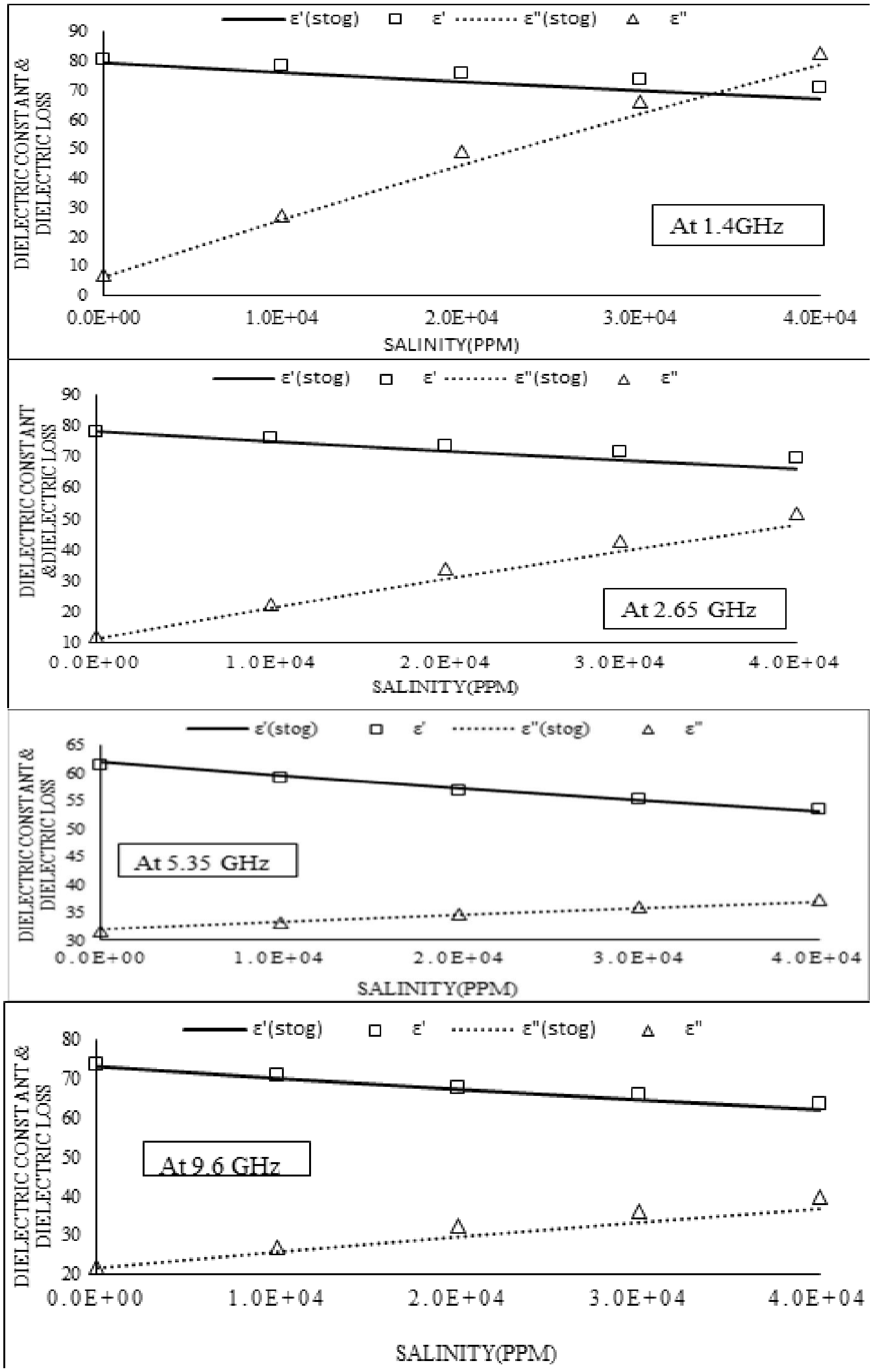
Fig(8) Comparison of complex permittivity of 30,000 ppm saline water with Stogryn model

From fig (8) it can be observed that experimental values of dielecric constant are higher than calculated values using Stogryn model uptoabout 3.2 GHz anddielectric loss is higher than calculated from Stogryn model upto about 7.6 GHz, after which these values are in good agreement with values calculated from Stogryn equations.



Fig(9) Comparison of complex permittivity of 40,000 ppm saline water with Stogryn model

From Fig (9) it can be observed that experimental values of dielecric constant are higher than calculated values using Stogryn model uptoabout 4 GHz and dielectric loss is higher than that calculated from Stogryn model upto about 8.4 GHz, after which these values are good in agreement with values calculated from Stogryn equations.



Fig(10) Comparison of ε' and ε'' with values calculated using Stogryn model at fixed frequencies of (a) 1.4 GHz, (b) 2.65 GHz, (c) 5.35 GHz, (d) 9.6 GHz

Fig (10) shows comparison of experimental values of ε' and ε''with the values calculated using Stogryn model at frequencies 1.4 GHz, 2.65GHz, 5.35 GHz and 9.6 GHz. At 1.4 GHz and 2.65 GHz values of ε' and ε'' obtained from Stogryn model shifts downward, away from experimental values for different salinities.At 5.35 GHz,thevalues of ε' and ε" calculatedby Stogryn model are good in agreement with experimental values.At 9.6 GHz, ε' obtained from Stogryn model aregood in agreement with experimental values but values of dielectric loss calculated using Stogryn modelshift downwards away from the experimental values.

CONCLUSIONS

For the given frequency range 1 GHz to 20 GHz at 20 ° C (I) Dielectric constant of distilled water is higher than that of saline water, ε' of distilled water decreases with increase in frequency.(II) Dielectric loss of distilled water increases with increase in frequency, whereas that of saline water decreases with increase in frequency up to certain frequency showing a deep, after which it increases with increase in frequency. (III) Dielectric loss increases with increase in salinity in water up to about 10 GHz after which no much variation is observed upto 20 GHz. (IV) tanδ of distilled water increases with increase in frequency, whereas in case of saline water it decreases with increase in frequency upto some extent showing a deep after which it start increasing with increase in frequency. (V) Conductivity of pure water is lowest as compared to other saline solutions. As salinity of water increases, conductivity also increases. Conductivity of pure water and saline solutions increases with increase in frequency. (VI) For the frequency range above 3 GHz, measured values of dielectric constant and dielectric loss are in good agreement with values calculated using Stogryn model.

ACKNOWLEDGEMENT

Authors are thankful to the funding agencies DST, New Delhi and UGC, New Delhi for providing financial assistance through DST – FIST project (SR/FST/PSI-198/2014) for development of experimental facilities to carry out this work. Authors are also thankful to Prof. P. N. Gajjar, Head, Dept. of Physics, University School of Sciences, Gujarat University, Ahmedabad for his constant encouragement and support.

REFRENCES

1. Cheng EM, Abdul Malek MF, Khor SF, You KY, Lee KY, Rojan MA, Abu Bakar S, Mohd Nasir S, Zakaria Z, and Tan WH. Reflection and Dielectric measurement for salinity of water using microscopic loop antenna and dielectric probe. International Journal of GEOMATE. 2016; 11: 2235-2340.
2. Gadani DH, Rana VA, Bhatnagar SP, Prajapati AN and Vyas AD. Effect of salinity on the dielectric properties of water. Indian J. PureAp. Phy. 2012; 50: 405-410.

3. Singh RP, Kumar V and Shrivastav SK. Use of microvave remote sensing in salinity estimation. INT. J. REMOTESENSING. 1990; 11: 321-330.
4. Ho W, Hall WF. Measurements of Dielectric Properties of Sea water vand NaCl solutions at 2.65 GHz. JOURNAL OF GEOPHYSICAL RESEARCH. 1973; 78: 6301-6315.
5. Stogryn A. Equations for Calculating the Dielectric Constant of Saline Water. IEEE Transactions on Microwave Theory Techniques. 1971; MTT-19: 733-736.
6. Ellison W, Balana A, Delbos G, Lamkaouchi K, Eymard L, Guillou C, and Prigent C. New permittivity measurements of sea water. 1998; 33: 639-648.
7. Miller RL, Bradford WL, and Peters NE. Specific Conductance: Theoretical Considerations and Application to Analytical Quality Control.U.S. Geological Survey water-supply paper ; 2311 Bibliography: p. Supt.of Docs.no.: 19.13:2311 . TD370.B 86-600214.