Aims & Objectives
Fundamentals of Dielectrics
Relationship of Dielectric Constant
Measurement of Dielectric Constant
Frequency Dependence of Dielectric Constant
Article’s Review
Applications
AIMS AND OBJECTIVES

1. To determine the dielectric, electrical and optical properties of Ferrites using LCR meter.
2. To study the correlation among complex dielectric constant and electrical susceptibility, electrical conductivity and refractive index.
3. To implement this study in the application of electronics on nanoscale.
Dielectric Material

A substance that is insulator or poor conductor of electricity.

A material in which energy can be stored by the polarization of molecules.

A material that increases the capacitance, insulation or charge storage ability of a capacitor.
Relative Permittivity or Dielectric constant ($\varepsilon_r$)

The fractional increase in the stored charge per unit voltage on the capacitor plates.

The fractional increase in the capacitance of the capacitor when insulation b/w plates is charged from vacuum to dielectric material.

A material property that is frequency dependant.
Complex Relative Permittivity ($\varepsilon_r^' + \varepsilon_r^''$)

It has real part ($\varepsilon_r^'$) that determines the charge storage ability and an imaginary part ($\varepsilon_r^''$) that determines the energy losses in material as a result of polarization mechanism.

Real part ($\varepsilon_r^'$) represents a relation between AC signal transmission speed and dielectric material’s capacitance.

Imaginary part determines energy power dissipation per unit volume as heat from an AC signal by $E^2 \omega \varepsilon_0 \varepsilon_r^''$.

$$\varepsilon_r = \varepsilon / \varepsilon_0$$
**Dielectric Strength**

It is the maximum critical field ($E_{br}$) that can be sustained in dielectric beyond which dielectric breakdown occurs and a large discharge current flows through the dielectric.

Factors effecting dielectric strength of solids are: Molecular structure, Impurities, Microstructural defects, Sample geometry, Temperature, Frequency

A voltage reached that causes a substantial current to flow b/w the electrodes which appears a short b/w electrodes and leads to dielectric breakdown.

In solids, dielectric breakdown leads to permanent conducting channel and hence permanent damage.

Link for dielectric breakdown animation [www.doitpoms.ac.uk/.../dielectrics/printall.php](http://www.doitpoms.ac.uk/.../dielectrics/printall.php)
Dielectric Loss

It is the electrical energy lost as heat in the polarization process in applied AC field.

The energy is absorbed from the AC voltage and converted to heat during polarization of molecules.

Dielectric loss is influenced by $\omega$, $E$, $\tan \delta$

$$W_{vol} = E^2 \omega \varepsilon_0 \varepsilon_r$$
Loss Tangent (\(\tan \delta\))

It is the ratio of the imaginary part (\(\varepsilon_r''\)) to the real part (\(\varepsilon_r'\))

It is the measure of amount of energy loss from the material due to applied external field.

The angle \(\delta\) is the phase angle b/w the capacitive current and the total current.

If there is no dielectric loss, then the two currents are the same and \(\delta = 0\).
Electric Susceptibility ($\chi_e$)

It is a material quantity that measures the extent of polarization in the material per unit field.

It relates to amount of polarization $P$ at a point in the dielectric to the field $E$ at that point via $P = \chi_e \varepsilon_0 E$.

The electric susceptibility of a medium is related to its dielectric constant by

$$\chi_e = \varepsilon_r - 1.$$
It is a measure of material’s ability to conduct an electric current. 

It is a measure of how fast an electron can flow through a material. 

To analyze the conductivity of materials exposed to alternating electric fields, it is necessary to treat conductivity as a complex number. 

The electric conductivity of a medium is related to its dielectric constant by 

\[
\tan \delta_e = \frac{\varepsilon''}{\varepsilon'} + \frac{\sigma_s}{\omega \varepsilon'} = \frac{\varepsilon''}{\varepsilon'}
\]
The refractive index of a medium is a measure of how much the speed of light is reduced inside the medium.

\[ n \approx (\varepsilon_r)^{1/2} \] at optical frequency.

Refractive Index is a complex number having both real part and imaginary part.
Equipment

MEASUREMENT OF DIELECTRIC CONSTANT & LOSS

QuadTech 1920 LCR Meter includes:

- Measurement Instrument
- Test Fixture
- Connecting Cables & Adapters
Procedure

Connection of test fixture to the measuring instrument (an LCR meter).

Material sample is installed in the test fixture depending on material type for evaluation of dielectric properties.

Calibration is performed for best accuracy of results over a wide frequency range, from 20 Hz to 1 MHz.

When connected to an automatic LCR meter, the capacitance (C) and loss (\(\tan \delta\)) measurements can be readout directly yielding fast, reasonable results.
The dielectric constant can be determined from the formula

\[ \varepsilon_r = \varepsilon_r' + i\varepsilon_r'' \]

The real part of dielectric constant \((\varepsilon_r')\) can be calculated by

\[ \varepsilon_r' = \frac{Cd}{\varepsilon_o A} \]

The tangent of dielectric loss angle can be calculated using the relation

\[ \tan \delta = \frac{1}{2\pi fR_sC_s} \]

The dielectric loss \((\varepsilon_r'')\) factor can also be measured by the relation

\[ \varepsilon_r'' = \varepsilon_r' \tan \delta \]
Frequency dependence is governed by relaxation and resonance phenomena.

The frequency dependence of real and imaginary parts of dielectric constant in presence of different polarization mechanisms. Link for animation [www.doitpoms.ac.uk/.../dielectrics/printall.php](http://www.doitpoms.ac.uk/.../dielectrics/printall.php)
The frequency dependence of real and imaginary parts of dielectric constant showing the loss peaks.
Variation of dielectric constant with $\ln f (\text{Hz})$ of CoFe$_{2-x}$Al$_x$O$_4$ ferrite nanoparticles at room temperature.

Variation of dielectric loss factor with $\ln f (\text{Hz})$ of CoFe$_{2-x}$Al$_x$O$_4$ ferrite nanoparticles.
Variation of tangent of dielectric loss angle with ln f (Hz) of CoFe$_2$–xAlxO$_4$ ferrite nanoparticles.
Use of dielectrics in fabrication of capacitors, filtering out noise from signals as part of a resonant circuit and in a camera flash system.

Dielectric constant is helpful in determining other properties i.e. $n, \sigma, \chi_e$. This is useful for the study of resonance phenomena in dielectrics, and critical phenomena at ferroelectric transitions.

The ultralow dielectric constant is useful for high-frequency switching applications.

Dielectric constant and loss plays a vital role in microwave technology and devices because of very high requirements to electric parameters. Dielectric loss is utilized to heat food in a microwave oven:

Dielectric constant is a sensitive parameter in fabrication of sophisticated electronic equipment such as rectifiers, semiconductors, transducers, and amplifiers.

The phenomenon of dielectric breakdown is utilized in cigarette lighters where a spark must be produced in order to ignite the fuel.

The dielectric constant of materials is important in material processing, electronics & biomedical engineering.