CHAPTER 2
LITERATURE SURVEY

Dielectric measurement is a research field from several decades, pertaining different types of electronic, biomedical, geological and several other fields. Each application area has its own challenges and measurement requirements. Hence there is a continuous research thrust towards improving the dielectric measurement methods and practical setups. Unlike several other research topics in electronics, dielectric measurement research involves challenges in addressing conceptual (or algorithmic) issues and also establishing practical setups. This chapter discusses the key dielectric associated concepts observed from literature and work published by other researchers for dielectric measurement.

Dennis Trebbels, et al., [1] presented a phase delay measurement based dielectric constant with digital techniques. This method measures the phase shift and amplitude distortion of the test cell with sample material. A two channel DDS synthesizer from Analog devices AD9958 is used to generate a measurement signal. This method is based on pure digital Delta modulation. Such devices are often bulky and expensive, which limits their use when low-cost.

Agilent Application [2] introduced a split cylinder resonator method for the measurement of dielectric constant. The cylindrical cavity of Split cylinder resonator is splitted into two halves. The sample is placed in between these two half cylinders. The first half cylinder is fixed and the second is adjusted to allow different dimensions of the samples. The dielectric constant is measured from both loaded and unloaded resonator cavity.

The dielectric constant measurement techniques can be classified into two categories. The first category measures the capacitance with and without the dielectric being present in between the parallel plates. The real part of the dielectric is measured based on the ratio of these capacitances. This concept is used in LCR meter based
techniques and suitable for very low frequencies to few hundreds of Mega Hertz. The second category of techniques allows the electromagnetic wave pass through the dielectric and measure the reflection coefficient and transmission coefficient. Based on this the dielectric constant is estimated. This category of techniques can work right up to few tens of giga-hertz (GHz) frequencies. These two methods require very costly setups and most of them become frequency specific. So, broadband measurement techniques have taken its importance in research for dielectric constant measurements.

J. Friedman [18] invented an apparatus for dielectric constant measurement of a single substrate or a mixture of substrates. The apparatus included an oscillatory system and transmission line as delay element or a sensor. But it is a destructive testing.

Sz.Maj and M. W. Modelski [19] developed a measurement method to find out complex permittivity of low loss microwave high dielectric materials using a cylindrical dielectric resonator on micro strip line. Author used TE01 mode to find out dielectric constant and loss tangent, compared the results with dielectric rod resonator using TE11 mode. Author concluded that the accuracy is improved.

For measuring the dielectric constant and loss factor of a homogeneous material, A. Kumar [20] developed an innovative technique by using a rectangular shaped perturb cavity. Experimentally the S-parameter values are measured by keeping the sample in the centre of the rectangular shaped perturb cavity. The dielectric properties can be determined from the difference between the resonance frequency of an unloaded cavity and a loaded cavity. The conditions for this approach are, the dimensions of the sample should be small when compared with the cavity and the cavity must be very much similar with and without sample.

The sample is inserted at the centre of the wider dimension of the cavity. The shape of the sample is cylindrical. In this technique, along with the cavity resonator HP8510 network analyzer and PC are used to measure the dielectric and loss tangent of a homogeneous material at microwave frequencies in TE_{105} mode and is more
accurate in the measurement of small loss tangents. In this method there is no need to calibrate the network analyzer, but this needs a high frequency resolution (VNA) vector network analyzer.

Panzner, B., et al., [21] presented dry soil dielectric parameters measurement by using two techniques in frequency domain. The first method is based on wave guide transmission reflection technique. The second approach is a free space method used for frequency range of 7-20GHz. The author concluded that free space technique is less sensitive than waveguide technique with respect to relative permittivity variations.

P. A. Bernard and J. M. Gautray [22] presented a permittivity measurement by using micro strip ring resonator approach in X-band. B. R. De and M. A. Nelson [23] developed a different method and apparatus for measurement of dielectric properties. Apparatus is designed with transmitting and receiving antennas for the analysis of materials with different dielectric properties. The proposed method is suitable for wide frequency ranges, but later proved to be costly.

M. M. Neel and F. J. Schiavone [24] developed an apparatus for thin-materials dielectric constant measurement. The open coaxial transmission line is used to construct resonator. The fringing fields penetrate through MUT from the resonant frequency due to material dielectric constant. The resultant accuracy is high and the resolution is less than one percent. Though it is a non-destructive testing method, a metal cladding is to be removed from the area of interest.

A. Baysar and J. L. Kuester [25] utilize the waveguide cavity measurement technique to measure the dielectric constant of alumina, cobalt, dolomite and sand as a function of temperature. M. Saed [26] used aperture coupled structure to calculate the low loss planer microwave substrates complex permittivity.

M. D. Deshpande, et al., [27] presented a new approach for dielectric materials complex permittivity measurement using waveguide at microwave frequencies. Waveguide methods for dielectric measurement involve the comparison of empty
waveguide with a waveguide including the sample material or the comparison of measured scattering parameters and numerical electromagnetic solutions. The waveguide may be either fully or partially filled with the material under test. The material under test partially fills a shorted waveguide and the measured reflection coefficient is compared to a FEM solution of the system.

Z. Abbas, *et al.*, [28] introduced an effective complex dielectric constant measurement of a system composed of two rectangular waveguides separated by a relatively thin piece of sample material.

Thomas Meissner and Frank J.Wentz [29] published that the knowledge of the complex dielectric constant (permittivity) of sea/ocean water is essential for studying the radiative transfer of microwave radiation that is emitted by the ocean surface, transmitted through the earth’s atmosphere and received by passive microwave sensors.

Y. Kantor [30] developed micro strip line resonator, closed disk resonator and printed strip resonators to determine the dielectric constant of thin laminates like copper clad printed circuit substrates. Kantor methods are applicable for the dielectric constant measurement of materials with dielectric constant ranges from 2 to 20.

S. O. Nelson [31] calculated the limestone and coal powdered mixture dielectric constant using the waveguide technique at 11.7GHz and 20°C. S. Nagata, *et al.*, [32] described a method for determining a calibration curve for an open or radiating resonator that relates the resonant frequency to the dielectric constant and thickness of a sheet for which dielectric constant is known. This calibration curve is then applied to find the dielectric constant of the material, with unknown properties.

A. Muqaibel and A. Safaai-Jazi [33] developed a method to measure the dielectric properties of large slabs of material using two standard horn antennas. The authors also used some algebraic manipulations to reduce the problem from a 2-D search of a complex space to a search on a real-valued function.

J.M. Heinola, *et al.*, [34] developed an approach to determine the FR-4 type PCB materials dielectric constant and dissipation factor using micro strip ring resonator under
wide frequency range. Author presented a survey on dielectric constant and micro strip line losses of materials like high loss PCBs.

N. Gagnon, et al., [35] developed a dielectric constant measurement method at Ka-band in free-space with low cost. Authors used root-finding algorithm and generic algorithms. The requirement of a smoothing process with a correction term is the main limitation of this method.

Y.S.Yeh, et al., [36] calculated the complex permittivity of a cylindrical rod from the resonant frequency and bandwidth of the transmission spectrum. Author claimed that the conductivity of particle decreases with decrease in size and the metallic nano particles dielectric constant is negative.

An improved waveguide based method was described by J. L. Sebastian, et al., [37] for characterizing the biological tissues at the frequency of 2.45GHz. The practical results were compared with numerical analysis results and achieved satisfactory results.

R. Weerasundam and G.G. Raju [38] developed an algorithm for complex dielectric permittivity computation using FFT technique and Hilbert transform through KramersKrong relation. KramersKrong transform is used for relating the real and imaginary components. Authors proposed algorithm is verified with both theoretical as well as measured data for some dielectric materials at high temperatures.

M.S. Venkatesh and G.S.V. Raghavan [39] presented an overview on measuring techniques of dielectric properties. Author published the importance of dielectric constant in different applications like package design, physical or chemical analysis and process control, agri-food and biomedical. With the help of comparison table he concluded that one single method is not suitable for testing all materials in all conditions.

K. Sarabandi and F. T. Ulaby [40] measured the reflection coefficient of a thin sample in a matched waveguide and compared it to a model of the system using an infinitesimally thin resistive sheet as the sample.
D. K. Ghodgaonkar, et al., [41] used a free-space method for dielectric constant and loss tangent measurement of materials at microwave frequencies. Free-space methods for measuring dielectric constant rely primarily on reflection and transmission of electromagnetic waves through the sample of the material under test. The author established a relation between the reflection coefficient and the complex permittivity of the material under test to determine dielectric constant and loss tangent.

Tereshchenko O., et al., [42] developed a contacting electrode method for permittivity measurement. In this method permittivity can be derived by calculating the electrodes capacitance that is directly in contact with Material Under Test (MUT). Special equations are used to calculate loss tangent and permittivity. This measurement technique is straightforward as it does not require sample preparation. So, this is most preferable and simple method for measuring permittivity. But it suffers from measurement errors that occur due to air gap between the electrode and the Material Under Test (MUT).

To overcome the drawbacks of contacting electrode method again non-contacting electrode method [42] is developed. In non-contacting electrode method, thin film electrodes are not required but it is able to eliminate the air gap errors. In this method permittivity is measured using with and without MUT. But the air gap has to be smaller than the thickness of material under test.

Umenyiora and Chidubem Andrew [43] presented the sand dielectric constant measurement using Time Domain Reflectrometry (TDR) and Frequency Domain Reflectrometry (FDR) methods along the co-axial line. Here authors concluded that dielectric constant has a great impact on the moisture constant of the soil.

Salah I. Yahya Al-Mously [44] presented an inexpensive setup for dielectric constant measurement using amplitudes of transmission and reflection coefficients in presence of sample material. It is shown that by considering large plates, the multiple
reflections between the two surfaces of the sample are reduced and the accuracy is improved.

Yanhui and Zhong [45] researched on relationships between measuring frequency and dielectric constant of cement concrete materials. To characterize dielectric constant for analyzing the performance of ground penetration RADAR applications.

Chalashkanov N. M., et al., [46] published the Kramers-Kroning transform limitations in calculation process of DC conductance magnitude from dielectric constant measurement. Author concluded that the K-K transform is useful for relating the real and imaginary parts of the complex susceptibility. The practical limitations of numerical implementation of the Kramers-Kroning transform were investigated.

Ortega-Palacio R., et al., [47] explained that as medical field, started using the dielectric information of body tissues and vessels for DNA analysis, cancer cell analysis etc., the importance of dielectric constant measurement methods are increasing in recent years. Information about the dielectric properties of biological systems is essential in modern medical field.

P.R. Chaudhary [48] studied the importance of variation of dielectric constant due to physical constituents and chemical composition and presented that the dielectric constant of dry soils place an important role in the field of agriculture. The soil has chemical, electrical and physical properties. As the dielectric constant depends on the physical constituents and chemical composition of the soil, the measurement of variance of dielectric constant with physical constituents and chemical composition is required.

For measuring the permittivity in broad band, Z. Chen [49] introduced a new method which is based on Vector Network Analyzer (VNA) coupled with coaxial transmission line cell and it is suitable for flat surface soft and hard materials with limited volume in the order of cm$^3$. This non-destructive method of coaxial transmission line cell is also used for the characterization of various materials like
biological tissues. Whereas the open-ended coaxial probe coupled with vector analyzer is suitable for non-destructive measurement of large volume samples.

Precise estimation of dielectric constant with loss tangent at high frequencies has been a great importance now-a-days. Parallel plate wave guide resonator is used to extract only dielectric constant but can’t be applicable to extract loss tangent. Pasunoori P. and Engin A.E [50] developed full-sheet resonance method which can measure loss tangent along with the dielectric constant using tracking sensitivity algorithm. The full-sheet method is less expensive than existing methods and the measurement time is negligible by the use of macro model. Author applied this method to extract FR-4 dielectric constant and loss tangent.

With a view to introduce simple dielectric constant measurement, CH.V.V Ramana [51] designed and developed a dielectric measurement mechanism based on frequency measurement to determine the capacitance by using mono-stable multivibrator. In this method author claimed an accuracy of ±1%. This method is applicable for solid materials.

Ray K.P., et al., [52] presented a very simple and accurate method to determine the dielectric constant of the substrate, by measuring the resonance frequency and the dimensions of any regular shaped Microstrip antenna (MSA) such as Rectangular Microstrip antenna (RMSA), Circular Microstrip antenna (CMSA) and ET Microstrip antenna (ETMSA). Authors also explained the steps to measure the dielectric constant of the material. In this method, 0.3% is the maximum error found between different frequencies.

Isaac Waldroni [53] explained the ring resonator method to determine the dielectric constant and loss tangent of the expanded polystyrene (EPS) foams which are used in modern antenna research as supporting materials for antenna construction. He explained the structure, interface and complete device model for both planer ring resonator method and suspended ring resonator method.
Rohde and Schwarz [54] developed a free space method for wide band dielectric constant measurement of materials, tested under high temperatures and hostile environments. A typical measurement system consists of a Vector Network Analyzers (VAN), free space fixture (antennas, tunnels, arches, etc). The two antennas are kept opposite to each other and they are connected to a VNA. The calibration of network analyzer is needed before measurement. The reflection standard is achieved by placing a plate on the sample holder. The two antennas focal planes are separated by quarter wave length to obtain the line standard. The dielectric constant can be measured after calibrating S-parameters of reflection and transmission co-efficient by placing the sample holder in center of the two antennas with and without material under test (MUT).

Lee W. Ritchey [55] in his research has depicted various dielectric materials used in the manufacture of printed circuit boards (PCB). Two major classes of materials based on woven glass reinforcement and non-woven glass reinforcement are explained. For production and processing woven glass reinforced laminates are cheaper than non-woven laminates. Laminate properties which are important to use depending on the application, such properties are Relative Dielectric Constant ($\varepsilon_r$), Glass Transition Temperature ($T_g$), Loss tangent, Dielectric Breakdown Voltage, Moisture Absorption are discussed. Commonly used woven glass materials for digital applications and very low glass content laminate materials are tabulated by the author.

Y. H. Chou, et al., [56] presented the quarter-wavelength open stub resonator method to measure the dielectric constant and loss factor. The loss factor comparison of the design frequency with other design frequencies and the total test structure along with formulae and diagram of quarter-wavelength open stub resonator are explained. They analyzed the results and tabulated the dielectric constant values and loss factor at different frequencies.

Afsar M.N, et al., [57] covers the different techniques used to measure dielectric properties of materials for wide frequency range. The detailed development of different
methods including resonant, free space, time domain, frequency domain and broad band methods are explained by the author.

J.Hinojosa [58] presented broad-band technique for measuring the dielectric permittivity of isotropic non-magnetic film-shaped material at low microwave frequencies. $S_{11}$ reflection parameter is used for extraction of dielectric permittivity, which is measured at the open-end CPW cell whose substrate is the material under test. Permittivity of several low-loss nonmagnetic materials is also presented.

Jerzy Krupka [59] depicted an overview of different techniques for the measurement of the complex permittivity in frequency domain at microwave frequencies and used different materials in resonant structures to describe the general theory of measurements with mathematical background and explained the limits for theoretical and experimental results.

Tzu-Yang Yu, Jose Alberto Ortega [60] proposed an integrated methodology for determining the unique combination of complex permittivity based on measured transmission coefficient and time difference of arrival information in free-space. This method is validated by the measurements of several materials with known dielectric properties.

Various resonant measurement techniques of dielectric constant and dielectric loss at microwave frequencies have been studied by Jyh sheen [61]. Many suggestions as to how to select proper techniques for measurement of microwave properties are discussed.

Cylindrical cavity measurement technique is presented by R. Keam and A. D. Green [62] to measure the complex dielectric permittivity at microwave frequencies for two materials and it is based on a model which fully considers the coaxial form of the cavity excitation, shown to produce very accurate results for a wide range of frequencies.
E. Semouchkina, et al., [63] demonstrated the FDTD (finite-difference time-domain) simulation method and measurement of $S_{21}$ spectra of microstrip ring resonators to determine the high frequency permittivity of the substrate. The measured and simulated results of the substrate are also plotted and analyzed. They also showed that the present method performance is more consistent than wheeler-Hammerstad method.

A. E. Fathy, et al., [64] developed an innovative technique to determine the dielectric and conductor loss of microstrip ring resonator. To determine the overall loss performance, they separate dielectric and conductor loss precisely.

Radim ZAJICEK, Ladislav OPPL, Jan VRBA [65] evaluated a method for determining complex permittivity and found a phantom of biological muscle tissue, and some industrial chemicals which are suitable in the frequency range of approximately from 30MHz to 1GHz. It uses a probe with dimensions of SMA connector in the range of 30MHz to 3 GHz.

William R. Humbert [66] presented a new method based on resonant technique for measuring the permittivity and loss tangent of cylindrical dielectric rods. Finite element method was used to model the measurement fixture to get accurate results for low loss dielectrics.

Sekar, V, et al., [67] used microwave oscillators to measure the dielectric constant of materials. In this paper split ring resonator (SRR) is used as a sensing element to determine the dielectric constant of the material. This calculation is based on change in oscillation frequency caused by MUT (material under test). Finally a novel approach is developed by the authors to calculate the dielectric constant of the materials.

Based on literature survey it is observed that no research has been published against the low cost, high speed, non-destructive, SDR based wide band dielectric measurement method and practical setup by adopting VLSI and Embedded technology trends.