Dielectric probe kit for determination of electromagnetic properties over a wide band of frequencies

Dr. M Jaleel Akhtar
Asst. Professor
Microwave Imaging and Material Testing Laboratory
Department of Electrical Engineering IIT Kanpur
E-mail: mjakhtar@iitk.ac.in, Tel. +91 512 259 6523

Background

In recent years, there is lot of interest to explore the use of microwaves for imaging, nondestructive testing, characterization and remote sensing of materials, media and objects. It has got application in a number of areas spanning over many branches of science and engineering. The main advantage offered by microwaves is that they can provide information about the inner structure of the media or objects by carrying out measurements at the surface. The determination of complex permittivity of the material or the object under test is the basic problem in the microwave characterization, imaging and sensing. Some of the applications, where the dielectric properties data of the material or the object under test in the RF/microwave frequency range are required, are as follows:

1. The microwave imaging is relatively a new area of research, where the idea is to make use of low power microwaves to determine the electrical and physical properties of the object or medium under test. It is an efficient diagnostic procedure for non-invasively visualizing dielectric properties of non-metallic bodies. It may be noted here that these properties of the object can not be measured using any *in-situ* procedure, as any direct or *in-situ* methods are usually destructive in nature. The measurement of dielectric properties of a variety of materials over a wide frequency band is the first and quite crucial step in order to pursue this new research field of microwave imaging and sensing.
2. For planar antenna and filter applications, the accurate determination of dielectric properties of the substrate is quite important for getting optimized performance as well as for performing accurate simulations. The knowledge of dielectric properties of the host material is equally important for RFID tags as well as for meta-materials.
3. In civil engineering applications, the microwave techniques are being explored to be used in a number of areas starting from remote sensing, surveying, geophysical prospecting and archeological applications to the nondestructive evaluation and testing of concrete structures and buildings. The basic idea behind microwave nondestructive testing and remote sensing is that various objects in the underground and the concrete structure can be differentiated due to their difference in dielectric properties.
4. For biological applications, there is a lot of interest to use microwaves nowadays for the imaging of soft tissues as they have substantial difference in their dielectric properties. It has recently been

established that dielectric properties of cancerous or malign tissues are quite different from that of the healthy tissues. This principle has been explored to detect the breast tumor at an early stage. As the photon energy of microwave is sufficiently low, hence it is considered to be relatively safe compared to X-rays. However, to fully explore this research field, the dielectric properties of a number of biological tissues (both healthy and malign) should first be accurately determined in order to find out the contrast between dielectric properties of two types of tissues.

5. The advanced composites are nowadays quite often being used in lieu of conventional metals in the aerospace and luxury automobile industries for increasing the strength to weight ratios, and thereby reducing the weight of the airplanes and high end cars. However, one of the bottlenecks till now in the wider applicability of these advanced composites is their higher costs as compared to their metal counterparts. There is some research going on in recent years to cure these composites using microwaves, which actually helps in saving the energy by a substantial amount. The knowledge of dielectric properties of all the associated materials is crucial in order to find their suitability for microwave curing applications.
6. There is lot of interest nowadays to use nano-particles in order to modify the material properties of the base polymer matrix. As the amount of nano powder added to the matrix is usually small, hence it is quite difficult to observe the effect of these powders using any direct method. The measurement of dielectric properties of the nano-modified samples over a wide frequency band provides the possibility of studying the effect of nano particles on the material properties of the base material.

It is obvious from above discussion that the establishment of an experimental test facility for measuring the dielectric properties of a range of materials over a wide frequency band is quite beneficial for researchers working in different field of science and engineering. This kind of facility is also helpful in doing some inter-disciplinary research, where researchers from various fields and background can come together in order to achieve a result oriented goal. The procurement and installation of dielectric probe kit in the Department of Electrical Engineering is the first step in this direction.

Dielectric Probe Kit

The dielectric measurement facility in the microwave frequency band was established in the Department of Electrical Engineering in the year 2010 with CARE grants from IIT Kanpur. The facility is based on the Agilent Technologies 85070E Dielectric Probe Kit, which comes along with the vector network analyzer and associated microwave components. The established facility enables one to determine the intrinsic electromagnetic properties of wide range of materials in the broad frequency range of 200 MHz to 20 GHz. As the dielectric properties of materials are related with their molecular structure, the measurement of dielectric properties leads to much other useful information which is otherwise quite difficult to obtain. These properties are usually expressed in terms of permittivity and permeability, which might change with frequency, temperature, orientation, mixture, pressure etc.

The electromagnetic characterization facility using the dielectric probe kit is currently installed in the Microwave Imaging and Material Testing Laboratory of the Electrical Engineering department as shown in Fig. 1. The facility is expected to be used by departments of Civil Engineering, Bio Engineering, Material Science and Engineering, apart from the host department. The dielectric probe kit is one of the most useful methods for electromagnetic characterization of materials in the broad frequency range. The complete system is based on a network analyzer, which measures the material’s response to RF or microwave energy. The probe transmits a signal into the material under test (MUT), and the reflected data is used to determine the dielectric properties of the MUT using special software, which is supplied along with the kit.

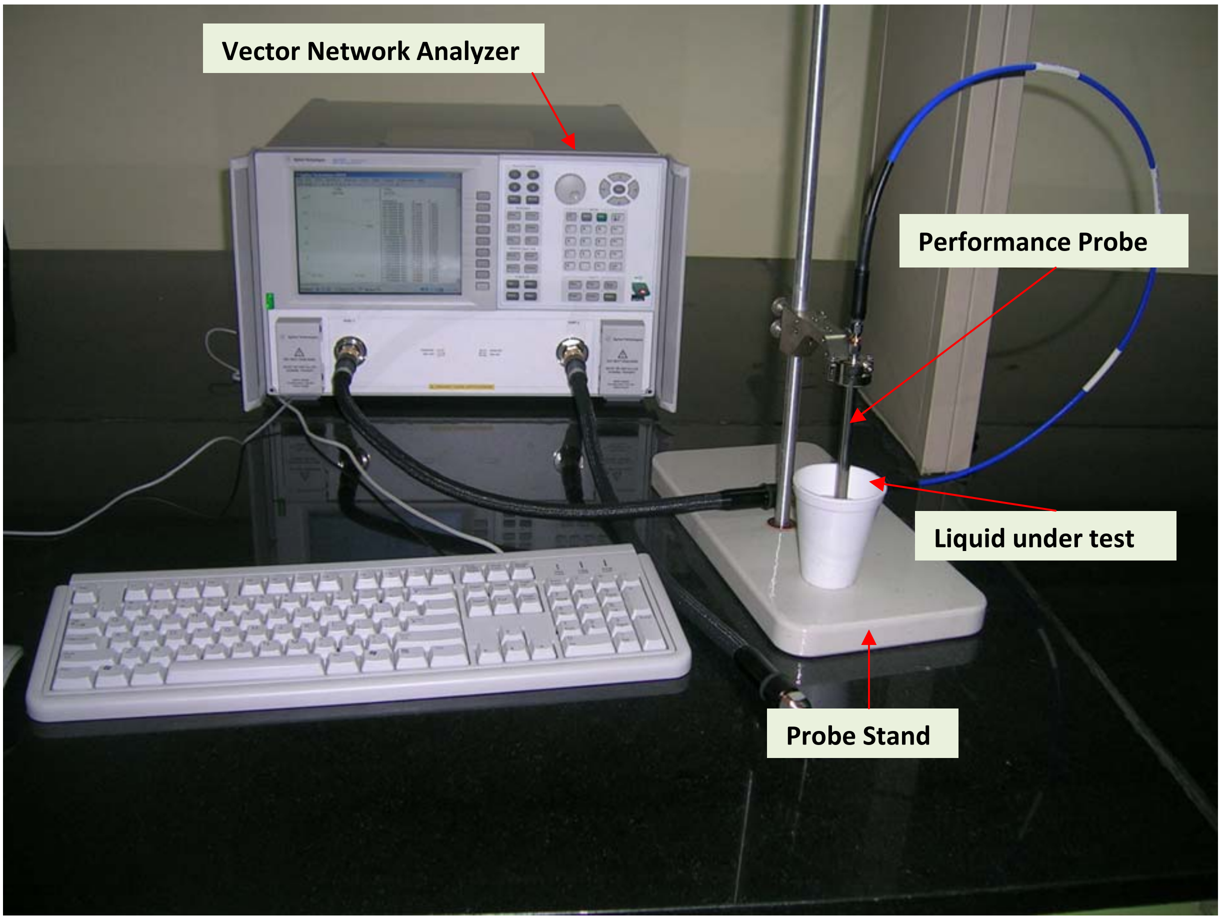

Fig. 1: Dielectric Probe Kit for electromagnetic characterization of materials

The probe supplied with the kit is quite versatile, and dielectric measurements can be carried out by simply immersing the probe into test liquids or semi-solids without requiring any special fixtures or containers. The procedure does not require any sample preparation, and the measurements are quite often non-destructive and can be made in real time. The software controls the network analyzer and guides the user through easy setup and measurement procedures. The complex permittivity of the test sample is finally displayed on screen of the network analyzer using the supplied software.

The major components of the dielectric probe kit are as follows:

1) Performance Probe
2) Probe Stand
3) 20 GHz PNA Series network analyzer
4) Dielectric Probe Software
5)

1. Performance Probe:

The Performance Probe has many features such as ruggedness, high temperature and frequency performance in a slim design. The probe is sealed on both the probe tip and the connector end. The probe withstands a wide -40°C to +200°C temperature range. It is useful for measuring liquid, semi-solid as well as flat surfaced solid materials. The performance probe kit comes complete with a calibration short. The small diameter of the probe makes it possible to do measurement with small samples.

2. **Probe Stand:**

The probe stand is used to hold the performance probe. The probe stand has 13 x 7 inch porcelain base and 24 inch high by 0.5 inch diameter metal support.

3. **20 GHz PNA series vector network analyzer:**

The Vector Network Analyzer is quite versatile device, which includes a synthesized source, a wide dynamic range receiver, and a built-in test set. The Network Analyzer consists of two ports, a control panel, an information display and two RF cables to connect the device under test DUT with the analyzer. The types of these cables depend upon the frequency range of operation. One of the important steps in the measurement using Vector Network Analyzer is to do a proper calibration at the measurement reference planes. The calibration is usually done at the end of the test cables to eliminate any systematic errors occurring from the effects of the test fixture and its associated cables and hardware. The calibration procedure calculates the difference between measurement data of known calibration standards and ideal measurement data to create error correction array, which are then applied to actual measurements. The dielectric probe shown in Fig. 1 employs three calibration standards, which are air, a metal piece working as short, and water at room temperature in order to minimize the error during actual measurement.

4. **Dielectric Probe Software**

The dielectric probe kit shown in Fig. 1 comes with a software, which controls the network analyzer and guides the user through easy setup and measurement steps. The software may run on a PC or internally on the PNA series of Network Analyzer. The software controls the network analyzer to measure the complex reflection coefficient of the MUT (material under test). Then it converts the reflection coefficient into the complex permittivity of the MUT. Finally it displays the measurement results in a variety of graphical and tabular formats. The software also facilitates printing or plotting the results, saving the result in a number of formats. The software guides the user through normal “three standards calibration”, which are short, open and water, performed at the end of the probe. After the probe calibration, the measurement of the actual test sample can be performed by either pressing the probe against the specimen (for solid samples), or by immersing the probe into the specimen (for liquid samples).