TITLE: Data acquisition with Coaxial dielectric probes

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SHORT DESCRIPTION: This document's intention is to provide a generic and instrument-unspecific guideline to help in the process of acquiring reliable and reproducible data with a Coaxial dielectric probe. Areas covered are sample and coaxial dielectric probe handling, data storage and a few quick reminders on data analysis. Extensive advice on data analysis is beyond the document's scope.

ABBREVIATIONS / TERMINOLOGY:

VNA - Vector Network Analyzer:

S11 - Scattering parameter

ESD - Electrostatic discharge

CDP - Coaxial dielectric probes

RFI - radio-frequency interference

MUT – material under test

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Introduction

This document attempts to provide a generic and instrument unspecific guideline for use of dielectric probes. The intention is to provide basic information needed to perform reliable and repeatable and safe measurements. Text gives notes on probe handling and maintenance, performing measurements, and common sources of errors.

Coaxial dielectric probe is a rigid coaxial structure of well-defined, known dimensions and electrical characteristic. The fields at the probe end “fringe” into the material and change as they come into contact with the MUT. The material is measured by immersing the probe into a liquid or touching it to the flat face of a solid (or powder) material. The reflected signal (S11) can be measured and related to dielectric permittivity. Probe is typically connected to VNA that performs S11 sweep over desired frequency range.

Equipment and operator safety

Performing CDP measurements may expose operator to material under test. Necessary persuasions should be taken to avoid injury or exposure to harmful substances.

VNA is sensitive to static electricity, special care should be taken to avoid damage from ESD. Conducting wrist straps should be used to prevent high voltages from accumulating on workers bodies, also anti-static mats or conductive flooring materials are desirable. No highly-charging materials should be in the vicinity. The inner conductors of any RF cables, connectors or probes should never be touched, or come in contact with an electrostatically charged surfacethe .

Calibration and measurement

A typical measurement system using a coaxial probe method consists of a network analyzer or impedance analyzer, software to calculate permittivity, and a coaxial probe, probe stand and cable.

Ensure proper connection of coaxial cables from VNA to the CDP. Therefore all connectors should be checked in case there is any damage on the inner or outer connector or any dirt. To tighten cables the appropriate torque wrench should be used which ensures good connection and prevents damage to the connectors. Ensure a stable position of all the cables and respecting their specific minimal bending radius. Moving cables can lead to significant change in S11 phase thus voiding the probe calibration. Keep cables as short as possible to reduce signal losses. If application allows use rigid cables and avoid movement. Make sure cables are specified to work in the frequency range used in experiments.

Before measuring, calibration of the probe must be performed. A three-term calibration corrects for the directivity, tracking, and source match errors that can be present in a reflection measurement. In order to solve for these three error terms, three well-known standards are measured. The difference between the predicted and actual values is used to remove the systematic (repeatable) errors from the measurement. The three commonly used known standards are air, a short circuit, and distillate and de-ionized water. Even after calibrating the probe, there are additional sources of error that can affect the accuracy of a measurement.

Stable environment is important for experiment repeatability, environment temperature should be stable and known, sample temperature should be known, controlled and recorded. Sample contamination should be avoided by use of clean containers, tweezers and other instruments that contact the sample including the probe itself. Clean the probe between measuring calibration materials (especially I case of liquids) and MUTs. If using cleaning agent such as alcohol, make sure it evaporated from the probe surface.

The MUT volume must be sufficient for correct results, sensing volume depends on probe aperture. As a rule of thumb the MUT depth should be several times greater than the probe aperture, container diameter, (lateral dimensions of the sample) should be double of the aperture diameter. These are general rules and exact minimal dimensions should be experimentally determined. Minimum depth of the MUT can be determined experimentally by applying conductive metal plate behind the MUT, if no change in measured S11 or dielectric parameters is observed, sample depth is sufficient.

If measuring liquids, ensure there are no air bubbles at the probe end after immersion. Measuring rigid solids is difficult cause it is not possible to ensure good contact between the probe end and the material; any tilt and the air gap will introduce a large error.

Soft solids can be measured if it is possible to ensure contact without air gaps. It should be noted that force applied to the sample in contact with the probe can cause changes in material properties.

After a measurement session it is good to measure a known standard to check if calibration is still valid and if system parameters have changed. Ideally the known standard is measured after calibration and once more after measurement session.

The computer software calculates dielectric properties from S11 data. The final results always depend on the software algorithm and probe model used, its limitations should be known and taken into account.

Feedback from collaborators (May 2020)

In the practical use cases there are two major limiting factors of the dielectric probe kit:

- The cable movements and corresponding influence on the calibration [1]
- The contact quality between probe kit and the material under investigation [2]

For the first item, the dielectric constant and loss factor measurements are only valid if there is minimal or no cable movement, as even a slight perturbation as moving the cable e.g. 10 mm is enough to invalidate the calibration of the dielectric probe and causing a standing wave pattern to appear in the measurement result [1]. To remedy cable movement two solutions are identified. Firstly, the calibration refresh using ECal and ensuring rigid connection between dielectric probe and ECal. Secondly, using a handheld network analyzer (NA) to maintain a rigid connection directly to the NA and avoid cables altogether. Both types have been investigated in the project.

For the second item, the quality of contact between probe kit and the material under test (MUT) to be investigated, there are less efficient methods to overcome the issues [2]. When measuring solid materials with rough, concave or convex surfaces, in general a problem of contact between dielectric probe and material is typically observed. The same contact issue can be caused by having the probe-kit contacting the MUT at an angle instead of perpendicular to the surface. Also, effects of bad contact can be due to an air gap being present between dielectric probe and the MUT, creating two additional boundary layers and resulting reflections interfere with MTU measurement and corrupting the results. In some cases contact problems can be mitigated by use of matching medium or by applying pressure in order to remove the air gap, but exact quantifications of contact pressure and angles are difficult under routine applications.

References

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2. Keysight App note, Basics of Measuring the Dielectric Properties of Materials, https://www.keysight.com/us/en/assets/7018-01284/application-notes/5989-2589.pdf?success=true