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Non-invasive liquid recognition based on interdigital capacitor

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ABSTRACT

In this paper we investigated the possibility to conduct a non-invasive identification process of liquid samples packed in glass and polypropylene containers. Interdigital capacitor (IDC) structures were designed as solid (build using standard PCB fabrication procedure) and flexible (paper based) structure. Testing was performed using benzene, olive oil, acetone, alcohol, methanol, purified water and formaldehyde. Sample volume and container influence was examined. Information about the sample is available on a 2×16 character and through RS232 connection on PC. Experiments showed promising in building a portable and cost-effective sensing unit for on-field application where it is necessary to discriminate between several packed liquid samples.

1. Introduction

Dielectric properties of materials can be determined with the use of electromagnetic (EM) waves (radar/microwave) in the investigations of material and structural assessment. Permittivity of a material may be used to determine various properties usable for research and application in food science, medicine, biology, agriculture, chemistry, electrical devices, defense industry (security), and engineering. Many techniques have been applied for the measurement of dielectric properties of a material [1–5].

Identification of liquids is of great importance in security, biology and beverage industry. Some of the measurable physical properties like melting point, boiling point, refractive index, density, solubility, and viscosity can discriminate between two possible compounds [6].

In the development of basic elements for sensing applications, the most important features of every sensor are suitability for integration of the sensor element and signal-processing electronics, and also an inexpensive way for manufacturing. Compared to other sensor technologies [7–11] interdigital capacitors (IDC) have been extensively researched [12–15] and successfully used as sensors for large variety of applications [16–21]. Non-destructive testing and evaluation based on electromagnetic principles become widely used due to simplicity, fast response and low cost [22].

The purpose of this paper was to investigate the possibility to distinguish between liquids without a direct contact between a sample and an IDC sensor. Conditioning circuit measures the change in capacitance of the IDCs as a change in a charge/discharge time converted into frequency. Data were processed by a microcontroller with results available on 2×16 character display as well as PC. The system has been experimentally tested against benzene, olive oil, acetone, alcohol, methanol, purified water and formaldehyde. Container type and sample volume dependency was examined and results reported.

2. Interdigital capacitor operation principle and design

An interdigital capacitive sensor is a coplanar structure consisting of multiple comb electrodes. Compared with parallel plate capacitor structure, IDC electrodes open up thus providing planar structure (Fig. 1). By applying different potential on electrodes [23] electromagnetic field generates in between. Electrode and geometry as well as dielectric properties of material under test (MUT) affect the capacitance and conductance between electrodes.

For sensing applications two electrode arrangements can be considered (Fig. 2): invasive (direct contact between a sample and electrodes) and non-invasive (no direct contact between the sample and electrodes). Present study examines the possibility to conduct the recognition process of liquid samples packed in predefined containers. This approach can be considered as a non-invasive electrode arrangement, because the interaction between the metal electrode and MUT occurs over a container.

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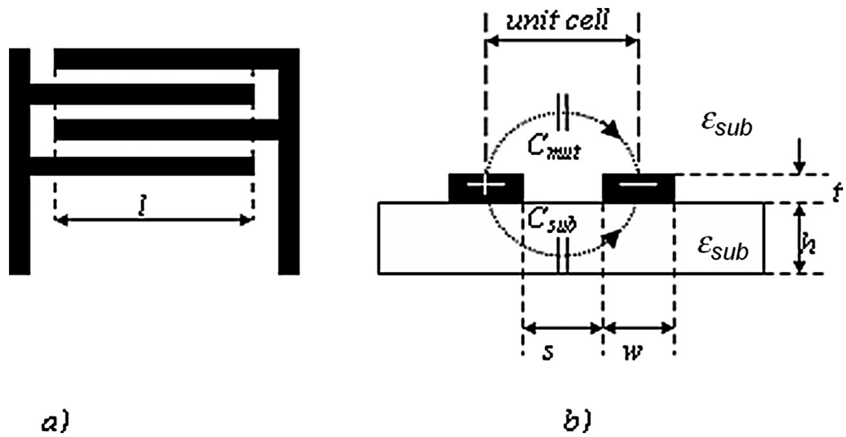

Fig. 1. IDC: (a) planar structure, (b) cross-sectional view (l – length of the fingers, h – height of the substrate used, t – thickness of the conductive material forming electrodes, ε_{sub} – permittivity of substrate, ε_x – permittivity of MUT, s – electrode spacing, w – electrode width).

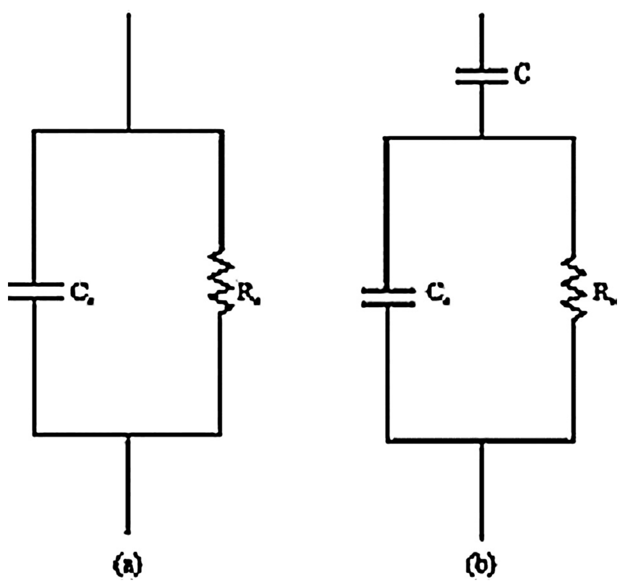

Fig. 2. Equivalent circuits for: (a) invasive and (b) non-invasive electrode arrangement.

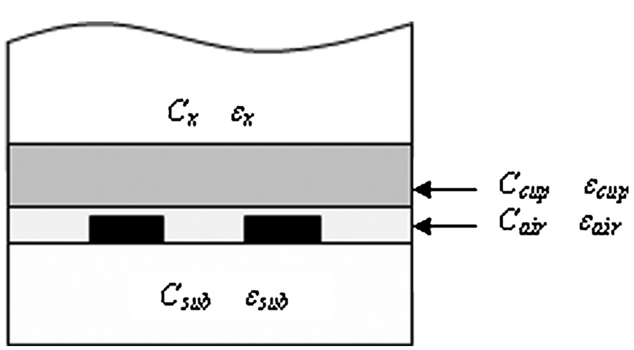

Fig. 3. Cross-section view of IDC sensor with its superimposed layer capacitance configuration.

As it can be seen (Fig. 3), there are three layers above the electrodes: air (in sub-mm height due to non-ideal contact between electrodes and the container), container wall (with substantial thickness) and a liquid sample. Electromagnetic field lines must penetrate through air, the container and sufficiently into the MUT. As reported in [24] maximum electric field penetration height, occurs at about half the sensor wavelength λ. This means that

Fig. 4. Fabricated sensors.

the sensor is not sensitive to a distance from the electrode plane greater than $w+s$. Containers prepared for sample packing were polypropylene (PPC) and glass (GC) containers. PPC has 55 mm in diameter, approximately 0.5 mm floor thickness. GC has 55 mm in diameter, approximately 3 mm floor thickness. Based on this dimensions, $w+s$ must be greater than 0.5 mm in order to penetrate PPC container floor, and greater than 3 mm when used for GC. Solid PCB IDC's structure was fabricated using standard PCB fabricating procedure. Structure on FR2 board, consists of seven fingers with $l = 37.5$ mm, $w = 4$ mm, $s = 0.5$ mm.

During experiments in our previous work [25] it was established that some of the fast vaporizable samples (such as benzene, acetone and ethanol) deteriorate, if measurement process lasts. This can cause degradation in sensor readings. In order to avoid this, standard 5 ml polypropylene syringes were prepared for these samples with flexible paper based IDC structure to be taped around. Syringes have 10 mm in diameter, with 1 mm wall thickness. Paper IDC needs $w+s$ greater than 1 mm in order to penetrate into the MUT. Flexible paper-based IDC structure [26] consisting of seven fingers with $l = 28$ mm, $w = 3$ mm, $s = 2$ mm was fabricated on regular blank piece of paper with traces drawn using nickel conductive emulsion provided from CircuitWorks. Traces drown in this way have μm thickness fully conductive in air cure reached in 45 min. Fabricated sensors are reported in Fig. 4.

3. Experimental setup

3.1. Interface circuit

As used in our prior work, capacitance was measured using timer TLC555 [27]. This timer operates at frequencies up to 2 MHz.