Method and device for measuring dielectric properties of a fluid through an array of cavities in a stack of printed circuit boards

The present invention relates to a method and device for measuring the dielectric properties of a fluidum containing at least 10 percent by volume of a fluid, characterized by at least a first metal plated cavity, or an array of metal plated cavities, present in a first printed circuit board (PCB), at least a first transmission line connector mounted on the first PCB, at least a first stripline resonator printed on the first PCB and connected to the first transmission line connector, at least a second PCB, said second PCB having at least a second metal plated cavity or an array of metal plated cavities at exactly the same PCB lay-out coordinates as the cavities in the first PCB, means to stack and attach the second PCB onto the first PCB, whereby at least a first metal plated cavity in the first PCB is galvanically connected to at least a second metal plated cavity in the second PCB so that at least the connected individual first and second cavities merge into a third metal plated cavity with a larger volume than the first metal plated cavity or the second metal plated cavity. At least the third metal plated cavity is filled with the fluidum under investigation. The first stripline resonator is connected to a function generator and to a spectrum analyzer and an amplitude versus frequency plot (A-f) plot is made. The shape of the A-f plot reflects the dielectric properties of the fluidum under investigation.

Introduction

The present invention relates to a method and device for inline measurement of the properties of a fluidum, without the use of chemicals, using the physical principles of transmission line technology. More specifically, the present invention relates to a method and device to measure the dielectric properties of fluids, fluid - solid suspensions, fluid – gas suspensions and solid – gas suspensions. Even more specifically, the present invention relates to a method and device to assess the properties of water, such as drinking water, waste water and industrial process water.

Many prior art methods to determine the quality of drinking water, process water and industrial water are labor intensive, require the use of chemicals for chemical and / or biological analysis and are offline. As a result, many prior art water analysis techniques are expensive and introduce a time delay before measurement information is available.

A promising technique to track changes in the quality of a water stream is to asses its dielectric properties. Existing prior art methods to measure the dielectric properties of a solution are based on classic capacitance measurements in discrete elements such as a plate capacitor. These methods are offline and suffer from relatively large parasitic capacitance and / or parasitic inductance, thereby limiting the sensitivity of the measurements, and / or require a relatively complex measurement set-up, involving relatively high investment cost. A recently developed technique for inline measurement of the dielectric properties of fluids is based on transmission line technologie. A fluid sample is applied as dielectric in a transmission line resonator, such as a coaxial stub resonator or a stripline resonator. Subsequently, the electric properties of the transmission line resonator, further on referred to as stub resonator, are characterized by an amplitude versus frequency plot, further on referred to as A-f plot. The shape of the A-f plot is determined by the dielectric properties of the fluid under investigation. By the use of transmission line theory i.e., by solving the telegrapher's equations, the dielectric properties of a fluid i.e, its dielectric permittivity and loss tangent as a function of frequency, can be derived directly from the A-f plot. More qualitatively, an A-f plot provides a fingerprint of the fluid and can be used to track changes of the fluid composition and to use these changes in an early warning system.

The technology according to the present invention deals with a unique combination of stripline resonator design and design of resonator cavities in the dielectric of the stripline that are electromagnetically coupled with the stripline, resulting in a very sensitive and specific sensor system. The sensor technology according to the present invention is based on printed circuit board (PCB) technology so that the sensor according to the present invention can be produced in a reliable, reproducible and cost effective way.

Description of the technology according to the present invention

According to a first aspect, the present invention relates to a function generator FG. This function generator preferably produces a sinus or square wave electrical signal with a frequency that can be adjusted in the range between 1 Hz and 50 GHz.

According to a second aspect, the present invention relates to a spectrum analyzer or a hf (high frequency) rectifier SA, preferably able to measure the amplitude of a sinus or square wave electrical signal with a frequency in the range between 1 Hz and 50 GHz.

According to a third aspect, the present invention relates to a first PCB with a first stripline resonator on it. The definition of a stripline resonator in this document is any geometric shape on the PCB, that behaves as a transmission line, including a wire according the definition in this document or a ground plane according to the definition in this document.

According to a fourth aspect, the present invention relates to at least a first metal plated cavity or an array of metal plated cavities present in the dielectric of the first stripline.

According to a fifth aspect, the present invention relates to at least a first metal connection point that is galvanically connected to the first metal plated cavity and that is located on the PCB surface and around the first metal plated cavity.

According to a fifth aspect, the present invention relates to at least a second PCB, said second PCB having at least a second metal plated cavity or an array of metal plated cavities at exactly the same PCB lay-out coordinates as the first PCB.

According to a sixth aspect, the present invention relates to at least a second metal plated cavity or an array of metal plated cavities at exactly the same PCB lay-out coordinates as the cavities in the first PCB.

According to a seventh aspect, the present invention relates to means to stack and attach the second PCB onto the first PCB, whereby at least a first metal plated cavity in the first PCB is galvanically connected to at least a second metal plated cavity in the second PCB so that at least the connected individual first and second cavities merge into a third metal plated cavity with a larger volume than the first metal plated cavity or the second metal plated cavity. The means to stack and attach the second PCB onto the first PCB may consist of, but are not limited to, glue, screws in accurately designed screw cavities in the PCBs, a resin like polyurethane resin and a hotmelt polymer like Pattex hotglue.

According to an eighth aspect, the present invention relates to at least the third metal plated cavity being filled with the fluidum under investigation.

According to a nineth aspect, the present invention relates to at least a microcontroller that is connected to the function generator or to the spectrum analyzer and equipped with software to automatically determine amplitude versus frequency plot (A-f) plots. The shape of the A-f plots reflect the dielectric properties of the fluidum under investigation.

Figure 1 gives a schematic overview of the technology according to the present invention.

The numbers in figure 1 have relate to the following elements that were previously described in aspects one to nine:

1. First PCB
2. Second PCB, feasible for stacking onto the first PCB
3. Third PCB feasible for stacking onto the first PCB
4. First transmission line connector
5. First metal plated cavity, galvanically connected to a first metal connection point on the PCB surface, shown in figure 1 as the surface area between the 2 concentric circles of element 5.
6. First stripline resonator on the first PCB. It is noted that the first PCB may be plated and grounded on the backside. In that case, the PCB consists of a wire placed at a fixed distance from a ground plane. Note that, in case a ground plane is applied, the cavities are NOT connected to the ground plane.

The main aspects of the present invention have now been described. In the following, the aspects of the present invention will be further detailed. Also a number of preferred embodiments of the present invention will be explained.

Preferably, the function generator FG and the spectrum analyzer SA have an internal resistance of 50 Ohm. The characteristic impedance of the stripline resonator preferably amounts 50 Ohm. All metal connections on the PCB are preferably gold plated. The length over diameter ratio of the cavities is preferably large than 1. The base resonant frequency of the stripline resonator is preferably lower than that of the cavity or array of cavities. Preferably, the base resonant frequency of the stripline is a factor of 10 lower than the base resonant frequency of the metal plated cavities. More preferably, the base resonant frequency of the stripline is more than a factor 50 lower than that of the metal plated cavities. Preferably, the base resonant frequency of the stripline is in the range of 1 MHz to 200 MHz. Preferably, the base resonant frequency of the cavities is in the range of 100 MHz to 10 GHz.

In order to explain a number of preferred embodiments, a definition of a wire, a ground plane and a stub resonator is given.

In this document, a wire is defined as a metal containing conductor shaped as a cilinder, a rectangular cuboid, a cuboid or any other 3D shape that may act as an electrical conductor.

In this document, a ground plane is defined as any metal containing plane that may act as a conductor and / or shield for electromagnetic waves. In this document, the characteristic dimensions of a cilindrical wire are defined as the diameter of the wire and the length of the wire. In this document, the characteristic dimensions of a rectangular cuboid as defined as the length of the cuboid, the width of the cuboid and the height of the cuboid. In this document, the characteristic dimensions of any other wire are defined as the value of the minimum number of mathematic parameters that are required to exactly define the dimensions of that wire. In this document, a ground plane is defined as any metal containing plane that may act as a conductor and / or shield for electromagnetic waves. In this document, the characteristic dimensions of the ground plane are defined as the length of the ground plane and the width of the ground plane in case the ground plane is a rectangle. The characteristic dimensions of any other ground plane than a rectangular ground plane are defined as the value of the minimum amount of mathematical parameters that are required to define the exact shape of the ground plane. In this document, a stub resonator is defined as a resonator based on any type of transmission line such as, but not limited to, a coaxial transmission line resonator, a stripline or any combination of striplines and / or coaxial transmission line resonators.

In a first preferred embodiment, the ground connection of the first stripline resonator on the first PCB is limited to the ground of the first transmission line connector that is mounted on the PCB.

In a second preferred embodiment, the ground connection of the first stripline resonator on the first PCB is a ground plane. It is noted that the cavitities in the dielectric of the first stripline resonator are not galvanically connected to this ground plane.

In a third preferred embodiment, the first stripline resonator consists of a first discrete wire, placed at a fixed distance from 2 parallel wires, such that the first discrete wire is present between the other 2 wires. Preferably, the 3 wires are present in the same plane. It is noted that also so called "off center" transmission lines in which the first discrete wire is not placed exactly in the center between the other 2 discrete wires make part of the present invention.

In a fourth preferred embodiment of the present invention, the first stripline resonator on the first PCB consists of 2 discrete parallel wires. Preferably, the 2 parallel wires are present in the same plane.

After explaining the preferred embodiments, the working principle of the new sensor system according to the present invention will now be further detailed. A function generator and a spectrum analyzer or rectifier are connected to the first stripline resonator on the first PCB. Subsequently, the function generator is programmed to produce a number of sinus or square wave signals, with a known amplitude, and different frequencies. At each frequency, the attentuation of the signal is measured by the use of the spectrum analyzer or rectifier so that an amplitude versus frequency plot (A-f plot) is produced. From transmission line theory, it is known for a person skilled in the art that the first stripline resonator has a base resonant frequency and higher harmonics. The third metal plated cavity of the array of metal plated cavities formed by stacking at least the first PCB and the second PCB behaves like a half wavelength resonator. Since the third metal plated cavity is at least partly filled with the fluidum under investigation, the resonant frequency of the third metal plated cavity or the array of metal plated cavities will change with changes in composition of the fluidum under investigation. The amount of electromagnetic energy that is coupled from the first stripline resonator into the third metal plated cavity or the array of metal plated cavities, where it is dissipated for the greater part, is high at the resonant frequency of the third metal plated cavity or the array of metal plated cavities. The amount of electromagnetic energy that is coupled from the first stripline resonator into the third metal plated cavity or the array of metal plated cavities, where it is dissipated for the greater part, is maximum in case a higher harmonic resonant frequency coincidences with the resonant frequency of the third metal plated cavity or the array of metal plated cavities.

From the reasoning above, it can be concluded that the system according to the present invention can be designed such that it is very sensitive to small changes in dielectric properties of the fluidum under investigation. Additionally, the reasoning above provides design criteria for the first stripline and for the third metal plated cavity or the array of metal plated cavities:

- the first stripline resonator should have a high quality factor, especially at higher harmonics, in order to efficiently couple electromagnetic energy into the cavities.
- the length of the cavities should be sufficiently long in order to ensure that the base

resonant frequency of the cavities is in the frequency range at which higher harmonics of the first stripline resonator are still stable.

- by the use of a Maxwell equation solver, the geometry of the first stripline resonator and the cavities can be designed iteratively and such that their (higher harmonic) resonant frequencies will coincidence at, at least one, frequency. Around this frequency, the sensor is very sensitive to small changes in the dielectric properties of the fluidum under investigation.
- by designing cavities of different length, simply by the use of additional PCBs in the stack that have partially unplated cavities or no cavities at all, a sensor is obtained with high sensitivity in a broad frequency range.

It is noted that the technology according to the present invention is very feasible to detect bacterial growth in the cavities. By filling the cavities with a gel or medium for bacterial growh and by placing the sensor into a fluid under investigation, the bacterial growth potential of a fluid under investigation can be determined, see also figure 2 in which object #7 stands for a bacterium. By filling the cavities with a polymer that selectively adsorbs or absorbs components present in a fluid under investigation, the technology according to the present invention can be applied to detect very low concentrations of those components in a fluid. A commercially available polymer that is very feasible to be applied as polymer dielectric in the metal plated cavities according to the present inventions is a propylene macroporous polymer of the type Accurel.

Clauses

1. Sensor for measuring the dielectric properties of a fluidum consisting for more than 10 percent by volume of a fluid characterized by
    - a function generator and
    - a spectrum analyzer or rectifier both connected to
    - first strip line resonator according to the definition in this document present on
    - a first printed circuit board (PCB) characterized by
    - at least a first metal plated cavity, or an array of metal plated cavities, present in the dielectric of the first stripline resonator
    - at least a second PCB, said second PCB having at least a second metal plated cavity or an array of metal plated cavities at exactly the same PCB lay-out coordinates as the first PCB
    - means to stack and attach the second PCB onto the first PCB whereby at least a first metal plated cavity in the first PCB is galvanically connected to at least a second metal plated cavity in the second PCB so that at least the connected individual first and second cavities merge into a third metal plated cavity with a larger volume than the first metal plated cavity or the second metal plated cavity.
    - at least one sample of the fluidum under investigation placed into at least a third metal plated cavity
    - at least one microcontroller connected to the function generator and the spectrum analyzer or rectifier equipped with software for automated measurement of A-f plots.
2. Sensor according to clause 1 whereby a least a first metal plated cavity on a first PCB and a second metal plated cavity on a second PCB are galvanically connected to a metal surface around first the metal plated cavity and the second metal plated cavity respectively, that is printed on the front side and / or the back side of the first PCB and the second PCB respectively, thereby facilitating a good galvanic connection between the first metal plated cavity and the second metal plated cavity, after stacking of the first PCB onto the second PCB.
3. Sensor according to any of the previous clauses 1 or 2 characterized by a stripline with a base resonant frequency that is in the range between 1 MHz and 200 MHz and at least a metal plated cavity with a base resonant frequency that is in the range between 100 MHz and 10 GHz.
4. Sensor according to any of the previous clauses 1 to 3 characterized by a stripline with a base resonant frequency that is more than a factor 10 higher than the base

resonant frequency of the metal plated cavities.

5. Sensor according to any of the previous clauses 1 to 3 characterized by a stripline with a base resonant frequency that is more than a factor 50 higher than the base resonant frequency of the metal plated cavities.
6. Sensor according to any of the previous clauses 1 to 5 whereby the metal plated cavities are filled with a gel or polymer on which bacteria can grow so that a sensor for detecting bacteria and / or biofouling is obtained.
7. Sensor according to any of the previous clauses 1 to 5 whereby the metal plated cavities are filled with a gel or polymer on which chemical compounds can adsorb or absorb resulting in a chemical compound specific sensor.
8. Sensor according to clause 7 whereby polymer is a polypropene macroporous polymer.
9. Sensor according to any of the previous clauses 1 to 8 containing cavities of different length thereby of different resonant frequencies.
10. Method for measuring the dielectric properties of a fluidum consisting for more than 10 percent by volume of a fluid characterized by a sensor according to one of the previous clauses 1 to 8.