LIQUID EXPLOSIVE DETECTION BY MICROWAVE RESONATORS

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Abstract: It is well known that the direct observation of the complex dielectric permittivity of liquids at microwave frequency enables fingerprint detection of certain categories of liquids, such as aqueous, organic and corrosive. Over the past seven years, we have been working on ultrafast detection of liquid explosives in sealed containers based on the evanescent field of a patented multimode cavity. Our research has led to the development of a bottle scanner for airport checkpoints, which has achieved the certification for use in European airports and passed a large number of field trials in airports worldwide. In this contribution the technology of evanescent field liquid sensing and its implementation into a user friendly software and hardware interface are explained. Moreover, orthogonal sensor approaches and verification schemes aiming to reduce false alarms will be discussed.

Scientific background

Microwave absorption of liquids is well understood on term of Debye relaxation [1]. As the most common experimental method the complex dielectric permittivity $\varepsilon^*(f)=\varepsilon_1(f)+i\varepsilon_2(f)$ in the range from about f=50 MHz to 50 GHz can be easily determined using a coaxial probe and a vector network analyzer [2]. In this way, a large variety of different liquids can be identified according to the frequency dependence of their complex dielectric permittivity, which varies quite a lot over the microwave frequency range – as a result of molecular relaxation by the intermolecular bond network and the degree of polarity (see Fig. 1). EMISENS possesses a database of complex permittivity data of most commons liquid explosives and precursors.

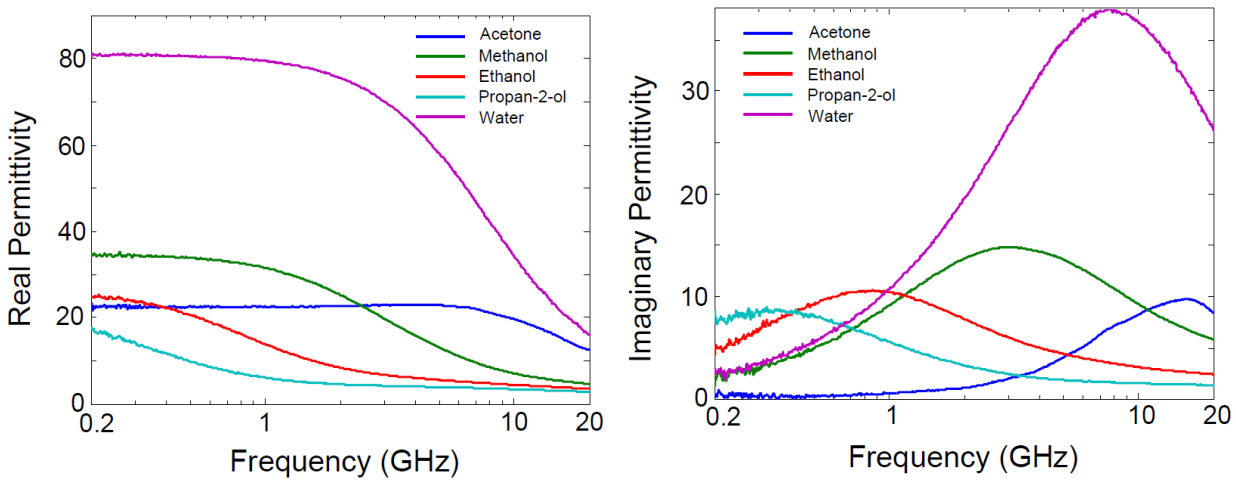

Fig. 1: Frequency dependence of the complex microwave permittivity of distilled water in comparison to a range of semi-polar liquids.

In addition, the level of ionic conductivity has a strong effect on $\varepsilon_2(f)$ below about 1 GHz, which helps to separate typical consumer liquids from a range of threat liquids and provides a clear signature of corrosive liquids such as acids. Hence, wideband dielectric microwave measurements enable fingerprint detection of many common threats. However, for recording a full spectrum like in Fig. 1, an invasive approach Is required, which requires the opening of the container for inspection. Non-invasive measurements through the container wall are much less accurate and can currently only be performed by resonator measurements at spot frequencies – provided that the container wall is non-metallic. A severe difficulty arises due to the huge variety of size and shape of non-metallic containers in a typical checkpoint situation.

EMISENS

EMISENS was founded by one of the authors (N. Klein) in 2007 as a spin-off from Forschungszentrum Juelich in Germany, the largest interdisciplinary Research Centre in Germany (www.fz-juelich.de). Together with EMISENS's partners and major shareholders Link Microtek ltd in the UK (www.linkmicrotek.com) and GLOBES Electronic GmbH&CoKG in Germany (www.globes.de), EMISENS develops, manufactures, and commercializes sensor products based on their patented microwave evanescent field sensor technology. Since 2010, the manufacturing and development site of EMISENS is with Link Microtek in Basingstoke. EMISENS products are modular assemblies of a multimodal evanescent field resonator, a tailored high-frequency analogue electronic module providing functionality and performance comparable to state-of-art microwave network analyzers, a fast data analysis software, a database containing characteristic properties of a large variety of materials, and a user interface which accommodates with the demands of non-microwave experts and commercial users.

EMILI 2 bottle scanner

Fig.2: EMILI 2S bottle scanner with integrated weight sensor (left) and dual-mode cavity small scale manufacturing at Link Microtek in Basingstoke (right).

The EMILI 2 (Fig. 2) bottle scanner (EMILI = Electromagnetic Identification of liquids) is a plug and play instrument which enables fast identification of threat liquids in non-metallic containers without the need of opening the bottle (datasheet and video see www.emisens.com). As described in [3], EMILI 2 is based on a patented semi-open dielectric-loaded dual-mode cavity. The bottle under investigation is brought with its sidewall close to the aperture of the cavity, such that the evanescent modal field leaks by a few centimeters into the liquid. Our patented dual-mode cavity utilizes two high-Q modes at around 150 MHz and 2 GHz, espectively, with strongly overlapping evanescent fields. Bottle-induces changes of the resonant frequencies and *Q* factors of both modes are determined from the measured transmission within less than one second by employing an integrated circuit-board version of a scalar network analyzer. The results are compared to a database which contains the threat liquids parameter ranges. In the most simple modus of operation, EMILI 2 displays “PASS” or “REJECT” on the output monitor within one second – depending on the result of the measurement and database comparison. For the highest possible throughput and ease of operation as well as minimal training requirement, the bottle is recognized by the software during its manual approach: the measurement is triggered automatically, as soon as the bottle is in the correct measurement position. EMILI 2 stores bottle raw data, enabling reconstruction of any possible incidence during operation within a security area. The particular detection configuration, i.e. the range of threat items to be rejected by a scan, can be adjusted by uploading a configuration file. In the latest version, EMILI 2 is equipped with a touch screen monitor, which allows customization and user interaction (see next chapter).

EMILI 2 is officially approved (Standard 2) by ECAC (European Civil aviation conference, https://www.ecac-ceac.org/), hence eligible to used at all European Airports. Over the last 12 months, EMILI successfully passed a range of field trials at a large number or airports within the EU and beyond.

Tackling the false alarms – upgrade EMILI 2S

According to valid European legislation, screening of liquids in airport checkpoint will be launched from Feb. 2014 onwards. Within a Phase 1 which is expected to last at least for one year, screening will be restricted to items which are currently exempted from the ban, such as baby food, liquid medication and liquid dietary products. Based on the success of Phase 1, which is critically dependent on the performance of the equipment in terms of reproducibility, reliability, throughput and false alarm rates, it is planned that the range of items to be screened will be gradually expanded, ultimately leading to a complete release of the ban.

Although EMILI 2 has the highest throughput in comparison to the full range of competitor’s products on the market, we have started to tackle the relatively high false alarm rates of EMILI 2 for some spirits and perfumes, which will become an issue along with the realistic possibility of screening duty-free items after re-entry into a security area. This is a particular problem of large airports like London Heathrow. On the other hand, combinations of advanced X-ray and Raman systems, as currently being favoured by some large international airports, significantly compromise the throughput and are very expensive.

Emisens and Link Microtek are currently concentrating their research and development efforts on the implementation of “orthogonal” sensing techniques into the EMILI platform. Orthogonal means that the physical properties of the liquid to be tested by the “orthogonal”

channel are not correlated to the microwave dielectric properties. As a first successful approach, the integration of a weight sensor was recently certified by ECAC. Provided that the volume of the liquid is known and that the weight of the empty container can be estimated, the physical density of the liquid can be determined, which represent an additional physical parameter which is "orthogonal" to the complex microwave permittivity. Since the scale is integrated into the EMILI detector, the additional weight determination does not compromise the measurement speed significantly.

The EMILI 2S software and hardware upgrade can be used in two different modes (Fig. 3) :

Mode 1: Database of barcoded benign items. Frequently occurring duty free items such as high-valued spirits can be easily recorded into the EMILI database, just by placing a "cleared" bottle on the EMILI 2S machine and reading the barcode with a USB-attached handheld barcode reader. If a bottle under test fails because of the microwave analysis, the user is requested via output monitor to read the barcode of the item. Provided that the barcode is in the database, EMILI compares the measured weight and microwave parameters with the entries in the database and "passes" in case of data matching within carefully defined error windows. In cases of either database mismatch or if the item is *not* in the database, the item will be rejected (see Fig. 3).

Mode 2: Manual selection of content volume and container material (ECAC approved). If a bottle under test fails because of the microwave analysis, the operator is asked to select volume and material (glass, PET, metal can) via touchscreen. In many cases the volume is indicated on the container. Partially compromised by unavoidable errors in the container weight in case of smaller glass containers, this method allows to reduce the false alarm rates significantly (see Fig. 4).

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Modes 1 and 2 can be combined in order to achieve the highest possible performance. It is worth to note that semi-filled bottles are excluded from the weight analysis, which is in accordance with existing rules for duty free items in hand luggage.

Summary

EMILI is a platform of an autonomous microwave-resonator based detection unit for fast bottle scans within checkpoint scenarios. Apart from airport checkpoint, the system software can be re-configured for other applications such as alcohol and liquid drug detection.

References

[1]: *see for example* J. Barthel and R. Buchner, "High frequency permittivity and its use in the investigation of solution properties", Pure&Appl.Chem., 1991, vol. 63 issue 10, pp. 1473-1482.

[2]: Agilent dielectric probe kit, see http://www.home.agilent.com

[3]: N. Klein et al., "Dual-mode microwave cavity for fast identification of liquids in bottles", Conference Digest of the International Microwave Symposium, 2011, Baltimore.

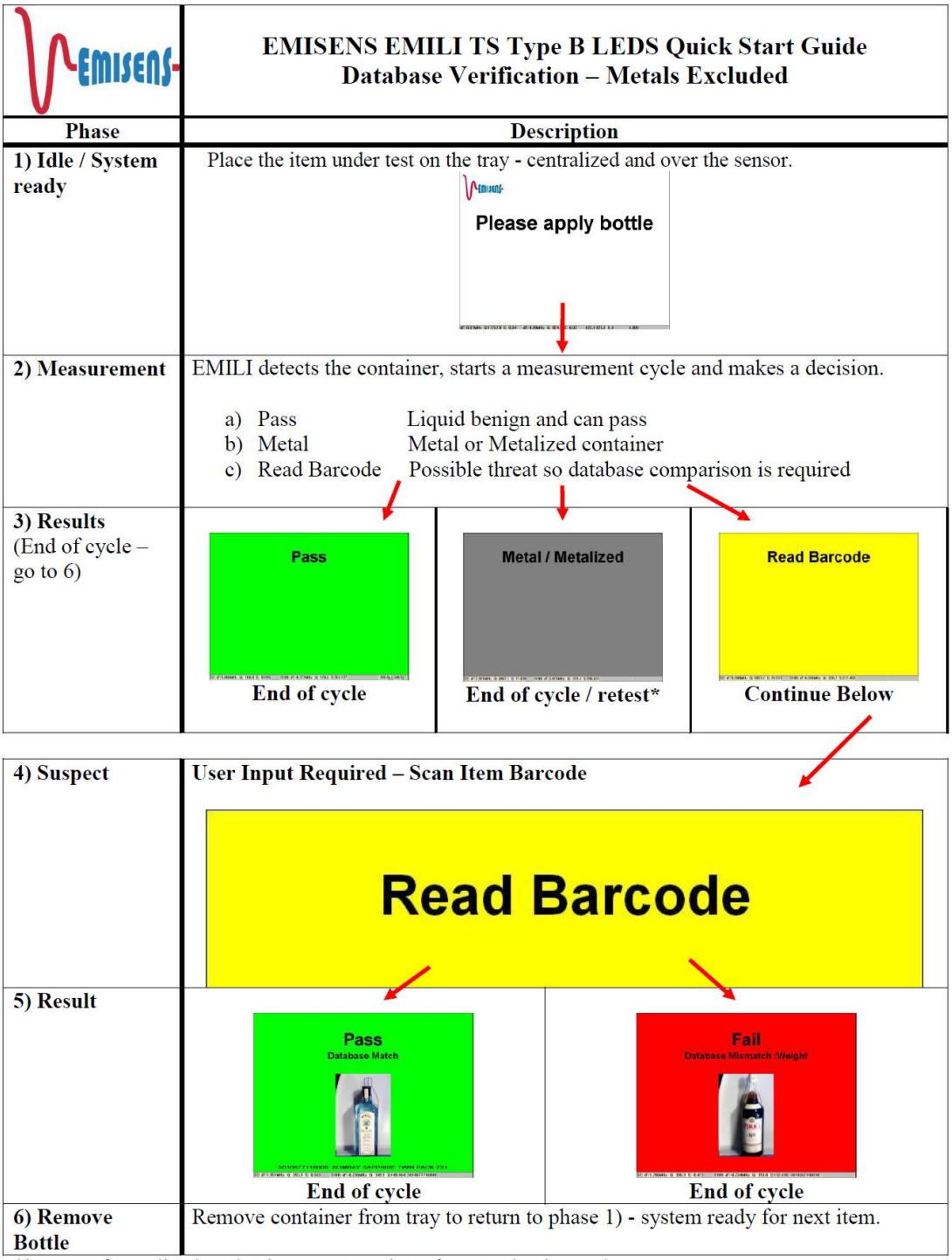

Fig. 3: Illustration of the CONOPS of the EMILI 2S upgrade by use of an integrated weight sensor, employing a barcode database

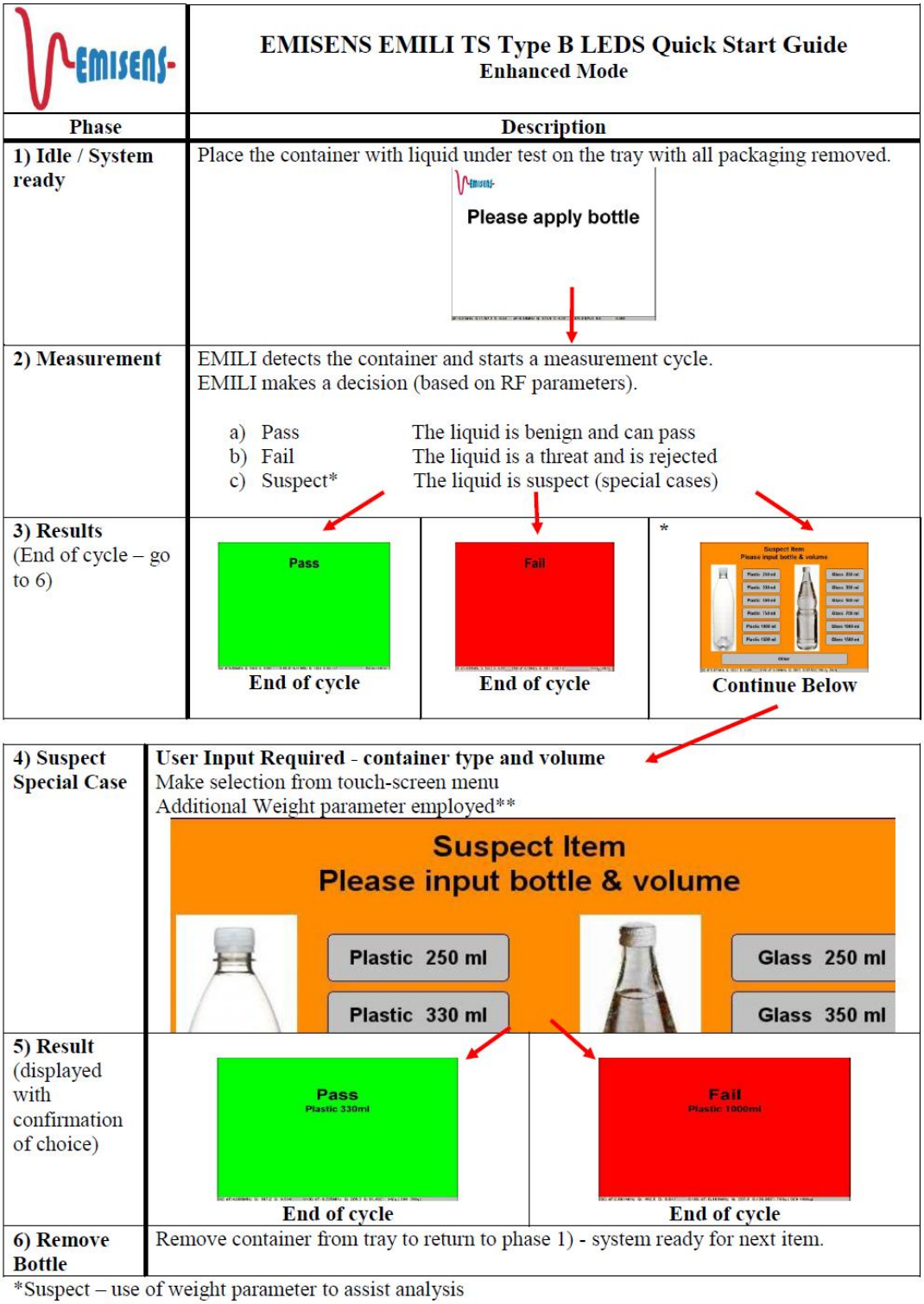

Fig. 4: Illustration of the CONOPS of the EMILI 2S upgrade by use of an integrated weight sensor, employing manual volume and container materials section via touchscreen.