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Microwave Mass Flow Sensor for Online Measurements of Pure Liquids and Mixtures

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Summary:

This work reports on the design and measurement results of a circular waveguide sensor filled with dielectrics tuned at 5.6 GHz for online process monitoring applications of low loss liquids and mixtures of liquids with liquids or air. Connecting the sensor to a Universal Software Radio Peripheral (USRP), an online mass flow meter is realized, that can simultaneously detects the concentration and velocity for liquid/air mixtures.

Keywords: circular waveguide sensor, cavity perturbation technique, low dielectric materials, concentration measurements, velocity measurements, online measurement

Introduction

Real-Time Monitoring of liquids using microwave signals became a growing interest recently. Applications can be found in food, oil and pharmaceutical industries, especially when a non-invasive technology is mandatory [1]. For permittivity extraction, the cavity perturbation method was applied [2]. Changing the material inside the sensor causes a shift in the resonant frequency that is directly related to the dielectric constant of the liquid or liquid/air concentration. Additionally, the velocity of the liquid can be detected by applying the spatial microwave velocimetry [3]. The sensor is attached to a Universal Software Radio Peripheral Ettus B210 [4] to enable online measurements at microwave frequencies.

Sensor Design

The microwave sensor, shown in Fig. 1, consists of a resonant configuration of two cavities made of Rogers RT/duroid 5880 substrates and a PTFE pipeline.

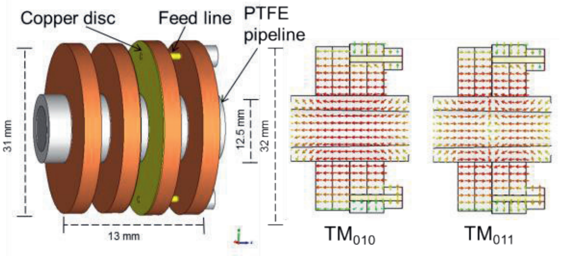

Fig.1. Microwave sensor exploded drawing and Transversal Magnetic (TM) modes

The coupling of the microwave sensor to an external circuitry is applied using two H-field probes that are located parallel to the material flow. Transversal Magnetic (TM) modes are excited in the flow direction in the measure section. To obtain two symmetrical transmission maxima inside the pipeline only one fully copper disc is used in the middle of the sensor.

Concentration measurement

A change in the permittivity or the concentration of liquids or liquid/air mixtures in the measurement section causes a change in the resonant frequency. Due to the fact that liquid/air mixtures absorb energy from the sensor, attenuation of the transmitted signal occurs. This effect can be measured by the complex transmission type S-parameter $\underline{S}_{21}$.

In order to extract the value of the dielectric constant, *a* sensor prototype was operated by the two-port vector network analyser HP 8722.

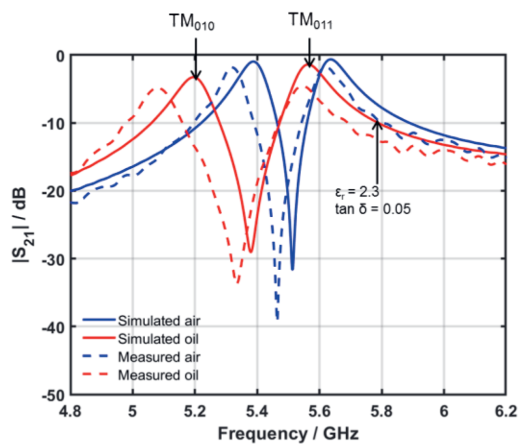

Fig.2. Simulated and measured results of the transmission $|s_{21}|$ with air/sunflower oil dielectric (preliminary results)

RF-simulations using CST Microwave were conducted using sunflower oil with a permittivity of 2.3 and low losses at 5.6 GHz.

Two transmission maxima (TM_{010} and TM_{011}) were measured with this sensor configuration as shown in Fig. 1 and Fig. 2. The comparison of the empty sensor and the oil-filled sensor at the fundamental TM_{011} mode shows a frequency shift of nearly 73 MHz for measurement and simulation. The observed frequency deviation between simulation and measurement for the TM_{010} mode is related to the assembly of the sensor and tolerance of the parts. Additionally, the oil measurement shows a higher attenuation, compared to the simulated results. The results of frequency shift air/oil are summarized in Tab.1.

Tab. 1. Frequency shift air/oil

	TM_{010}	TM_{011}
	Δf / MHz	Δf / MHz
Sim.	192	73
Meas.	290	76

Velocity measurement

In order to extract the velocity of liquids or liquid/air mixtures particles with the microwave sensor, measurement results versus time are analysed [3]. If a dielectric droplet enters in the measurement section the phase of the transmitted RF signal $\underline{S}_{21}$ describes a squared sinusoidal signal.

Fig. 3 shows the time depending amplitude and phase when a water droplet travels through the sensor. There are two sinusoidal half-waves. The amplitude of the half-waves depends on the position of the droplet inside the sensor measured section.

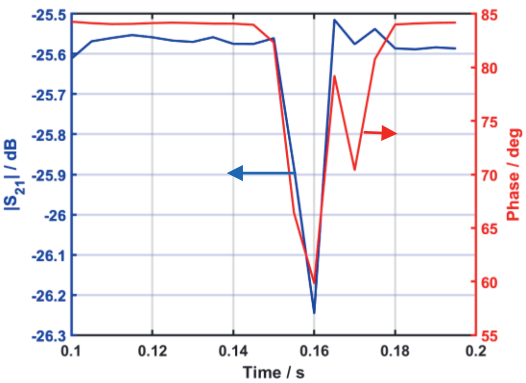

Fig. 3. Influence of a water droplet to the phase and magnitude of $S_{21}(t)$ for CW measurements at the sensors resonance frequency for the TM_{011} mode

Online Measurements

Fig. 4 depicts the fabricated microwave sensor and a block diagram of the USRP Module.

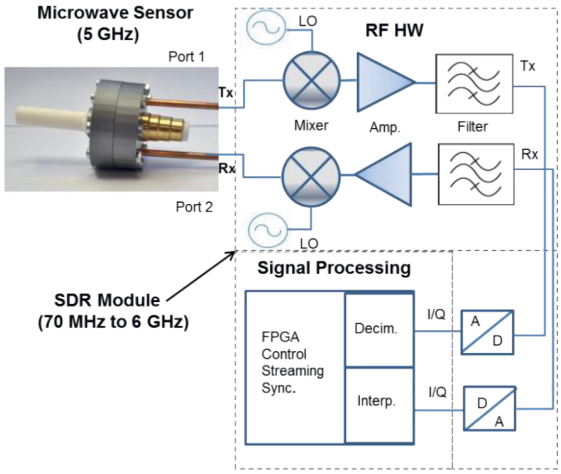

Fig. 4. Fabricated microwave sensor and USRP

A USRP transceiver B210 [4] is a software defined radio module that consists of a flexible RF hardware und a baseband platform for signal processing applications. In the USRP device, some of the key hardware functions can be implemented with MATLAB. Applying the Graphical User Interface, Real-Time Monitoring of the microwave sensor signals and extracting the concentration and velocity of liquid particles are possible.

Conclusion

The implementation of a microwave dielectric mass flow sensor for online monitoring without disturbance of the flow distribution was shown. The first prototype exhibits promising results for precise simultaneous concentration and velocity detection of low dielectric liquids and liquid/air mixtures.

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