Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Compact Wireless Ice Detection System with electrode used as antenna

To cite this article: W. Stocksreiter *et al* 2018 *J. Phys.: Conf. Ser.* **1065** 102001

Compact Wireless Ice Detection System with electrode used as antenna

W. Stocksreiter[1], H. Zangl[2], D. Glaser[3], M. Kaur[3], M. Moser[4]
1 Senior Lecturer University of applied sciences FH JOANNEUM Institute Electronic Engineering, Graz, Austria
2 Professor, Alpen-Adria-University Institute for Smart Systems Technologies, Sensors and Actuators, Klagenfurt, Austria
3 Master Students University of applied sciences FH JOANNEUM Institute Electronic Engineering, Graz, Austria
4 Managing Director, eologix sensor technology gmbh, Graz, Austria
E-mail: wolfgang.stocksreiter@fh-joanneum.at

Abstract
This paper presents a sensor system for capacitive ice detection, with planar electrodes located on a PCB. In order to minimize the required area, the electrodes are concurrently designed as an antenna structure for wireless data communication. With this approach a compact and thin sensor system for capacitance measurements can be realized. The capacitive sensor works on the principle of a mutual capacitance measurement method. An electrode of the sensor system works on one hand as an excitation source, emitting an electric field with a few hundred kHz and at the same time on the other hand the electrode acts as a 2.45GHz ISM patch antenna for wireless data communication. The scientific questions addressed in this paper are: Are the parasitics introduced as a result of the patch antenna and transmitter/receiver electrodes controllable under the assumption that the measured capacities are within the range of several hundred femtofarads? Do the capacitive couplings of the measuring electrodes influence the matching and the radiation pattern of the antenna, so that wireless data transmission is still possible? For both questions also the impact of the temperature is investigated.

Keywords: Planar, Electrodes, Capacitive sensor, Differential capacitance, CDC, Wireless, Patch antenna

1. Introduction

Measurements of icing on the surfaces of wind turbines, wings of airplanes on roads or rails have been research topics for decades, as ice formation and the associated changes to the systems in terms of aerodynamics, weight, controllability, etc. represent a safety risk that should not be underestimated [7] and [8]. There are currently different systems based on different physical principles in use [6]. In this paper a planar capacitive sensor concept is used for detection of icing. The changes in the permittivity of the medium between the sensor electrodes due to the occurrence of water or ice, cause a change in the capacitance and thus a measurable change of the environment condition. This measuring principle is basically not new and described e.g. on [1]. The special feature of the sensor concept described in this paper is, that the planar electrodes for measuring the capacitance are concurrently used for wireless data transmission. The main focus of the research was the question whether it is possible to control the mutual influences of the sensors and the radio transmission to such an extent, that the systems operate perfectly alongside each other although the same structures are used. The paper gives an overview of the structure and design of the sensor elements, the selected test setup and the performance that can be achieved with it. The evaluation circuitry can be reduced in size, such that the size of the complete sensor will be close to the size of the sensor element/antenna. In this case, with a planar patch antenna including sensor electrodes on a ceramic substrate it is possible to reduce the area of the sensor to a size of approximately 40x40mm.

2. Test Setup

The capacitance sensor system consists of four sense electrodes arranged around the bigger electrode, denoted as source electrode, in the middle of the structure (Figure1). This electrode in the middle acts as a transmitter or source for the 250kHz excitation signal which is capacitively coupled to the four smaller electrodes around. The sense electrodes are working as receivers of the source signal. The measured capacitance is depending on the dimensions and the distances of the sense to the source electrode [1]. The identified capacitances are only the capacitance between the sense and the source electrodes (differential capacitances) and not the ones to other conducting planes in the vicinity like ground planes, if the planes are guarded [2].

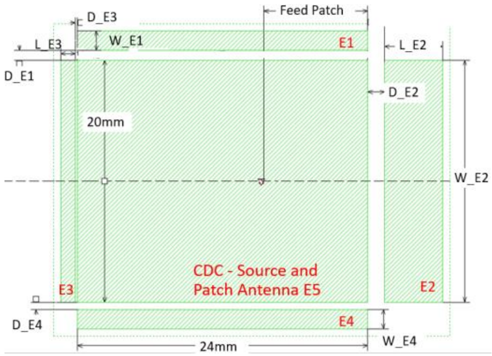

Figure 1: Sensor Electrodes (E1 to E4) with different copper areas arranged around the source electrode (E5) in the middle of the configuration. For research purposes different distances to the source electrode were chosen.

Concurrently the big electrode in the middle is designed as a linear polarized patch antenna with a resonance frequency at approximately 2.45GHz [3].
The structure is built upon a double sided 17µm copper plated high frequency ceramic filled PTFE composite laminate with a thickness of 0.64mm. The PTFE material was chosen because of its high stability of the dielectric constant regarding the temperature and frequency and its low dielectric losses. With a chosen relative dielectric constant of 6.15 the necessary size of the antenna becomes smaller than for materials with lower dielectric constants and the radiation efficiency is still sufficient with this type of material [4]. The PTFE part was stacked on a 1mm double sided FR4 composite material for carrier purposes and for the electrical connection of the electrodes to the mutual capacitance measurement chip and in particular the antenna feed line to the transceiver chip (Figure 2). The traces were carried out as 50 Ohm impedance controlled coplanar microstrip lines. The essential ground plane of the patch antenna was galvanically coupled with the guarding pin of the capacitance measurement chip for reducing the parasitic line capacitances (Figure 3).

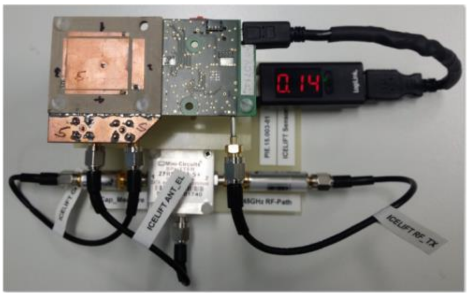

Figure 2. Electrode structure on PTFE stacked on a FR4 carrier.

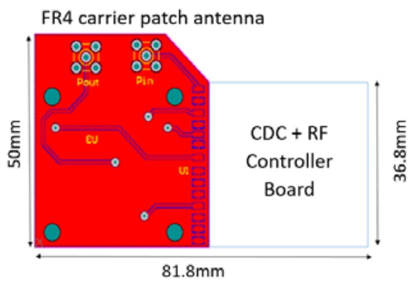

Figure 3. Bottom side of the FR4 carrier with 50 Ohms coplanare microstrip lines.

For capacitance measurement a programmable capacitance to digital converter (CDC) with an on chip environmental calibration was chosen. The CDC has 14 input channels, four of them were used. The channels were switched through a chip integrated matrix to a 16 bit, 250kHz sigma delta analogue to digital converter. The converter provides a typical capacitance input range of 2pF with a resolution of 1fF and an update rate of 36ms. The CDC communicates to a low energy 32-bit ARM Cortex M0 Processor with an embedded 2.4 GHz Bluetooth transceiver. In the prototype setup, the radio frequency transceiver output was connected via a discrete coaxial 50 Ohm high pass filter and a 50 Ohm

IOP Conf. Series: Journal of Physics: Conf. Series **1065** (2018) 102001 doi:10.1088/1742-6596/1065/10/102001

broadband two way-0° resistive signal combiner to the electrode (E5) of the patch antenna. A coaxial 50 Ohm low pass filter connects the source electrode (E5) with the source pin of the CDC (Figure 4). With the shared use of the electrode E5 it is possible to measure the capacitance simultaneously to the wireless data transmission.

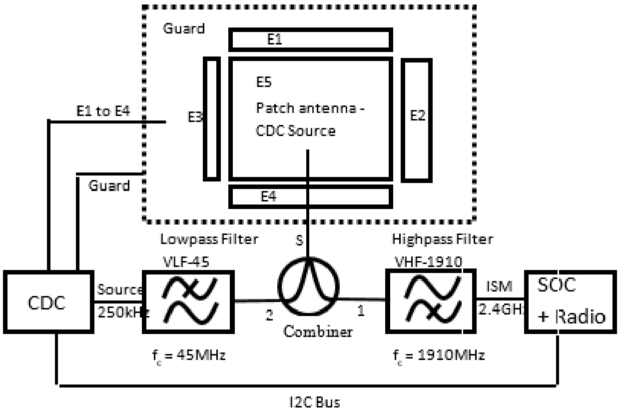

Figure 4. Prototyp setup with electrodes (E1 to E4), source electrode and combined patch antenna (E5). The capacitance measurement chip and processor with integrated Bluetooth radio. 250kHz source signal and 2.45 GHz radio signal combined via filter and signal combiner.

The four sense electrodes were designed with different copper areas and distances to the source electrode. The defined dimensions were based on simulations in dry conditions and under the appearance of ice and water. The dimension of the source electrode was determined from the necessary size of a patch antenna tuned to a resonance frequency of 2.45GHz.
For capacitance measurements under ice conditions the sensor prototype was placed into a climate chamber. The temperature was set between 30 and -50°C, to the lowest possible humidity to protect the exposed electronics. A special plastic foil was used to protect the electrodes against the water, which was filled in a plastic water tank mounted above the foil (Figure 5). This construction allowed to simulate water droplets and differently defined and equally distributed ice thicknesses from 1 to 10mm.

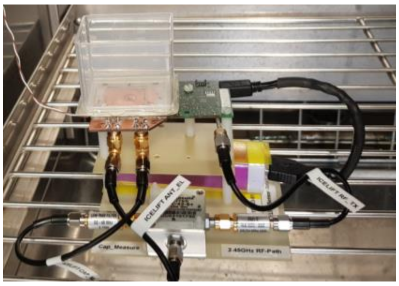

Figure 5. Sensor Prototype inside the climate chamber, with mounted plastic foil and water tank above the electrodes.

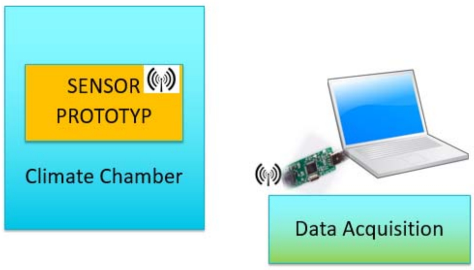

Figure 6. Test setup with prototype inside the climate chamber, wireless data acquisition via MATLAB.

The measured data were transmitted wirelessly via Bluetooth and fetched by a data acquisition code executed in MATLAB (Figure 6). For monitoring reasons, the values were constantly updated in a live graph.
The influence of the external filters and the combiner reduced the performance of the radio communication as well as the source path. The return loss of the antenna path decreased from -20dB to -6dB at 2.4 GHz. The transmission losses increase in the source path by 2.8dB, in the antenna path by 4.9dB.

3. Measurement and Results

To investigate the change in capacitance resulting from different dielectric constants, four fundamental test cases (TC) have been considered. TC1 air - dry condition, TC2 water droplets, TC3 water and T4 glaze ice – equally distributed in different heights. In the test series pictured in Figure 7, a trial with 5mm water was done. The capacitance measurement starts at 30°C with 15% humidity and steps down to -40°C and back, up to 30°C. The time per step were set in such a way that the prototype reached a steady temperature.
As long as there is water on the electrodes, the capacitance on all four electrodes is more than 2pF with the present electrode configuration. This is outside the measuring range of the CDC. Depending on the electrode surface and the distance to the source electrode, the capacitance of the largest and most distant electrode E2 varies between 140fF under dry and 5500fF under 5mm water condition. The capacitance of the electrode with the smallest area and the

smallest distance E3 is between 520fF and 2200fF. E3 is even with 5mm water with 2200pF only 10% above the measuring range (Figure 8).

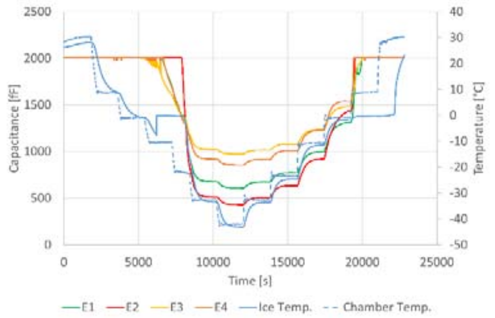

Figure 7. 5mm water between 30 and -50°C. Temperatures in chamber (blue dotted) and water tank (blue). Measured capacitances E1(green), E2(red), E3(yellow) E4(brown).

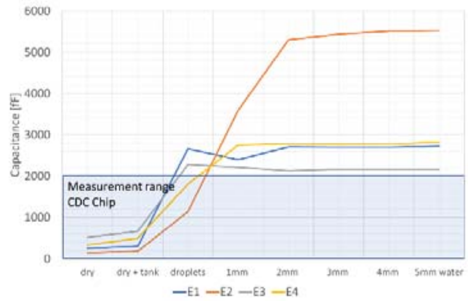

Figure 8. Measured capacitances between 140fF and 5600fF, from dry up to 5mm water, in 1mm steps at 25°C. Measured with Hioki LCR bridge.

At 5mm water, the capacitance measurement chip does not leave saturation until the end of the phase transition from water to ice, whereas this is the case with E2. E3 comes out of saturation a little earlier, during the phase transition at 0° Celsius. The measured capacitances are depending on the temperature and change immediately under ice conditions at negative temperature of the medium. In the heating phase, all four electrodes go into saturation almost simultaneously at the beginning of the phase transition from ice to water (Figure 7).
The radio link was not interrupted at any time during the entire measurement cycle of 25000 seconds, starting from the liquid to the solid phase and back again. The measurement data were transmitted every second. If the temperature falls below -40°C, outside the working area of the chips, an error in data transmission occurs within a few seconds.

4. Conclusion and Outlook

The integrated capacitive sensor concept described in this paper, demonstrated the function of a planar electrode structure for capacitance measuring and simultaneously wireless data communication using the same structure. The mutual influence of the parasitics between antenna and sensor electrodes is controllable with the shown structure. No additional temperature dependence was observed due to the parasitic effects.
By optimizing the sense electrodes, it is likely possible to avoid saturation even under water conditions. An electrode structure with more than four sense electrodes shall be considered. By better matching of the antenna path and reduction of insertion losses, it should be possible to increase the transmission range of the system from currently 6 meters. An essential factor for this improvements is the replacement of the used filters and the combiner to SMD components and a higher integration density. In order to test the behaviour of the sensor at rime ice, it must be sealed waterproof and tested in an ice tunnel.

5. References

[1] Schlegl, T., Moser, M., and Zangl, H., "Wireless and Flexible Ice Detection on Aircraft," SAE Technical Paper 2015-01-2112, 2015, doi:10.4271/2015-01-2112
[2] Zangl, H. “Capacitive Sensors Uncovered: Measurement, Detection and Classification in Open Environments.” 2010 Published by Elsevier Ltd. 393–399 1877-7058 c doi:10.1016/j.proeng.2010.09.130
[3] Stocksreiter, W., Zangl, H., Moser, M., “Environmental impacts on antennas for wireless sensors on outer aircraft surfaces” doi:10.1109/MetroAeroSpace.2017.7999625
[4] John Coonrod, “Choosing Circuit Materials for Low-PIM PCB Antennas”, Microwaves & RF, Technical Paper, December 2017
[5] Kwadwo Poku Owusu David C.S. Kuhn Eric L.Bibeau “Capacitive probe for ice detection and accretion rate measurement: Proof of concept” https://doi.org/10.1016/j.renene.2012.06.003
[6] Matthew C. Homola Per J.Nicklasson Per A.Sundsbø “Ice sensors for wind turbines“ doi.org/10.1016/j.coldregions.2006.06.005
[7] Olivier Parent, Adrian Ilinca “Anti-icing and de-icing techniques for wind turbines: Critical review” doi.org/10.1016/j.coldregions.2010.01.005
[8] Thomas Richards “ON Wing Ice DetectioN and MonitorinG System” ACP8-GA-2009-233838