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Topic: Development and Analysis of Microcontroller Based Signal Conditioning Circuit for Thin Film Humidity Sensor

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The main focus of this thesis is on the development and analysis of microcontroller based signal conditioning circuit for thin film capacitive humidity sensor. For this, we first fabricate the capacitive type thin film humidity sensor (for both %RH and trace moisture (ppm) level). The sensor is then characterized to deter-mine its important response characteristics such as capacitive response, response time, recovery time, repeatability, hysteresis, effects of ambient temperature and aging. Based on the experimental response behaviour, the sensor is then modelled to develop an accurate circuit model. The humidity sensors are usually represented by a parallel combination of resistance and capacitance. In case of trace moisture sensor, the value of shunt resistance is very large and its effect can be neglected, but in case of relative humidity sensors, the shunt resistance significantly varies with the variation of relative humidity. Therefore, its effect is taken into account and must be measured by the electronic circuit. Hence, a capacitive humidity sensor for ppm level moisture measurement can be considered as a perfect capacitor (approximate) and %RH level can be considered as an imperfect capacitor. Several interface electronic circuits are designed and implemented for both perfect and imperfect capacitive sensors for measuring humidity and dielectric constants of edible oils.

The humidity sensor has been fabricated by using nanostructure porous aluminium oxide (Al_2O_3) thin film by sol-gel method. Porous Al_2O_3 is one of the most suitable ceramic sensing materials that have potential to measure humidity over wide range. Its small pore radius makes it very sensitive and attractive to low humidity. Two capacitive sensors have been fabricated; one parallel plate capacitor for low level moisture detection and the second is the inter-digitated capacitor for measuring RH level humidity. Details of fabrication of the sensors using sol-gel dip coating method have been discussed. The boehmite Al_2O_3 sol solution for the metal oxide film was prepared successfully by adopting the Yoldas method.
The sensor has been modelled using the theoretical models proposed in literature to obtain the dielectric model of the nano-structure γ-Al_2O_3 film at various values of trace moisture and %RH. The model output matches the experimental value with maximum error of ±0.79%.

CMOS compatible oscillator based two electronic circuits suitable for interfacing capacitance sensor having negligible conductance effect have been developed. In the first circuit, a microcontroller-based digital hygrometer using the fabricated moisture sensor in the range of 3.7–100 ppm has been presented. The circuit in the hygrometer converts the capacitance change of the sensor exposed to different concentration of moisture into frequency. The circuit is based on a relaxation oscillator, whose output is suitable for interfacing to a digital device like micro-controller. The sensor has been characterized with the circuit and then the output frequency of the oscillator is calibrated in ppm. The accuracy of the developed system when compared with the commercial dew-point meter is found to be ±1 ppm of moisture.

Second circuit deals with the development of a signal conditioning circuit, with microcontroller compatibility, for interfacing the capacitive sensors, suitable for wide range applications. The circuit comprises of capacitive active bridge, along with a relaxation oscillator for converting the capacitance change into frequency directly. The design, analysis, and experimental results of the circuit, and its application to a thin film based humidity sensor as well as capacitive transducer for the measurement of dielectric constant of edible oil, are reported. Experimental results confirm the theoretical values predicted. Frequency output of the circuit has been used to determine the response characteristics of the trace moisture sensor and dielectric constants of edible oils. As in first solution, the output frequency of the oscillator has been calibrated in ppm, by using a commercial dew point meter (SHAW, UK). Accuracy of moisture measurement using custom designed capacitive sensor for the full scale moisture range of 4-100 ppm, when compared to the dew point meter (accuracy ± 0.1%) is found to be nearly ±1% and the resolution is 1 ppm moisture. The proposed solution is less complex and is easy to integrate for application specific integrated circuit in a standard CMOS technology with high sensitivity (selectable). It can be easily reproduced with the cheapest possible components, while achieving fairly good performance in terms of both accuracy and dynamic range.

For an imperfect capacitive sensor, two interfacing circuits have been designed. The first circuit is a simple and low cost design based on the measurement of in-phase and quadrature components of the output voltage. The in-phase and the quadrature components of the output signal have been separated with the help of a quad bilateral switch. The average output voltages of the in-phase and the quadrature components correspond to the value of lossy resistance and capacitance. The averaging has been done in software with the help of 32-bit microcontroller having in-built 12-bit ADC. Further signal manipulation has also been done using the microcontroller. For the capacitance variation from 22 pF to 682 pF in the step of 22 pF for different fixed values of shunt resistance, a full scale error of less than 0.65% and a high linearity has been observed. Similarly, for the variation of the shunt resistance from 201 kΩ to 612 kΩ with different fixed values of capacitance, the maximum relative error of less than -5% has been observed. Moreover, the average values of output voltages of in-phase and quadrature components and the corresponding values of the resistance R_S and the capacitance C_S have been dis-played with the help of a display system. A PCB of the circuit has been made and it is employed to measure the relative humidity of the humidity sensor. It is
also used to measure the dielectric constants of edible oils. Performances of the proposed circuit have been compared with the circuits reported in literature.

The second circuit presents the development of an active bridge based virtual humidity sensor system, where the capacitive humidity sensor and a reference capacitor form two arms of the bridge. The bridge is excited by an AC voltage source of 1 kHz with amplitude of 200 mV (rms). The amplitudes of the input and output voltages and their phase difference are measured by National Instruments (NI) LabVIEW virtual instruments (VI) blocks with the help of NI data acquisition (DAQ) card. The governing equations for evaluating the capacitance and resistance of the sensor are implemented by Virtual Instruments blocks to directly display the measured values. The sensor capacitance is also measured with Agilent Impedance Analyzer and the accuracy of the measured pure capacitance is found to be ∼1%.