Design of a high – sensitive capacitive sensor for wireless monitoring of bulk material's level

Teodora Trifonova [1], Valentina Markova [2], Valentin Todorov[3] and Ventseslav Draganov [4]

Abstract - **The design of high sensitive capacitive sensor achieved by reducing the destabilizing impact of temperature and supply voltage is reported. The possible influence of the generators' frequencies on the capacitance measurement is analyzed. Stability and sensitivity of several types of stabilized quartz generators is also investigated. Based on results a new intelligent capacitive sensor for measuring the extremes level of bulk materials is created. The developed sensor is suitable for use in wireless sensor network.**

Keywords – **Capacitive sensor, sensor network, quartz generator.**

I. INTRODUCTION

In recent years there has been an explosion in sensor technology. The selection of sensor for a given application depends on the nature of physical objects that must be observed, such as temperature, pressure, humidity or level of materials [1].

Traditionally, environmental monitoring is achieved through expensive sensors with high accuracy. Creating a wireless sensor network provides an alternative solution by deploying a larger number of sensor nodes with less precision. Network as a whole, however, provides better spatial resolution of the area and users can have immediate access to data [2].

The capacitive sensor that controls the extremes of bulk materials with very low permittivity has been developed by authors in [3-5]. The sensor provides high sensitivity in spite of the influence of destabilizing factors like variation of temperature and supply. Changing the capacity of the sensor leads to a change in the frequency of quartz stabilized generator to which the sensor is plugged.

The aim of this work is to further enhance the sensitivity of the sensor by choosing appropriate generators and quartz resonators, and its adaptation for inclusion in the wireless sensor network.

II. SCHEMATIC DIAGRAM OF THE CAPACITIVE CONVERTER

The block diagram of developed capacitive sensor is shown on fig.1. A capacitive converter S with capacity CX is connected to quartz stabilized generator G1. The frequency of the generator is varying within a certain range in capacity adjustment C_X. The output signal with frequency f_X from the digital comparator compares the frequency fr of the second supporting quartz stabilized generator G2.

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Upon reaching certain, predefined ratio of the both frequencies, control signal is generated at the output of the comparator [6].

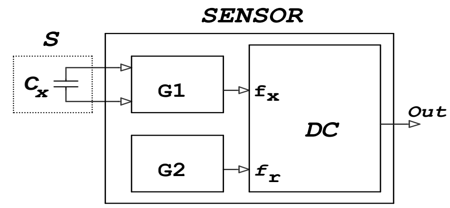

Fig.1. Scheme to monitor the capacity variation of capacitive sensor

The sensitivity of the sensor is determined by the ratio of the frequencies of both generators. It can be changed in wide ranges by setting the digital comparator [7].

To increase the sensitivity of the capacitive sensor it is necessary to reduce the instability of the two generators' frequencies, caused by alteration of the temperature and supply voltage changes of both generators.

There exist a great variety of quartz generators in the literature. Only several schemas of stabilized quartz generators - with an active element transistor, TTL or CMOS integrated circuit fulfill the requirements of our development.

A great number of investigations on selected schemes have been made. It was found different variation of the frequencies of each generator for changes in the ambient temperature and alteration of the supply voltage.

In this publication, due to the limited number of pages only the best results obtained for the two of analyzed schemes are presented. Studies have shown that two basic patterns of quartz stabilized generator - with TTL integrated circuit (Fig. 2) and with CMOS integrated circuit (Fig. 3) are the most appropriate for our sensor. Both schemes are similar. Primary capacitive converter with capacity C_X is connected to the stabilized quartz generator serially linked with quartz resonator. The frequency of the generator can be adjusted in small ranges.

III. EXPERIMENTAL RESULTS

For greater accuracy and precision of the sensor it is necessary to use two identical generators. The experiments were performed with two pairs of generators. It was used different types of quartz resonators with serial resonance frequency F_S varying from 1 MHz to 10 MHz in dependence on the lowest temperature fluctuation.

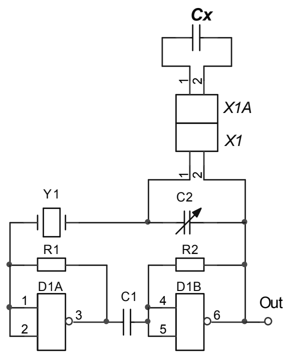

Fig.2. Capacitive converter with TTL integrated circuit

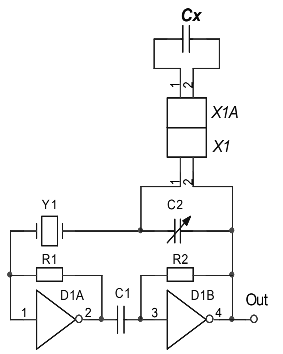

Fig.3. Capacitive converter with CMOS integrated circuit

IV. Experimental results

For greater accuracy and precision of the sensor it is necessary to use two identical generators. The experiments were performed with two pairs of generators. It was used different types of quartz resonators with serial resonance frequency F_S varying from 1 MHz to 10 MHz in dependence on the lowest temperature fluctuation.

A. Investigations of capacitive converter with TTL integrated circuit

Temperature dependences of the generators' frequency F_X for frequencies of the quartz resonators, respectively $F_{S1.1}=F_{S1.2}$ = 1 MHz and $F_{S2..1}=F_{S2..2}$ = 5 MHz are display on Fig.4 and Fig.5.

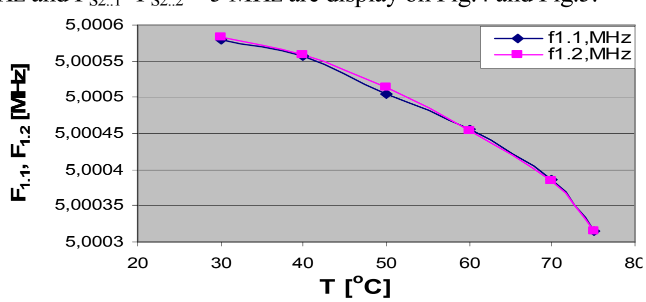

Fig.4. Dependence Fx = φ (T), where F_S = 5 MHz

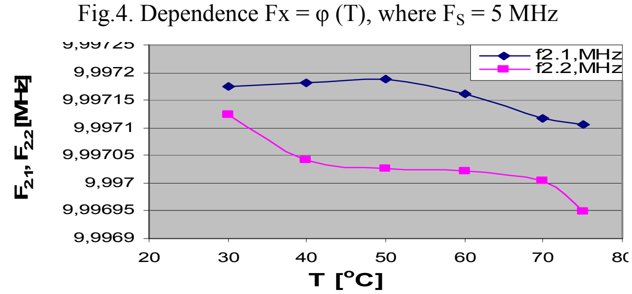

Fig.5. Dependence Fx = φ (T), where F_S = 10 MHz

It is clearly seen from results that the deviation of the frequencies is extremely small – bellow 10^{-4} for F_S = 5 MHz and bellow 2.10^{-5} for F_S = 10 MHz with changes in ambient temperature with 45° C. This corresponds to instability, less than 10^{-5} / °C (F_S = 5 MHz) and less than 10^{-6} / °C (F_S = 10 MHz).

As the output of the sensor (fig.1) is given control signal upon reaching a predefined ratio of the frequencies of the two identical generators, it is more important to compare the temperature dependencies of the frequencies ratio of both generators. The results for two quartz generators with frequencies $F_{S1.1} = F_{S1.2}$ = 5 MHz and $F_{S2.1} = F_{S2.2}$ = 10 MHz are presented, respectively on fig.6 and fig.7.

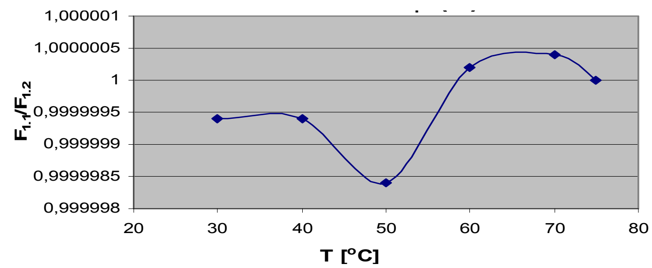

Fig.6. Dependence $F_{1.1} / F_{1.2} = \varphi$ (T), where F_S = 5 MHz

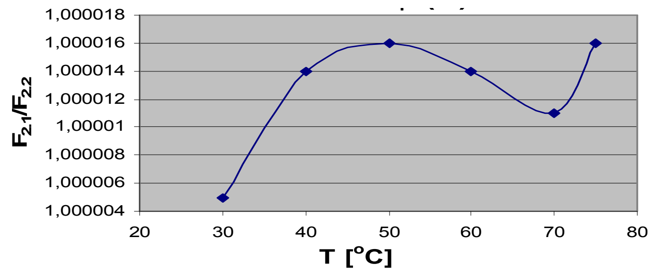

Fig.7. Dependence $F_{2.1} / F_{2.2} = \varphi$ (T), where F_S = 10 MHz

Obviously, the deviation of ratio of both generators' frequencies for variation of environmental temperature with 45°C is much less – below 2.10^{-6}/°C for first generators and below 10^{-5}/°C for others. This corresponds to instability, less than 10^{-7}/°C.

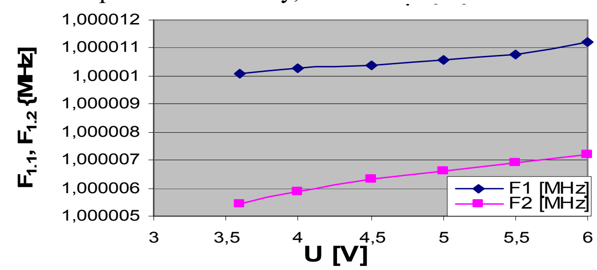

Fig.8. Dependence $F_{1.1} = \varphi$ (U), $F_{1.2} = \varphi$ (U)), where F_S = 1MHz

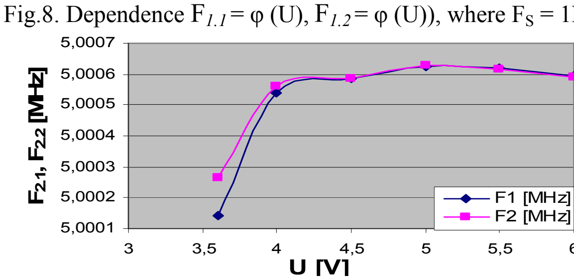

Fig.9. Dependence $F_{2.1} = \varphi$ (U) $F_{2.2} = \varphi$ (U), where F_S = 5 MHz

Fig.8 and fig.9 illustrate the dependences of the generator's frequency F_X for change of the voltage U_X if the frequencies of quartz resonators are $F_{S1.1} = F_{S1.2}$ = 1 MHz and $F_{S2.1} = F_{S2.2}$ = 5 MHz. The figures show that the frequency is changed in very small range – of the order of 5.10^{-6}/V for the first resonator and below 10^{-4}/V for the second in case of voltage alteration U from 4 to 6V.

Next two figures (fig.10 and fig.11) are connected with investigation the impact of the variation of the voltage on the ratio of the generators' frequencies, respectively, for frequencies of both quartz generators $F_{S1.1} = F_{S1.2} = 1$ MHz and $F_{S2.1} = F_{S2.2} = 5$ MHz.

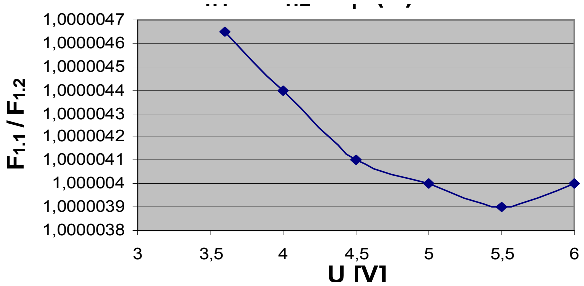

Fig.10. Dependence $F_{1.1} / F_{1.2} = \varphi$ (U), where F_S = 1 MHz

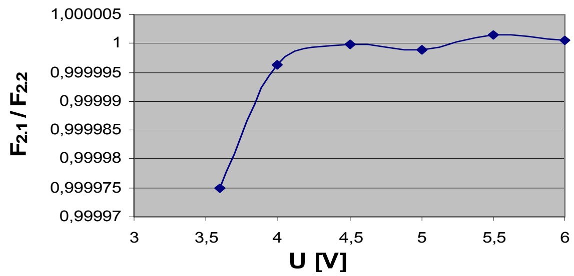

Fig.11. Dependence $F_{2.1} / F_{2.2} = \varphi$ (U), where F_S = 5 MHz

As it was expected variation of voltage U led to alteration in ratio of the frequencies of both generators bellow 5.10^{-7}/V for F_S = 1MHz and less than 10^{-5}/V for F_S = 5 MHz.

B. Investigations of capacitive converter with CMOS integrated circuit

The results of experimental studies of the scheme on fig.3 are presented on fig.12 ÷ fig.19.

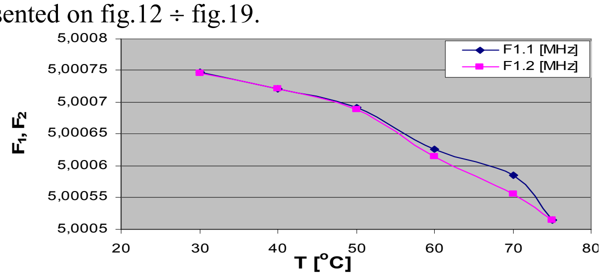

Fig.12. Dependence $F_{1.1} = \varphi$ (T), $F_{1.2} = \varphi$ (T), where F_S = 5 MHz

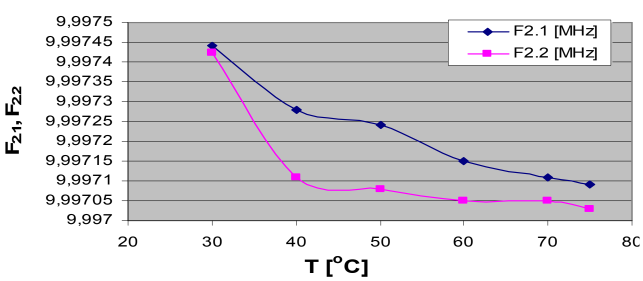

Fig.13. Dependence $F_{2.1} = \varphi$ (T), $F_{2.2} = \varphi$ (T), where F_S = 10 MHz

Dependencies of the frequencies of the generators $F_{X.Y}$ by the variation of the ambient temperature T, given frequencies of the quartz resonators, respectively F_S = 5 MHz and F_S = 10 MHz are presented on fig.12 and fig.13. Temperature instability under these conditions is less than 10^{-5}/°C for F_S = 5 MHz and bellow 10^{-6}/°C for F_S = 10 MHz.

As mentioned in the previous section for proposed schemes (fig.2, fig.3) the temperature dependence of the ratio of both generators' frequencies is more importantly. It can be seen from fig.14 and fig.15 that the temperature instability of the ratio $F_{1.1} / F_{1.2}$ is less than 10^{-6}/°C if $F_{S1.1} = F_{S1.2} = 5$ MHz, respectively for $F_{2.1} / F_{2.2}$ the instability is bellow 3.10^{-7}/°C for $F_{S2.1} = F_{S2.2} = 10$ MHz.

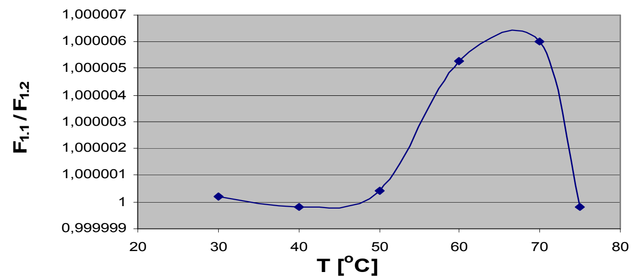

Fig.14. Dependence $F_{1.1} / F_{1.2} = \varphi$ (T), where F_S = 5 MHz

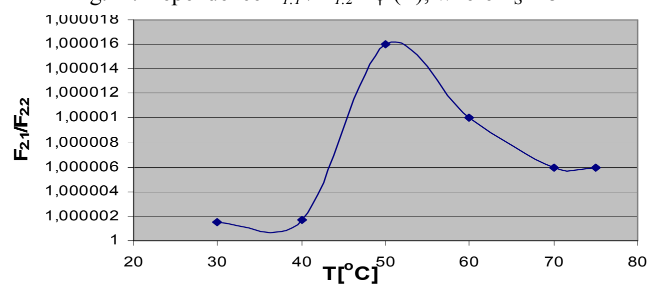

Fig.15. Dependence $F_{2.1} / F_{2.2} = \varphi$ (T), where F_S = 10 MHz

The last group of studies are related to determining influence of changes in voltage on the frequency of generator, given frequencies of quartz resonators, respectively $F_{S1.1} = F_{S1.2} = 1$MHz and $F_{S2.1} = F_{S2.2} = 5$MHz.

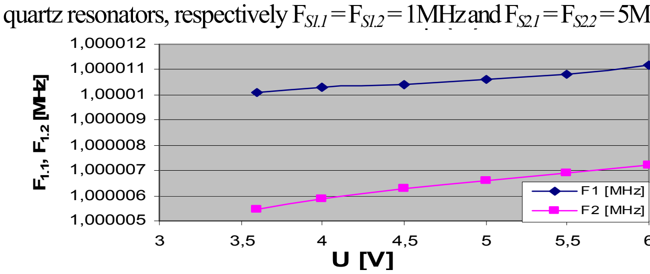

Fig. 16. Dependences $F_{1.1} = \varphi$ (U), $F_{S1.2} = \varphi$ (U), for F_S = 1 MHz

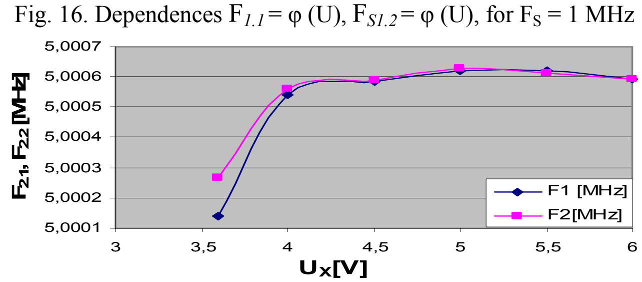

Fig.17. Dependences $F_{2.1} = \varphi$ (U), $F_{2.2} = \varphi$ (U), for F_S = 5 MHz

From the resulting dependences, shown on fig.16 and fig.17 follows that the instability of the generators' frequencies under the relevant conditions ($F_{1.1}$, $F_{1.2}$, $F_{2.1}$, $F_{2.2}$) to alteration the voltage is less than 10^{-5}/V for $F_S = 1$ MHz and bellow 10^{-4}/V for $F_S = 5$ MHz.

Finally, the ratio of frequencies of both generators dependences to variation of voltage, respectively, for frequencies of both quartz generators $F_{S1.1} = F_{S1.2} = 1$ MHz and $F_{S2.1} = F_{S2.2} = 5$ MHz are displayed on fig.18 and fig.19. The frequency instability of both generators is less than 10^{-6}/V.

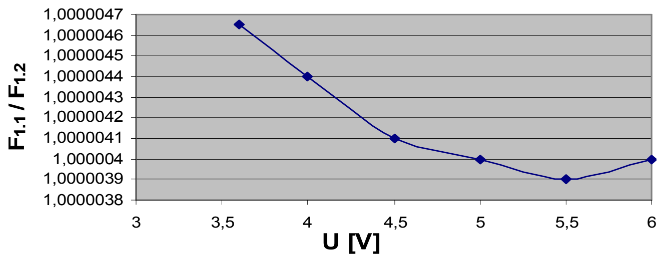

Fig.18. Dependence $F_{1.1} / F_{1.2} = \varphi$ (U), for $F_S = 1$ MHz

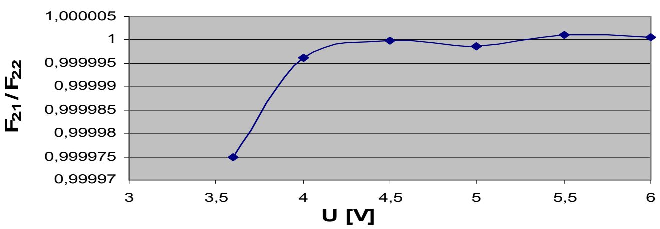

Fig.19. Dependence $F_{2.1} / F_{2.2} = \varphi$ (U), for $F_S = 5$ MHz

V. ANALYSIS

As it is well known the value of frequency instability varies depending on particular scheme and used quartz resonator. It can be concluded from made experiments that for proposed schemes of capacity sensor the influence of the variation of the ambient temperature and voltage to generated frequencies is extremely small.

In addition for further increasing the sensitivity of the designed capacitive sensor it is necessary to be ensured the equal working conditions for both (the measuring *G1* and the supporting *G2*) generators of the scheme shown in Fig.1.

This was achieved in following ways:

1. To ensure a very small difference in operating temperatures of both generators it was proposed constructive decision using common integrated circuit for both generators. The quartz resonators were mounted much close to each other. Their temperature was aligning by an additional thermal connection with heatsink with heat-conveying paste.

Thus, it was assured the temperature difference substantially below 1°C, which leads to increase of the capacitive sensor's sensitivity more than 10 times, as seen from experimental results.

2. Using a common stabilized power source of both generators (fig. 20), with instability of the output voltage below 0,125 V, also enhanced the sensitivity of the capacitive sensor over 10 times.

The proposed integrated stabilizer gives one additional advantage of the sensor – the option of its power to be turned on and off for a predefined period of time. This allows the insertion of the sensor in wireless sensor network.

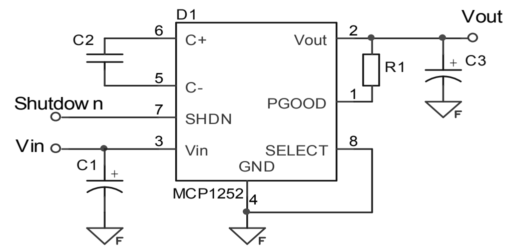

Fig.20. Source of stabilized voltage with control options

VI. CONCLUSION

It has been made a number of investigations related to reduction of the destabilizing influence of ambient temperature and supply voltage to the frequencies of two quartz generators used in capacitive sensor. Based on results was developed high-sensitive intelligent capacitive sensor for monitoring extremes of bulk materials. The proposed sensor can be used as a node of a wireless sensor network.

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