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Quantifying the weight of pressure Using a Planar Interdigital Capacitor Sensor

***Abstract**. This article introduced the Digital Capacitor Sensor, developed to use pressure surveillance. The Planar Interdigital Capacitor Sensor have adopted the basic principles of IDC design and are generally applied and tested with input frequencies of 1KHz and 10KHz. Pressure testing with the TUTMFT machine. The test results found that the electrical capacity of the pressure acting on the Planar Interdigital digital Capacitor sensors decreased according to the weight of the pressure being tested. The electrical conductivity value of the Planar Interdigital digital capacitor increased based on the pressure. From the results, these Planar Interdigital digital capacitor sensors can be used in conjunction with microcontroller applications in relevant industries.*

Streszczenie.** W tym artykule przedstawiono cyfrowy czujnik kondensatorowy opracowany do stosowania w monitorowaniu ciśnienia. W planarnym międzycyfrowym czujniku kondensatorowym przyjęto podstawowe zasady projektowania IDC i są one powszechnie stosowane i testowane przy częstotliwościach wejściowych 1 kHz i 10 kHz. Próba ciśnieniowa maszyną TUTMFT. Wyniki testu wykazały, że pojemność elektryczna ciśnienia działającego na cyfrowe czujniki kondensatorowe Planar Interdigital zmniejszała się w zależności od ciężaru testowanego ciśnienia. Wartość przewodności elektrycznej kondensatora cyfrowego Planar Interdigital wzrasta w zależności od ciśnienia. Wyniki wskazują, że cyfrowe czujniki kondensatorowe Planar Interdigital mogą być stosowane w połączeniu z mikrokontrolerami w odpowiednich gałęziach przemysłu. (**Określanie ciężaru ciśnienia za pomocą płaskiego czujnika pojemnościowego międzycyfrowego)

Keywords: Planar Interdigital capacitor, Pressure sensor, resistance
Słowa kluczowe: Planarny kondensator międzypalcowy, czujnik ciśnienia, rezystancja

Introduction

An interdigital capacitor detector or detector that uses the principle of electrical capacity is a type of device that can be considered to be multifunctional [1] The structure of the digital capacitor is the same, so it can be produced by design and construction of a commonly existing printed circuit board. When the width of the conductor plate, and the distance between the conductor plate and its length are changed, the electric capacity of the Digital Capacitor is changed [2]. It is popularly used to measure various parameters such as volume intensity, humidity, distance measurement, level measurements, and voltage changes [3, 4], which have been implemented in a variety of applications such as water level measuring [5], water quality monitoring [6], finding the amount of water filled in raw milk water [7].

A pressure sensor is a type of sensor used to measure changes in pressure caused by pressure. It means the amount of force that acts on the area, causing physical changes. From the distinction of a conveyor-type pressure sensor, it consists of a simple design, inexpensive production, and can be combined with other electronic components. [8] The pressure-sensing conductor uses the principle of electrical capacity measurement or digital pressure sensors. Capacitors have found that most of them bring sensors that can be flexible in applications [9-11], but the introduction of interdigital captors produced from circuit boards as pressure sensors has also been studied for their applicability concerning field sensing, which is wide-ranging and widespread.

So, this article presents the results of a study that results from the weight of a pressure that affects the electrical capacity and electrical induction of an interdigital capacitor sensor. The purpose of this study is to study the relationship between the mass of the pressure, which affects a digital capacitor sensor, and to analyze such a relationship with mathematical equations.

Material & Methods

The test's interdigital capacitors use conductor sheets measuring (a_1)2 mm wide. Conductor width (a_1) with the spaces between the conductor plates (a_2) (b) Conductor plate length (L) 20 mm and number of electrodes (N) 10

Measurement of the weight of force using the Table Top Universal Testing Machine Force Test MCT Series, developed by A&D, model MCT-2510 (Maximum Load 500 N). It consists of a 5 to 70 Newton test pressure range. FR4-type printed circuit boards are utilized for developing the planar interdigital capacitor sensors. (Figure 1 a)), then connect the positive and negative cables with wires, enter the frequency and voltage, and measure the electrical capacitance, electrical resistance, and the absolute value of the impedance (Impedance) using the LCR Meter model LCR-6100, GW Instek brand.

a) b)

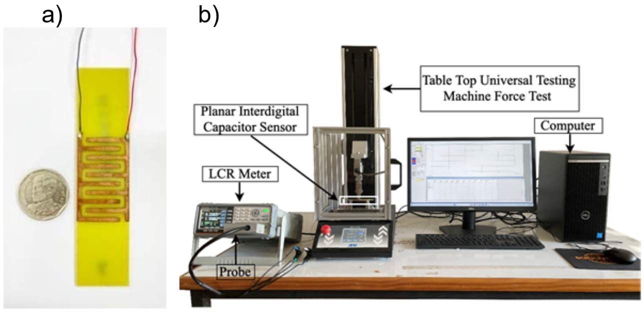


Fig.1. a) Top view of a Planar interdigital capacitor Sensor. b) Experiment setup

Then take the horizontal interdigital capacitor sensing device. The positive and negative terminals are connected to the LCR Meter to supply a voltage of 2 volts and a frequency of 1KHz and 10KHz., open the machine's control program window (able Top Universal Testing Machine Force Test: TUTMFT) to set the width, length, and thickness of the horizontal interdigital capacitor sensors to be tested. Set the speed range required for testing. Set the deflation period Then place the horizontal interdigital capacitor sensor at the position used to test the pressure of the TUTMFT machine. Press the start button of the program to allow the TUTMFT machine to begin pressing the electrical capacitance value, electrical resistance, and an absolute value of impedance will be displayed and recorded with an LCR Meter. In the experiment, each level of pressure will be tested 5 times.

It includes a 5 to 70 Newton test pressure range. FR4-grade print circuit boards are used for developing the planar interdigital capacitor sensors.

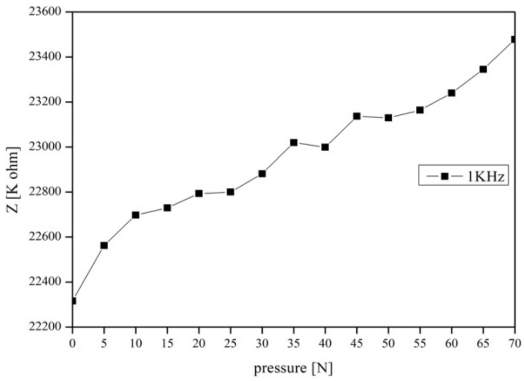
Result & Discussion

1. Change in the electrical resistance of the horizontal interdigital capacitor sensor.

Research has indicated that when pressure increases, a planar interdigital capacitor sensor's resistance rises as well. by gradually applying more pressure 5 newtons at a time. 0 to 5, 10, 15, 20, 25, 30, 40, 45, 50, 55, 60, 65, and 70 newtons respectively. According to test results, an interdigital capacitor's electrical resistance increased from 22315.52 $K\Omega$ to 23477.46 $K\Omega$ at a frequency of 1KHz. Figure 2 a) shows the graph of the relationship between pressure and frequency at a frequency of 10KHz and also at 1KHz. The electrical resistance increased from 3034.01 $K\Omega$ to 3057.29$K\Omega$, according to the experiment results. Figure 2 b) displays the graph of the connection between pressure and frequency at 10KHz.

Analysis of the relationship between the amount of pressure and the change in parameters. (Resistance) of the planar interdigital capacitor sensing Shows that it is statistically significant at the α = 0.000 level. The correlation coefficient level is 0.979 $\leq r \leq$ 0.993 and the R-Square level is between R^2 = 0.9591 (1KHz) and R^2 = 0.9855 (10KHz). The mathematical relationship between the amount of pressure applied to a planar interdigital capacitor and its electrical resistance. This can be explained using a regression equation with the frequency tested (Table 1)

a)



b)

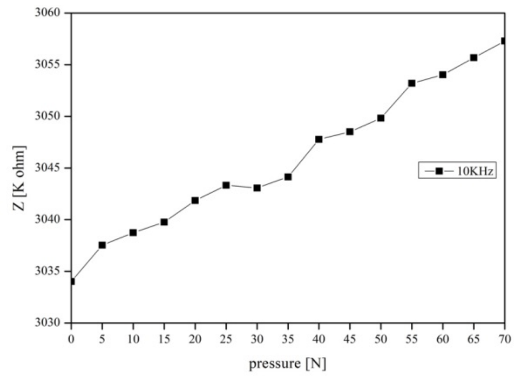


Fig. 2. Change in resistance of planar interdigital capacitor sensors arising from the amount of pressure using frequency a) 1KHz b) 10KHz

Table 1. Analysis of the relationship between the quantity of pressure (Pressure : P) and changing the resistance value (Impedance: Z) of the planar interdigital capacitor sensor

Frequency (Hz)	Measuring Parameters	r	α	Regression equation
1000	Z	0.979	0.00	P=13.628xZ +22476
10000	Z	0.993	0.00	P=0.315xZ +3034.9

Note : P, Pressure added, r , correlation coefficient, α , significance level, computed.

The experiment above shows that the resistance change of the planar interdigital capacitor sensing caused by a specific pressure and frequency appears to increase. This is because something changed when the experiment's pressure and frequency were changed, affecting the conductor plate's width (a_1), the distance between its plates (a_2) (b), and length (L).

2. Change the electrical capacitance value of a planar interdigital capacitor sensor.

Studies have indicated that the planar interdigital capacitor sensors' capacitance (C) diminishes in proportion to the frequency (F) and force applied. The experiment involved increasing the force. Starting with 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, and 70 newtons respectively and repeat 5 time (Figures 3 a) and 3 b)). The planar interdigital capacitor sensing's capacitance (C) test findings revealed that the impedance's absolute value dropped at a frequency of 1KHz. based on the level of pressure increase. The capacitance is displayed as decreasing from 7.7259 pF to 7.6170 pF. Figure 3 a) shows the pressure-capacitance relationship graph at 1KHz. (Figure 3 a)) and capacitance at a frequency of 10KHz. The capacitance of the planar interdigital capacitor sensor decreased from 6.1011 pF to 6.0529 pF. The pressure capacitance relationship graph at frequency 10KHz is shown in Figure 3 a) (Figure 3 b)).

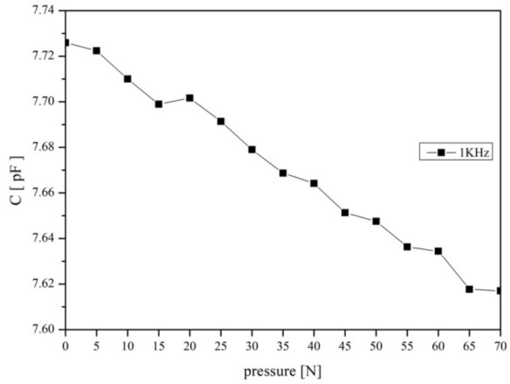
Analysis of the relationship between the amount of pressure and the change in capacity parameters. of planar interdigital capacitor sensors It shows that the statistical significance is at the level α = 0.000, the level of the correlation coefficient is -0.996 $\leq r \leq$ -0.990, and the level of R-Square is between R^2= 0.9914 (1KHz) and R^2 = 0.9807 (10KHz). The mathematical relationship between a planar interdigitated capacitor sensor's electrical capacitance and the pressure applied to it. This can be explained by using the regression equation with the tested frequencies (Table 2).

According to the results of the preceding experiment, the capacitance change generated by a given quantity of pressure and frequency tends to decrease. The length of the conductor plate (L) changes as the receiving pressure and frequency chosen for the experiment vary the width of the conductor plate (a_1) and the distance between the conductor plates (a_2) (b).

Table 2. Analysis of the relationship between the quantity of pressure (Pressure : P) and change in the capacity value (Capacitance: C) of the planar interdigital capacitor sensor

Frequency (Hz)	Measuring Parameters	r	α	Regression equation
1000	C	- 0.996	0.00	P=-0.0016x C+7.7280
10000	C	- 0.990	0.00	P=-0.0007x C+6.1004

Note : P, Pressure added, r , correlation coefficient, α , significance level, computed a)



b)

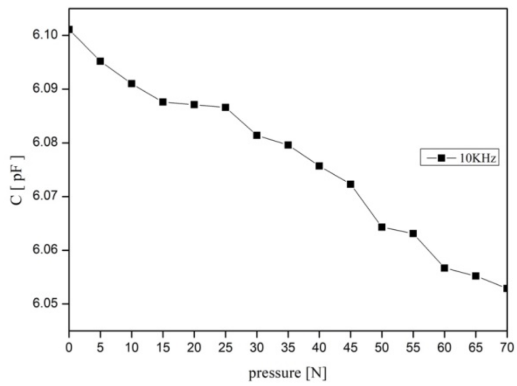


Fig. 3 Capacitance change of planar interdigital capacitor sensor arising from the amount of pressure using frequency a) 1KHz b) 10KHz

The electrical conductivity (Z) and capacitance (C) were measured experimentally in a planar interdigital capacitor sensing device. It illustrates the correlation between these values and the pressure applied to a planar interdigital capacitor sensing device. The average change in the conductivity parameter caused by a pressure of 0-70 N, regardless of the operating frequency, The coefficient of association between the change in conductivity parameter and the amount of pressure applied to the planar interdigital capacitor sensor unit. The equation utilized in the investigation is $y = ax \pm b$, with a statistically significant value of 0.979 to 0.993. (invariant) at level α = 0.000 (Figure 2 a), 2 b)) (Table 1).

The relationship between pressure and linear interdigital capacitor sensors is investigated. The plane of change in electrical capacitance was found to be highly correlated with -0.996 $\leq r \leq$ -0.990. The value of this connection reveals that as the pressure (P) grows, the electrical capacitance (C) value of the horizontal interdigital capacitor sensing decreases, which is statistically significant at the α = 0.000 level, suggesting beneficial reliability. It can also be determined by applying the mathematical equation P = aC+b, which expresses the relationship between the electrical capacitance (C) of a planar interdigital capacitor sensor and pressure. As shown in Table 2.

The results of testing electrical conductivity, resistance, and capacitance. It demonstrates that the change in pressure acting on the planar interdigital capacitor sensor increases. It will affect the conductivity and capacitance changes of the planar interdigital capacitor sensor.

Conclusion

This article presents a planar interdigital capacitor sensing device. Let's apply. The pressure sensor is a novel sort of pressure measurement that employs IDC, which was previously used to measure water level, humidity, and so on, to determine pressure. This sensor is meticulously designed and constructed. Tests have revealed that it responds effectively to pressure. The pressure utilized in the test ranges between 0-70 newtons. The test frequencies are 1KHz and 10KHz, with the possibility of improving and developing them for use in inspections. Pressure from low production costs In industrial applications, this could be used with a microprocessor to measure pressure.

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REFERENCES

[1] George, S. P., Issac, J., & Philip, J. Geometry, "dependence of the response of inter-digital capacitive structures: a finite element analysis". *Sensors & Transducers*, (2018). 228(12), 71-78.
[2] Kim, Y., & Oh, J. H. "Recent progress in pressure sensors for wearable electronics: From design to applications". *Applied Sciences*, (2020). 10(18), 6403.
[3] Ye, X., Fang, L., Liang, B., Wang, Q., Wang, X., He, L., ... & Ko, W. H. "Studies of a high-sensitive surface acoustic wave sensor for passive wireless blood pressure measurement". *Sensors and Actuators A: Physical*, (2011). 169(1), 74-82.
[4] Chetpattananondh, K., Tapoanoi, T., Phukpattaranont, P., & Jindapetch, N. "A self-calibration water level measurement using an interdigital capacitive sensor". *Sensors and Actuators A: Physical*, (2014). 209, 175-182.
[5] Boonkirdram, S., & Sa-Ngiamvibool, W. "A novel planar interdigital capacitor level sensor". *Przegląd Elektrotechniczny*, (2015). 91(8), 91-95.
[6] Wongmeekaew, T., Boonkirdram, S., & Phimphisan, S. "Wireless Sensor Network for Monitoring of Water Quality for Pond Tilapia". *In 2019 Twelfth International Conference on Ubi-Media Computing (Ubi-Media)*. (2019, August) (pp. 294-297). IEEE.
[7] Phimphisan, S., & Sa-ngiamvibool, W. "Determination of water added in raw milk using interdigital capacitor sensor". *Przegląd Elektrotechniczny*, (2015). 91, 265-267.
[8] Rachmanita, R. E. "The high capacitance for electrode structure of interdigital capacitor thin film models". *Creative Science*, (2019). 11(2), 55-63.
[9] De Guzman, S., Lowe, A., Williams, C., Kalra, A., & Anand, G. "The Development of a Built-In Shoe Plantar Pressure Measurement System for Children". *Sensors*, (2022). 22(21), 8327.
[10] Chowdhury, A. H., Jafarizadeh, B., Pala, N., & Wang, C. "Wearable Capacitive Pressure Sensor for Contact and Non-Contact Sensing and Pulse Waveform Monitoring". *Molecules*, (2022). 27(20), 6872.
[11] Ha, K. H., Huh, H., Li, Z., & Lu, N. "Soft capacitive pressure sensors: trends, challenges, and perspectives". *ACS nano*, (2022). 16(3), 3442-3448.