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Possibility of using Interdigital Sensor (IDS) in estimating different level of blood glucose

Z. ZAHARUDIN, I. ADAM, S. KHAN, A. HASSAN, A. NORDIN*, T. GUNAWAN

Medical Engineering Technology Section, Electronics Technology Section, University Kuala Lumpur, Malaysia

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Abstract: This paper presents the relationship of an effective capacitance of the interdigital sensor (IDS) with effective relative permittivity ($\mathcal{E}_{re}$)of the material under test (MUT). The relationship of the effective capacitance of the interdigital sensor against the $\mathcal{E}_{re}$ is examined by using the curve fitting tool provided by MATLAB®. Investigation shows there is a promising new technique in using of the IDS for properties of blood detection. The simulation results are presented and discussed.

Keywords: IDS, $\mathcal{E}_{re}$, blood dielectric

1. INTRODUCTION

Diabetes is on the rise even in developing countries, as it is no longer regarded a disease of predominantly developed societies. Its complication impacts harshly on the finances of individuals and their families. Common complications associated with diabetes include cardiovascular disease, nephropathy, and retinopathy. According to World Health Organization (WHO) report of 2009, more than 220 million people worldwide are suffering from the metabolic disorder of diabetes mellitus. This number may possibly rise to 366 million by 2030 with demographic distribution shown in **(Fig-1)** and listed in **(Table-1)** (World Health Organization 2009), (International Diabetes Federation, 2012)



Fig-1: Prevalence of diabetes in the world (World Health Organization 2009).

Currently, monitoring blood glucose concentration is most frequently measured through invasive techniques. The most common of the techniques is a blood glucose meter which utilizes a lancing device on the side of a finger to produce a drop of blood (Cihakova, 2001). The drop of blood is placed on a test strip and the blood glucose meter calculates the blood glucose concentration and displays the results to the user.

Table 1: Statistics for the number of people affected by diabetes (International Diabetes Federation, 2012)

	REGION	2011 MILLIONS	2030 MILLIONS	INCREASE %
	Africa	14.7	28.0	90%
	Middle East & North Africa	32.8	59.7	83%
	South East Asia	71.4	120.9	69%
	South and Central America	25.1	39.9	59%
	Western Pacific	131.9	187.9	42%
	North America & Caribbean	37.7	51.2	36%
	Europe	52.6	64.0	22%
	World	**366.2**	**551.8**	**51%**

In non-invasive monitoring technique, researchers have used number of parameters from dielectric permittivity, dielectric permeability, resistivity and conductivity (Yvanoff, 2008) to characterize the blood glucose level. (Johnson, 1999). Among all of the principles, electromagnetic sensing technique is well known and can detect these parameters. In this study, capacitive based .

2. PRESENT METHOD

However, the system block diagram also has certain drawbacks. The problems arose from the main circuitry,

++Corresponding author:Zarimin Zaharudin email: zarimin@unikl.edu.my
*Medical Engineering Technology Section, Universiti Kuala Lumpur, Batu 8 Jalan Sungai Pusu, Gombak, Selangor, Malaysia.

which is the VCO to provide multiple steps of frequency for dielectric assessment. Changing of frequency generated by VCO suffers from frequency deviation. This is potentially due to the mismatch and degradation of components. In addition, as frequency is varied to higher frequency, voltage deviates due to loading effect. This will cause error in measurement. These few drawbacks degrade the performance of the circuit and reduce its efficiency. Furthermore, the existence of VCO and its support circuitry also contribute to the higher cost of the system developed. Thus, this study is aims to identify the solutions and overcome the problems above. The intention is to eliminate the VCO and its circuitry by discover a simple technique to provide a single fixed frequency to the system.

3. INTERDIGITAL SENSOR

This research proposes the use of low-cost IDS to estimate different concentration levels of blood glucose. The working principle of such IDS is based on the interaction of the electrical field generated by the sensor with the material or substance under test.

IDS are mainly used to determine the near-to-the-surface properties, such as dielectrics, permeability and conductivity, as reported in (Goldfine, *et al.,* 2002). In addition, according to (Abdalla*, et al.,* 2010) the glucose level change can be detected using inter digital electrode sensor by measuring changes in conductivity and permittivity. The electromagnetic field interacts with the material under test. So, the resultant electromagnetic field is altered and consequently the impedance of the sensor is changed. IDS also has been widely used in many applications such as food safety (Zia, *et al.,* 2013) and bacterial content detection (Syaifudin, *et al.,* 2013), where the sensors are sensitive to the different magnetic susceptibilities and dielectric properties of each material (Müller, *et al.,* 2011), (Korostynska *et al.,* 2012).

The basic structure of a capacitor as shown in **(Fig-3)** consists of two parallel plates also called electrodes, each of area *A* and separated by an insulator or dielectric material of thickness *d* and permittivity where are free-space permittivity and relative dielectric constant, respectively (Ballou, 1997). Any variation in the dielectric constants (e), the plate area (*A*), or the plate spacing (*d*) will cause a change in capacitance (*C*).

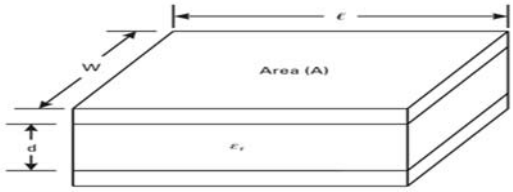


Fig: 2 Basic Parallel Plate Capacitor

There are number of methods use to characterize the inter digital capacitors. Among the methods includes approximate analysis, *J*-inverter network equivalent representation, full-wave methods, and measurement-based models. This study focused on the approximate analysis characterization. A general expression for the total series capacitance of an inter digital capacitor can also be written as explained in (Bahl, 1988).

$$C = 2\varepsilon_0\varepsilon_{re}\frac{K(k)}{K'(k)}(N-1)\ell \text{ (F)} \qquad (1)$$

$$= \frac{10^{-11}}{18\pi}\varepsilon_{re}\frac{K(k)}{K'(k)}(N-1)\ell\times 10^{-4} \text{ (F)} \qquad (2)$$

$$C = \varepsilon_{re}\frac{10^{-3}}{18\pi}\frac{K(k)}{K'(k)}(N-1)\ell \qquad \text{(pF)} \quad (3)$$

Where ℓ is in microns, N is the number of fingers, and ε_{re} is the effective dielectric constant of the microstrip line of width *W*. The ratio of complete elliptic integral of first kind *K* (*k*) and its complement *K* '(*k*) is given by

$$\frac{K(k)}{K'(k)} = \begin{cases} \dfrac{1}{\pi}\ln\left\{2\dfrac{1+\sqrt{k}}{1-\sqrt{k}}\right\} & \text{For } 0.707 \le k \le 1 \quad (4a) \\ \dfrac{\pi}{\ln\left[2\dfrac{1+\sqrt{k'}}{1-\sqrt{k'}}\right]} & \text{For } 0 \le k \le 0.707 \quad (4b) \end{cases}$$

3.1 Variations of Capacitance against Frequency

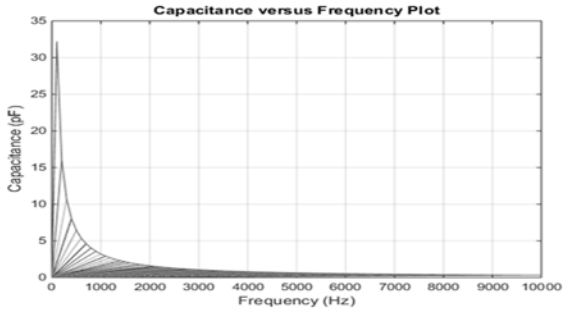


Fig 3: Frequency vs Capacitance

Fig-3 depicts the relationship of varying frequency and capacitance of the IDS. The graph shows the IDS acts merely as a capacitor.

3.2 Variations of Capacitance against $\mathcal{E}_{re}$

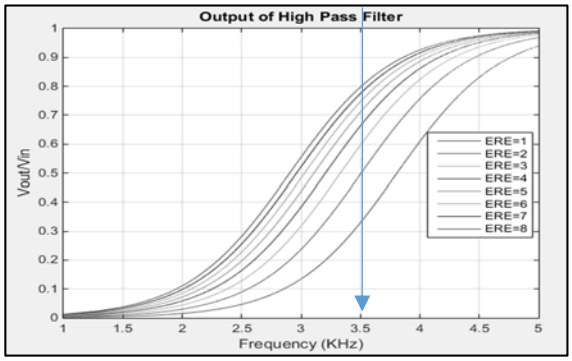


Fig 3: Vout vs. Frequency

The IDS discussed previously is used to form the High Pass filter. The investigation of Vout against frequency for number of $\mathcal{E}_{re}$ is conducted and the result is plotted in **(Fig-5)**. The lowest plot (which closes to x-axis) has the lowers value of $\mathcal{E}_{re}$ and the top has the highest value starting from 1 to 8. With reference to **(Fig-5)**, it is clear that at frequency of 3.5 KHz, there is a substantial distinctive between Vout. By taking the frequency reading vertically at point 3.5 kHz, multiple value of $\mathcal{E}_{re}$ with regards to a single frequency can be obtained. The graph **(Table-2)**: Dataset of $\mathcal{E}_{re}$ vs Vout demonstrates there is a correlation between Vout and $\mathcal{E}_{re}$ at certain fixed frequency. In this study the fixed frequency is found to be 3.5kHz. For instance, while at 3.5 kHz and $\mathcal{E}_{re}$ =1, the Vout = 0.7.V.

Graph in **(Fig.4)** demonstrates the enlarge view of the plots taken at 3.5 kHz. **(Table-2)** lists the corresponding Vout with respect to $\mathcal{E}_{re}$.

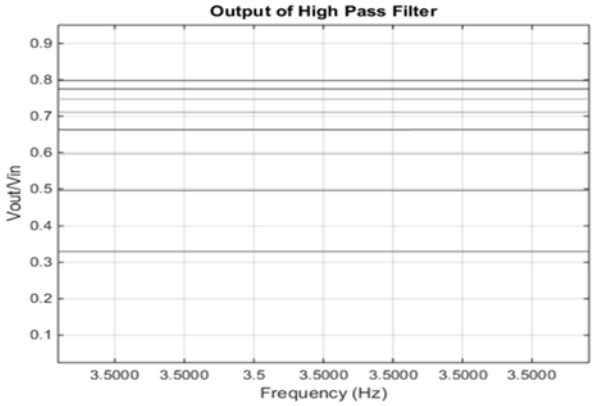


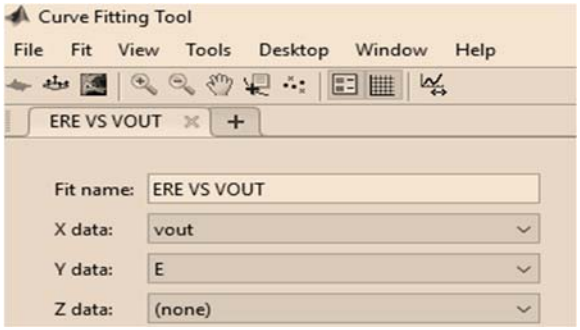
Fig 4: Enlarge view of the plot at 3.5kHz

Table 2: Dataset of $\mathcal{E}_{re}$ vs Vout

Ere	Vout
1	0.3297
2	0.4959
3	0.5961
4	0.6630
5	0.7110
6	0.7469
7	0.7750
8	0.7974

3.3 Relationship of Vout and Ere by curve fitting technique.~~$\mathcal{E}_{re}$~~

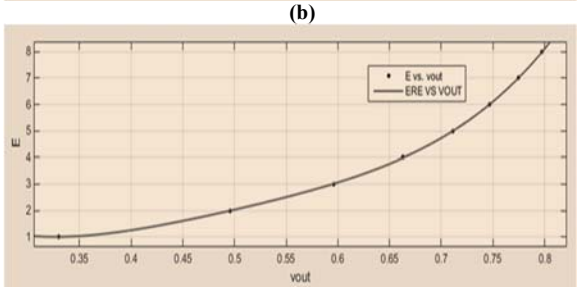
By using the data of **Table 2** and curve fitting tool of Matlab®, the equation representing the relationship of Vout and $\mathcal{E}_{re}$ is fitted.



(a)



(b)



(c)

Fig. 5 Curve Fitting Tool – Polynomial function

In this simulation, the polynomial function with power of 4 is discover to be best fitted. Result shows that the Root Mean Square Error (RMSE) is approximately 0.01944 which is too small and can be ignored.

4. DISCUSSION

It is investigated that at a certain fixed frequency there exist a substantial distinctive between Vout correspond to Ere. Therefore, the curve fitting methods can be used to formulate the relationship of Vout and Ere. It is shown that the deduced formula can be used to estimate the concentration of blood glucose with remarkable result. The simulation result suggests that by using this technique, the $\mathcal{E}_{re}$ of the MUT can be acquired with an acceptable error. Further the deduced formula will be used as an algorithm within the microcontroller of the system.

5. CONCLUSION

The result proved that there is a relationship between the effective capacitance versus $\mathcal{E}_{re}$ at certain fix frequency. The outcome demonstrates that there is a possibility of using the inter digital sensor to evaluate the level of blood glucose. Indirectly the single fixed frequency can be used to estimate the relative permittivity thus determine the blood glucose level.

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