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# RLSE Based Batteryless Telemetry Capacitive Sensor System

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***Abstract*** **– In case, sensor system performs where it is difficult to access physically and it is in the poor environment, it is limited to communicate by using wire and installing power module in sensor system.**
**In this paper, it suggests how information is obtained from telemetry sensor by means of inductive coupling without battery. Comparing with the telemetry sensor system of inductive coupling by the power supply, this system estimates the capacitance of sensor with high precision in using RLSE, not the process of modulation and demodulation. In order to activate this system, inductive model is used and in case of time variant parameter, telemetry sensor system which has got high rate in accuracy is implemented by using the forgetting factor.**

## I. INTRODUCTION

In the instrumental applied field, a wireless system is suitable for sensor system used in situation impossible of physical access or operated in the poor condition. Because this sensor system is applied to a implantable blood pressure sensor, and a detailed instrumentation field difficult to connect the wire with each sensor , the sources of electricity should be reconsisdered. Recently instruments developed on purpose to give ID to parents are implanted to human's body through a simple operation. And sensor is implanted in the body in order to measure the pressure in the particular position, like an intraocular pressure sensor used to measure the pressure of the inside of the lens implanted in eyes.

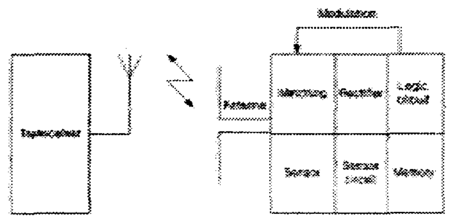

Fig 1 Schematic of the traditional passive telemetry sensor system

Fig. 1 shows a schematic of the traditional passive telemetry sensor system. Above all, a transmitter transmits a measurement instruction signal, and at the same time supplies sources of electricity by giving a regular RF signal. The measured value is transformed into digital signal, and stored in memory. After then, this transformed signal is instantly transmitted through an antenna. In case of increasing a sampling ratio or oscillation frequency in this process, even if there is necessity to boost electric power, in some cases, it is not easy if it is restricted by size and output. In order to solve this problem of the traditional system, in this paper, it is proposed to measure capacity of capacitive sensor by using various frequency signals, contrary to the traditional method, so as to obtain sensor signal. In this paper, capacity of sensor can be measured with recursive least square estimation as a method of measurement.

## II. MODEL OF PASSIVE TELEMETRY SENSOR SYSTEM

Telemetry sensor system is divided into two parts, transceiver and sensor part. The sensor part, contrary to typical telemetry sensor system, doesn't have active components inside. Fig. 2 shows the principle of inductive coupling between two antenna coils.

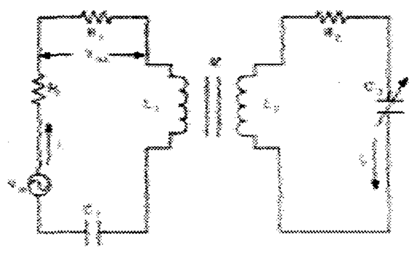

Fig 2 Principle of passive telemetry sensor system

Alternate current is generated in transceiver for the purpose of inductive coupling, hence electric motive force is induced in the coil of sensor side by linkage flux. In case that the capacitance of capacitive sensor is changed, the impedance of sensor part is found to be variable. This means that the reflecting impedance equivalent with the impedance of sensor part is varied. The capacitance of sensor can be estimated by measuring the variation of impedance.

### *A. Capacitive Humidity Sensor*

In general, the material of humidity sensor is ceramic, polymide and so on. In this paper, capacitive humidity sensor made of polymide is selected due to good linearity and hysteresis. Polymide is a dielectric material. Like as equation (1) and Fig. 3, the relation between capacitance $C_2$ and relative humidity RH is obtained.

$$C_2 = 0.0000225RH^3 - 0.002448RH^2 + 0.3942RH + 162[pF] \quad (1)$$

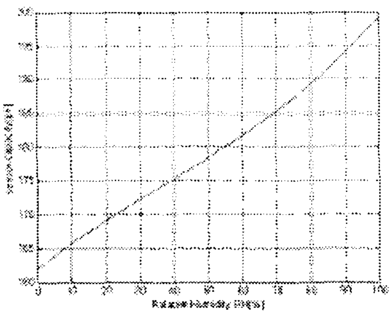

Fig 3 Characteristics of humidity sensor

### *B. Capacitive Humidity Sensor*

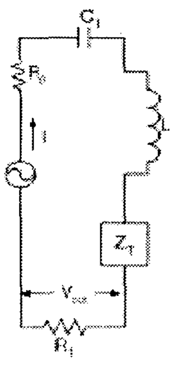

Fig 4 Equivalent circuit model of proposed passive telemetry sensor system

Fig. 4 is the equivalent circuit of Fig. 2. Transceiver part and sensor part is coupled inductively with mutual inductance M and impedance of sensor part $Z_{sensor}$ is included in reflect impedance.

$$Z_T = \frac{(\omega M)^2}{Z_{sensor}} = \frac{\omega^2 M^2}{(j\omega L_2 + R_2 + 1/j\omega C_2)} \quad (2)$$

where, $\omega$ is angle velocity.

The ratio between input voltage $V_{in}$ and the measured voltage $V_{out}$ of resister $R_1$ is equal to equation (3). Where, M and $C_2$ ate the known variables. Recursive least squared estimation is introduced to estimate the variables M and $C_2$. In order to simplify this model, equation (4) becomes to be as following equation (5) and (6).

$$G(j\omega) = \frac{V_{out}}{V_{in}} = \frac{R_1}{(R_1 + R_0) + j(\omega L_1 - 1/\omega C_1) - (\omega^2 M^2 / (R_2 + j(\omega L_2 - 1/\omega C_2)))} \quad (3)$$

$$\frac{1}{G(j\omega)} = y_1 + jy_2 \quad (4)$$

$$y_1 = \frac{(R_1 + R_2)}{R_1} - \frac{\omega^2 R_2 x_2 / R_1}{R_2^2 + (\omega L_2)^2 - 2L_2 x_1 + x_1^2/\omega^2} \quad (5)$$

$$y_2 = \frac{\omega L_1 - 1/\omega C_1}{R_1} + \frac{(\omega^2/R_1) x_2 (\omega L_2 - x_1/\omega)}{R_2^2 + (\omega L_2)^2 - 2L_2 x_1 + (x_1/\omega)^2} \quad (6)$$

$y_1$ and $y_2$ are able to be obtained through absolute value and phase difference of $G(j\omega)$.

$$y_1 + jy_2 = \frac{1}{|G(j\omega)|}(\cos\phi + j\sin\phi) \quad (7)$$

where, $\phi$ is $-\angle G(j\omega)$.

For the purpose of linearization of equation (5) and (6), parameters are rearranged like as $x_3 = x_1^2$ and $x_4 = x_1 x_2$.

$$\phi_1 x_1 + \phi_2 x_2 + \phi_3 x_3 + \phi_4 x_4 = z_1 \quad (8)$$

$$\phi_5 x_1 + \phi_6 x_2 + \phi_7 x_3 + \phi_8 x_4 = z_2 \quad (9)$$

$$\begin{bmatrix} z_1 \\ z_2 \end{bmatrix} = \begin{bmatrix} \phi_1 & \phi_2 & \phi_3 & \phi_4 \\ \phi_5 & \phi_6 & \phi_7 & \phi_8 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix}$$

or

$$Z = \Phi X \quad (10)$$

These recursive variables $\phi_1 \sim \phi_8$ are varied by input frequency like Table 1 and four variables $x_1 \sim x_4$ are estimated using RLSE. The data pairs desired in estimation are acquired through gain $G(j\omega)$ and phase difference $\angle G(j\omega)$.

Table 1 Regressor variables and Outputs

| | | | |
|---|---|---|---|
| $\phi_1$ | $(y_1 - \frac{R_0 + R_1}{R_1})2L_1$ | $\phi_2$ | $-\omega^2 R_2 / R_1$ |
| $\phi_3$ | $(y_1 - \frac{R_0 + R_1}{R_1})\frac{1}{\omega^2}$ | $\phi_4$ | $0$ |
| $\phi_5$ | $(y_2 - \frac{\omega L_1 - 1/\omega C_1}{R_1})2L_2$ | $\phi_6$ | $\omega^3 L_2 / R_1$ |
| $\phi_7$ | $(y_2 - \frac{\omega L_1 - 1/\omega C_1}{R_1})\frac{1}{\omega^2}$ | $\phi_8$ | $-\omega / R_1$ |
| $z_1$ | $(y_1 - \frac{R_0 + R_1}{R_1})(R_2^2 + (\omega L_2)^2)$ | | |
| $z_2$ | $(y_2 - \frac{\omega L_1 - 1/\omega C_1}{R_1})(R_2^2 + (\omega L_2)^2)$ | | |

Prior vector $\hat{X} = [\hat{X}_1 \hat{X}_2 \hat{X}_3 \hat{X}_4]'$ is updated with correction factor K(t). The estimated output $\hat{Z} = [\hat{z}_1 \hat{z}_2]'$ approaches to measured output $Z = [z_1 z_2]'$ with little error. Because this calculation procedure is achieved recursively, this estimation can be used online.

$$\hat{X}(t) = \hat{X}(t-1) + K(t)(Z(t) - \Phi(t)\hat{X}(t-1)) \qquad (11)$$

$$K(t) = \hat{P}(t-1)\Phi^T(t)(\lambda I + \Phi(t)P(t-1)\Phi^T(t))^{-1} \qquad (12)$$

$$P(t) = (I - K(t)\Phi(t))P(t-1)/\lambda \qquad (13)$$

where, forgetting factor $\lambda$ is used in estimating time variant variables $\hat{X}$ . Based on above equation, estimation model is implemented like as Fig. 5.

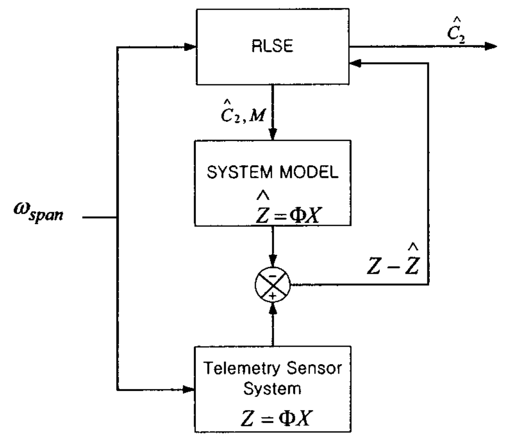


Fig 5 Block diagram of RLSE system

Where, $\omega_{span}$ means the frequency area between $\omega_{start}$ and $\omega_{stop}$ . $\hat{C}_2$ is the estimated value of $C_2$ which is obtained in resonant frequency $\omega_0 = 2\pi f_0$ .

*C. Results*

Table 2 shows the parameters used in simulation.

Table 2 System Parameters

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| $L_1$ | 700[$\mu H$] | Initial value of $C_2$ | 4000[$pF$] |
| $C_1$ | 80[$pF$] | $M$ | 8.2[$\mu H$] |
| $L_2$ | 50[$\mu H$] | $R_{source}$ | 30[$\Omega$] |
| $C_2$ | 160,180,200 [$pF$] | $R_2$ | 10[$\Omega$] |
| $R_1$ | 5[$\Omega$] | $\omega_{span}$ | 1[kHz] ~ 2[$MHz$] |
| $\lambda$ | 1 | Distance between two coils | 2.5[$cm$] |

In case of $C_2 = 160[pF], 180[pF], 200[pF]$ , Fig. 6 shows the convergence pattern of system gain and phase.

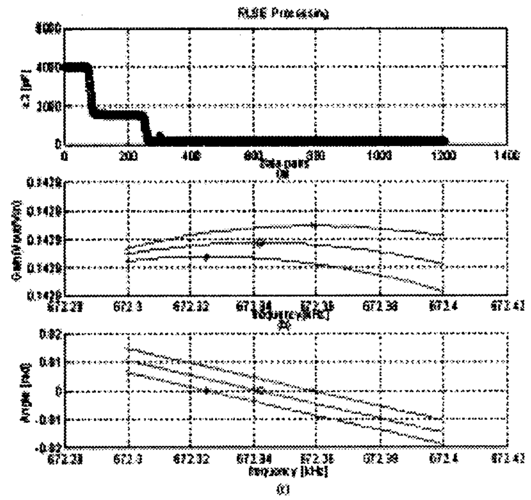


Fig 6 Convergence Patterns, Gain and Phase Diagrams by RLSE

The system using error estimation algorithm is converged to the desired value with few error through 1200 data pairs like as Fig. 6(a).'*','o','x' marked in Fig. 6(b) and Fig. 6(c) are denoted as the resonant frequency in $C_2 = 160[pF], 180[pF], 200[pF]$ respectively. Fig. 7 shows the relation between resonant frequency and capacitance $C_2$ .

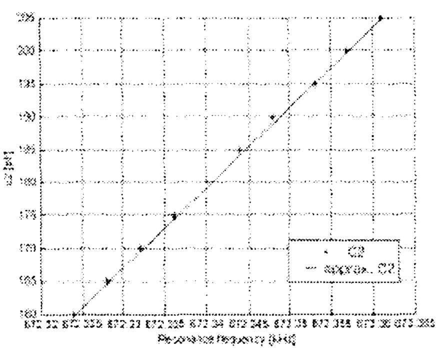

Fig 7 Resonance Frequency vs $C_2$

Fig. 8 (a) shows the performance of RLSE algorithm when the capacitance of humidity sensor $C_2$ is changed with 100[Hz] period. '-' shown in Fig. 8 (a) means the change of $C_2$ and '*' marked in Fig. 8 (b) is the error which is generated in estimating parameter $C_2$.

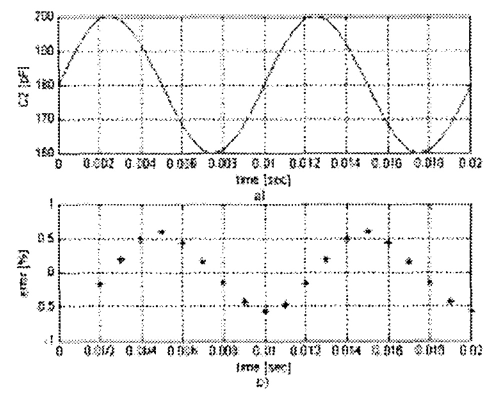


Fig 8 Simulation of estimation for time variant $C_2$(100 [Hz])

Where, forgetting factor $\lambda = 0.6$ .

## III.CONCLUSION

In this paper, capacitance of humidity sensor is estimated in the accurate ratio of mean error ±0.36[%] using RLSE. Also, estimation system considering forgetting factor with regards to time variable is developed and the performance of the system is verified. In the future, the algorithm estimating noise system properly is desired.

## IV. REFERENCE

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