Proximity Coupled Vital Sign Sensor Based on Phase Locked Loop Under Injection

Byung-Hyun Kim, *Student Member, IEEE*, Jong-Gwan Yook, *Member, IEEE*

***Abstract*— In this paper, a phase locked oscillator under injection is designed with proximity vital sign sensor at 2.4 GHz. The proposed system is composed of a sensor oscillator with a planar resonator, a phase locked loop (PLL) synthesizer, and a voltage controlled oscillator (VCO). The planar resonator functions not only as a series feedback component to an oscillator but also as a detector which measures respiration and heartbeat signal. The input impedance of the planar resonator varies according to a distance between the human body and the planar resonator. This impedance variation changes the oscillation frequency of the sensor oscillator. The sensor oscillator injects its output into the VCO so that the VCO is locked to the sensor oscillator's frequency. At last, the PLL puts out control voltage to the VCO to prevent frequency from shifting by vital signs. Therefore, the VCO control voltage mirrors vital signs. Measurement results prove that this sensor can detect vital sign up to 40 mm away from a subject.**

***Index Terms*—Injection locking, phase locked loop, planar resonator, Vital sign sensor.**

I. Introduction

DUE to the growing attraction about health, health care systems have emerged as an industry with great prospects. One of the most active research subjects in health care system is wireless vital sign detection at microwave frequencies. A novel type of the vital sign sensor using the impedance variation of the planar resonator by motion of human body within near-field range of the planar resonator is proposed [1]. The impedance variation of the resonator causes output frequency of sensor oscillator to change. A surface acoustic wave (SAW) filter is utilized to transform frequency deviation to amplitude deviation in real time. This sensor can measure respiration and heartbeat signal up to 20 mm away from the chest. The drawback of this sensor is that the frequency deviation range has to coincide with skirt range of SAW filer for high sensitivity. If frequency deviation range is off the skirt range by the surrounding such as temperature or humidity, the sensor does not operate as expected. In this paper, so as to track the vital sign well even in extreme condition, the phase locked oscillator under injection is combined with the proximity sensor.

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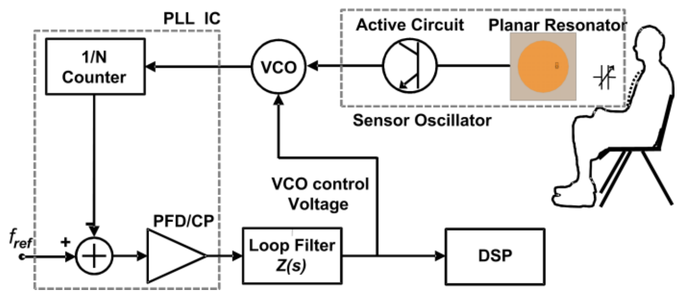

Fig 1. System block diagram of the proposed sensor.

II. Operation Principle

A. Sensor Oscillator

The negative resistance oscillator is used to convert the impedance variation of the resonator to the frequency variation. As is well known, the oscillation can occur only when the startup conditions given by (1) and (2) are satisfied [2].

$$R_{IN} + R_R < 0 \quad (1)$$

$$X_{IN} + X_R = 0 \quad (2)$$

Fig. 2 shows that Z_R is defined as impedance looking into resonator side and Z_{IN} as impedance looking into negative resistance side. To make sure that the oscillation conditions change when human body is nearby the sensor, simulation is performed by full wave EM solver with simplified muscle model. The frequency satisfying the oscillation conditions is slightly different averagely 0.5 MHz/mm depending on distance between the resonator and the simplified body model as shown in Fig. 3.

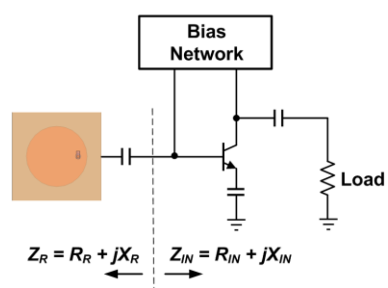

Fig. 2. Conceptual diagram of negative resistance oscillator

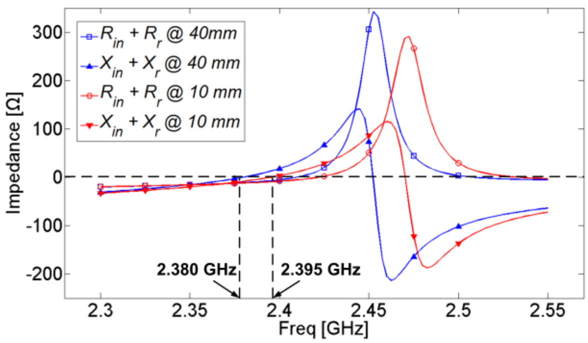

Fig. 3. Simulated input impedance looking into resonator side and BJT side varying distance between the simplified muscle model and the resonator.

B. Phase Locked Oscillator under Injection

In the proposed system, the output signal from sensor oscillator functions as injection signal to the VCO. Without human body, the sensor oscillator is designed to free run around 2.4 GHz. Also, the PLL synthesizer is set to fix the VCO output at 2.4 GHz. Approaching the sensor in the proximity of subject's chest, the output of the sensor oscillator varies with movement of chest or heart. Then, the VCO start to follow the oscillation frequency of the sensor oscillator, it is said that injection locking occurs. As a result, the PLL puts the control voltage to the VCO. This voltage now reflects the vital sign. After digital signal processing (DSP), it is more explicit.

III. Fabrication and Measurement Results

The proposed vital sensor system is fabricated with two layers. As shown in Fig 5, the planar resonator is printed on top, the system is mounted on bottom, and they share ground plane in the middle. The Resonator and the system are connected through via hole. Vital signs are measured at 40 mm away from subject, and results are shown in Fig. 5 (a) - (c). In order to confirm validity of the proposed sensor, heartbeat is also measured by finger pressure sensor using piezoelectric transducer (UFI-1010) concurrently. Fig. 5 (a) is the data after low pass filtering (0 ~ 5 Hz), which contains vital signs. DFT is taken to the Fig. 5 (a) and the pressure sensor. From Fig. 5 (b) and Fig. 5 (c), the proposed sensor can detect vital sign up to 40 mm.

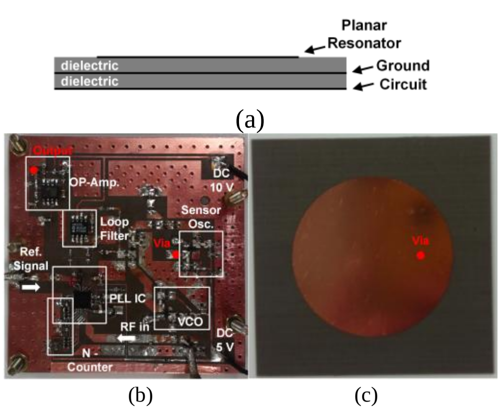

Fig. 4. Fabricated system: (a) Side view (b) Circuit part (c) Planar resonator.

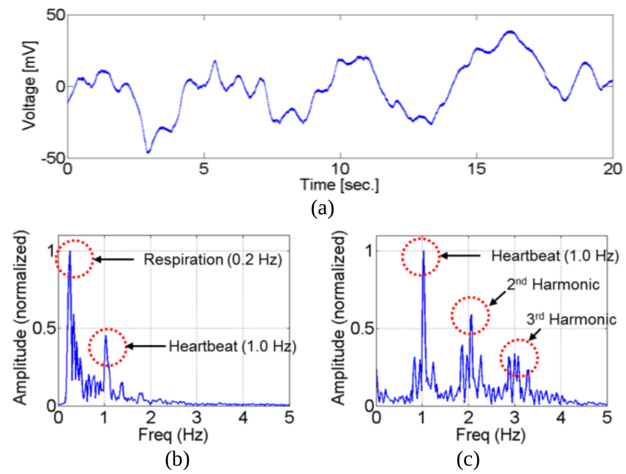

Fig. 5. Measurement results. (a) Raw data with LPF (0~5 Hz). (b) DFT result at 40 mm. (c) DFT result of reference sensor.

IV. Conclusion

This research applies the phase locked oscillator under injection to proximity vital sensor. It is shown that the resonator input impedance variation changes oscillation conditions. The sensor oscillator's output is exploited as an injection signal to the VCO in the proposed system. Due to the locking phenomenon, the VCO's frequency is locked to sensor oscillator's frequency. Consequently, the PLL synthesizer stabilizes the VCO, and control voltage reflects vital sign.

The prototype of the proposed system with commercial component has proven the feasibility that injection locking phenomenon can be used to proximity vital sign sensor. Measurement results show that the proposed system can detect vital sign up to 40 mm away from the subject.

V. Next Career Plan

It is an honor for me to receive the Undergraduate-Pregraduate Scholarship from MTT-S. Thank to this scholarship program, I was able to bring my career to graduate school with pleasure. My research interest is about RF vital and bio sensor system. I want to contribute to developing and commercializing RF vital and bio sensor system. In addition, attending IMS 2013 in Seattle was exciting experience. From a number of professionals, I could learn their idea and method about bio sensing.

V. Reference

[1] S. -G. Kim, G. H. Yun, and J. -G. Yook, "Compact Vital Signal Sensor Using Oscillation Frequency Deviation," *IEEE Trans. on Microw., Theory Tech.*, vol.60, no.2, pp.393-400, Feb. 2012.

[2] G. Gonzalez, *Foundations of Oscillator Circuit Design*. Boston, MA: Artech House, 2007.W.-K. Chen, *Linear Networks and Systems* (Book style). Belmont, CA: Wadsworth, 1993, pp. 123–135.

[3] R. Adler, "A Study of Locking Phenomena in Oscillators," *Proc. of the IRE* , vol.34, no.6, pp.351-357, June 1946.

[4] F.-K. Wang, C.-J. Li, C.-H. Hsiao, T.-S. Horng, J. Lin, K.-C. P, J.-K. J, J.-Y. Li, and C.-C. Chen, "A Novel Vital-Sign Sensor Based on a Self-Injection-Locked Oscillator," *IEEE Trans. on Microw. Theory Tech.*, vol.58, no.12, pp.4112-4120, Dec. 2010.