A Passive Implantable Biopotential Measurement Sensor With An Inductive Coupled Readout Circuit

Reza Ranjandish*, Ali Agharasooli†, Majid Tayarani‡ and Omid Shoaei§
*School of Electrical and Computer Engineering, University of Tehran, Tehran, Iran
Email: reza.ranjandish@ut.ac.ir
†Applied Electromagnetics Lab., Iran University of Science and Technology, Tehran, Iran
Email: ali_agharasooli@elec.iust.ac.ir
‡Applied Electromagnetics Lab., Iran University of Science and Technology, Tehran, Iran
Email: m_tayarani@iust.ac.ir
§Nano-Electronic Center of Excellence, School of Electrical and Computer Engineering, University of Tehran, Tehran, Iran
Email: oshoaei@ut.ac.ir

***Abstract*—To measure biopotentials, a measurement method with a passive LC filtering is presented. The measuring system consists of two sections: an implantable sensor section and an inductive coupled readout circuit. The proposed sensor section consists of an inductor that receives power from outside of the body and a LC filter with which the received signal is filtered. This filter consists of an inductor that acts as a transmitter, too. So, the filtered signals could be sent outside of the body. The capacitive component of the LC filter is a varactor that its capacitance varies with the amplitude of the biopotential signal. This induces a change in the resonance frequency of the filter which can be measured over the inductive link. The overal system works like a spectrum analyzer.**

***Keywords*—Wireless sensor; Implantable sensor; biopotential; Passive telemetry; Readout circuit; Inductive telemetry.**

I. Introduction

In most medical and biomedical areas, implantable biomedical devices are currently of a great interest because they can help physicians to recognize and treat diseases such as heart arrhythmias, epilepsy and seizure [1]. An important group of these devices are biopotential recorders. These recorders can measure different types of biopotentials such as action potential of neurons and intra-ocular pressure. All these sensors are divided in two groups: active and passive.

Both active and passive sensors have been published in literature. However, passive sensors last for a long time in the human body because they don't need any external power. This advantage makes this type of sensors favorable for implanting in the human body. On the other hand, for some applications especially neural recording applications, potential hazards such as heat dissipation by active components, reliability of batteries, etc. restrict the realization and implementation of these kind of sensors in the clinical setting [2], [3]. Therefore, a fully passive circuitry reduces the risks related to heat dissipation and any failure of the batteries, regulators or energy harvesters. In addition, the fully passive measurement system is extraordinary simplified in comparison to active microsystems.

In some recent articles, the used wireless link is a RF link [3], [4]. However, inductive link has more advantage than the RF link. Inductive link can offer designers several benefits such as low-power and low-cost communication. In addition, by using inductive links, many of the drawbacks of RF links can be overcome such as interferences, scattering and multi-path fading. Therefore, inductive communication has become the major method used in implantable microelectronic devices (IMD) [5]–[10].

By means of the method that is presented in the paper, the measurement of the biopotentials is simplified and also the sensor section can be easily implanted in the patient body without any need to add an external power, e.g. battery, to the implantable sensor.

The organization of this paper is as follows: section II reviews the methods that have been introduced in literature. In section III the devised method is described. By simulation results, it is shown that how this method has more benefit in comparison to the published methods in section IV.

II. Litrature Review

The conventional biopotential recording devices consist of two parts that are connected together using inductive link. Reference [11] introduces a microsystem in which there is no need for an interior battery because its power is supplied from outside of the body. The sensing part is a varactor that its capacitance value is changed by the biopotential voltage and resonates with an implanted coil, so the center frequency of the resonator changes with the biopotential voltage level. At the outer body there is a reader that recognizes these changes and extracts the output data in two ways. First approach is using a slope detector. The circuit is shown in Fig. 1(a). At the reader end there is an AC signal generator that sets a center frequency for the inductive link (34 MHz). As it was mentioned, a change in the biopotential voltage causes a variation in the center frequency of the resonator and thus changes the equal impedance seen at the coil of the reader. This impedance is a part of a voltage divider. At a defined frequency that has been set by the AC signal generator the impedance would be changed by the data. This variation is amplified and finally, the biopotental voltage is measured. The major drawback of this approach is that the impedance matching between the AC-source and measurement reader is a problem because this is done only at a certain frequency and at a certain distance.

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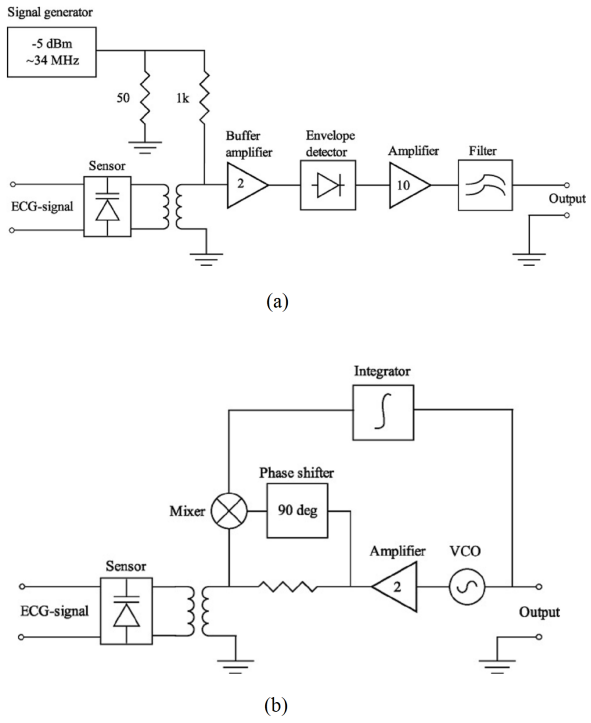


Fig. 1. Block diagram of the two methodes represented in [11]. (a) Block diagram of the slope detection method, (b) Block diagram of the phase locked reader

As it was stated, the center frequency of the sensing part is changing by the biopotential voltages, another way is to use the PLL at the reader unit to lock at the resonating frequency of the sensing unit. As it is shown in Fig. 1(b), the input signal that comes from the reader is mixed by the output of the VCO. The output of the mixer is passed through an integrator to get the output DC voltage from it. In the case where there is no variation in center resonating frequency, the output of the integrator would be zero. This approach shows a better SNDR and works at further distances with regard to the previous mentioned work because a phase detector used instead of amplitude detection. However, this approach is highly sensitive to capacitive disturbance because it will mistune the LC resonating frequency in coils and the output data could be distorted.

Another way was reported in [12]. As shown in Fig. 2, Z_{eq} is the impedance of the secondary that is reflected to the primary. The changes in Z_{eq} are due to the variations on C and are sensed by the remote detection of the resonance frequency. Resonance of the sensor corresponds to a peak in Z_{eq}. This peak can be obtained by observing Z_{eq} during a frequency sweep. A voltage controlled oscillator (VCO) is used to perform the frequency sweep. However, the results show that the detection of the resonance peak is so difficult and therefore the sensitivity of the sensor is very low.

In most implantable sensor applications, the power is transmitted over an inductive link to the measurement unit to make them light and implantable. Making use of passive resonance sensor in all these microsystems, makes them good candidate for low power applications. Lower need for power yields

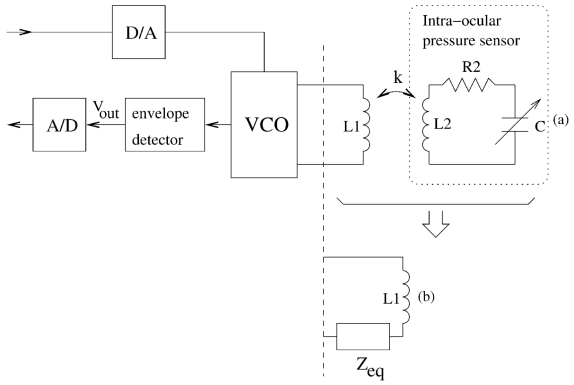


Fig. 2. Schematic of the method used in [12] for pressure measurment. (a) System for the measurement of the intra-ocular pressure, and (b) its equivalent circuit.

longer operating distance and lesser sensitivity to coupling coefficient.

III. Detection Principle

An overview of the proposed system is depicted in Fig. 3. In the implantable sensor section, there are two inductors. L2 acts as a power receiver that receives signals from VCO. L3 is part of a LC filter with which the received signal is filtered. This inductor also acts as a transmitter that transmits the filtered signals outside of the body. An important notion for implementing the system is that these two inductors (L2 and L3) should be enough far away from each other because of the coupling effect. Another component of the LC filter is a varactor that should be able to operate around zero volt.

In the implantable sensor section, the biopotential signal can change the capacitance of the varactor in the LC filter which leads to a change in the resonance frequency of the LC filter. On the other hand, in the reader section, a ramp generator produces a ramp signal with a specific period that is applied to the VCO changing its frequency. This signal is received by the L2 in the implantable sensor section. Whenever the frequency of the received signal reaches the resonance frequency of the filter, a peak can be seen in the output of the peak detector. Since the amplitude of this peak might not be high enough to trigger the ADC to strobe the data, a comparator is used to make a trigger pulse for the ADC. The

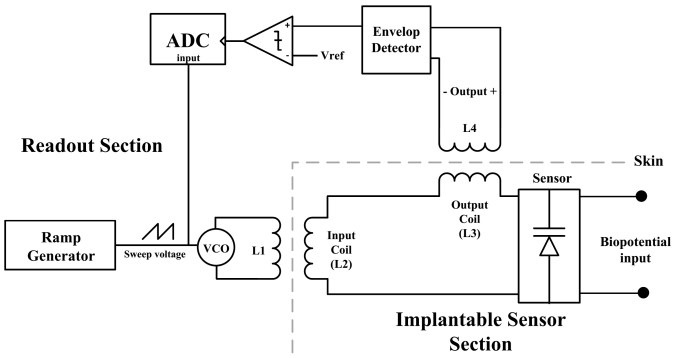


Fig. 3. Schematic of the proposed system for biopotential measurment.

ADC digital output is a representative of the VCO frequency that is aligned with the resonance frequency at this peak. A change in the biopotential amplitude leads to a change in the LC filter resonance frequency. This frequency variation could be sent out of the body by means of an inductive link (L3 and L4). Hence, a change in the position of this peak and therefore the shape of the biopotential signal can be determined by the variation of the peak in the output voltage across L4.

The overall system works like a spectrum analyzer. The output voltage of the envelop detector is exactly like the output of a spectrum analyzer when its input is a sinusoid. As shown in Fig. 4 a swept-tuned spectrum analyzer down-converts a portion of the input signal spectrum to the center frequency of a band-pass filter by sweeping the voltage-controlled oscillator through a range of frequencies, enabling the consideration of the full frequency range of the instrument. In this kind of spectrum analyzer, the bandwidth of the band-pass filter dictates the resolution bandwidth, which is related to the minimum bandwidth detectable by the instrument. If too narrow the bandwidth of the band-pass filter is chosen for the filter, the output spectrum will be distorted because the sweeping signal does not stay at a specific frequency long enough for the filter to accurately discern the signal shape. A solution is to simply increase the sweep time until an undistorted spectrum is achieved. Spectrum analyzer theory has an equation for the best sweep time. Given the frequency span S, the filter bandwidth RBW and the constant K which is between 2 and 3, the sweep time (ST) is [13]

$$ST = \frac{K * S}{RBW^2} \tag{1}$$

Sweeping too fast causes a drop in displayed amplitude and a shift in the displayed frequency [14].

In the proposed sensor section, the LC filter acts like the band-pass filter in the spectrum analyzer. As it is discussed above, this narrow band filter could distort the output signal. Hence, this design needs a determined sweep time for producing an undistorted output. Just like a spectrum analyzer, the sweep time for the proposed microsystem can be determined by (1).

IV. Simulasion Results

The proposed system is designed and simulated in a circuit simulator. For simplifying the simulation of the proposed system, despite of using a varactor model, a fixed capacitor

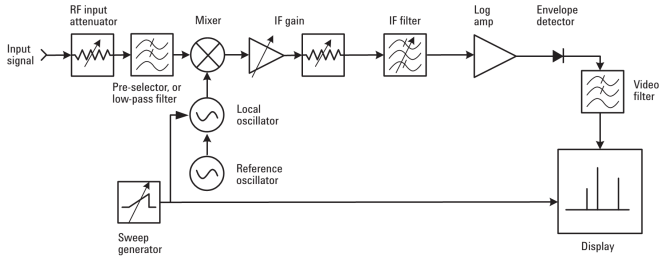


Fig. 4. Block diagram of a classic spectrum analyzer [15].

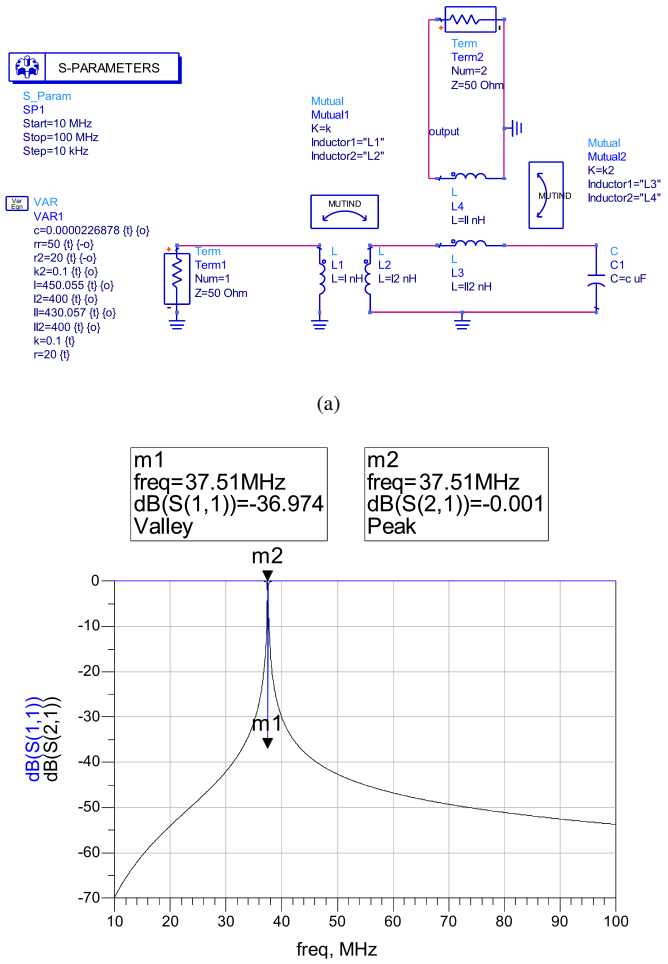


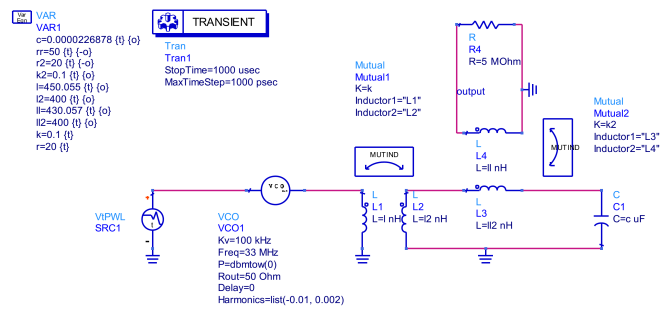
Fig. 5. S-Parameters simulation and its result. (a) The schematic of the modeled system, (b) Insertion loss (S21) and return loss (S11) of the system.

is used. Since, the value of the varactor changes with respect to the biopotential value, therefore, this capacitor would be a representative of the varactor value for certain voltage amplitude of the biopotential signal.

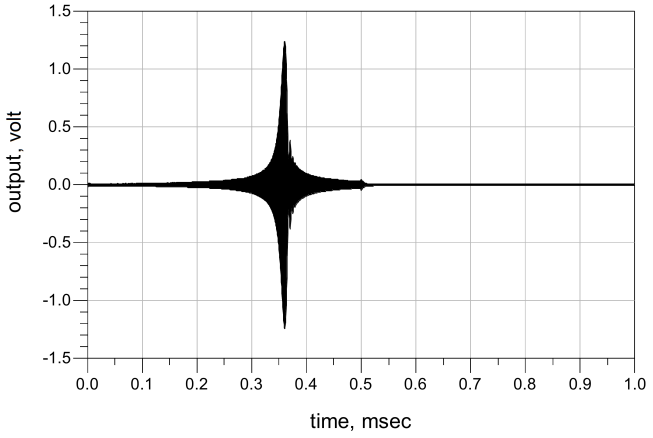
Both S-Parameters and transient simulation of the design are done and their results are depicted in Figs. 5 and 6, respectively. The circuit is designed for the worst case. The coupling coefficient value of the circuit is set to 0.1. The coupling coefficient varies in different environments such as skin, skull and body tissues. However, the simulation results show that this system can operate with a coupling coefficient lesser than 0.1.

In Fig. 5 the S-parameters simulation and its result can be seen. Fig. 5(b) shows that the return loss (S11) of the circuit is good enough for the proposed microsystem. The better the value of the return loss, the better the matching of the circuit. On the other hand, this system has an improved insertion loss (S21). This leads to a higher noise immunity of the system.

The transient simulation result is depicted in Fig. 6. As it is discussed, the output voltage has a peak with which the ADC is triggered to strobe its value. The voltage of the output (the



(a)



(b)

Fig. 6. Transient simulation and its result. (a) The schematic of the modeled system, (b) The signal received at the "output" node.

input of the peak detector in Fig. 3) is depicted in Fig. 6(b). The measured filter bandwidth (RBW) is 180 KHz and the frequency span (S) is 10 MHz (34-44 MHz). K is supposed to be 2.5. Therefore, the best sweep time is 0.8 ms which is determined by (1). For the better resolution, the sweep time is set to 1 ms which leads to 1 KSPS sampling rate of the biopotential signal.

V. Conclusion

This paper demonstrated the ability of the proposed microsystem to wirelessly recover biopotetials through a medium using a fully passive implantable sensor. As it is shown in the paper, the simulation results show better insertion loss coefficient and also better quality factor in comparison to the published papers. By considering the simulation results, it can be concluded that this method can be used for cortical recording because it is shown that this method works well, even in a medium that has low coupling coefficient.

References

[1] K. D. Wise, A. M. Sodagar, Y. Yao, M. N. Gulari, G. E. Perlin, and K. Najafi, "Microelectrodes, microelectronics, and implantable neural microsystems," *Proceedings of the IEEE*, vol. 96, no. 7, pp. 1184–1202, 2008.

[2] N. G. Hatsopoulos and J. P. Donoghue, "The science of neural interface systems," *Annual review of neuroscience*, vol. 32, p. 249, 2009.

[3] H. N. Schwerdt, F. A. Miranda, and J. Chae, "A fully passive wireless backscattering neurorecording microsystem embedded in dispersive human-head phantom medium," *Electron Device Letters, IEEE*, vol. 33, no. 6, pp. 908–910, 2012.

[4] H. N. Schwerdt, W. Xu, S. Shekhar, A. Abbaspour-Tamijani, B. C. Towe, F. A. Miranda, and J. Chae, "A fully passive wireless microsystem for recording of neuropotentials using rf backscattering methods," *Microelectromechanical Systems, Journal of*, vol. 20, no. 5, pp. 1119–1130, 2011.

[5] M. Ghovanloo and S. Atluri, "An integrated full-wave cmos rectifier with built-in back telemetry for rfid and implantable biomedical applications," *Circuits and Systems I: Regular Papers, IEEE Transactions on*, vol. 55, no. 10, pp. 3328–3334, 2008.

[6] W. H. Ko, S. P. Liang, and C. D. Fung, "Design of radio-frequency powered coils for implant instruments," *Medical and Biological Engineering and Computing*, vol. 15, no. 6, pp. 634–640, 1977.

[7] M. W. Baker and R. Sarpeshkar, "Feedback analysis and design of rf power links for low-power bionic systems," *Biomedical Circuits and Systems, IEEE Transactions on*, vol. 1, no. 1, pp. 28–38, 2007.

[8] D. C. Galbraith, M. Soma, and R. L. White, "A wide-band efficient inductive transdennal power and data link with coupling insensitive gain," *Biomedical Engineering, IEEE Transactions on*, no. 4, pp. 265–275, 1987.

[9] C. M. Zierhofer and E. S. Hochmair, "High-efficiency coupling-insensitive transcutaneous power and data transmission via an inductive link," *Biomedical Engineering, IEEE Transactions on*, vol. 37, no. 7, pp. 716–722, 1990.

[10] G. Wang, W. Liu, M. Sivaprakasam, and G. A. Kendir, "Design and analysis of an adaptive transcutaneous power telemetry for biomedical implants," *Circuits and Systems I: Regular Papers, IEEE Transactions on*, vol. 52, no. 10, pp. 2109–2117, 2005.

[11] J. Riistama, E. Aittokallio, J. Verho, and J. Lekkala, "Totally passive wireless biopotential measurement sensor by utilizing inductively coupled resonance circuits," *Sensors and Actuators A: Physical*, vol. 157, no. 2, pp. 313–321, 2010.

[12] J. Coosemans, M. Catrysse, and R. Puers, "A readout circuit for an intra-ocular pressure sensor," *Sensors and Actuators A: Physical*, vol. 110, no. 1, pp. 432–438, 2004.

[13] Agilent, *Appl. Note 150*, p. 23.

[14] ——, *Appl. Note 150*, p. 22.

[15] ——, *Appl. Note 150*, p. 10.