Capacitive Sensor for Respiratory Monitoring

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Introduction. Signals such as pulse or respiratory rates, blood pressure, temperature are necessary to monitor for evaluation of health condition. Respiratory rate can figure out the progress of rehabilitation or training process. Respiration rate monitoring plays significant role in the control of rare diseases, such as Sleep Apnea or Sudden Infant Death syndrome (SIDS). Usual methods such as spirometry or pulse oximetry can be used as well as other methods, based on indirect measurements. One of promising methods for indirect evaluation of lung activity is based on capacitive sensing.

Previous studies revealed different types of capacitive sensors [1]-[5]. They differ by electrode configuration, placement and operating principles. Optimal position of two electrodes was studied in [1] while other approach is to use multi-electrode arrays [2], [5]. Non-contact capacitive electrodes can be used to monitor ECG [3] and then respiratory signal can be filtered as the base line variations. Other sensors are devoted to detect capacity change between electrodes by the human body permittivity changes during respiration [4], [5].

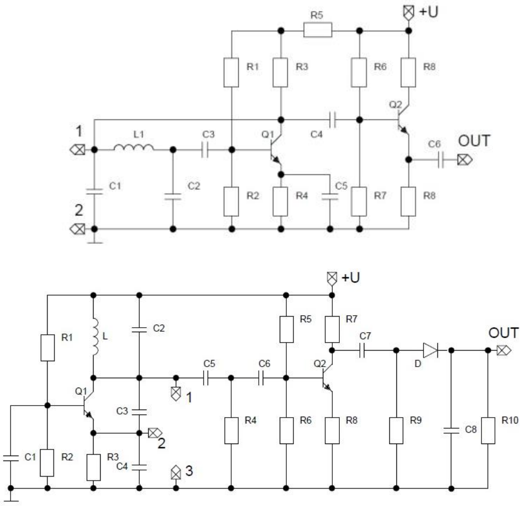
In this study the discussion centers on two types of low-cost, high-sensitivity capacitive sensors with a different size of electrodes. Both capacitive sensors are based on Colpitts oscillator, whose frequency changes by the change of electrodes capacitance.

Theory of capacitive sensing. The sensor working principle is based on capacity change impacted by the human body dielectric properties and movement. Sensing element capacity *C* can be simplified as a flat capacitor:

$$C = \varepsilon_r \varepsilon_0 \frac{S}{d}, \qquad (1)$$

where *S* is electrode area and *d* is distance between them. This distance is changing during respiratory movements while relative permittivity of the body ε_r also depends on respiration due the change of amount of air in lungs, thus the body capacity is varying.

There are few ways of fast and continuous measuring of capacity changes, one of them is based on measuring oscillator frequency changes. A Collpitts oscillator can be used as capacity sensing device [4], [5]. Frequency and magnitude of oscillator output then can be converted to voltage using differentiator and envelope detector [5]. Another method is to use constant output oscillator and capacitance divider, where variable body capacitance is connected.



a)

b)

Fig. 1. Sensors circuits: a) common emitter, b) common base

Two sensor circuits were assembled and tested. The main difference between the sensors is in connection of LC circuit. The first design has capacitance connected in series with inductance in base of transistor (Fig.1 a) and common emitter while the second uses common base schematic (Fig.1 b). Both circuits oscillate in 6-14 MHz frequency range depending on electrodes capacity. First sensor uses two electrodes connected between points 1 and 2. Output of sensor was designed as current follower to connect to frequency counter. Second sensor (Fig.1 b) can operate using two electrodes connected to points 1 and 3 as well as four electrode system where two of them connected to point 1 and other two connected between points 2 and 3 [5]. This sensor contains Colpitts oscillator, differentiator, amplifier and envelope detector. Oscillator output voltage is divided approximately 50 times in a differentiator circuits consisting of C5, R4 and C6, Rin2, where Rin2 is the input resistance of second transistor circuit. Capacities C5 and C6 were selected 5…10 pF and fine-tuned to prevent compressing of signal in second stage. Thus input voltage of second transistor depends on frequency. It is amplified and then detected by envelope detector with low barrier voltage Schottky diode. Low frequencies are filtered with R10, C8 circuit.

Design and placement of electrodes. Despite the fact that capacitor has two electrodes, a four electrode system is recommended to be used to reach higher stability and sensitivity of the sensor [5]. Such electrode system (see Fig. 2, c) initially was designed to register heart activity and it's ability to register the respiratory signal was investigated.

The sensitivity of sensors relies on electrodes size, distance between them and a position of electrodes. Two size electrodes were made for this study:

50x50 mm separate electrodes, with unshielded (Fig.2 a) and shielded other side (Fig.2 b) that could be connected to the both sensors, and 30x30 mm four electrode array (Fig.2 c) that could be connected to the second sensor. All electrodes were manufactured from FR-4 material. Basing on previous investigation, connecting cables was made from RG174 coaxial cable with shielding connected to oscillator ground.

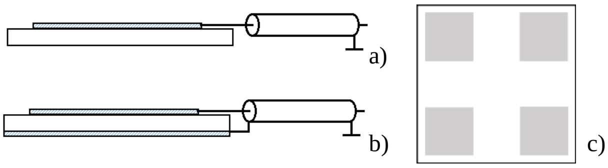


Fig. 2. Design of electrodes: a) unshielded b) shielded c) four electrode array

Subrata *et al*. investigated a different positions and placement of electrodes [1]. In our study the question under discussion is the influence of different size and position of electrodes as well as use of two and four electrode systems. Electrodes were placed on opposite sides of a human body (Fig.3 a) and on one side of body (Fig.3 b) near to each other.

Electrodes could be connected flexibly or tightly. Electrodes with a flexible elastic connecting belt (girdle) can adjust better to the human body, while tight electrodes eliminate capacitive changes impacted by electrodes moving.

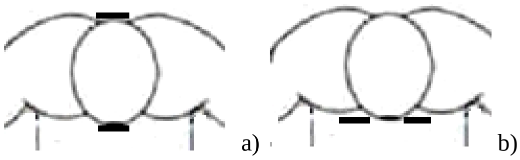


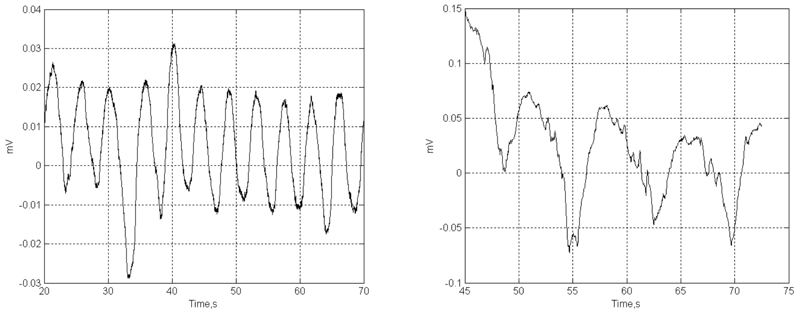
Fig. 3. Placement of two electrodes: a) opposite, b) anterior.

Experimental setup. Preliminary testing of both sensors was performed using the same electrode set and (as frequency change indicator) software defined radio FunCube Dongle Pro+ with software SDR#. A frequency deviation during breathing for first sensor was Δf=48 kHz, while the second had Δf=115 kHz. Therefore second sensor was chosen for the further research because of higher frequency deviation.

Detector output voltage was collected using Biopac MP36 data acquisition system with SS39L-1 Signal+Probe input cables. Internal 0,05-30 Hz band pass filtering was used and then signal was amplified 10000-20000 times. Collected data was processed using Matlab. One measurement was performed simultaneously acquiring ECG signal.

Four male and two female volunteers were investigated. Four electrode system was tested in chest and back sides while two electrodes were applied in one anterior side and opposite sides.

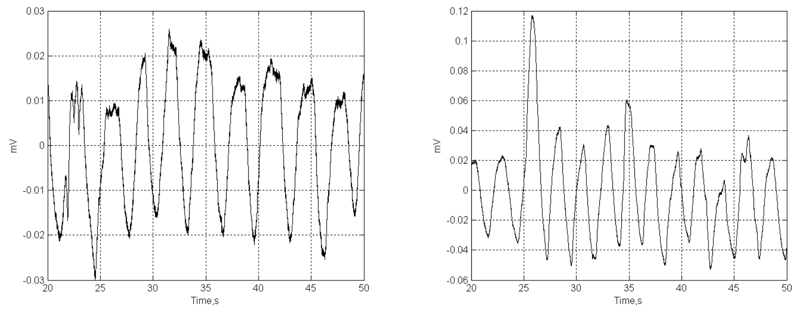
Results. Analysis of collected data exhibits that magnitude of respiratory induced frequency change with consequent detection to voltage is in tens to hundreds of microvolts range. Typical peak-to peak magnitude values are 20 μV-0,25 mV. There was found no evident dependence between magnitude and system of electrodes or placement so analysis was made based on respiratory signal and noise comparison.



a) b)

Fig. 4. Typical respiratory data from 4 electrode system: a) male, anterior placement, b) female, posterior placement.

Testing of 4 electrode system showed high sensitivity to heart rate (Fig. 4). Electrode placing was complicated for anatomically smaller persons due the inability to attach electrodes without air gap. Change of this gap was main source of noises. Placing of electrodes on posterior side allowed reducing of movement-related noises (Fig. 4 b).

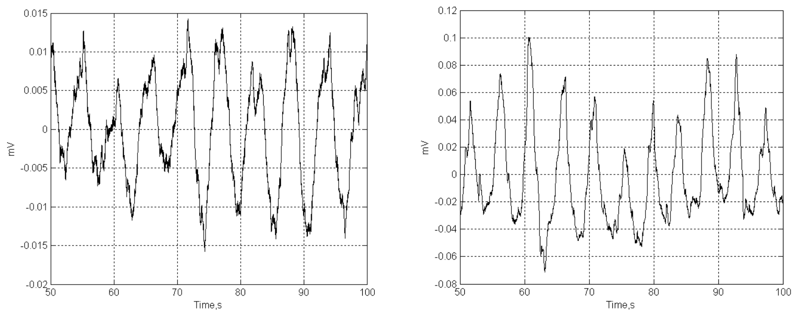


a) b)

Fig. 5. Signals collected using 2 shielded electrodes placed on: a) anterior side, b) opposite sides

Comparison of placement of 2 electrodes on one anterior and opposite sides exhibited more cleanly respiratory pattern for opposite placement (Fig. 5). It is related to small changes of distance between electrodes using elastic girdle during respiratory due the sliding of electrodes. Effect has lower influence when electrodes are placed on opposite sides of body.

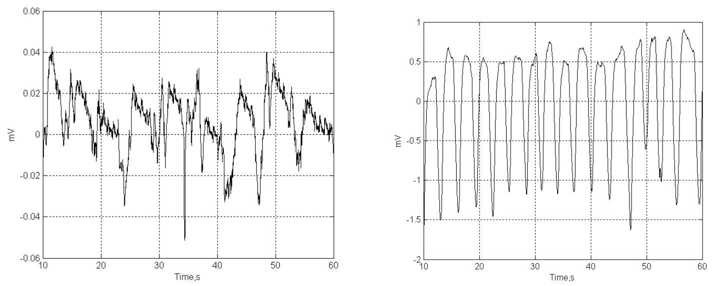
Shielding of the electrodes also reduces the noises in the respiration sensor output signal (Fig. 6). On the other hand, use of shielded electrodes and cables increase parasitic capacitance of electrodes which is connected in parallel to resonant circuit. Therefore capacitor C2 (see Fig. 1 b) should be removed to keep oscillator in same frequency range as with unshielded electrodes.



a) b)

Fig. 6. Typical signal from two unshielded (a) and shielded (b) electrodes placed on opposite sides

Comparison and analysis of worst and best data shows that main difficulty is in matching of placement of sensor to the individual anatomy of tested person. Moving air gap can create high frequency noises (Fig. 7 a). A solution was found in filling of air gap with elastic and compressible material which prevents rapid change of distance between sensor electrode and body (Fig. 7 b).



a) b)

Fig. 7. Comparison of worst and best case for one female person: a) 4 electrodes on chest, b) 2 unshielded electrodes on opposite sides

Conclusions and discussion. Testing of various electrode systems and placement allow concluding that signal quality mostly depends on fixed placement of electrode to body. Changes of distance between skin and electrode surface is main source of noises. Therefore flexible parallel connected multi-electrode array can be recommended for further improvement of capacitive sensing of respiratory. Shielding of electrodes and preventing of sliding them can also significantly reduce noises in acquired signals. Other direction for development of capacitive sensor is separation of breathing and heart rate signals using adaptive filtering. Investigation of influence of heart rate to capacitive sensed signal can give more information for health conditions monitoring.

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Capacitive sensor for respiratory monitoring

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Dielectric properties of human lung in chest and diaphragm area are changing during respiratory activity. This process can be monitored measuring capacity of sensor which consists of two or more electrodes attached to the body. A simple device with electrodes for capacitive sensing of respiratory was developed and tested. This capacity was connected to Colpitts oscillator LC circuit and causes frequency change. Two different circuits were tested as well as two and four electrodes sets. Influence of electrode placement and shielding was investigated.