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A novel single-chip RF-voltage-controlled oscillator for bio-sensing applications

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Abstract

A novel interdigiated capacitance (IDC) based affinity biosensor system is presented that detects C-Reactive Protein (CRP), a risk marker for cardiovascular diseases, and transmit the information to a distance location wirelessly. The biosensor system consist of a voltage controlled oscillator (VCO) and an IDC. In the presence of CRP the capacitance of the IDC changes and this directly reflects to the oscillation frequency of the VCO. In the presence of 800 ng/ml antigen the frequency of the system shifts from 1.9438 GHz to 1.94175 GHz and with 64 ug/ml frequency shifts from 1.95975 GHz to 1.94875 GHz with -120 dBc/Hz phase noise.

Keywords: Biosensor, VCO, Affinity biosensor system, C-Reactive protein, Cardiovascular diseases

1. Introduction

Advances in microfabrication techniques, in the recent decades, enable integrating biosensors and electronic circuits on the same chip resulting in higher performance, cost efficient, smaller size, more compact and robust devices, commonly called as system-on-chip (SoC). On the other hand, label free affinity biosensors becomes more popular in detecting cardiovascular diseases (CVD) comparing to traditional methods; since, they are more sensitive, immune to non-specific interactions, easy to use, and more cost effective[1]. Moreover, the advances in RF integrated circuits make it possible to build single-chip, high performance transceivers and this commonly finds its place in bio-telemetric systems, in which certain signals are monitored wirelessly[2]. Benefiting from all of these developments, we present a novel interdigiated capacitance (IDC) based affinity biosensor system that detects C-Reactive Protein (CRP), a risk marker for CVD and transmit the information to a distance location wirelessly.

2. Bio-sensor Design

Presented biosensor system consists of a voltage controlled oscillator (VCO) and an IDC as shown in Fig. 1. – Gm LC topology is selected in VCO and the designed VCO is fabricated using IHP 0.25μm SiGe-BiCMOS process. The operating frequency of the VCO is selected as 2 GHz which is in ISM (Industrial Scientific Medical)

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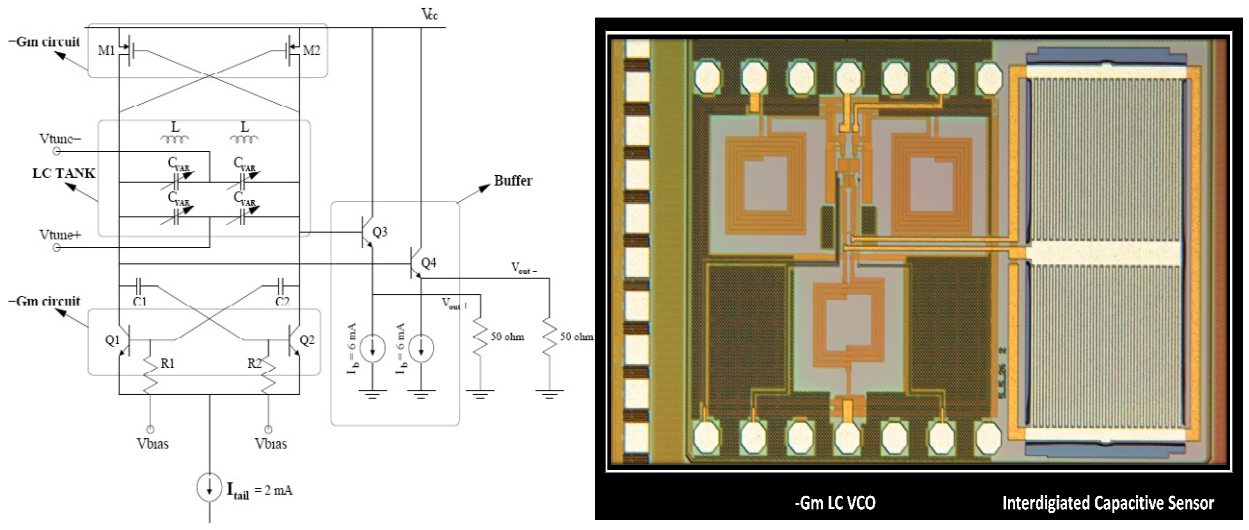

Fig. 1. Schematic (a) and micrograph of fabricated bio-chip VCO (b) where IDCs are represented as CVAR schematic

band. Also the IDC is fabricated using the metal layers of the fabrication process on the same chip. A post-processing is applied to the chip to thin the oxide layer on top of the IDCs in order to define the active sensing/working area for bio-markers.

The working principle of the sensor system is as follows. LC tank in the VCO is composed of inductor and capacitor and it determines the oscillation frequency of the VCO. The capacitor in the LC tank is replaced with IDC. In the presence of CRP (CVDM) the capacitance of the IDC changes and this directly reflects to the oscillation frequency of the VCO. Therefore, from the oscillation frequency shift, we can extract the quantity of risk markers.

3. Measurement Procedure and Results

The bio/chemical procedure applied to the IDC + VCO transducer is listed in Table 1 and also described in Ref. [1]. During this procedure, measurements were made using Karl-Suss PM-5 RF probe station and Agilent-E4407B spectrum analyzer and data were taken after each of 6-steps. Antigen/CRP concentration of 64 µg/ml and 800 ng/ml concentrations were used in testing.

Table 1. Change in the oscillation frequency of the Bio-VCO, at different CRP Concentration

Antigen Concentration	64 µg/ml	800 ng/ml
1. Blank 3	1.96325 GHz	1.9585 GHz
2. Self Assemble Monolayer 3	1.89370 GHz	1.947 GHz
3. Surface Activation 3	1.85375 GHz	1.94GHz
4. Antibody Blocking 3	1.95975 GHz	1.9438 GHz
5. Antigen 3	1.85300 GHz	1.94175 GHz

3.1 800 ng/ml antigen concentration

In the final step of measurement procedure, after antibody blocking, 800 ng/ml antigen solution is applied to the biosensor and the oscillation frequency, output power and phase noise performance is measured using spectrum analyzer. Oscillation frequency change is given in Fig.2 and the output power and phase noise change is given in Fig. 3.

Blank VCO oscillates at 1.9585 GHz and produces 1.322 dBm output power. After blocking of antibodies, the oscillation frequency decreases 1.9438 GHz and output power decreases -0.74 dBm. When the bio-sensor is subjected to 800 ng/ml antigen solution, VCO oscillates at 1.94175 and produces 0.032 dBm output power. This decrease in the oscillation frequency indicates that the capacitance value of the IDT increases. This increase is due to the chance in dielectric constant of the medium, which is the result of the binding of the antigens to the antibodies. Bio-capacitance integrated VCO achieves -126 dBc/Hz phase noise performance.

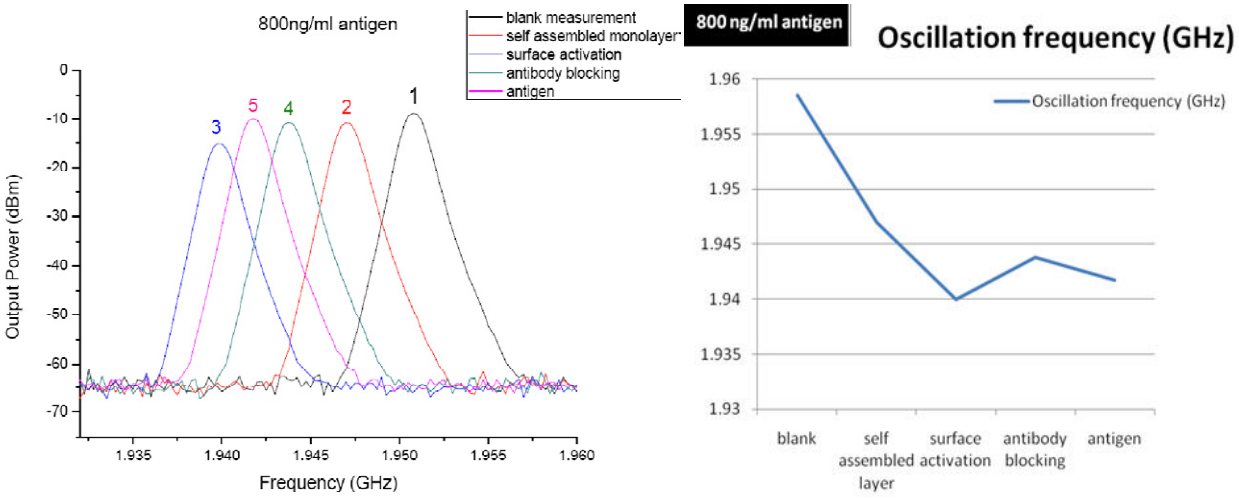

Fig.2. Frequency change of the bio-capacitor integrated VCO at each measurement point in measurement procedure.

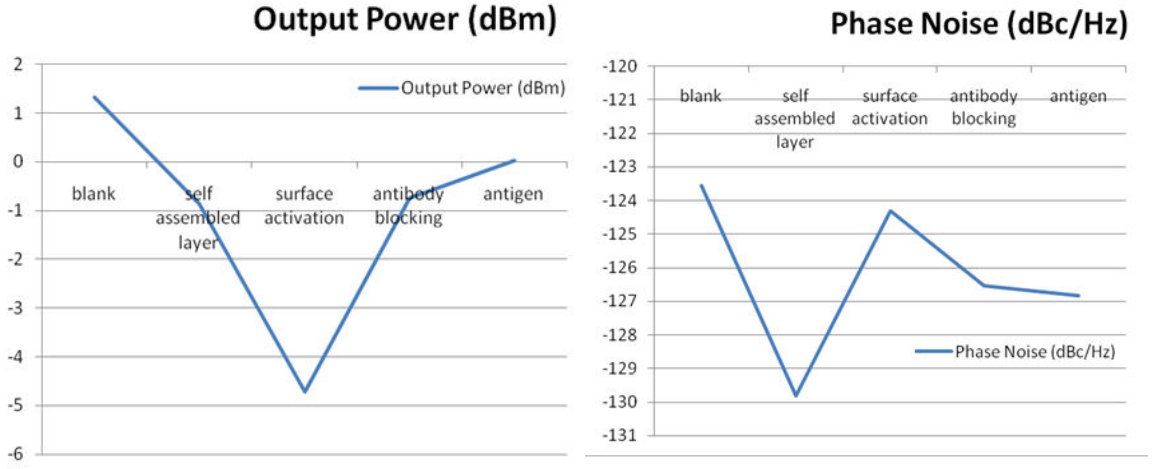

Fig.3. (a) Output power and (b) phase noise change of the bio-capacitor integrated VCO at each measurement point in measurement procedure

3.2. 64 µg/ml antigen concentration

The measurements in the previous section are repeated for 64 µg/ml antigen concentration. In blank measurements the VCO oscillates at 1.96325 GHz and gives 1.351 dBm output power. After antibody blocking the oscillation frequency decreases 1.95975 GHz and output power decreases -0.3 dBm. After antigen solution is applied, binding occurs again and more than the previous one and the oscillation frequency changes form 1.95975 GHz to 1.94875 GHz. Increased antigen concentration increases the number of antigen-antibody pairs and that

results in higher capacitance change and higher frequency shift. This behavior is given in Fig. 4 and indicates that antigen concentration can be calculated from frequency shift magnitude. Biosensor achieves roughly -120 dBc/Hz phase noise.

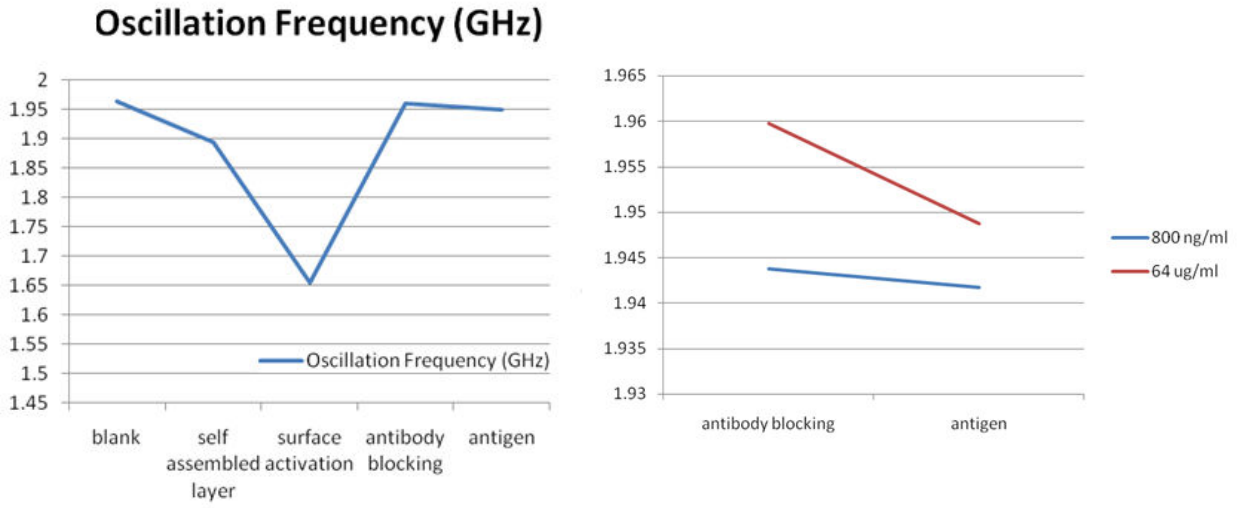

Fig.4. (a) Oscillation frequency change of the bio-capacitor integrated VCO at each measurement point for 64µg/ml antigen concentration. (b) Oscillation frequency change from antibody blocking to antigen applied for both antigen concentrations.

4. Conclusion

In this work, a novel interdigiated capacitance (IDC) based affinity biosensor system is presented that detects C-Reactive Protein (CRP), a risk marker for cardiovascular diseases and transmit the information to a distance location wirelessly. The biosensor system consist of a voltage controlled oscillator (VCO) and an IDC. In the presence of CRP the capacitance of the IDC changes and this directly reflects to the oscillation frequency of the VCO. In the presence of 800 ng/ml antigen the frequency of the system shifts from 1.9438 GHz to 1.94175 GHz and with 64 ug/ml frequency shifts from 1.95975 GHz to 1.94875 GHz with -120 dBc/Hz phase noise. Increasing the concentration increases the frequency shift so the system can quantify the concentration of antigen from the frequency shift. The system is capable of delivering successfully a number of key aspects (such as lower power consumption, lower in price, reliable detection, remote sensing, etc.) in medical, defense and environmental applications.

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