

## Short communication

## Enhanced sensitivity of quartz crystal proximity sensors using an asymmetrical electrodes configuration

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## ABSTRACT

A new approach for using quartz resonator (QR) with asymmetrical electrodes for proximity detection has been proposed. This approach takes advantage of the sensitive ability of QR to external electric stimulus. The proximal detecting target disturbs the fringing electric field generated near the electrodes of QR, and changes the series and parallel resonance frequencies of QR. Our experimental results indicate that the parallel resonance frequency is more suitable to be used as a measure parameter, and the detection sensitivity can be significantly enhanced by using an asymmetrical electrodes configuration. The proximity detection sensitivity of the '5-3' QR is about 8 times larger than that of the traditional '5-5' QR. More interesting, we found that the detection sensitivity enhancement of QR using the asymmetrical electrodes configuration does not weaken the stability of the QR. Meanwhile, the influence of physicochemical properties of the detecting targets on the proximity sensing properties of QR has also been studied. This approach provides simple and cost-effective method to achieve proximity detection.

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## 1. Introduction

Quartz resonator (QR), which is a classical frequency component, has been extensively used in these areas of frequency control and sensor platform for a long time due to its low cost, high frequency stability and digital frequency output [1–3]. In the past, the application of QR in the sensor field is mainly focused on small mass detection according to the Sauerbrey relationship [3]. The addition of mass on the electrode surface of QR decreases the resonance frequency. Beside the application of small mass detection, QR has also been found to be sensitive to force [4] and acceleration [5].

In general, QR is constructed with two identical circular electrodes (known as the symmetric electrode structure) on both sides of a thin quartz disk, so it can be actually viewed as a parallel-plate capacitor. Therefore, the fringing electric field generated near the electrode edges of QR can be affected by adjacent medium, as a result, the resonance frequency of QR changes when the electrical properties of adjacent medium changed. It is known that this electrical sensitive behavior can be attributed to the inherent capacitance characteristics of QR. In the past, several research groups have observed that the resonance frequency of QR is

influenced by the conductivity and dielectric constant of the liquid when it operates in liquid [6–9]. More interestingly, Rodahl et al. experimentally explored the frequency response of the QR with a symmetric electrodes structure to the change of the conductivity of the liquid when one electrode of QR was exposed to a liquid, and demonstrated that the contacting conductive liquid increased the equivalent electrode area of QR on the liquid side and thereby affected the parallel (but not the series) resonance frequency [6]. This useful finding prompted a lot of research work focusing on the electrical sensitive behavior of QR operating in liquid phase environment. Further, Josse [7] and Zhang [8] found that the frequency response of QR to the change of the conductivity and dielectric constant of the liquid could be increased through decreasing the size of the electrode facing to liquid (also called sensing electrode), i.e. forming asymmetrical electrode structure. The asymmetrical electrodes structure means that the sizes of the two electrodes of QR are not equal, and the size of sensing electrode is smaller than that of non-sensing electrode. They explained that the enhancement of the fringing electric field provide by asymmetrical electrode structure resulted in the improvement of electrical sensitive ability. More recently, Yu and Janata utilized this effect of QR for proximity detection in gas phase, and accidentally found that the resonance frequency of QR with a symmetric electrodes structure slightly shifted when the metal was close to it [10]. Further, they also observed that the frequency response of QR to adjacent

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metal was associated with the damping of QR. The QR with a higher damping displayed a larger frequency response to adjacent metal. Based on this experimental phenomenon, Chang proposed a proximity sensor using an acrylic rubber compound coated QR [11]. The coated material (acrylic rubber compound) was used to increase the damping of QR. The result indicated that the QR coated with an acrylic rubber compound displayed a higher frequency response to adjacent object than an uncoated QR. However, it should be noted that the enhanced proximity response sensitivity of the above two approaches was obtained under the condition of increasing the damping of QR. Unfortunately, the increase of the damping inevitably weakened the frequency stability of QR which is usually quantified in terms of quality factor ( $Q$ ), and therefore caused a large frequency fluctuation during the measurements [12].

In this paper, we propose a new approach for enhancing the proximity detection sensitivity of QR by modifying the electrodes configuration of QR based on the electrical sensitive ability of QR [6]. Because the conventional QR usually adopts the identical electrode size, this configuration makes the fringing electric field generated near the electrodes is relatively weak and limits its ability of proximity detection [10]. So, we consider modifying the electrode size to form an asymmetrical electrode structure which is expected to enhance fringing electric field and increase the proximity detection sensitivity of QR. Because the electrodes modification does not obviously change the damping of QR, this new approach makes the QR can maintain its high frequency stability during proximity detection. The frequency responses of QR with different electrode size configurations were measured and analyzed. Meanwhile, the effect of the electrode sizes of QR on the frequency stability was also discussed. Moreover, the influence of physicochemical properties of the detecting targets on the proximity sensing properties of QR has also been studied.

## 2. Experimental

The experimental setup is shown in Fig. 1(a). A series of 16 MHz AT-cut QRs with three different electrode size configurations were designed and fabricated by Wuhan Hitrusty Electronics. Regarding the three different electrode sizes, two gold circular electrodes were deposited on quartz disk in the form of concentric circles structure. The diameters of the non-sensing electrode on one side of quartz disks are all 5 mm, and the diameters of the sensing electrode on the another side of quartz disk are 5 mm, 4 mm and 3 mm, respectively. The QRs with different electrode sizes are named as ‘ $m$ - $n$ ’ QR, where  $m$  and  $n$  are the diameters of the non-sensing and sensing electrode, respectively. Fig. 1(b) shows the schematic diagram of ‘5-5’, ‘5-4’ and ‘5-3’ QR, respectively. Among the three QRs, the electrode structure of ‘5-4’ and ‘5-3’ QRs are asymmetrical. An impedance analyzer (Wayne Kerr 6500) was used to measure the resonance parameters of QR, including the series ( $f_s$ ) resonance frequency, parallel ( $f_p$ ) resonance frequency and  $Q$ . A micro-displacement platform (Sofn Instruments 7STM02125) was used to adjust the proximal distance between the sensing electrode of QR and detecting target. In this study, a diameter of 8 mm circular copper piece (conductor,  $\rho = 1.75 \times 10^{-6} \Omega \text{ cm}$ ) is used as the detection target. Meanwhile, to learn the influence of the physicochemical properties of the detecting targets on the proximity detection sensitivity of QR, other two materials, including N-type silicon (semiconductor,  $\rho = 50 \Omega \text{ cm}$ ) and Polytetrafluoroethylene (PTFE) (dielectric material,  $\rho = 1.18 \times 10^{16} \Omega \text{ cm}$ ), were also used as the detecting targets. For the purpose of fair comparison, N-type silicon wafer and PTFE plate were cut into circular plates with a diameter of 8 mm. The detection targets are floating during proximity detection. In order to eliminate electromagnetic interference, the wires connecting the impedance analyzer or QR are coaxial cables, and the electronic equipments are covered with a layer of copper foil.

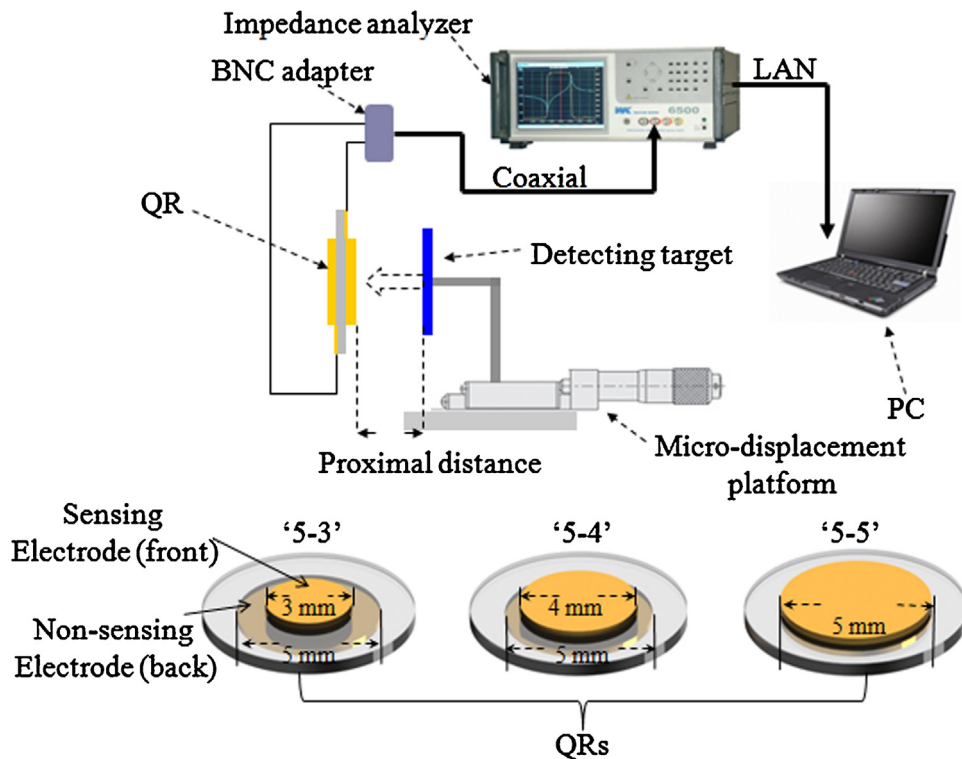


Fig. 1. (a) Schematic diagram of the experimental setup; (b) The QRs with three different electrode size configurations.

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