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CAPACITIVE SENSOR ARRANGEMENT TO DETECT EXTERNAL LOAD ON A MOBILE TERMINAL ANTENNA

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Abstract—The feasibility of using a capacitive sensor to sense the proximity of an external load, especially a finger, to a mobile terminal antenna was experimentally studied using a PIFA-type antenna as one of the sensor's electrodes. It was found that with the proposed arrangement it is possible to detect objects with permittivity close to that of body tissue or the conductivity level of aluminium and the size of a human finger at distances up to 15 mm.

1. INTRODUCTION

Mobile phone handset antenna performance is affected by the proximity of external objects like the user's body [1, 2], usually causing impedance mismatch losses and absorption of radiated power. The main contributors are commonly the user's hand and head, the hand often being the more important one [3]. Positioning of the hand, especially the fingers, on top of the antenna is of great significance to its performance [4]. Additionally, the proximity of external metallic or

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dielectric objects can decrease the performance of the antenna in other mobile terminals, like laptops. Careful antenna design can alleviate this effect, but also active tuning methods like adaptive matching networks [5] and multiple antennas can be used. However, this requires information about the position of the external object, preferably in real time. One way to gather that information is to use sensors.

This paper describes the feasibility of using a capacitive sensor to provide information about objects that affect antenna performance. In this research we used a capacitive sensor that utilises the fringe electric fields of a capacitor formed by the sensor electrodes to detect a change in external loading of the surrounding material. The benefits of capacitive sensors over other sensors are that they can detect any objects with high enough permittivity or conductivity and they can work through dielectric materials, e.g. plastic covers. Since body tissue has much higher permittivity (muscle $\varepsilon_r' \approx 56$ [6]) than air or common plastics ($\varepsilon_r' < 10$ [7]), detection of human body parts is also possible. In this research, the sensitivity of the capacitive sensor to finger-sized objects made of metal, wood and body-tissue-simulating phantoms was measured with a commercial capacitance measurement circuit. An antenna was used as an electrode because this way capacitance changes were expected to match changes in antenna performance. This kind of correlation with the whole hand has been studied in [8].

2. MEASUREMENT SETUP

The capacitance between the sensing electrodes was measured with a commercial capacitance-to-digital converter chip from Analog Devices, AD7747. According to the data sheet, the measurement chip uses square wave excitation of 16 kHz, which is fed to the unknown capacitance and then measured with a 24-bit sigma-delta converter, reaching a resolution of 20 aF and an accuracy of 10 fF. In this configuration the magnitude of the excitation was 5 V.

The AD7747 chip measures the capacitance between the capacitance input and the power supply ground of the chip. In this work, the capacitance input was connected to the antenna element ($4\,\mathrm{cm} \times 2\,\mathrm{cm}$) of a PIFA structure and the sensor ground was connected to the ground plane ($4.5\,\mathrm{cm} \times 11\,\mathrm{cm}$) of the antenna. The antenna was a dual-band (900 MHz & 1.8 GHz) PIFA presented in [9]. The shorting pin of the PIFA was cut in order to break the short circuit, thus forming a capacitor and enabling measurement of capacitance. Cutting the pin makes the antenna inoperative, so instead some form of decoupling circuit should be used to break the short circuit.

The response of the capacitive sensor to different kinds of materials

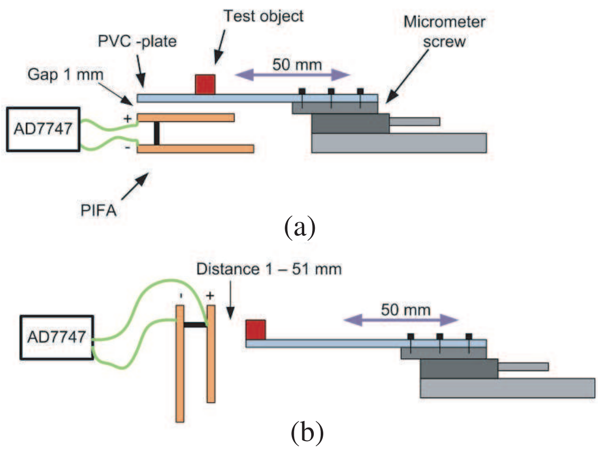

Figure 1. Measurement setup when a test object is moved (a) horizontally over the electrode and (b) towards the electrode.

was measured by moving roughly human-finger-sized objects across and towards the antenna element with a contraption shown in Fig. 1. The materials tested were aluminium, particle board (i.e., wood) and human-body-tissue-simulating liquid. The solid materials were cut into 75 mm × 15 mm × 15 mm blocks, and human tissue was simulated with a phantom tissue liquid ($\varepsilon_r = 46.69$ @ 835 MHz, IndexSAR Ltd.), which was put into a finger of a rubber glove. The test objects were placed on top of a 5-mm-thick PVC (Polyvinyl chloride) plate attached to a micrometer screw that enabled it to be moved in 1-mm steps. To keep the effect of the PVC plate constant while moving an object over the antenna (Fig. 1(a)), the plate always covered the whole antenna and the test object was placed in the middle of the plate. When moving the object towards the antenna (Fig. 1(b)), the object was placed on the tip of the plate.

3. MEASUREMENT RESULTS AND DISCUSSION

The capacitances measured while moving an object horizontally over the antenna are presented in Fig. 2. At zero position the object was 20 mm away from the edge of the antenna and was then moved over the antenna. Although the absolute value of capacitance is not relevant since it was not calibrated to any standard, it is shown here to make the graphs more comprehensive. The maximum change in capacitance is clearly observable, being 0.38 pF for the metal or body tissue phantom and 0.06 pF for the particle board compared with the change using the bare PVC. These measured values are well above the resolution limit given on the data sheet of the chip.

When the object was moved towards the antenna (Fig. 3), the results showed the same kind of trend in capacitance changes −0.2 pF, 0.45 pF and 0.98 pF — when the test material was particle board, body tissue phantom and metal, respectively. Additionally, it can be concluded that for body tissues, sensing is usable at distances below 15 mm, and at distances of a few millimetres, good accuracy can be achieved.

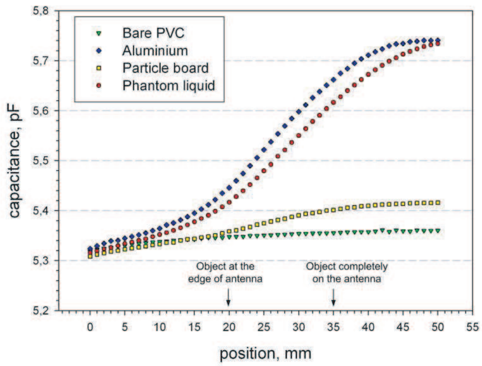

Figure 2. Measured capacitance values when a test object is moved horizontally over the antenna. At zero position the object is 20 mm off the edge of the antenna.

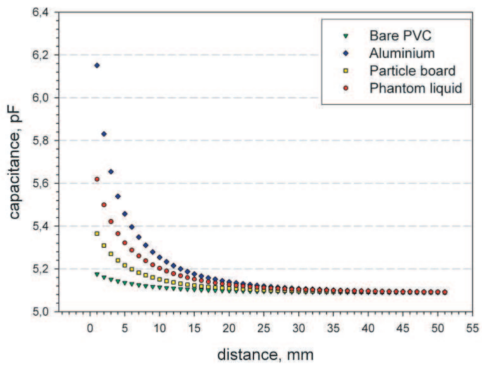

Figure 3. Measured capacitance values when a test object is moved towards the antenna. Plotted against the distance between the antenna and the object.

However, in both of these cases it must be noted that it is not possible to obtain unambiguous information about the material and its size and proximity. Metallic objects cause the greatest alteration in the capacitance value, which is the case if the user of the device has items such as rings or a wrist watch nearby. To estimate how much variation there was between individual capacitance measurements, 10 readings were taken at each measurement point presented in Figs. 2 and 3. The standard deviation was found to be less than a femtofarad, usually 0.3–0.6 fF. However, one must keep in mind that the absolute value and the magnitude of the difference in capacitance depend on the size of the electrodes; in this case they were fairly large. Also, the sensor's negative electrode is the power supply ground, so in theory the whole power source acts as an electrode, which in this case was kept far enough from the electrodes. Additionally, although the difference in the frequencies of the capacitive sensor and the antenna itself was large, compatibility with RF performance needs further investigations.

4. CONCLUSION

The results of this work show that a capacitive sensor is a very effective way to detect external objects with conductivity or high permittivity properties if an antenna is used as one of the sensor's electrodes. If the external object is the size of a human finger, proximity less than 15–20 mm from the antenna could be detected fairly accurately. Furthermore, the proposed method enables measurement of capacitance directly from the antenna element if the signal path of the capacitance measurement forms a capacitor with high DC resistance. This information can be used to adjust the antenna according to the changed conditions.

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