Understanding the Capacitive Coupling with Influence Factors and Applications

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Abstract. After the concept of electromagnetic fields was summarized by scientists, a new technique called capacitive coupling was invented. This technique is a way to transmit signals. The front-end circuit and back-end circuit may be connected together by a capacitive coupling to eliminate physical contact. Such a capacitive coupling minimizes the possibility of poor physical contact between two circuits due to vibration, corrosion and the like. Thus, the reliability and stability of data between the two circuits are improved. It can be applied to many practical aspects. At the same time, the application of capacitive coupling electrode has its limitations. The limitations come from the coupling area and distance, electrode materials and other influencing factors. There are many problems in the application process. Scientists have come up with a number of solutions. This paper summarizes the information about capacitive coupling electrode. Then this paper lists some factors that influence capacitive coupling as well as some practical applications of it.

1. Introduction
Electronic technology was developed between the late 19th century and the beginning of the 20th century. It was one of the most rapid developments in recent years. There is no doubt that it has become an important symbol of the development in modern science and technology.

With the promotion of the third new technological revolution, electronic computers were widely used, such as in finance transactions, computer-aided design and manufacturing, health care, telecommunication, education and so on. As the advances in hardware technology and rapid development of software technology, computers are looking for new applications. By combining these types of independent devices together, a network environment can be formed to greatly enhance the function of computing equipment. Within a networking environment, users can use resources in the network together, easily, such as exchanging files, sharing or storing information and communicating via electronic mails [1]. The computer seems to have become an indispensable part in our lives. However the earliest computers were not as small and convenient as we have seen today.

In 1946, Pennsylvania and Moche at the University of United States developed the world's first electronic computing machine [2]. But the first generation of electronic products was large volume, power consumption and short life. People began to innovate the material of the electronic components which made computers toward the direction of miniaturization, high precision and high reliability. In the 1940s, scientists have discovered the semiconductor materials. In 1948, Shockley, Bardeen and Brattain discovered the transistor [3]. The transistor radio television, transistor computer and so on quickly instead of all kinds of vacuum tube products. In 1959, Noyce co-invented the integrated circuit in United States. Microelectronics technology was born [4]. Large scale integrated circuit was born in
1967 [5], a grain of rice can be integrated on a silicon chip the size of more than 1000 transistor circuit. In 1977, scientists made very large scale integrated circuit, 30 flat square millimeters of silicon wafers used 130000 transistors. Integrated circuit with all sizes (from small to large and very large) scale integrated circuit which made electronic products to highly efficient, low consumption, high precision, high stability and intelligent direction. Microelectronics has greatly promoted the upgrading of electronic computers to make the computers we use today so smart.

To cater to the needs of development and use, electronic circuits and other components greatly get reduced with their sizes. Components of integrated circuit are getting smaller and smaller. It has laid the foundation for the application of the capacitive coupling electrode we're using today. Capacitive coupling electrodes have been designed for a long time and it has been widely used in various aspects.

This paper focuses on the capacitive coupling electrode. The first part is the development history and practical significance of the electronic. The second part is the detailed description of capacitive coupling principle. The third part is some factors that affect coupling. The last part is some applications and comprehension.

2. Capacitive coupling principle
Capacitive coupling is known as electric field coupling or electrostatic coupling. It is a coupling method generated due to the existence of distributed capacitance. Capacitive coupling makes the signal transmit from the first stage to the second level through the electric field. It is also referred to the exchange coupling, which is between the front and rear circuits (or two unit circuits). If it is between two stage amplifiers, then it can be called inter-class coupling capacitance.

It is worth mentioning that only Alternating Current (AC) signals can be added to the input terminal of the back-end circuit. The purpose of the coupling capacitance between the two circuits is to transmit the useful AC signals to the input terminals of the back-end circuit. As is shown in Figure 1, Direct Current (DC) cannot be added to the back-end circuit, which is convenient for circuit design and maintenance. The principle of this phenomenon is that if the voltage of the circuit at one side is increasing gradually, the charge gathers gradually in this side. When the voltage of the circuit in this side reduced, the charge that accumulates in the high voltage will be returned to the circuit and vice versa. Capacitors are insulated and the current does not pass through in capacitance. The capacitor gathers and releases electric charge as the potential increases and decreases. It was mistaken for an electric current. Therefore, it can isolate the DC, and the AC signal is coupled to the following circuit elements by means of both elevating and reducing potential.

![Figure 1 the difference between AC and DC in the circuit](image)
3. Influence factors
In different applications, we all hope that the signal with capacitive coupling can be strong. Thus what is affecting capacitive coupling is an important issue. After reading a lot of literature, I found the following points.

3.1. Coupling distance and area
The system has relatively stable coupling capacitance which is the precondition for the system to stabilize the signal transmission.

For example, a classic flat plate capacitor consists of two parallel sheets. As shown in the Figure 2. The plates are filled with an electric dielectric with a relative dielectric constant of $\varepsilon$. $\varepsilon_0$ is the permittivity of vacuum and the numerical of it is $8.85\times10^{-12} \text{ m}$. $\varepsilon$ is the relative dielectric constant between the two capacitor plates. The effective area for the two plates is $s$ and the distance between the two plates is $d$. From the formula, it can be seen that the main factors affecting the coupling capacitance are the effective area of the two plates and the distance between the two plates.

![Figure 2 A classic flat plate capacitor](image)

Formula:

$$C = \varepsilon_0 \varepsilon \frac{s}{d}$$

Coupling distance is inverse proportion to the capacitance. As the coupling distance increases, the coupling capacitance will decrease and the intensity of the output signal will be reduced.

Coupling area is proportional to the capacitance. As the coupling area increases, the coupling capacitance will increase too and the coupling will be enhanced.

Many scientists have come up with ways to increase the coupling area. In one embodiment, we can see from the paper by Riemenschneider that he invented a new method and apparatus for improving capacitive coupling. Compare to traditional methods, his invention provided an increase in the capacitively coupled area [6].

3.2. Electrode materials
In different applications, the electrode material is not the same. But the objective is to make the coupling signal as good as possible.

Igor and Edward stated in the research on Capacitive Touch Screen that the electrodes can be made from one or more metals, such as copper, aluminum, chromium, gold, silver, and tin. These materials
have good performance, for example silver ink can achieve the accuracy of 99%. However it is not limited to metallic materials. It may be other conductive materials such as carbon [7]. Jeffrey has stated in his work, "the electrodes are usually made of indium tin oxide or fluorine tin oxide, due to their concurrent high transparency (95%@550nm) and high electrical conductivity (100 ohms sq)" [8].

The use of materials is not limited to one medium. There is no doubt that the good coupling result will be obtained by choosing the suitable materials.

3.3. Electrode patterns
Jeffrey and his team have done this experiment before. Through simulations and empirical analysis of conventional capacitive touch sensing patterns, they have found that there was a correlation between the presence of fringing fields and touch sensitivity. Then they designed and presented three new electrode patterns, 1-square, 4-square, and 5-square. The purpose of the design was to maximize the number of such fringing fields and hence to increase the touch sensitivity. Through comparison testing, the designed 5-square electrode patterns indeed resulted in improved touch sensitivities by up to 5.4%. This also proved that a good model made coupling work better [9].

4. Applications
Capacitive coupling electrode has many applications. Most of the applications are interacting between the human body and the machine. The main content of this part is based on the principle of capacitive coupling which introducing several common applications.

4.1. Capacitive touch screen
Conventional computing devices offer several ways to input. For example, a user can use an alphanumeric keyboard to input a choice or a selection. Additionally, a user can use a cursor control device [10]. However, sometimes traditional touch-tone controls have failed to satisfy people. Touch sensing technology is gradually used. It can be used to provide an input selection to a computing device or other electronic device. The appearance of the touch screen made the graphical human-computer interaction interface more intuitive and easier to use.

Figure 3 shows the principle of capacitive touch screen. It is intuitive and clear. Capacitive touch pane is used to make use of the human body's current induction. It is plated with long, narrow electrodes on the four sides of the touch screen. When a user touches capacitive screen, an electric field will be generated by the human body and your fingers. Then there is a coupling capacitance. For there is a high frequency signal on the working plane, and a very small current appear on the fingers respectively from the current screen in the four corners of the electrode. Theoretically, through the four electrodes to the four corners, the current is proportional to the distance and precise calculation of the 4 current ratios, which will locate the finger touch.
4.2. Fingerprint identification
Fingerprint identification technology is based on capacitive fingerprint sensor. Its principle is shown in the Formula 1. There is a myriad of small capacitor plates just like the one in Figure 2 with the same size on the sensor. Your finger is just like pressing “b” in Figure 2. When your finger attaches to the sensor, the skin surface matches the capacitor plates on the sensor. Countless tablet capacitors have appeared, and each is with its own capacitive value. The capacitance depends only on the distance from the plates on the sensor to the fingerprint. The difference in distance data corresponds to the difference in capacitance value. When the same voltage is charged, the mutual differential capacitance will give the discharge rate of the difference in the discharge process. The different discharge rate can be collected by sampling and replaced by an 8-bit output, which can form a very good original fingerprint image. Then it will utilize complex software algorithms for fingerprint identification.

4.3. Electrocardiogram signal acquisition
Capacitive coupling electrode can also be used to collect electrocardiogram signals. In recent years, the capacitive coupling electrode is applied to the wearable electrocardiogram signal acquisition system.

Capacitive coupling electrode is using the principle of capacitance coupling. The electrode plate of human skin and electrode are considered as the two conductive plate electrodes of the coupling capacitor. An equivalent coupling capacitor is made up of electrical poles, clothing and human skin. As is shown in Figure 4. Through the coupling of capacitance, the electrical signals on the skin surface are transmitted to the pad of capacitively coupling electrode. Then the two electrical signals obtained by two electrodes placed at different positions on the skin surface of the human skin can be obtained by differential operation, which can obtain a weak electrocardiogram signal. The process is shown in Figure 5.
4.4. *A pressure sensing device for measuring pressure*
Some researchers have invented a kind of a capacitive sensing device which can measure various dynamical forces. The device contains a diaphragm that can be distorted according to the various forces that need to be measured, such as pressure or acceleration. The diaphragm contains the microcrystalline silicon substrata. A small gap is formed between the glass substrate and the silicon substrate to form an induction capacitor. When the force is applied to the diaphragm, the diaphragm will be transmutative and a capacitance of the sensing capacitor will start changing. Therefore, when the capacitance of the sensing capacitor is measured, the magnitude of the force can be estimated [11].

5. Conclusion
According to previous research, capacitive coupling is becoming more and more important. The application of this technology is changing the world now. It's applied in field of touch area which makes us operate manipulations more directly; it's applied in field of electrocardiogram signal acquisition area which makes us keep our life real-time monitoring; it's applied in field of stress testing area which makes our perception of the force faster.

A general introduction of capacitive coupling electrode is given in this paper, including its principle, influence factors as well as some applications. The purpose of this paper is make the capacitive coupling easier to understand.
However it still needs to be studied further in this field. Research on factors that are affecting capacitive coupling is needed. For example, we also need to analyze the specific situation of electrode materials. In both the touch screen and the electrocardiogram acquisition system, we need to have better electrode materials which can obtain strong coupling signal with low cost. Improving electrode materials will be a great help for application performance.

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