

# Capacitive Fibre-Meshed Transducer for Touch & Proximity Sensing Applications

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*Abstract-* Capacitive sensing is been used in E-Textiles for touch sensing and proximity sensing applications. The common approach is been to construct electrode on top of a non conducting fabric structure. Woven & knitted fabric structures are been used for the construction. Metallic wire and conductive material coated fibres are primarily been used. Due to the performance degradation and poor comfort of these constructions we had constructed electrodes with inherently conductive polymers and multifilament metallic fibres by integrating into fibre meshed structures such that the electrodes are a part of the base structure. We had used capacitive and resistive techniques for the measurements. Out of many mechanical methods of fibre integrating processors we had used flat bed knitting technology. In This paper we had discussed the construction, sensing and applications of capacitive fibre-meshed transducers and their applications.

Keywords-Fibre-Meshed Transducers, Capacitive Sensing, E-Textiles and Wearable Computing

## 1.0 Introduction

Touch and proximity sensing E-Textiles are been developed by using capacitive sensing techniques. Several methods are been used including printing electroconductive materials onto a textiles substrate [1], using piezoresistive coatings [1], embroidering electroconductive fibres on to a textiles substrate [2], weaving and knitting electrode areas and interconnecting tracks with conductive metallic fibres [3,4]. The disadvantages involving these approaches are the aging effects of the electrodes constructed with piezoresistive materials (polypyrrole PPY [1] / metal loaded rubber such carbon loaded rubber CLR [1]), damage with washing and variable performance with deformation (due to time dependencies of the these materials and could not repeat the same readings), false alarms due to capacitance change due to parasitic deformations, Calibration difficulties where absolute readings are necessary.

The electrode structures in fabrics are integrated into both single [2] and multiple layers (parallel electrodes arrangements) [15]. Single layer fabric electrode arrangements are used as touch sensors [2]. Commonly electric field sensing [EFS] [2],[8] is used for the detection. Multiple layer fabric electrode arrangements with conductive fibres are used for constructing patch antennae, electrodes of batteries and as touch and pressure sensing [15]. Variation in displacement between the electrodes are been used for the sensing. In addition touch sensing is been achieved by using piezoresistive coatings [1] as well. However both methods tend to produce false predictions when using under dynamic situations. These were due to the variations in impedance between the electrodes due to deformation of the electrodes while wearing, variance in performance after washing, aging and thermal drifts of the electrical and mechanical parameters.

Therefore in order to overcome the difficulties we had constructed electrodes with conductive polymeric fibres and metallic fibres had by using flat bed knitting technology. Two electrodes arrangement (Figure 1.0) was used for touch sensing and instead of using an AC source we used DC source to power the electrodes. The electrodes were arranged in such way that when they are touched with a finger the body conductance will complete the circuit (Chapter 2.0). In another arrangement we had constructed parallel plate electrode pads with an elastic dielectric medium in between and used to detect touch and the relative compression between the electrodes.

In addition we had discussed the performance of the electrodes, the detection circuitry and applications in wearable computing field particularly for computer human interfacing (CHI).

## 2.0 Fibre Meshed Touch Sensor

Under This chapter we have discussed the construction of the fabric electrodes for touch sensing, measuring technique and circuitry, transient analysis and advantages and applications.

### 2.1 Construction of Electrodes

The advantages of constructing smart structures with knitting technology were discussed in the papers (knitted fabricated technology) [5], [6]. We had used a technique which is used for fabricating a given area of shape with a selected fibre in a fabric to construct the electrodes and also the connectors were constructed with the same technique (intarsia feeding in flat bed knitting) [7]. We had used conductive polymer (polyester) as the selected fibre for the electrodes and polyester as the base fibre. We had selected polyester in both cases this is because the base structure and the electrode needed to have similar mechanical and electrical properties. Two electrodes were arranged such that when a person touched it with a finger the two electrodes will come into contact with the touching finger (Figure 2.0). The prototype of the electrode arrangements are shown in the following Figure 1.0. Also the electrodes are constructed with different shapes to perceive different symbols.

The conductive polymer is made out of polyester fibres with chemically bonded CuS which is acting as the conductive material [8]. Therefore the fibre is behaved as an inherently conductive material. Advantages of using such an inherently conductive polymer include lower degradation of conductance with time, superior temperature performance than PPY or CLR, better comfort and flexibility than metallic fibres, lower chemical reaction with environmental gases and

stable conductance after repetitive washes in addition inherent anti bacterial properties makes it the better choice.

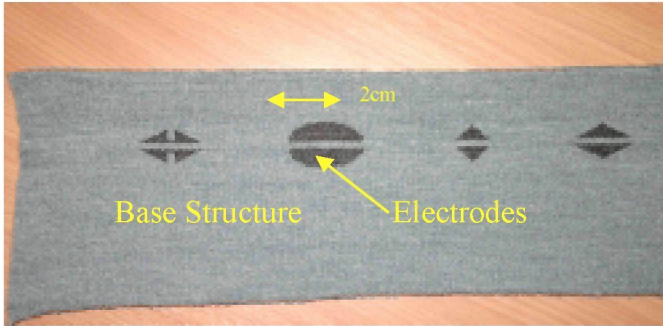


Figure 1.0 Conductive Polymer Electrodes for touch Sensors.

## 2.2 Measurement Technique in Detection of Touch

As illustrated in the Figure 1.0 the two electrodes were knitted closer to each other and also the distance in between the electrodes have to be maintained in order to prevent any short circuiting that might occur due to the filamenting (short circuiting with the stray filaments) of the multifilament conductive fibres. The impedance between the electrodes was measured with an impedance analyzer. The measurements were taken in both the situations, with the touch and with open circuited. The impedance spectrums (20Hz-150kHz) are shown in the following Figures 3-4.

## 2.3 Observations

The impedance spectrums with the touch is depend on the individual parameters such age gender and the moisture level of the tissue as well [10]. We had experimented with several individuals with different and gender. The average spectrums were estimated from the accumulated measurement data. The results are illustrated in the following graphs.



Figure 2.0 operation of the switch

At lower frequencies (<10KHz) larger variations in impedance (>2dB) and phase (>60°) were observed between the touch and open circuited measurements. This was expected due to the capacitive nature of the skin electrode skin impedance (ESEI). Therefore this can be used to switch between two different levels and can be used as a switch. Even though any frequency less than 10KHz was suitable for the designing of the detection circuitry we had used DC measurements. Therefore we had experimented with DC resistance. The resistance variation (in dB) with open circuit and the touch is shown in the Figure 5.0. The variation of the

resistance ( $\Omega$ ) with time in the selected region A is shown in Figure 6.0. A settling time of less than 0.3S (Figure 6.0) was observed and this is much better than the performance of the switches that are constructed with piezoresistive coatings [1]. The spikes of the Figure 6.0 was expected due to the lose contact between the finger and the electrodes during the touch.

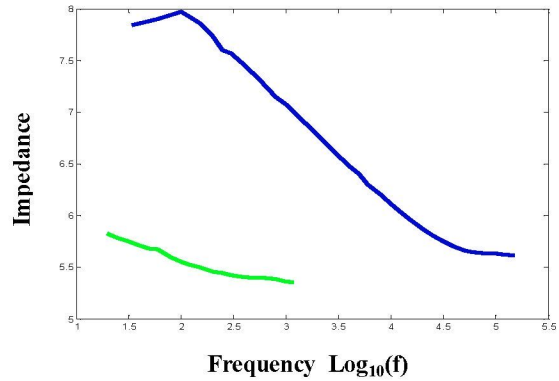


Figure 3.0 Amplitude Spectrum of an electrode pair

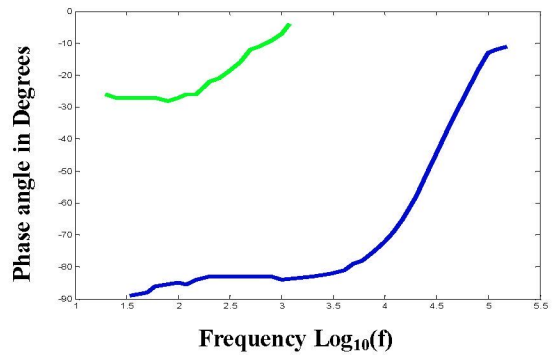


Figure 4.0 Phase Spectrum of an electrode pair

— Under Open Circuited — With Touch

The readings were taken at 1.0V (peak) with a precision LCR meter.

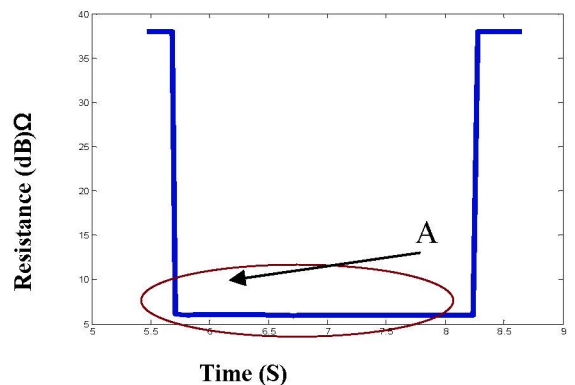
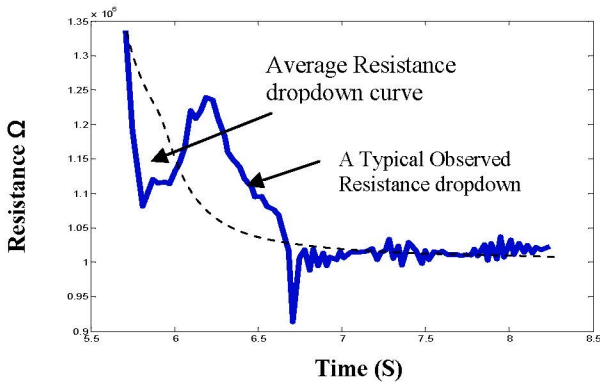


Figure 5.0: Variation of Resistance (dB) with Time.

## 2.4 Measuring Circuit

The measurement was done with a current sensing amplifier. In order to reduce the chip count DC measurements were used. An op-amp and a resistor were used for the implementation and positive feed back was used. The switching was achieved by driving the amplifier between upper saturation voltage ( $V_{SS}$ ) and lower saturation voltage

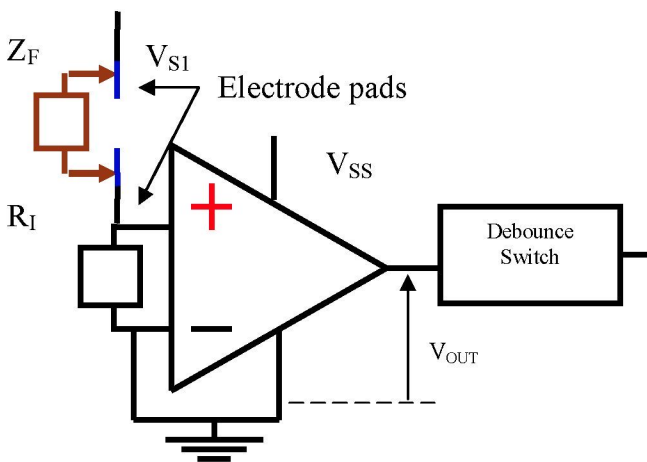
(Ground) and latching the information with a debounce switch. The debounce switch was used to reduce the mechanical vibrations. The circuit is shown in the following Figure 7.0.



**Figure 6.0: Reduction of Resistance with the Touch against Time (Selected Region A).**

The results were taken with a precision (6.5 digit multimeter with 0.1S sampling rate under 2wire resistance measurement configuration.

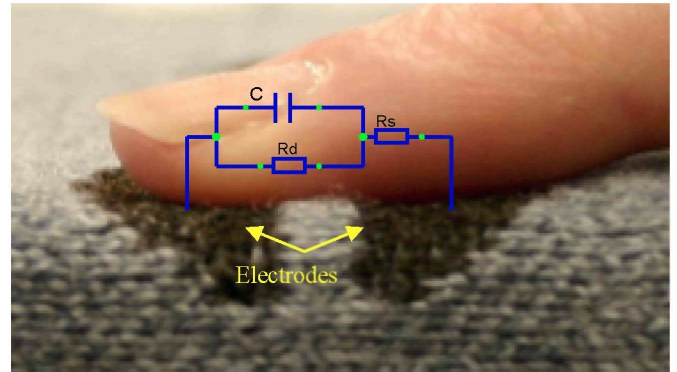
When designing the detection circuitry in addition to selecting an appropriate op-amp the decision parameters are the switching voltage ( $V_{SI}$ ) and the input Resistance ( $R_I$ ).  $V_{OUT}$  was designed to be TTL and COMS compatible. The  $V_{SI}$  and  $R_I$  were selected by considering the electrode skin electrode resistance (ESER). It was observed from the gathered data a maximum ESER of  $2M\Omega$  and a minimum ESER of  $800K\Omega$  between the electrodes under touched situation. As before readings from several individual were taken for the measurements. These values were used to estimate the decision making parameters. Since the positive feedback was used in order to drive the circuitry in to the lower threshold (0V) voltage an op-amp with a negative residual voltage at the non inverting terminal was required. Another alternative would have been to use a dual power supply with a preset adjustment at the inverting terminal of the op-amp to drive the  $V_{OUT}$  in to lower threshold.



**Figure 7.0: Detecting Circuit**

Moreover when designing the circuitry in order to switch to every person's 'touch' the  $R_I$ ,  $V_{SI}$  were selected for the maximum value of the resistance (With the touch). Also the upper limit of the  $V_{SI}$  was selected such that the current

passing through the body is lower than the maximum allowed safety level (Permitted standard values  $I_{Max}$ ) during the contact. Also the Cole Cole model [10] for the body impedance at lower frequencies was used as the model of the  $Z_F$  (Figure 8.0).

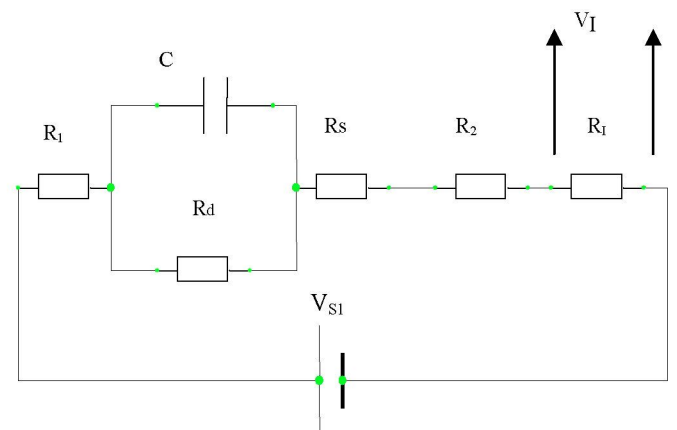


**Figure 8.0: Cole Cole Model Equivalent Circuit of the Electrode Skin Impedance (ESEI)  $Z_F$ .**

Another important feature is to avoid the switch from activating to the backhand touching. Under normal situations the ESER of the back of the palm is much greater ( $>1.5dB$ ) than that of the in side of the palm. This is mainly due to the lower moisture content of the skin tissue [10]. Therefore the switching due to back hand touching was avoided through carefully selecting the  $V_{SI}$  and  $R_I$  such that it was only operated with the finger touching.

Constrains for interfacing circuitry are the maximum allowed steady state current ( $I_{mAverage}$ ) through the finger and the maximum allowed peak current ( $I_{mPeak}$ ) through the finger. Moreover in order to switch only under finger contact  $V_{OUT}$  was selected to be less than the lower threshold limit of 0.8V.

The  $V_{SI}$  and  $R_I$  were selected by using following inequality equations. Equation 3 was derived by using the threshold voltage of the op-amp. In order to switch when touched the steady state voltage at the non inverting input must be greater than that of the threshold voltage ( $V_{TH}$ ). The steady state voltage at the non inverting input was obtained by using the following input stage circuit (from A to B of Figure 8.0). The differential mode input impedance of the op-amp was assumed to be infinite.



**Figure 9.0: Equivalent Circuit When Touched**

Where  $R_1$  and  $R_2$  are the resistances of the conductive polymers connecting the  $V_{S1}$  and the electrode and non inverting terminal and the electrode respectively,  $R_d$  is the epidermis resistance,  $C$  is the epidermis capacitance and the  $R_s$  is the dermis and the subcutaneous layer resistance for DC voltage at steady state.

The input voltage is  $V_I(S)$  is given by.

$$V_I(s) = \frac{V_{S1}(s)R_T(CSR_T + 1)}{((R_1 + R_2 + R_s + R_T)(CSR_T + 1) + R_d)}$$

------(1)

At Steady State for a step input of  $V_{S1}$

$$V_{I\text{steady}} = \frac{V_{S1}R_T}{(R_1 + R_2 + R_s + R_T + R_d)}$$

------(2)

Therefore;

$$\frac{V_{S1}R_T}{[R_1 + R_2 + R_s + R_T + R_d]} \geq V_{TH}$$

------(3)

$Im_{\text{average}}$  has to be smaller than standard maximum allowed value of  $I_M$  and peak value of the current has to be smaller than  $Im_{\text{Peak}}$ .

$$Im_{\text{average}} = \frac{V_{S1}}{(R_1 + R_2 + R_s + R_T + R_d)} \leq I_M$$

------(4)

$$Im_{\text{Peak}} = \frac{V_{S1}}{(R_1 + R_2 + R_s + R_T)} \leq I_{MP\text{Peak}}$$

------(5)

Also in order to avoid switching due to back hand touching.

$$\frac{V_{S1}(R_T)}{(R_1 + R_2 + R_M + R_T)} G_{\text{diff}} \leq 0.8V$$

Where  $R_M$  (under normal conditions  $>30M\Omega$ ) is the minimum observed back skin tissue ESER. Further the values of  $R_1$  and  $R_2$  are selected to be  $100K\Omega$ .

From the above equations and the practical data for  $V_{S1}$  minimum of  $15V$  and for  $R_T$  minimum of  $2.7K\Omega$  resistor were selected.

## 2.5 Transient Analysis

The transfer function was obtained from the equation (1) and then by using inverse Laplace transformation the transient time domain response was estimated (Equation (6)). An exponentially increasing response was observed (Figure 8.0).

$$V_I(t) = a(1 - e^{-k(t-t_0)})$$

------(7)

Where  $a$  and  $k$  are positive constants estimated from the data; and  $t_0$  is the touch initiation time.

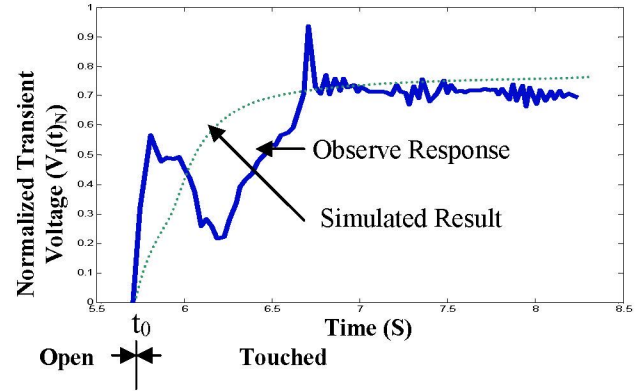


Figure 8.0: Normalised Transient Voltage with Time.

This was expected due to the values of  $R_s$ ,  $R_d$  and  $C$  are depend on the time and also the magnitude of the applied voltage. Further  $R_s$  and  $R_d$  are reducing with the time and  $C$  is increasing with time [10]. Therefore the switch can be programmed to be a time depended one as well.

## 2.6 Advantages & Applications

The main advantages of this construction are the simple detection and the implementation of the switch for the applications. Better performance after washes and better aging effects and the time response is much faster than that of the piezoresistive materials. Another advantage is the current passes through tissue is localized on the finger and does not go through the body as in the single electrode measurements also would be expected to have better comfort than the piezoresistive ones. Also since the mechanical properties and the thermal properties of the base structure and the electrodes are selected to be closer to each other the performance is expected to be much better.

Such transducers can be integrated into a sleeve of garments and fabrics that can be used in smart homes and etc. Thus can be used as a wearable keypad. A person wearing a sleeve of such switches is demonstrated in the following Figure 9.0.

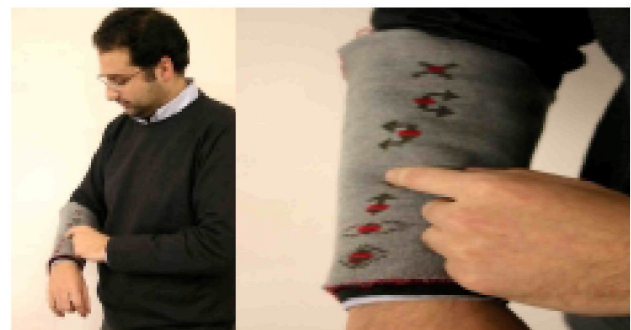


Figure 9.0 A Person Wearing Fabric Switches.

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