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Novel Knitted Switches for Smart Clothing Using Single and Double Electrodes Technology

***Abstract**. This paper presents non mechanical knitted switches. This type of switches was developed for the first time at WLIC, University of Manchester, UK. The switches are operating with single electrode and double electrodes. The switches are designed to work with finger without glove and with glove. Double electrode switch is working based on it impedance characteristics, open circuit and when it has been touched by bare finger or finger with glove.*

Streszczenie.** W artykule zaprezentowano nie-mechaniczne przełączniki dziewiarskie. Tego typu przełączniki zostały opracowane w WLIC, University of Manchester. Przełączniki pracują pod wpływem palców zarówno w rękawiczkach jak i bez. Przełączniki bazują na zmianie impedancji. Pod wpływem dotkniecia palcem. **Nowe przełączniki dziewiarskie przeznaczone do inteligentnych ubrań

Key Words: Technical Textiles, Wearable Computers, Smart Fabric, Sensor, Transducers.
Słowa kluczowe: przełączniki dziwiarskie, inteligentne ubrania

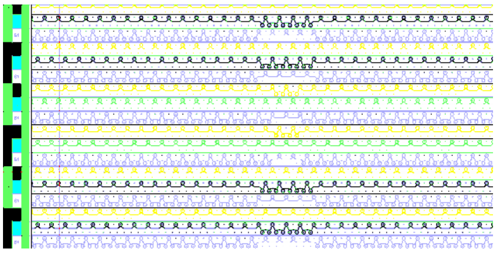
Introduction

Technical textiles have been very popular among the researchers recently. Apart from traditional knitted textiles during knitting process innovative techniques have been adapted to make it electrically active [1-4]. Several other methods have recently been developed and reported. Some of these include development of special yarns [5] so that the yarn itself acts as a light emitting source. Others make use of specially manufactured yarns in different configuration during knitting process. This gives rise to its use in specialised applications [6]. Research carried out at William Lee Innovation Centre (WLIC) has led to the development of fibre meshed (knitted) transducers from electro-conductive polymeric, metal and smart fibres that will behave as transducers. The transducer research at the WLIC has led to the development of knitted flexible switches, the "K switch" TM [7-10]. These two parallel courses act as a capacitor, the resistance is reduced to a virtual short circuit by virtue of the conductivity of the finger. Current knitted ECA's constitute the first generation of fibre meshed knitted transducers. These structures are basic and not yet integrated into complex knitted structures.

Knitted switches may operate upon two principles, single electrode and two electrodes. The principle of single electrode knitted switch is based upon the capacitance change as a result of a human finger touching the electrode. Most of these types of switches are referred to as 'Touch Switches'. However, these switches can not be relied fully upon due to the reason that by touching the electrode, ac hum already picked up by the human body from surroundings, is transferred to the circuit, hence generating a signal. Therefore, these switches are a problem when no 50 Hertz lines are passing nearby, hence the switch is inoperable. This reason also suggests that if a person wearing a glove wants to operate the switch, it may also not operate. This led to a design thought to operate the knitted switch on the basis of change of capacitance; however, the basic geometry was as mentioned above. Later in this article figures 4 and 5 show block diagrams for the electronic circuit of such switches. To show that of all the textile processes, electronic flat-bed knitting is uniquely positioned to deliver integrated conductive textiles.

The "K" switch is knit on a flat bed eletronic machine consisting of 2 directly opposing needle beds. Both needle beds are in action to produce an all needle jacquard. The switch consists of two or more conductive pathways which are isolated from each other by non-conductive yarns.

The conductive pathway, is incorporated into a three colour jacquard with the main body yarn (Blue) in system 1, conductive yarn (black) in system 2 and the switch indicator yarn (yellow) in system 3 as indicated in figures 1 and 2. The conductive yarn is knit on alternating needles on the back needle bed and only knitted on the front needle bed where the switch is to be activated. The face yarn (blue) is of a higher tex to insulate the conductive yarn. Each pathway consists of at least one knitted course of conductive yarn followed by at least 2 knitted courses of non-conductive yarn to isolate the pathway. The conductive yarn is knit the full width of the knitted article



Knitting Cycle for conductive Pathways
Blue - Non-Conductive
Black – Conductive
Yellow – Non-Conductive

Fig.1. Yarn path notation

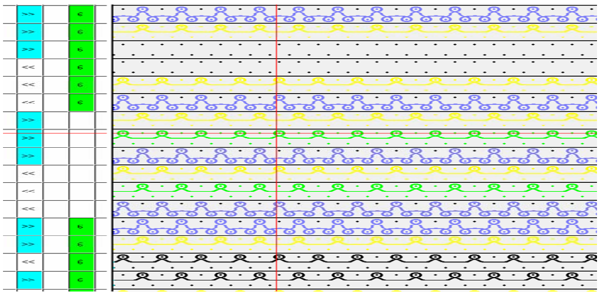
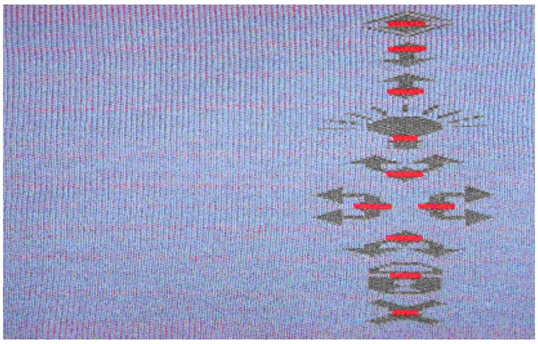


Fig.2. Yarn path notation.

To further the isolation of the conductive pathways one can be accessed from the right and terminated at the switch and the second accessed from the left and also terminated at the switch ,creating a dual electrode only at the switching area. The balancing of small area conductive structures (usually low modulus) within a larger area of textile (high modulus). The accessing of sensors is via conductive pathways. The effects of various structures and stitch densities may have on the conductivity of the ECA.

However, the need to isolate the switching behaviour to specific visual reference points on the textile requires the isolation of the conductive pathways with the exception of the switching area One elegant solution for the isolation of the conductive pathways is to incorporate them into a double needle bed jacquard insulating them from the face of the fabric. One added advantage is the ability to knit pattern motifs to map the switches for the individual as shown in figure 3.



graph of a double electrodes switch

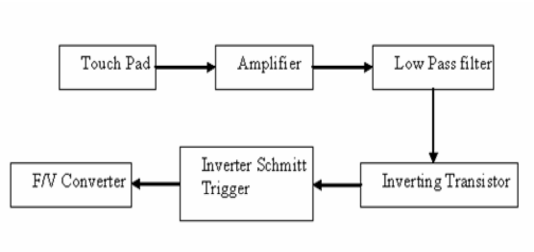


Fig. 4. Block diagram of a Touch Circuit.

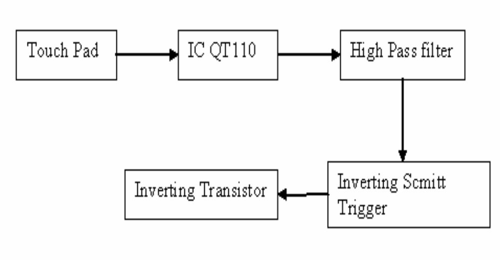


Fig. 5. Block diagram of a touch circuit using readily available IC.

Single Electrode Switches

The principle of single electrode is to measure the changes in the capacitance between the touch electrode and the earth ground. Figure 4and 5 show block diagrams for single and double electrode arrangements respectively. This is based upon the fact that human skin is thin and the blood running under it acts as an electrical conductor due to the salts and minerals present in it. The change in capacitance is further supported by large area of human body. Therefore, touch of a human finger to an electrode will make an electrical interface and hence a sizeable change in capacitance may be observed. A careful design of the circuit may record up to one Pico farad change in capacitance. Apart from the electronic circuit design the size of the electrode being used is also important, and this gives a trade off between its operation and random pickup. This problem is overcome by arranging field cancellation around the line of the electrodes in a knitted fabric, figure 6 and 7, shows the field cancellation arrangement.

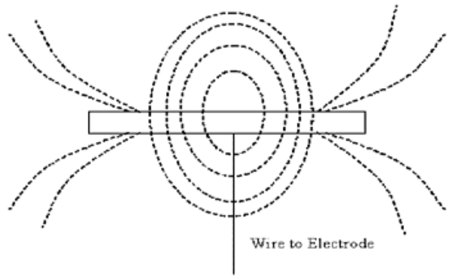


Fig.6.Electrode without field cancellation.

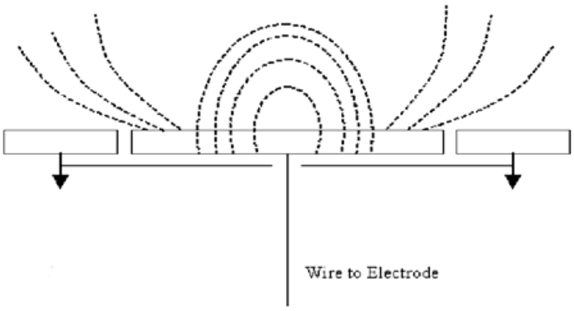


Fig 7 :Electrode with field cancellation.

Two Electrodes Switches

The potential at the B terminal when a 12V potential is supplied to the `A' terminal and a gloved finger is placed in the void between A and B was found to be in the region of 20 mV and more (depending on the glove). An open circuit voltage of around 5 mV was recorded. When the switch was touched by fingers (without glove) the observed voltage was more than 7 V. The equivalent circuit of the switch is depicted in figure 8.

The potential at the B terminal when a 12V potential is supplied to the `A' terminal and a gloved finger is placed in the void between A and B was found to be in the region of 10 mV and 60 mV.

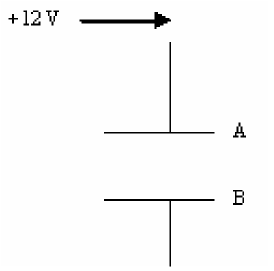


Fig.8. equivalent circuit of two electrode switch.

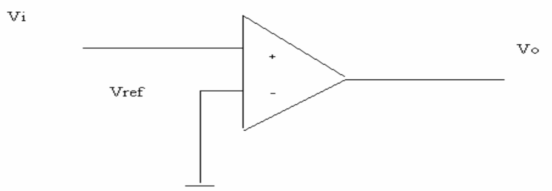


Fig.9. Block diagram of a Touch Circuit using readily available IC.

If we want to operate by finger we could choose the comparator in a voltage 6 V and if we want to work with glove worn then we choose 20 mV for comparator. A comparator circuit can be used to detect this small voltage, as shown in figure 9. A comparator can be built using 0V(or 20 mV) as the reference voltage (Vref) and the voltage from the 'B' plate of the switch as the comparable voltage (Vin). The comparator output (Vo) can be used to drive a circuit.

Figure 10 shows block diagram for glove operable K-Switch. The power supply provide a 12V DC signal. The received signal from pull down resistor (here it is 10M Ohm) has been amplified and the reference supply is provided by two resistors to the comparator. The output of the comparator then can be used for logic purposes.

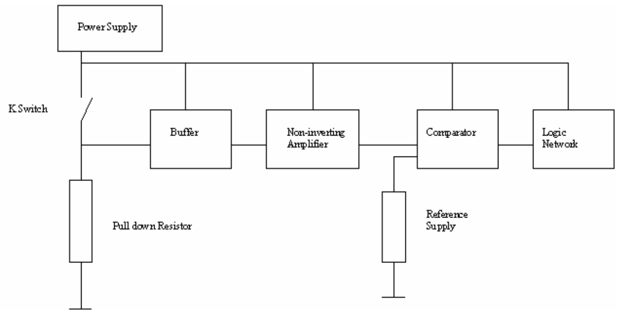


Fig.10. Block diagram of a glove operable K-Switch circuit.

The reference voltage can be derived from the supply 12V through a resistor network or through connecting the negative terminal to the ground.

Impedance Spectroscopy

The switch has an impedance characteristic including resistive and capacitive components. Figure 11a and 11b show the impedance models of a switch including the resistance and capacitance of the switch as well as wires.

The idea is to measure the impedance characteristics of the switch with touch and without touch. Figure 12 shows the measurement configuration. A Cole-Cole equivalent circuit can be adapted for touch by finger and with glove we will derive impedance characteristic. Applying an AC signal to the sample and using Phase sensitive detection technique using a DSP based technology we derived the impedance characteristics of the switches.

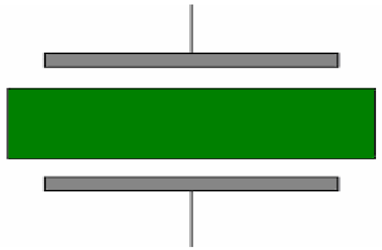


Figure 11a. Schematic of a knitted switch.

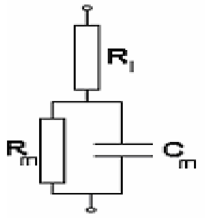


Fig.11b. Equivalent impedance models for the switch.

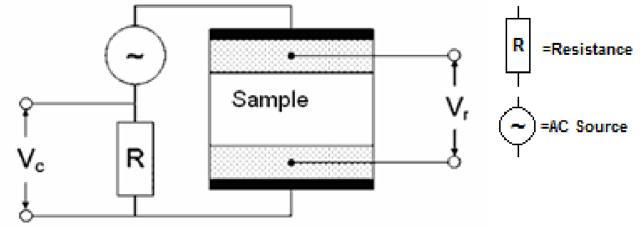


Fig.12. Arrangement for performance measurement.

In an impedance spectroscopy system (Figure 13), the excitation current is produced by the waveform synthesis. The voltage measurement process is generally performed synchronously to obtain in-phase and quadrature components of measured voltage and hence requires a reference waveform from the waveform synthesizer. In impedance analyzer systems necessarily implement some functions in analogue while as many other functions as possible are implemented digitally.

Waveform Synthesis

The best designs are to utilize digital waveform synthesis techniques to produce a sinusoidal waveform with very low total harmonic distortion, high stability, and good synchronization between the current generator and the voltage measurement demodulator. Digitized samples of a waveform can be stored in a PROM, or generated using a direct digital synthesizer (DDS) and fed through a digital-to-analogue converter (DAC) to drive the current source. In DDS, the frequency can be adjusted by varying the size of the phase increment. The limited size of the PROM requires rounding or truncation of the phase value that is used to access values in the PROM, introducing phase jitter that produces line spectra in the frequency spectrum of the resulting waveform.

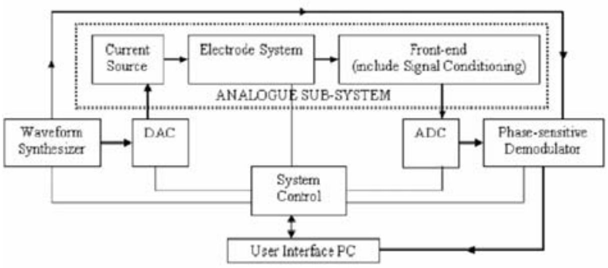


Fig.13. Block diagram of impedance spectroscopy system.

Analogue Sub-System

The impedance spectroscopy system has to provide current excitation to the subject and measure the resulting voltages. The current source is typically a voltage-to-current converter. The variation of its output impedance with varying load properties over the specified frequency range of the system operation is of critical importance. In addition, the existence of stray capacitance at higher frequencies has a detrimental effect on the output impedance. Therefore it is important to employ techniques to reduce the effect of stray capacitances. To do multiple impedance measurements a multiplexer may be required using a single current source and in systems that share voltage measurement circuitry between multiple electrodes. The multiplexer is typically controlled by a computer, or by a cycle stored in a look-up table in memory. Analogue signal conditioning is typically applied prior to digitisation and its properties in practice can be a limiting feature in any system design. Detailed discussion of the analogue sub-system is beyond the scope of the present paper.

Demodulator

In order to obtain accurate measurements, high-precision phase-sensitive demodulators (PSD)s are required. There is a debate as to the necessity of recording both real and imaginary parts of the voltage on the electrodes, or only recording the real part since in the latter case, it has been shown that the imaginary part can be calculated. The real part is least affected by errors resulting from stray capacitances. The stray capacitances associated with the input leads and circuitry introduce phase shift and therefore can cause a large systematic error in the measurements. The PSD that is used in an impedance spectroscopy system instrument generally uses a coherent reference obtained from the waveform generator. Analogue phase sensitive demodulation is limited, by the use of a square wave rather than a sinusoidal reference in switching based circuits, the properties of the analogue multiplier in analogue multiplier-based circuits and, the properties of the low pass filter. The outputs from analogue demodulators require a high performance ADC interfaced to the host computer. On the other hand, by using digital demodulators, a direct digital link between the output from the digital demodulator and computer can be implemented. In the digital implementation of the PSD, the conditioned voltage signal is sampled and digitised by an ADC, and the samples are multiplied by sine and cosine reference waveforms of exactly the same frequency. This voltage measurement structure is equivalent to the matched filter technique used in communications. Among all linear filters, a matched filter has the maximum output SNR for detecting a signal embedded in additive white noise. In the output it is necessary to integrate over a number of cycles of the signal in order to block the ‘double frequency’ components of the product of the output ADC samples and reference sine and cosine (low pass filtering).

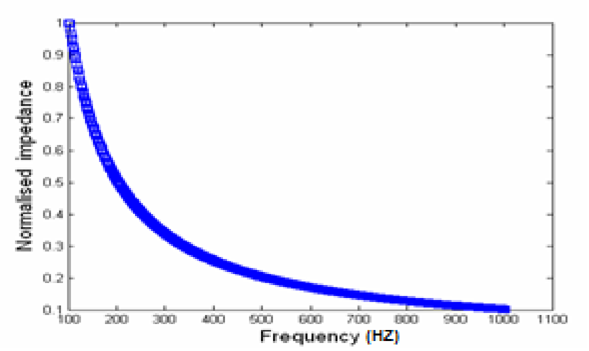


Fig.14. Impedance variation by frequency (100-1100Hz) .

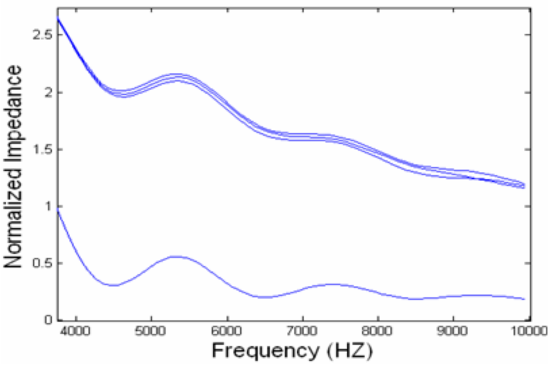


Fig.15. Impedance variation by frequency (4k-10kHz).

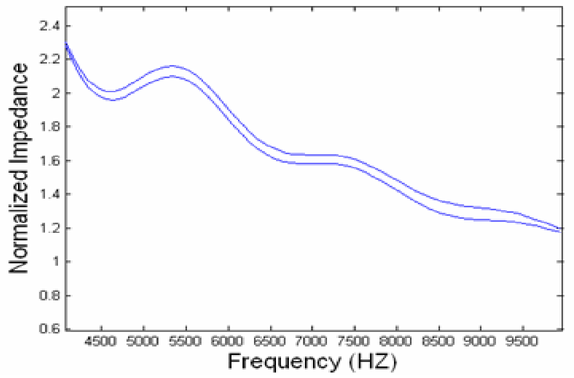


Fig.16. Zoomed view of Impedance by frequency (4.5k-9.6kHz).

In order to further derive the impedance characteristics of the switch in various frequencies. The impedance analyzer was built in LabView and worked based on Phase Sensitive Detention technology. The measured results are presented in figures 14, 15 and 16. It can clearly be seen in figure 14 and 15 that normalized impedance decreases with increase in frequency. Furthermore, figure 16 shows a zoomed in result for the range from 4kHz to 9.6kHz. The research is ongoing in deriving more details on AC impedance characteristics of the K Switches.

Conclusions

This switch operates on the basis of disturbance induced to the dielectric material which fill the gap between the two electrodes. As a result of this disturbance the overall impedance of switch is changed. This is noticed by applying *an AC bias cross the two electrodes. It is observed that with* the increase in frequency the impedance is reduced. This facilitates the sensitivity of the switch to change. Therefore, making it possible to operate the switch bare handed or while a glove is worn. The switch has a potential of its use in low power applications. The operation of the switch has been found consistent and reliable both in single and double electrode configurations. The responded well using impedance spectroscopy system which was designed using LabView.

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