

## Study on Different Techniques of Fabricating Conductive Fabrics for Developing Wearable Electronics Garments

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### Abstract

The mainstream research discourses and practices have been transforming into interdisciplinary studies recently. The combination of electronics and textiles can be classified as: wearable electronics, textronics and fibertronics, based on degree of integration. This paper discussed about development of cotton wrapped nichrome yarn, copper core conductive yarn, optical core conductive yarn POF of different diameters to produce, nichrome fabric, copper core conductive fabric, optical core conductive fabric and teleintimation fabric. The yarn and the fabrics were tested using a dedicated test rig developed for this research work. This work provides the platform for the methodology of developing conductive yarns and fabric for the wearable electronics product development to progress on the issue of user acceptability.

**Keywords:** Conductive fabric; Copper core yarn; Optical core yarn; Wearable electronic

### Introduction

Textiles are used in everyday life, for example as garment to protect ourselves from heat or cold, fabrics covering the surfaces of floors, or the upholstery of car seats. On the other hand electronic devices are spreading – but still some people do not have the knowledge to use them. So the next step to spread these electronics is to improve the user interfaces. Wearable Electronics could offer improved interfaces and make it easier for the user to accept electronic devices in everyday life.

Integrating electronic sensors and actuators into such textiles could be useful for a wide range of applications. Unfortunately, it is difficult to identify the needs without knowledge on the application in these fields. There is little interaction between the electronics-in-textiles community and respective industries. Today's textile conductors for electronics in textiles were not designed for the purpose of transmitting energy or data but rather for anti-static and anti-bacterial purposes. These threads need to be improved regarding conductance, process ability, reliability and signal transmission capability. Also isolation of textile integrated conductors has been neglected although it is required by most applications.

Existing garments are primarily designed for protective functions, including protection from extreme cold, physiological monitoring for emergency condition, and wearer GPS information for emergency intervention [1,2]. Continuous miniaturization of electronic components has made it possible to create smaller and smaller electrical devices which can be worn and carried all the time [1].

Researchers have developed user friendly techniques to develop methods that will make e-textile technology available to crafters, students, and hobbyists [3]. Also possible to develop transmission lines structures screen-printed on fabrics [4] as well as photonic textile displays woven on a Jacquard loom.

Wireless communication and wearable computers coupled with clothing forms a new approach to wearable computing [5,6]. "Tool Model" and "Clothing Model" describes the different usage models of wearable systems [7]. Steve Mann has carried out extensive work in the field of making computer systems wearable [8]. Probably the best-known example of smart clothing is a textile keyboard and a

synthesizer embedded into a denim jacket [9]. Intelligence in the form of electrical components has also been embedded into other pieces of clothing, e.g. gloves [10], ties [11], undergarments [12] and footwear [13]. Electro Textiles Company Limited has adopted another view in the development of smart clothes [14], active ventilation, heat transfer through garments, and reactive waterproof materials<sup>2</sup>. Conducting polymers are a relatively new type of material in terms of understanding, syntheses, and applications [15-18].

In this paper different type of yarn and fabric production techniques, modifications carried out in the conventional textile machines, problems faced during the production processes and the solutions were discussed. The specialty yarns and fabrics can be utilized for developing wearable electronic products.

### Development of Cotton Wrapped Nichrome Yarn

There are different methods for establishing conductivity of a yarn. A combed cotton yarn of 34s was used to wrap the nichrome wire, since coarser count would enable better wrapping with high surface area and also assist in quicker dissipation and to get protection against thermal shocks. M/s. Lohia Starlinker Braiding machine is used for wrapping of nichrome wire. To produce cotton wrapped nichrome yarn of 0.17 mm diameter and the linear density of the material is 156.32denier, the nichrome wire is placed in a bobbin on the centre shaft of a circular braiding machine and 16 Bobbins/2 Delivery combinations are used (Figure 1).

Onto the cut pattern of the knitted fabric, the Nichrome wire embedded cotton fabric is integrated. The total length of the nichrome wire is 10.4 m, in sleeveless pattern pad. The sleeve knitted fabric with

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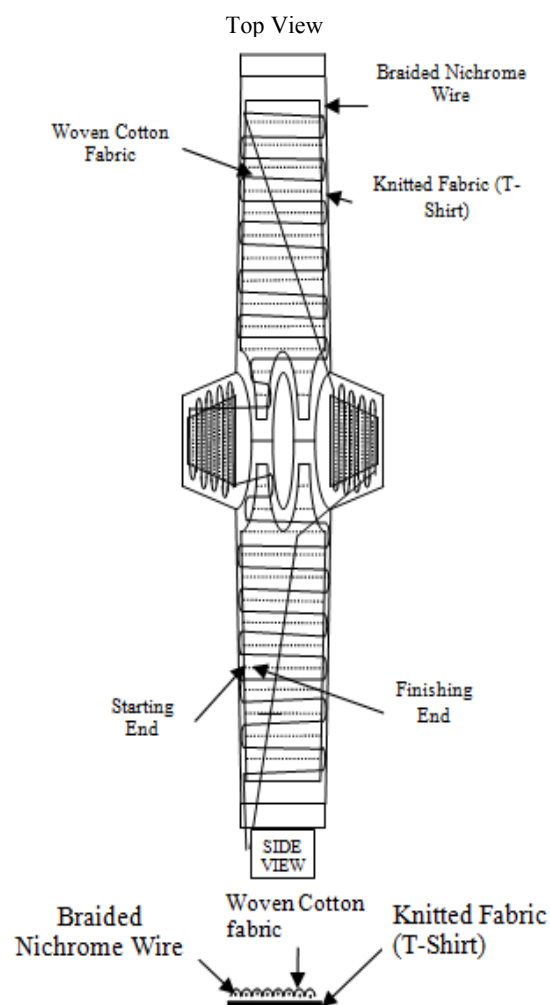
nichrome wire embedded cotton fabric integrated into the cut pattern is shown in Figure 2.

## Development of Copper Core Yarn

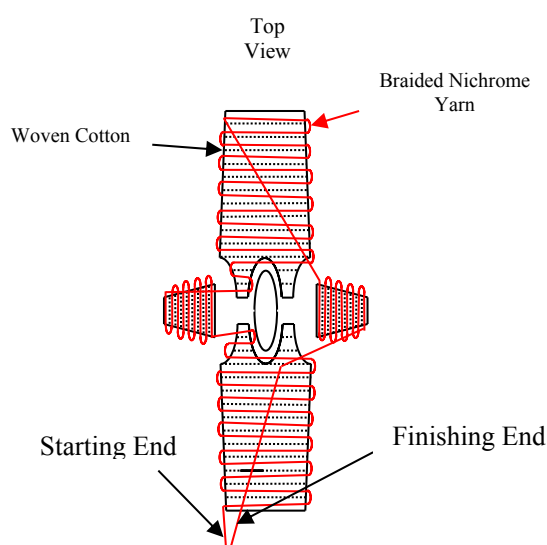
To develop copper core yarn, 38 SWG copper filaments of 261 Tex and cotton were used as core material and sheath material respectively, in this research work. To produce three different core-sheath ratios of conductive yarns, the Fehrer AG type DREF-3 friction spinning machine was used. With special guides, the copper core filament was fed in the first drafting unit. To increase the stability of spinning of the metal yarn, the guide device was designed and installed on the first drafting unit. To produce uniform yarn structure and which has the nominal yarn count of 328 Tex, the process parameters of DREF-3 spinning machine such as perforated drum speed and yarn delivery rate were set at 4000 rpm and 70 rpm respectively. Three different core-sheath ratio of 67/33, 80/20 and 90/10 copper/cotton yarns were produced, by varying the draft in the second drafting system. The cross sectional view of core sheath DREF-3 friction spun yarn is shown in Figure 3 and longitudinal view of core sheath DREF-3 friction spun yarn is shown in Figure 4 below. Special care was taken to wrap copper filament by adjusting the perforated drum speed, yarn delivery rate and draft in second drafting unit to produce uniform yarn structure, during the spinning process.

The conductive yarn that contained copper wire as core was fabricated by using special guide mechanism on DREF-3 spinning system. A comparison of three different core-sheath ratios of DREF-3 conductive yarns such as 67/33, 80/20 and 90/10 were produced by varying the draft in second drafting unit and it has average parent yarn linear density of 328 tex. Table 1 shows that the breaking elongation of the individual sheath component for all the samples are almost of a magnitude similar to that of the parent DREF-3 yarn, whereas in the case of the core component it breaks immediately (Table 1).

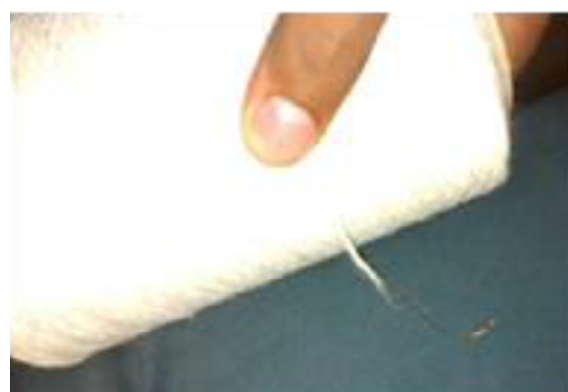
The physical characteristics of the conductive yarn were studied using different tests and found that the 67/33 core/sheath conductive yarn was having the highest tenacity of 3.27cN/tex and elongation to break 5.27% when compare to other core-sheath ratios, due to its better core-sheath interaction factor  $CSI_T$  -21.22%. It is also observed that



**Figure 2:** Integration of Nichrome Wire Embedded Cotton Fabric.



**Figure 1:** Woven Cotton Fabric Embedded with Nichrome Yarn.



**Figure 3:** POF Core Conductive Yarn.

the core-sheath interaction factor of conductive yarn sample C (90/10 core-sheath ratio) was found less core-sheath interaction factor  $CSI_T$  - 9.21% and it exhibits lower breaking tenacity and elongation to break, due to its behavior of copper filament.



**Figure 4:** Sample I: Communication Fabric with Warp as 2/60s Ne Cotton and Weft as ESKA POF.

Sample code	Tenacity (cN/tex)			Breaking Elongation (%)			Contribution Factor		
	Parent yarn (Z)	Core (X)	Sheath (Y)	Parent yarn	Core	Sheath	CC <sub>T</sub>	SC <sub>T</sub>	CSI <sub>T</sub>
Sample A	3.27	1.455	1.12	5.87	1.28	2.63	44.52	34.25	21.22
Sample B	2.89	1.455	1.01	4.52	1.28	2.51	50.37	34.98	14.64
Sample C	2.54	1.455	0.85	3.85	1.28	2.27	57.31	33.46	9.21

**Table 1:** Tensile Properties of Parent DREF-3 Yarns and Core-Sheath Components.

The values given in Table 2 shows that, the electrical resistance of conductive yarns is varying according to the length of the yarn and current also directly proportional to the applied voltage. The electrical properties of these conductive core spun yarns were exhibited very low resistance (3-28 MΩ) at 6 V, 12 V and 24 V applied voltage. The conductive complex core spun yarn can be woven and knit into fabrics that can be used as communication garment for measuring the body temperature and for mobile charging applications (Table 2).

By using copper core conductive fabric communication garment has been developed and it is integrated with mobile phone charging circuit and temperature measurement circuit for charging the mobile phone and measuring the wearer temperature respectively.

## Development of Optical Core Conductive Yarn

To develop communication fabric using optical core conductive yarn two types of POF yarn of 0.5 mm and 1 mm diameters were selected to produce two different samples. Two types of Polymeric Optical Fibres (POF) are used as core materials namely ESKA and CK-20 which is having diameter of 500 μm and 1000 μm respectively and 2/60s Ne cotton sliver as sheath materials for optical core conductive yarns. The Fehrer AG type DREF-3 friction spinning machine was used to produce the two different optical core conductive yarns. Four cotton carded slivers were fed in the first drafting unit and each sliver has 4.22 grams per meter and sliver irregularity of 3.8% (U%) respectively. The core material (optical fibre) was fed in the first drafting unit with special guides. They were designed and installed on the first drafting unit to increase the stability of the conductive yarn during spinning. To produce uniform yarn structure, the process parameters of DREF-3 spinning machine such as perforated drum speed and yarn delivery

rate were set at 4000 revolutions per min and 70 m/min respectively. The POF filament of ESKA and CK-20 type of 1024 Tex and 281 Tex were used as core material and cotton is used as sheath material in the proportion of 80:20 ratio.

During the spinning process, the optical fibre was fed from the first drafting unit with special guides. Special care was taken while wrapping optical fibre by adjusting the perforated drum speed, yarn delivery rate and draft in second drafting unit to produce uniform yarn structure. The POF core conductive yarns developed by DREF-3 spinning system are shown in Figure 3.

## Development of communication fabric using optical core conductive yarn

The communications fabrics are developed using hand loom with optical core conductive yarns as weft threads and 2/60s Ne cotton threads used as warp threads. During weaving, the special care was taken while inserting the optical core conductive yarn as weft, and the speed of the loom also reduced. Figure 4 shows the sample developed for communication fabric with warp as 2/60s Ne Cotton and weft as ESKA POF. Figure 5 shows the sample developed for communication fabric with warp as 2/60s Ne cotton and weft as CK-20 POF (Figures 4 and 5).

## Testing of communication fabric

To assess the physical characteristics and electrical properties of the above developed communication optical core conductive fabric samples, the various tests such as air permeability, air resistance, fabric thickness, aerial density and signal transferring capability were tested. Table 3 shows the results of the above physical tests (Table 3).

Conductive Yarn length (m)	Electrical Resistance (mΩ)	Applied Voltage		
		6 V	12 V	24 V
		Current (μA)	Current (μA)	Current (μA)
0.5	0.06	100	200	400
1	0.1	60	120	240
2	3	2	4	8
5	20	0.3	0.6	1.2
10	28	0.21	0.42	0.84

**Table 2:** Electrical Properties of Core-Sheath Conductive DREF-3 Spun Yarn.



**Figure 5:** Sample II: Communication Fabric with Warp as 2/60s Ne Cotton and Weft as CK-20 POF.



The aerial density of the ESKA type optical core conductive fabrics are 52% heavier than the CK-20 type optical core conductive fabrics due to its higher linear density (1028 Tex) and diameter as 1000  $\mu\text{m}$ . For the wearable electronic garments, CK-20 type optical core conductive fabrics are more suitable and it has higher air permeability due to the finer optical fiber (500  $\mu\text{m}$ ) and lesser fabric thickness (0.74  $\pm$  0.13 mm) when compare to the thickness of ESKA type optical core conductive fabrics (1.24  $\pm$  0.20 mm).

### Testing of communication fabric to assess signal transferring capability

POF core conductive fabrics developed using two samples ESKA and CK-20 type were tested by different input LEDs for 15 cm length fabric. The light signal transferring of ESKA and CK-20 type optical core conductive fabrics are analyzed by passing the input LED source at one end and to receive the signal at the other end. If the fiber got damaged during weaving process, there will be interruption of these light signals. The fabric was tested using a test bench. Light source is used at the one end of the optical fiber and a photodiode is used at another end of the optical fiber. When there is a light illumination on the photodiode, the output of the photodiode produces 0 V and when there is an illumination, it shows 5 V output in the display unit. Table 4 shows test results of signal transferring capability of communication fabrics.

It was found that the signal loss in terms of light intensity was higher due to the stress to the optical fibre during spinning and fabrication processes. It is evident from the Table 4 that the signal loss is only 24% both in communication fabric developed using CK-20 and ESKA POF, when LASER light is used as input light source. But the percentage of signal loss is higher when red LED is used as input light source. This is because red LED has the minimum lux value due to the maximum wavelength of red color 9 (Table 4).

From the test results it has been concluded that the communication

Particulars	Sample I Communication Fabric (ESKAPOF – Core Cotton – Sheath )	Sample II Communication Fabric (CK-20 POF -Core Cotton Sheath)
Ends per inch Warp: 2/60s Ne Cotton	42	42
Picks per inch Weft: POF Filament Core and Cotton Sheath yarn	13	21
Aerial density (GSM)	564.2	269.4
Fabric cover factor (Kc)	20.07	18.2
Air permeability ( $\text{cm}^3/\text{cm}^2.\text{s}$ )	311.375	259.84
Air resistance (Kpa.s/m)	0.04	0.048
Optical wire wt (g/m)	0.860	0.260
Fabric Thickness (mm)	1.24 $\pm$ 0.20	0.74 $\pm$ 0.13

**Table 3:** Physical Characteristics of Communication Fabrics.

Input Light Source	Input Voltage (V)	CK-20 POF		ESKA POF	
		Output Voltage (V)	Signal Loss (%)	Output Voltage (V)	Signal Loss (%)
Red	5.0	3.1	38	2.9	42
Infrared	5.0	3.1	38	3.2	36
White	5.0	3.6	28	3.5	30
LASER	5.0	3.8	24	3.8	24

**Table 4:** Test Results of Signal Transferring Capability of Communication Fabrics.

fabric can be used for the production of teleintimation garment and for applications where signal transferring is essential. The communication garment developed using optical core conductive fabric is used for signal transmission as well as to locate the number and the place of the bullet wound.

### Development of Yarn for Teleintimation Fabric

In this research work four different diameters of POF such as 0.25 mm, 0.5 mm, and 1.0 mm have been chosen to develop teleintimation fabric. These optical fibres are made into fabric form by three methods namely (a) Sequential work with POF integrated in the fabric and (b) Weaving of the POF using power loom and (c) Weaving of the POF using hand loom. The teleintimation fabric is developed to produce teleintimation garment which will locate a wounded soldier quickly, perform triage, monitor vital signs and relevant physiological information and display their status locally or remotely.

### Development of teleintimation fabric by sequential technique

It is a method of integrating POF with fabric by embroidery technique. For this technique, the cotton fabric of 2/40s Ne warp and 40s Ne weft woven fabric was selected which is having 140 GSM. The POF is placed over the fabric in the required matrix format and stitches are made on it to hold the POF on the fabric. The embedding/integration of POF on the fabric depend on binding of threads and number of binding points. The major problem faced in embroidery work with POF is, withdrawal of POF threads and fiber damage during integration on the fabric and also found less serviceability due to hand insertion. Figure 6 shows the fabric developed by embroidery technique with POF arranged in X-Y direction on the fabric (Figure 6).

### Development of teleintimation fabric by power loom

The teleintimation fabric was fabricated using power loom, the Polymeric Optical Fiber (POF) filament is integrated with the cotton yarn in both warp and weft directions using rigid rapier loom to produce teleintimation fabric. The POF fabric developed using rapier loom is in matrix format of POF pattern, since the maximum bullet size used in military is 7.62 mm, the matrix should have the maximum pixel of 5 mm of diameter. The quality particulars of POF fabrics developed using rapier loom are 54 inches fabric width, 32 picks per inch in which every alternative picks are inserted using polymeric optical fibre filament with 24 ends per inch, which has 2 ends per inch POF filament and 2/20s Ne cotton. The weave pattern selected for the POF fabric is 1 up and 1 down plain weave and loom running speed of 170 picks per min using Picanal PGW type rapier loom.

The major problems faced during weaving of POF fabrics are warping of polymeric optical fiber on the beam due to lack of flexibility, mounting the POF beam, drawing and denting of the POF fiber, separation of the warp ends, slough-off of the POF from the spool kept for the weft insertion, slippage of the rapier while picking in higher and as well as lower speed and rubbing of the warp ends while the rapier traveling which causes damage in the outer cladding surface of the POF.

While placing the POF wound beam in the normal beam position, it was noticed that loose and slackness of POF threads in warp direction, so to avoid these problems the mounting of the beam was done with a little lift from the normal beam position. The tension in the cotton yarn and the tension in the POF are entirely different and hence the drawing of the ends became a time consuming process. There was a chance of breakages of the fiber while knotting with the cotton ends. One of the

major problems with the Polymeric Optical Fiber is the slough-off of the fiber from package itself during weft insertion. Due to this slough-off of the fiber, the weft insertion is not made properly and steel rod arrangement has been made to avoid this problem. Slippage of the POF in the rapier during picking is another major problem faced during the process. While picking, the rapier could not hold the POF fiber at the middle of the race board due to the slippage. The POF is also present in the warp direction; the movement of the rapier over the warp ends will cause cladding (outer area of the POF) damage and thereby affecting the signal properties of the POF. The signal transmitting property of the POF in weft direction is also affected due to the rubbing of the rapier. The teleintimation fabric developed using rigid rapier loom with polymeric optical fibre in specific matrix format is shown in Figure 7.

### Development of teleintimation fabric by hand loom

The polymeric optical fibres are inserted in warp and weft direction to produce desired matrix for detecting the signal transmission characteristics using hand loom. The quality particulars of POF fabrics developed using hand loom are 22 inches fabric width, 32 picks per inch in which every alternative picks are inserted using polymeric optical fibre filament with 24 ends per inch, which has 3 ends per inch POF filament and 2/20s Ne cotton (Figure 7).

The weave pattern selected for the POF fabric is 1 up and 1 down plain weave. To weave POF fabrics, it needs few modifications in the preparatory process namely warping, drawing and denting of the POF, separation of the warp ends, winding of the POF on the shuttle for pick insertion processes. Warping of POF on the warp beam was done by

allowing the fiber manually with equal tension. The beam is marked properly so as to accommodate the POF with the cotton yarn in the fabric and this depends upon the number of warp ends and the winding of the POF on the warp beam. In order to avoid the tension variation between the POF and cotton warp ends, the drawing and denting of the warp ends are carried out manually because the width of the loom is small compared to power loom and rapier loom. The weave pattern is plain weave (1/1) and the POF is inserted for every alternate pick in the weft way. For the easy insertion of the pick the POF is wound in the shuttle with appropriate tension. The winding is done manually and is wound in the optimum tension to avoid the slough-off of the POF. The winding is done manually with the help of the manual winding machines for the cotton and POF. The weaving of the POF with cotton yarn in both warp and weft direction in the handloom started with the above arrangements. The pick insertion is done with alternate POF and cotton yarn of count 2/20s Ne. While the shed opening, the first color cotton yarn will be up and the next color will be down and vice versa. While shed is opened, the POF is inserted for one pick and the cotton yarn is inserted for the next pick respectively. The pick insertion is done manually in handlooms with the help of the shuttle wound with cotton yarn and POF. The cotton yarn of count 2/20s is inserted for every alternate pick with POF and fabric width of 22 inches produced. Figure 8 represents the teleintimation fabric developed by hand loom.

### Physical characteristics of teleintimation fabric

**Bending rigidity:** Bending rigidity measured with KES-FB2 Bending tester, is a measure of the force required to bend the fabric approximately 150°. Bending rigidity per unit fabric width value indicates greater stiffness/ resistance to bending motions. It is calculated for testing the maximum bend tolerance for the fabric with POF to transmit light energy from one end to another end. It was observed that the bending tolerance for the POF located in the warp way and weft way is 7.3 cm and 5.2 cm respectively. Beyond the bending length the attenuation of the light signals will increase resulting in loss of signals.

**Tensile strength:** The tensile test, done on the KES-FB1 Tensile-Shear Tester, measures the stress/strain parameters at the maximum load set for the material being tested. It measures the amount of stress applied to a material at its breaking point or the point at which it fails.

From the Table 5 it is noticed that the tensile strength is more in the warp way than in the weft way in both the POF integrated fabric. In case of the khaki fabric (Handloom) the arrangement of the POF is in such a way that for every half centimeter one POF is integrated in both warp and the weft way. Since the arrangement of the cotton yarn and the POF is compact the strength is more while in the other hand the blue fabric (Rapier loom) is integrated with POF for every one centimeter of the cotton yarn both in the warp and weft way (Table 5).

**Air permeability:** It was tested with KES F8 AP1 and it can be used to provide an indication of the breathability of weather-resistant and rainproof fabrics, or of coated fabrics in general, and to detect changes



Figure 6: Integration POF in X-Y Direction on the Fabric.



Figure 7: POF Integrated Fabric Using Power Loom.



Figure 8: POF Integrated Fabric Using Hand Loom.

during the manufacturing process. The air permeability of Handloom Fabric and Power Loom Fabric is 44 kPA/Sq.cm and 18 kPA/Sq.cm respectively.

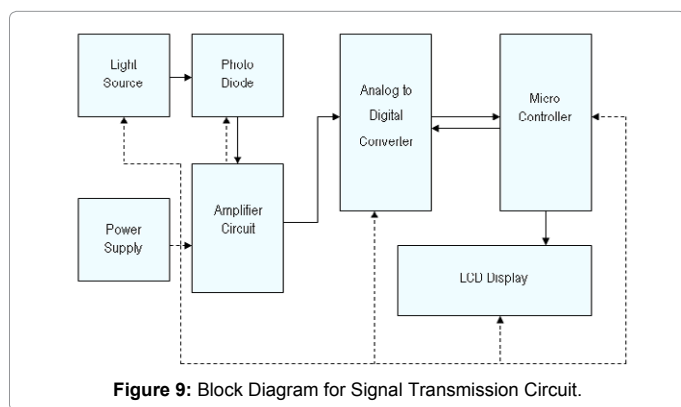
**Signal transferring efficiency of teleintimation fabrics:** The signal transferring efficiency of the handloom, power loom and sequential integrated woven POF fabrics are analyzed using the microprocessor ATMEGA 89C51 designed with IRF14F Optical Receiver as shown in Figure 9. The digital signal is given to the microcontroller, which is being programmed to display the result in terms of voltage<sup>1</sup>. From the signal values measured in various places of fabrics at 15 cm, 20 cm, 30 cm optical length are made into cumulative average and their signal output voltages are 3.13 V, 3.88 V and 3.01 V for power loom, hand loom and sequential integrated POF fabrics. The signal transferring loss percentage of 0.5 mm POF at 2 feet and 10 feet fibre length with infrared light, red light and white light for various input voltage of 4.5 V and 6 V respectively were tested. From this signal transferring analysis, the signal loss percentages for power loom, hand loom and sequential integrated POF fabrics are 37.44%, 22.40% and 39.84% respectively. It is noticed that the signal transferring loss percentage of handloom fabrics is less when compared to other fabrics (Figure 9).

## Conclusion

Today, the interaction of individual humans with electronic devices demands specific user skills. The cost level of important microelectronic functions is low enough and enabling key technologies are mature enough to exploit this vision to the benefit of society. Wearable Electronics are an emerging Tran's disciplinary field, bringing together concepts and expertise from a variety of disciplines, ranging from materials science, through computer engineering to textile design. This research work addresses an emerging new field of research that combines the strengths and capabilities of electronics and textiles in on, wearable electronics. In these paper different types of yarn and fabric

POF Fabric	POF Fabric	Tensile Strength (grams)
Handloom Fabric	Warp way	180
	Weft way	70
Power loom Fabric	Warp way	140
	Weft way	45

**Table 5:** Testing POF Tensile Strength.



**Figure 9:** Block Diagram for Signal Transmission Circuit.

production techniques has been developed for wearable electronic products. The Cotton wrapped nichrome yarn embedded cotton fabric integrated into knitted fabric for the development of Heating Garment. Copper core conductive yarn and Optical core conductive yarn were developed for the production of Communication Garment and POF integrated teleintimation fabric has been developed for Teleintimation Garment.

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