Comparison of Copper Covered and Copper Core Sheath Yarn for the Fabrication of Textile Antenna

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***Abstract*—This paper presents the comparison between copper covered and copper core sheath yarn performance for the development of conductive fabric antenna. Conductive fabric is a fabric that are able to conduct electromagnetic. This kind of fabric is crucial in the development of textile antenna for wearable application. Thus, the types of yarns to be used are important in order to develop conductive fabric antenna. Two designs of yarn are investigated, which are copper covered yarn and copper core sheath yarn. Antenna prototypes fabricated by using both yarns are developed and measured to validate the performance of the antenna. The antennas are fabricated on conductive fabrics, which are made from copper covered and copper core sheath yarn. The relation between different types of conductive yarns is studied and the antenna performance is analyzed. The results show that the copper covered yarn is superior as compared to the copper core sheath yarn in terms of its return loss (S_{11}) and radiation pattern performance. From the studies, copper covered yarn closely resembles PEC and hence the result of copper covered structure has good agreement with simulation.**

***Index Terms*—conductive yarn, conductive fabric, textile antenna, wearable.**

I. INTRODUCTION

Rapid development in Wireless Body area Network embark utilization of wearable antenna to fulfill requirement for application of miniaturization of wireless communication device [1]. Increasing interests on the wearable antenna is due to its potential in several areas which includes tracking, navigation, mobile computing, public safety and wireless communication [2]. Wearable antenna supposed to be flexible, robust, lightweight, low profile and can be easily integrated into garment [3]. Electro-textile are conductive fabrics developed by using conductive metal/polymer thread with normal fabric or conductive fabric and these fabrics are considered as strong candidate to be integrated into clothing for distributed body worn electronics because they are washable, durable, and flexible [4]

Numerous papers on wearable antennas have been published specifically on the design, fabrication techniques, applications, and manufacturing of fabric antennas. Recently, in Global Positioning System (GPS) applications, a military beret is integrated with the textile material/conductive fabric for indoor/outdoor positioning system [5]. While in medical application, a compact wearable antenna with a novel miniaturized electromagnetic bandgap (EBG) structure is demonstrated into clothing for wearable medical applications [3]. The effects of the antenna bending, water absorption and human proximity on the wearable antenna including SAR (Specific Absorption Rate) were analyzed in [2][6]. Detailed report on fabrication techniques were also discussed in [7-9]. More research on determination of substrate and dielectric constant of fabric materials was studied in [1][10-11]. All the above potential findings, will leads to the improvement in the development of conductive fabrics.

Though conductive fabrics have been used for the applications of wearable antennas, most researchers develop a conductive fabrics antenna using a commercially conductive material for example copper tape, and conductive fabric such as zell and fleece. Very few works had been done on studying the characteristics of conductive yarn that actually will influence the performance of conductive fabric. Thus, in this paper two structures of yarn which are copper covered yarn and copper core sheath yarn is proposed. The antenna performance using these two types of yarn is investigated including radiation pattern and return loss (S_{11}).

II. METHODOLOGY

The methodology is divided into three segment, which are development of conductive yarn, fabrication of conductive yarn, and fabrication of the antenna.

A. Development of conductive yarn

Figure1 shows the structure of copper core sheath and copper covered yarn

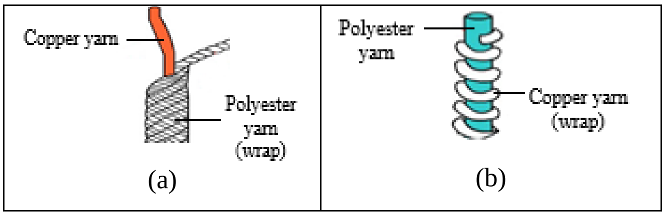

Figure1: (a) Copper core sheath yarn (b) Copper covered yarn [14]

There are two design of conductive yarn proposed, which are copper covered and copper core sheath yarn [12]. To develop this yarn, a non-conductive yarn (polyester yarn) and conductive yarn (copper yarn) is used. Copper covered yarn is a non-conductive yarn that is twisted with a conductive yarn and forming spiral covering along the non-conductive yarn. While copper core sheath yarn has the conductive yarn at the center and then covered by non-conductive yarn around it. Fancy Yarn Twisting machine is used to develop the conductive yarn. For copper core sheath yarn, the yarn produced will be thicker than the copper covered yarn.

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B. Fabrication of conductive fabric

Figure2 shows conductive fabric which made from copper covered and copper core sheath yarn.

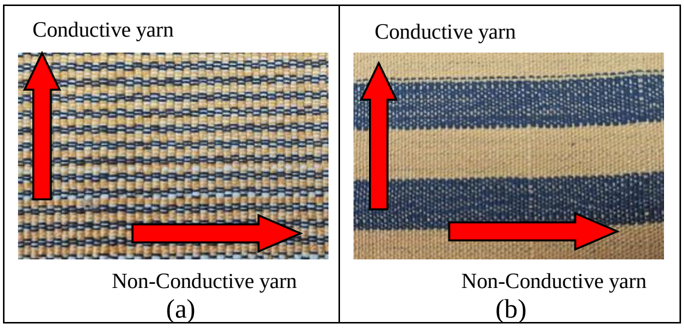


Figure2: (a) Copper core sheath yarn conductive fabric
(b) Copper covered yarn Conducive fabric

Weaving technique is used to fabricate the conductive fabric and a basic weaving pattern which is plain weave is used. Production of conductive fabric shall be done using SULZERTEXTIL G6300 Rapier Weaving machine. The conductive yarn and non- conductive yarn will be placed in warp (vertical) and weft (horizontal) direction to form conductive fabric.

C. Fabrication of the antenna

Table1 shows the parameters used to fabricate the antenna.

Type	**Parameters for copper covered yarn antenna**			**Parameters for copper core sheath yarn antenna**		
	Length (mm)	***Width (mm)***	***Thickness (mm)***	***Length (mm)***	***Width (mm)***	***Thickness (mm)***
Patch	42	85	0.46	42	85	0.95
Substrate	85	90	1.7	85	90	1.7
Feed	25	5.2	0.46	25	4.8	0.95

Table1:Parameters for antenna fabrication

Table 2 shows the measured dielectric constant (ε_r) and tangent loss (tan δ) of polyester fabric.

Polyester Fabric	
Dielectric constant (ε_r)	1.36
Tangent loss (tan δ)	0.031

Table2: Dielectric constant (ε_r) and tangent loss (tan δ) of polyester fabric.

Figure3 represent the fabricated conductive fabric antenna by using both copper covered yarn and copper core sheath yarn.

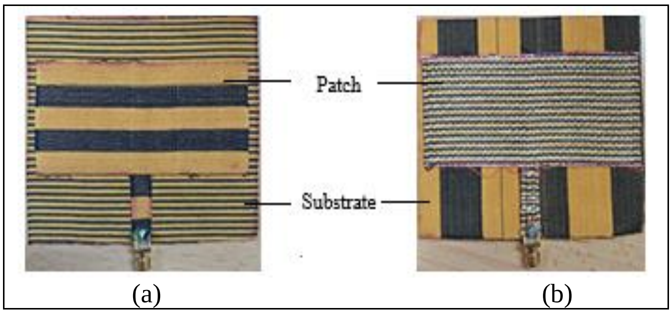


Figure3: (a) Copper Covered yarn conductive fabric antenna
(b) Copper core sheath yarn conductive fabric antenna

A simple patch antenna is used to design textile antenna. In the fabrication of textile antenna, fabricated conductive fabric is used as the antenna patch and polyester fabric is the antenna substrate. The textile antenna was designed by using CST Studio Suite software at 2.4 GHz resonant frequency. In the simulation, PEC was used as the patch material and polyester fabric with measured dielectric constant (ε_r) was used as the substrate. The dielectric constant (ε_r) of polyester fabric was measured by using coaxial probe [13]. The measurement for return loss (S_{11}) is done by using KEYSIGHT PNA-L Network Analyzer N5234A. The measurement for radiation pattern was done in Anechoic chamber OTA-500.

III. RESULTS AND DISCUSSION

In this section there are 3 sub-topic to be discussed which are composition of yarn, return loss (S_{11}), and radiation pattern.

A. Compostion of yarn

Table3 shows the composition of copper and polyester in both copper covered and copper core sheath yarn.

Yarn	**No. sample**	**Copper + Polyester (g)**	**Copper (g)**	**Polyester (g)**
Copper Covered Yarn	1	0.373	0.318	0.064
	2	0.386	0.302	0.062
	3	0.381	0.316	0.06
	4	0.375	0.321	0.06
	5	0.38	0.314	0.064
	Average	0.379	0.3142	0.062
	% Copper		82.90	
	% Polyester		16.36	
Copper Core Sheath Yarn	1	1.236	0.277	1.104
	2	1.217	0.229	0.892
	3	1.198	0.173	0.983
	4	1.225	0.229	0.971
	5	1.212	0.229	0.944
	Average	1.2176	0.2274	0.9788
	% Copper		18.68	
	% Polyester		80.38	

Table3: Composition of yarn

Structure of yarn such as density yarn, number copper turns in copper covered yarn, size of copper yarn and material used to make yarn will influence the antenna performance [4][12][15]. The composition of the yarn is investigated following the ASTM D269 standard which is mechanical separation of yarn. Five samples of yarns with 2m length each, are tested for each type of yarn and measured for the composition of copper and polyester in both copper covered and copper core sheath yarn. The results in Table3 indicates that the copper covered yarn has the highest percentage of copper which is 82.90% as compared to copper core sheath yarn which is only 18.68%. Higher density of copper will influence the textile conductivity, thus influence the antenna performance for a better.

Another factor that may influenced the performance of copper covered and copper core yarn conductive fabric is the thickness of yarn. As shown in Table1,the thickness of patch is based on the size of yarn. Thus, for the same width of patch, different numbers of conductive yarn are used in each conductive fabric. Figure4 shows the technique used to investigate the number of conductive yarn in 1cm^2 conductive fabric.

Figure4: Magnified view of fabric composition

Type of yarn	Number of conductive yarn / 1cm^2
Copper covered yarn	20
Copper core sheath yarn	8

Table4: Composition of conductive yarn in 1cm^2 conductive fabric

Table4 shows that number of copper covered yarn used is 20 yarns to develop 1cm^2 conductive fabric. Meanwhile, 8 copper core sheath yarn is used to develop conductive fabric. Different in number of conductive yarn will also effect the performance of the antenna. From the information gathered, the earliest hypothesis that can be made is that copper covered yarn is more suitable for fabrication of textile antenna compared to copper core sheath yarn as the density of copper yarn is high and the number of copper yarn in 1cm^2 conductive fabric is greater in copper covered yarn design. Further experiment in term of antenna return loss (S_{11}) and radiation pattern is carried out to determine which type of yarn is reliable for the fabrication of conductive fabric antenna

B. S_{11}

Figure5 and Figure6 shows the results of return loss (S_{11}) and resonant frequency of the conductive fabric. Both simulation and measured performance are compared.

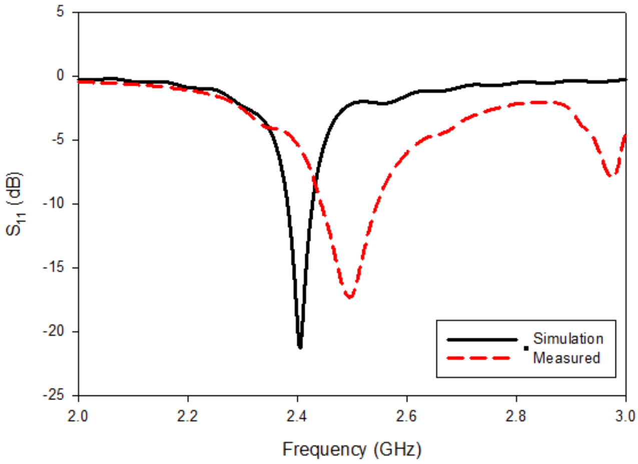


Figure5: Graph copper covered yarn Frequency vs S_{11}

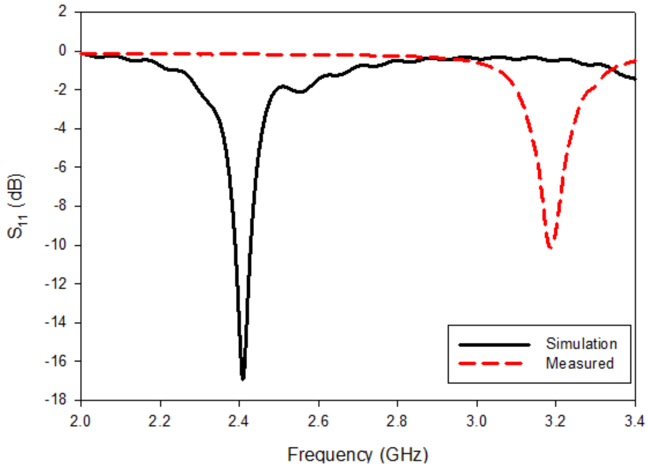


Figure6: Graph Copper copper core sheath yarn Frequency vs S_{11}

Table5 is the sumarization of the simulated and measured results of copper covered and copper core sheath yarn fabric antenna.

Type of yarn	Parameters	Simulation	Measured
Copper Covered Yarn	Frequency (GHz)	2.40	2.49
	S_{11} (dB)	-21.34	-17.23
Copper Core Sheath Yarn	Frequency (GHz)	2.40	3.19
	S_{11} (dB)	-16.81	-10.14

Table5: Simulation and measured results for copper covered and copper core sheath yarn fabric antenna

From the results in Table5, conductive fabric that is made up from copper covered yarn represents better performance as compared to the copper core sheath yarn. For S_{11} results, copper covered yarn indicate smaller return loss compared to the copper core sheath yarn. It is noticeable that there is a slight different in S11 and frequency between measurement and results that maybe due to the structure of the condcutive yarn. The fabricated copper covered conductive fabric antenna results is more similar to its simulation.

However, for copper core sheath yarn conductive fabric antenna the measurement results is totally contrast from simulation. Different mesured and simulated results of copper core sheath yarn is also due to the density of copper threads in the copper covered yarn, which is higher than the copper core sheath yarn. The density has great influence in the textile conductivity, thus may influence the antenna performance. Number of conductive yarn in 1cm^2 of conductive fabric will also effect the performance of the antenna. Hence, to improve copper core sheath yarn performance, size of conductive fabric antenna has to be increased so that conductive material in antenna will increased. However, large size of antenna is not convenient for a low profile wearable antenna.

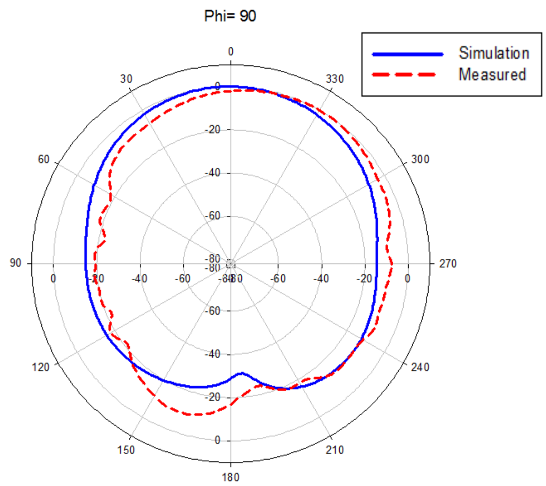
In simulation, PEC is used to represent patch. So, based on observation, copper covered yarn closely resembles PEC but not as perfect as PEC. Thus, it is reliable better to use copper covered yarn to fabricate conductive fabric antenna.

The gain for copper covered and copper core sheath yarn are 7.79 dB and 7.37 dB respectively.

C. Radiation Pattern

Figure7 and Figure8 shows the radiation pattern of copper covered and copper core sheath yarn conductive fabric antenna. The radiation pattern is measured on Phi=0 and Phi=90 respectively.

Copper covered conductive fabric antenna



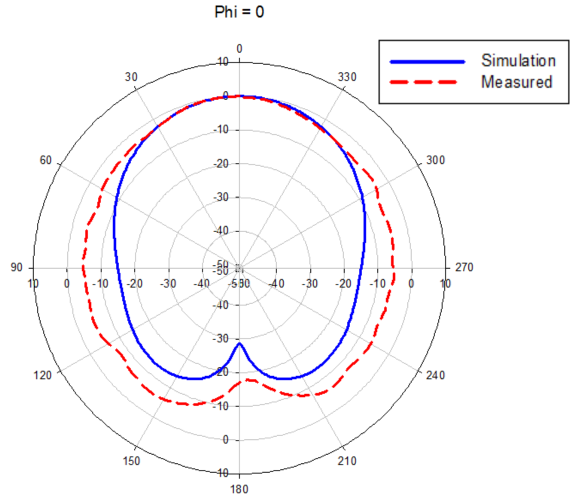


Figure7: Simulated and measured radiation pattern of copper covered yarn conductive fabric antenna

Copper core sheath yarn conductive fabric antenna

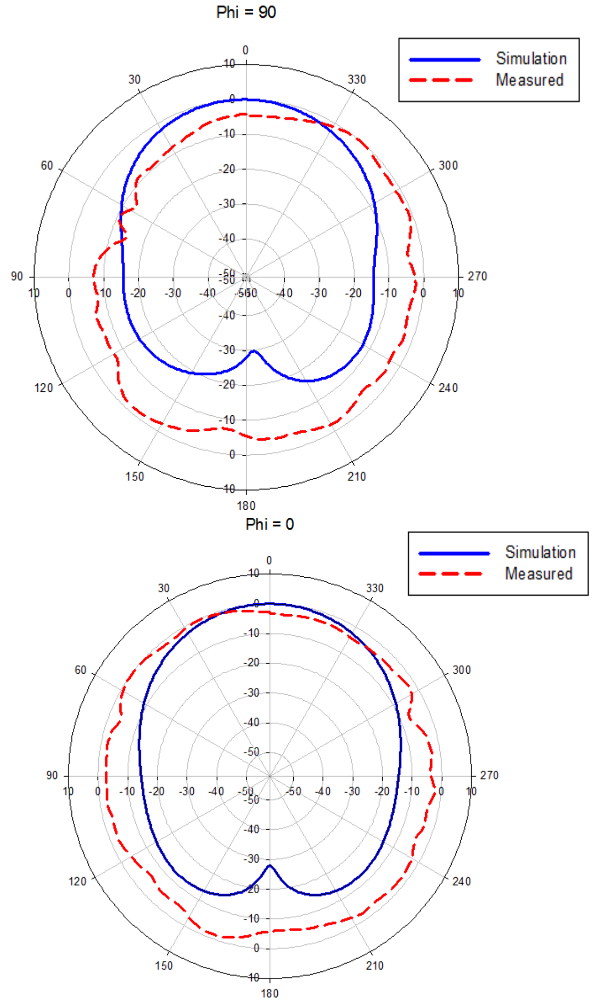


Figure8: Simulated and measured radiation pattern of copper core sheath yarn conductive fabric antenna

The far-field performance of the antenna in free space is measured in an anechoic chamber. Simulation and measured results is compared. In this results, copper covered yarn shows fewer side lobes as compared to copper covered sheath yarn which has more losses and side lobes. From the osbservation, it is realised that simulation and measured results in copper covered yarn is more simliar as to compared with copper core sheath yarn. It is proven that copper covered yarn has better performance than copper core sheath yarn.

On the other hand, the way that copper yarn designed in both type of conductive yarn also influence the results. In copper covered yarn, the copper yarn is coiled around polyester yarn. While for copper core sheath yarn, a straight copper yarn is placed in the middle and wrapped up with a polyester yarn. According to Ampere's Law, a circular magnetic field will formed as a current pass through any conductor. Hence, it is beneficial for copper covered yarn as the spiral shape of copper yarn will increase its magnetic strength [16]. Therefore, once the magnetic field increase, the conductivity of the antenna will also increase. Increasing of conductivity enable the conductive fabric antenna to radiate better. Hence the radiation pattern of copper covered yarn is less side lobe and more similar to simulation compared to copper core sheath yarn.

IV. CONCLUSION

In conclusion, copper covered yarn shows a superior performance in term of resonant frequency, return loss (S_{11}), and radiation pattern as compared to copper core sheath yarn. For the fabrication antenna, copper covered yarn shows only a slight difference to the simulation. However, for copper core sheath yarn the resonant frequency and return loss ($S_{11)}$ shows big difference from simulation. The difference in measured and simulated results are greatly influenced by the compositions of yarns. The compositions of yarns play an important role in the development of conductive fabric. This paper shows that the structure of copper covered yarn has more conducting elements as compared to copper core sheath yarn, which is good for conductive fabric antenna. Another advantage of copper covered yarn is its small size and structure, which means that more conductive fabric can be placed in each centimeter per square of conductive fabric. Based on this experiment, assumption can be made that copper covered yarn can closely resemble PEC but not as perfect as PEC. Most of the measured results have almost good agreement with the simulation. Slight difference in measured result is due the fabrication techniques. Therefore, it is recommended to use copper covered yarn for the fabrication of textile antenna.

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