(REFEREED RESEARCH)

ELECTRICALLY CONDUCTIVE TEXTILE SURFACES AND THEIR ELECTROMAGNETIC SHIELDING EFFICIENCY MEASUREMENT

ELEKTRİKSEL İLETKEN TEKSTİL YÜZEYLERİ VE YÜZEYLERİN ELEKTROMANYETİK EKRANLAMA ETKİNLİĞİNİN ÖLÇÜMÜ

Sema PALAMUTCU
Pamukkale University
Textile Engineering Department
e-mail: spalamut@pau.edu.tr

Ahmet ÖZEK
Pamukkale University
Electric-Electronic Engineering Department

Ceyhun KARPUZ
Pamukkale University
Electric-Electronic Engineering Department

Nermin DAĞ
Pamukkale University
Textile Engineering Department

ABSTRACT

In this work a unique design and construction of Electro Magnetic Shielding Efficiency (EMSE) measurement set is introduced and its reliability is discussed within the circumstance of the produced electrical conductive textile surfaces. Electrical conductive yarns, that are contending copper wire, silver and cotton staple fibers, are spun and used for production of plain woven and single jersey knitted specimens. Produced specimens are tested in the designed EMSE measurement set in the frequency range of cellular phone communication bands –between 860MHz-960MHz for 900MHz and 1750MHz -1850MHz for1800MHz- in Turkey. EMSE of the specimens are compared considering yarn components, fabric structure, number of fabric layers, and reference signal power (dBm) based on frequency changes. Considering EMSE values; structure of specimens (woven or knitted), ratio of copper wire in the content of yarn, number of fabric layers, reference dBm value of generated signals are found influential parameters. Thin copper wire containing yarn has higher EMSE comparing those specimens produced using thicker copper wire yarns. Double layer of specimen has better EMSE then the single layer of specimens. Attenuation of specimens can be different for different reference (dBm) levels of generated signals

Key Words: Electroconductivity, Electromagnetic shielding effectiveness (EMSE), Cotton textiles.

ÖZET

Bu çalışmada özel olarak tasarlanmış olan Elektro Manyetik Ekranlama Etkinliği (EMSE) ölçüm düzeneği tanıtılmış ve bu düzeneğin güvenilirliği için çalışma kapsamında üretilmiş olan iletken tekstil yüzeylerinde yapılan EMSE ölçümlerinin sonuçları tartışılmıştır. İletken iplikler ince bakır tel, gümüş–pamuk karışım iplikler ve %100 pamuk iplik kullanılarak oluşturulmuştur. Oluşturulan iplikler süprem örme ve bez ayağı dokuma yüzeylerin hazırlanmasında kullanılmıştır. EMSE ölçümleri Türkiye'deki GSM çalışma bandları olan 900MHz için (860MHz-960 MHz aralığında) ve 1800MHz için (1750MHz-1850MHz) yapılmıştır. Ölçümlerde farklı iletken iplikler; bakır içerikleri, kumaş yapısal özellikleri, tek-çift kat kumaş kullanımı ve referans sinyal gücü (dBm) değişimleri, frekans değişimlerine bağlı olarak birbiri ile karşılaştırılmıştır. Ölçümler sonucunda kumaş yapısal özelliklerinin, (örme, dokuma) ipliklerdeki bakır tel kalınlığının, numune kat sayısının ve referans sinyal büyüklüğünün etkin parametreler olduğu belirlenmiştir. İnce bakır tel kullanılarak üretilen ipliklerden elde edilen kumaşların kalın bakır tel kullanılarak yapılan ipliklerle elde edilen yüzeylere göre daha yüksek EMSE değerinde oldukları görülmüştür. Benzer olarak çift katlı kumaş yüzeylerdeki EMSE değeri tek kat yüzeylere göre daha yüksek bulunmuştur. Farklı referans değerrindeki sinyallerde numune kumaşların EMSE değerlerinin farklı olduğu, sinyal gücünün EMSE üzerinde etkili olduğu görülmüştür.

Anahtar Kelimeler: Elektriksel iletkenlik, Elektromanyetik kalkanlama etkinliği (EMSE), Pamuklu tekstiller.

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1. INTRODUCTION

Use of textile based materials in the electrically conductive products have widened in the last two decades. Conductive textile fibers and conductive textile products are the combination of textiles with electronics. Such interesting products are used for exhibitions of many new functions in many fields like comfort and well being, civil engineering, protection, medical and military applications (1-4). Some well known application areas of electrically conductive metal sheet or wire mesh shielding materials are replaced by lightweight, flexible and non-expensive conductive textile surfaces (1). One of the most common application areas of electrical conductive fabrics are shielding purposed surfaces from the harmful effects of radio frequency energy.

There has been ongoing research interest, parallel to the widened product applications, in determining the production methods of such textile surfaces and improving the shielding effectiveness of the electrically conductive textile materials. Related to electrical conductive textile products, extensively considered technical approach is use of electrical conductive filler materials in the traditional textile fabrics. Various conductive fillers are used in the currently known yarn spinning, doubling and twisting methods to make electrical conductive yarn structurescomposite yarns. Beside yarn structural properties textile surface constructional parameters of ends/cm, picks/cm, wales/cm, course/cm, number of layers, cell dimensions, rate of electrical conducting component in the fabric are reported as influential factors on the EMSE of the shielding materials (5-15). Lin and Lou (6) was used PP/stainless steel commingled yarn to make laminates for the purpose of electromagnetic shielding materials. EMSE performance of laminated materials has found in the range of 30 to 60 dB and sufficient to be used as electromagnetic shielding materials. Ueng, Cheng, (2000, 2001, 2003, 2006) (9-11) had carried out a series of intensive works about EMSE of conductive textile surfaces and textile reinforced composite plates. Blend of stainless steel/polyester fibers ring, core spun, and open end friction spun yarn were used to make woven and knitted fabrics for electromagnetic shielding applications. EMSE measurement had been carried out using a coaxial transmission set-up, in the frequency range of 300 kHz to 3 GHz. These conductive fabrics were found maybe suitable for electromagnetic shielding of home electrical and electronic appliances. In another work they used stainless steel wire-copper/kevlar and rayon open-end friction core-spun yarn to make hybrid woven fabrics. The fabrics containing stainless steel wire/staple fibers or copper wire/stainless steel staple fibers are found technically useful material (EMSE. 40 dB) for shielding home electronics. EMSE of all specimen fabrics is found to be higher in the frequency range from 1800 to 2450 MHz. Perumalraj et al (12) has studied EMSE of conductive woven fabric made using copper core yarn. They found that the conductive fabric produced from copper core yarn provides attenuation of 20–66 dB at the medium frequency range of 200–4000 MHz. Roh et al (13) introduced their study about electromagnetic interference (EMI) shielding purposed composite fabric. They have shown that the EMSE of the metal composite fabrics could be tailored by modifying the metal grid size and geometry. Perumalraj et al (12) has produced conductive textile surfaces using cotton/copper DREF 3 yarn. EMSE value of the produced conductive surfaces is measured in the frequency range of 20–18,000 MHz. They have found that increase in the number of conductive fabric layers, yarn fineness, warp density, weft density and cover factors provides increase in shielding effectiveness. With an increase in copper wire diameter, a decrease in shielding effectiveness is observed.

Shielding is defined as confining radiated energy within a specific region or prevention of radiated energy from entering into a specific region. It is mostly processed in screened or shielded room, known as Faraday cage. Shielding room is a complete enclosure with hollow interior (which may be lined with absorbing materials to give an anechoic chamber) that has no gaps or holes. (16) Body of shielding room is built using plates or sandwich panels made of conductive materials. Shielding efficiency measurement is known as quite complicated measurement method. There are several methods to measure EMSE, described by standards of IEEE Std. 299 (17) ASTM D4935 (18,19) TS EN 50147-1, 2005, (20) MIL Std. 285 (withdrawn) (21). Principle of EMSE measurement is mostly performed in two steps. Shielding efficiency is enumerated from transmission between two antennas with setting of an open door and the close door of the enclosure. The shielding efficiency (SE) is a difference of these two values (in dB unit). There are different configuration of transmitting and receiving antenna, references, positions of antenna in the enclosure, positions of some object inside the enclosure and covering material of inner walls (22). It is well known that enclosure is strongly influenced by resonances in the enclosure body. Current state of research development shows that there is lack of conventionally accepted standardized methods for measuring shielding effectiveness (4,23,24).

Main objectives of this work are to introduce an EMSE measurement enclosure and explain the EMSE behaviors of produced electrically conductive fabric specimens. EMSE measurements are carried out in the frequency range of cellular phone communication bands -900MHz and 1800MHz- in Turkey. EMSE measurement unit is specially designed with appropriate devices and equipments of antenna couple, connection lines, connectors, signal generator and spectrum analyzer. Shielding efficiency of electrical conductive textile materials changes depending on the yarn type, textile structure type, number of conductive surface layers, signal amplitude and frequency of radiation in the surrounding volume. In this work eight specimen fabrics are tested in the -special designed- EMSE measurement chamber without changing the antenna placement. EMSE of the specimen are reported for constant frequency bands (cellular phone communication bands in Turkey) and changing power of emitted EM signals in order to clarify the influence of reference signal dBm value on the EMSE of the specimen fabrics.

2. EXPERIMENTAL

2.1 EMSE Measurement Set

EMSE measurement set is a twin antenna (one transmitter and one receiver) used enclosure (Figure 1). Enclosure body is constructed using aluminum-insulation material-aluminum sandwich sheet and signal reflection prevention purposed pyramids. Aluminum box is divided into two rooms with aluminum plate having an empty window of 20cm * 20cm for specimen placement. Whole measurement unit is grounded for electrical purposes.

Specimen fabric is placed in vertical position on the frame inside the enclosure. The basic setup simulates the enclosure's performance in shielding specimen fabric against interference. Electromagnetic waves are generated by signal generator, and it is transmitted through the rod antenna to the other room of the enclosure. Signals from the signal generator are measured by the spectrum analyzer with receiver rod antenna placed in the other room. Attenuation of electromagnetic waves from the transmitter antenna to the receiver antenna through specimen surface gives the shielding performance of the related electromagnetic wave frequency. Miniwing GSM & S dual band antennas are used designed for the GSM dual bands of 900/1800 MHz and AMPS/PCS dual band of 800/1900 MHz. Appropriate positioning of rod antennas, enables the acquisition of relevant shielding-effectiveness data.

Calibration of the EMSE measurement system is carried out without the specimen fabric. It should be mentioned that EMSE measurement system is not subject to any certification in this area. And results are accepted reliable and comparable in the frame of defined study, since all specimens are tested in the same test set up and geometry.

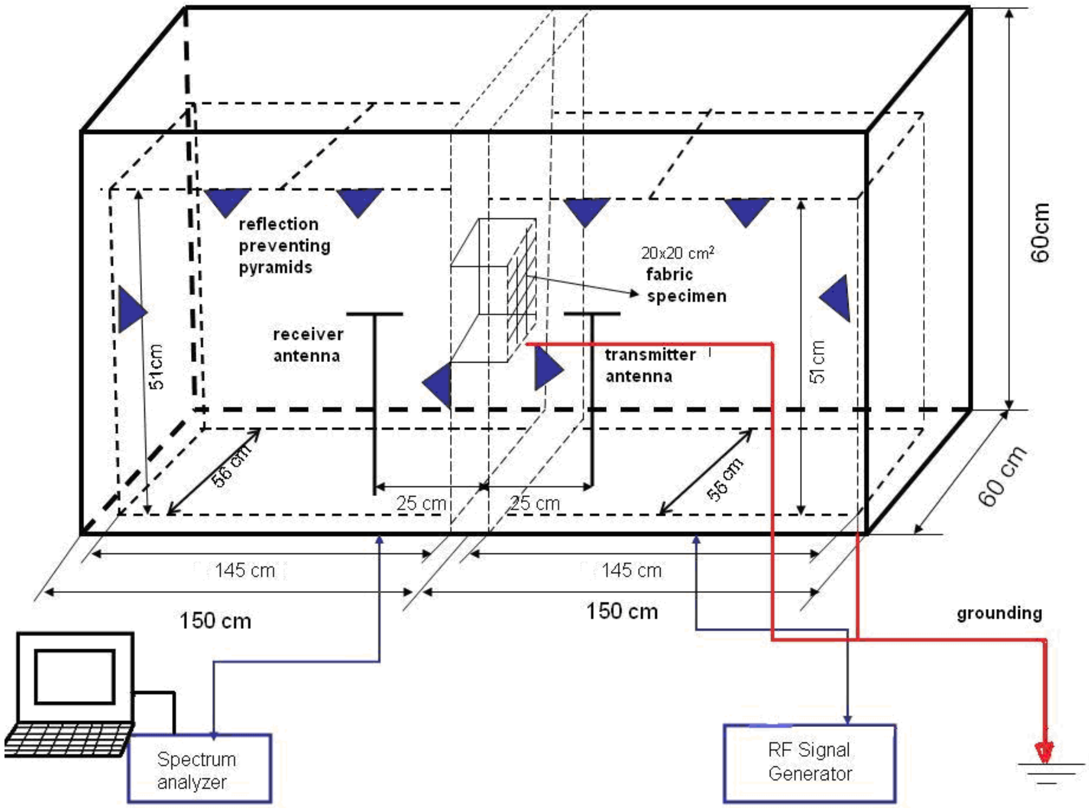

Figure 1. EMSE measurement set

Shielding efficiency (SE) measurement is explained under the definitions of screening effectiveness or insertion loss. Concerning electromagnetic screening property the basic characteristic of the conductive fabric is its attenuation. Attenuation of the electromagnetic energy is a result of the reflection, absorption and multi-reflection losses caused by a specific material inserted between the source and the receptor of the radiated electromagnetic energy. (12,19,25)

Screening effectiveness is defined as the ratio of electromagnetic field strength measured without (E_0) and with (E_1) the specimen material between the electromagnetic fields source and the receptor.

SE = E_0 / E_1....................................(1)

or, when expressed in decibels,

SE(dB) = 20log E_0 / E_1......................(2)

This depends on the distance between the source and receptor of electromagnetic energy. In the far field zone, it characterizes the attenuation of the electromagnetic wave. The measurement carried out in the near field zone characterizes the attenuation effectiveness for the electric or magnetic field component only.

Insertion loss (A) is a measure of the losses (or attenuation) of a transmitted signal caused by the tested material being inserted into the measuring channel where U_0 is channel output voltage without the tested material and U_1 is the same voltage with the specimen material.

A = U_0 / U_1.......................................(3)

or when expressed in decibels,

A(dB) = 20log(U_0 / U_1) .... (4)

2.2. Electrically Conductive Textile Surfaces

Conductive yarn production is processed in a commercially available doubling and twisting machine. Cotton yarns are doubled and twisted with silver/cotton (10/90) staple yarn and copper wires with diameter of 0,05 mm and 0.1 mm. using the listed materials four types of yarn produced. Specific resistance of conductive materials is given in the Table 1.

Table 1. Specific resistance of conductive materials

Conductive materials	Specific resistance, Ωm
Copper wire, 0,05 mm	$1{,}70.10^{-8}$
Copper wire, 0,1 mm	$1{,}70.10^{-8}$
Cotton/silver yarn, 90/10	$1{,}59.10^{-8}$

Produced conductive yarns are used for production of plain woven specimens and single jersey knitted specimens. Specifications of woven and knitted surfaces are summarized in the Table 2 and Table 3 respectively (26).

2.3 Frequency Change

Experimental measurements were carried out in the frequency band of 860 MHz to 960 MHz for GSM frequency of 900 MHz and 1750 MHz to 1850 MHz for GSM frequency of 1800MHz to understand the EMSE behaviors of the specimen fabrics in the constant signal power of 20watts.

2.4 Number of specimen layers

To understand the effect of number of specimen layers on the EMSE of the conductive textile surfaces all eight different specimens are tested as single layer and double layers of the 0° and 90° specimen placement.

2.5 Reference value of generated signal

EMSE of the conductive textile surfaces was also measured for the above defined frequency bands of 860 MHz to 960 MHz and 1750 MHz to 1850 MHz with the step of 10MHz with

Table 2. Woven fabric properties

Plain woven sample code	Warp Yarn	Weft yarn		ends/cm	picks/cm	Weight (g/m²)
		Yarn Component (% in weight)	Nm			
W1	100 % Cotton, Nm 12	Cotton/Cu(89/11)	7	11	9	237
W2		Cotton/Cu(62/38)	5	12	8	254
W3		Cotton/Cu/Ag(78/20/2)	10	11	10	205
W4		Cotton/Cu/Ag(50/48/2)	7	11	10	259

Table 3. Knitted fabric properties

Single jersey sample code	Yarn Component (% in weight)	Nm	Wale density (1/cm)	Course density (1/cm)	Weight (g/m²)
K1	Cotton/Cu(89/11)	7	5	16	362
K2	Cotton/Cu(62/38)	5	4	22	469
K3	Cotton/Cu/Ag(78/20/2)	10	5	12	222
K4	Cotton/Cu/Ag(50/48/2)	7	4	24	420

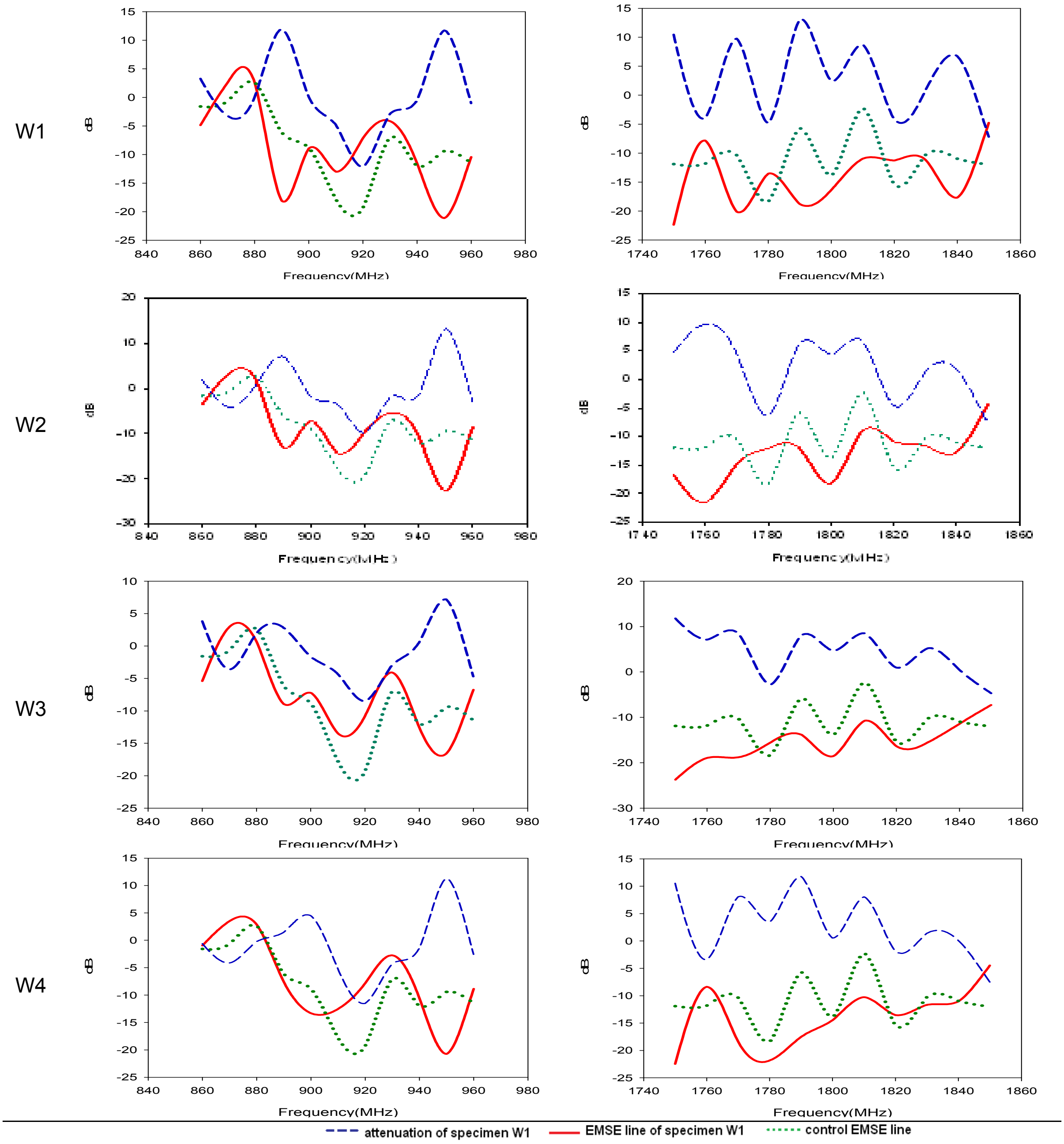

Figure 2. EMSE (dB) versus frequency for woven specimens (at 20dBm)

different reference values of 5, 10, 15, and 20 dBm. (dBm is an abbreviation for the power ratio in decibels-dB). Each specimen is appropriately mounted into the frame and EMSE measurement is completed with the step of 10MHz for 5, 10, 15, and 20 dBm reference valued EM signals.

3. RESULT AND DISCUSSION

EMSE measurement test results are used to draw line charts between frequency bands of 860 MHz to 960 MHz and 1750 MHz to 1850 MHz with the step of 10MHz. Charts are defined as frequency in the x-axis and shielding effectiveness in the y-axis.

3.1 EMSE measurement results of single layer specimen measurement results

Each eight specimen fabric is tested for their EMSE values at the frequency range of 860-960MHz and 1850-1950 MHz. In the graphs of Figure 2 and Figure 3 attenuation of the specimens are drawn with non continuous line. Attenuations of the specimens is calculated by subtraction of specimen EMSE value from the control EMSE value. Control EMSE value is measurement of the attenuation between antennas without any fabric or interfacing material in the sample nipping frame of the measurement chamber.

Specimen fabric attenuation (dB) = EMSE of control measurement – EMSE of specimen ……………………………....(5)

On the graphs of Figure 2 and Figure 3, EMSE value of specimen and EMSE value of control measurements are drawn using continue line and dotted line respectly.

It is found that EMSE value for the frequency ranges of 860MHz -960MHz and 1750 MHz - 1850 MHz are not the same level. For woven specimens at the 860MHz -960MHz frequency range the highest level of average EMSE value is found belong to specimen W1, which has the lowest level (finest conductive fiber) of conductive fiber content. For 1750 MHz - 1850 MHz frequency range level of average EMSE value is found similar among all three woven specimen except specimen W2. Average EMSE level of the specimen is found lower then the other three woven specimens (Figure 2).

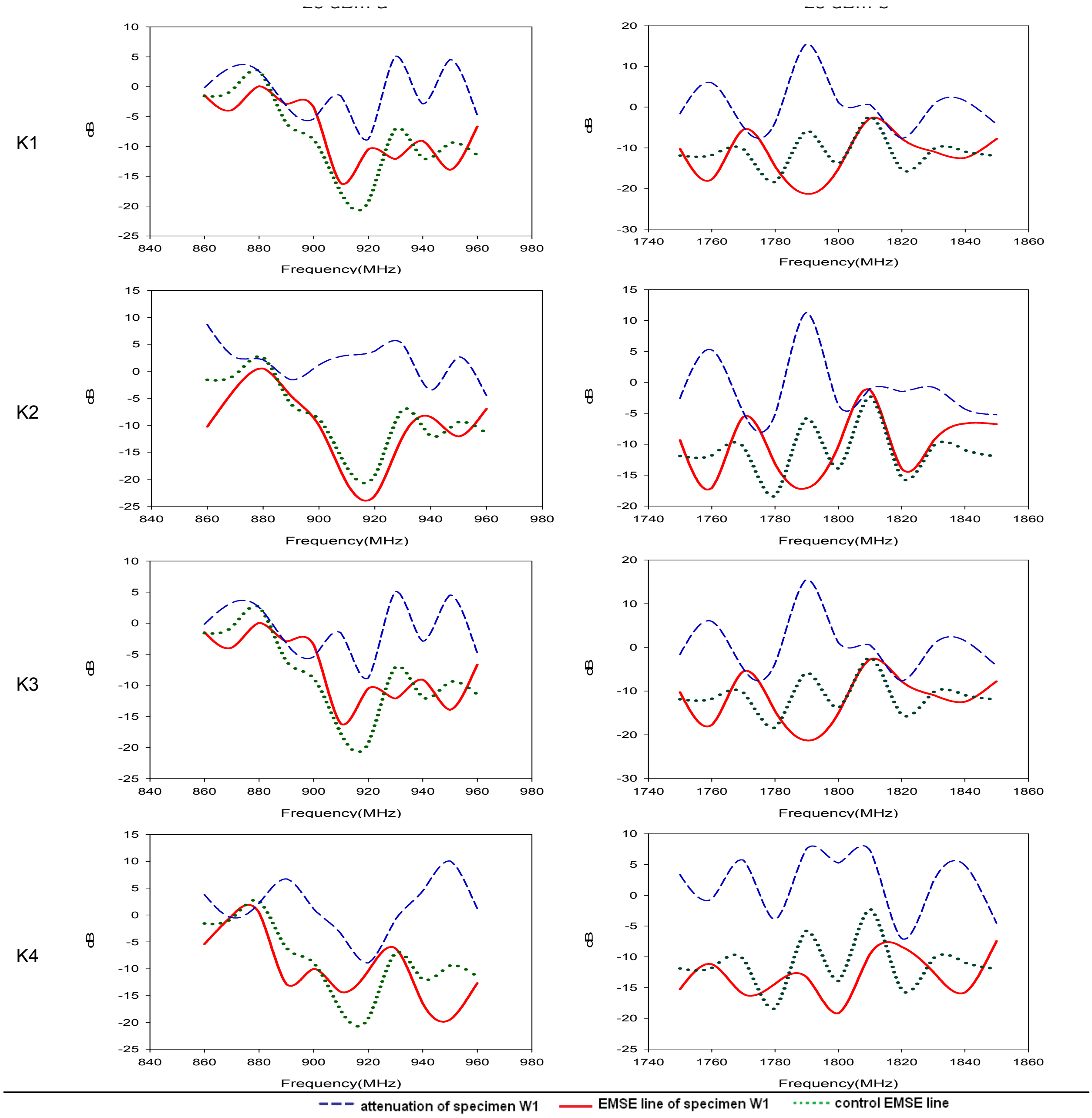

Figure 3. EMSE (dB) versus frequency for knitted specimen,(20dBm)

For knitted specimens at the 860MHz - 960MHz and 1750 MHz - 1850 MHz frequency ranges the level of average EMSE value is found similar among all four knitted specimens (Figure 3). Average attenuation value of the all knitted specimens is found lower then the woven specimens for each two frequency ranges. The best value for the targeted GSM frequencies of 900MHz and 1800MHz are found belongs to W4 and K3 respectively. It is also observed that the highest attenuation is obtained at 1790 MHz with specimen K1.

From view of the yarn thicknesses, it is seen that specimens processed using finer yarns has better attenuation, as it is mentioned by Perumalraj. Yarn fineness can also be explained with the conductive fiber content of the yarn. Less conductive fiber (finer conductive wire) contending yarns are found generally providing better fabric attenuation on the electromagnetic interference.

3.2 EMSE of the double layered specimens

EMSE values of single layer and double layers of specimens are drawn on the same graph in order to show the difference between them. During the measurement second layer of the specimen is placed into the frame with 90° clockwise rotation according to the first layer of specimen placement. All eight woven and knitted specimens are considered for effect of number of layers on the EMSE (There are 90° displacement between first and second layers of warp direction for woven specimen and course direction for knitted specimens). EMSE results of single and double layered measurements are drawn in the same graph for comparison purposes. In

Figure 4 results of woven specimens and in Figure 5 results of knitted specimens are shown. It was observed that EMSE of the single layer and double layers of specimens are not the same.

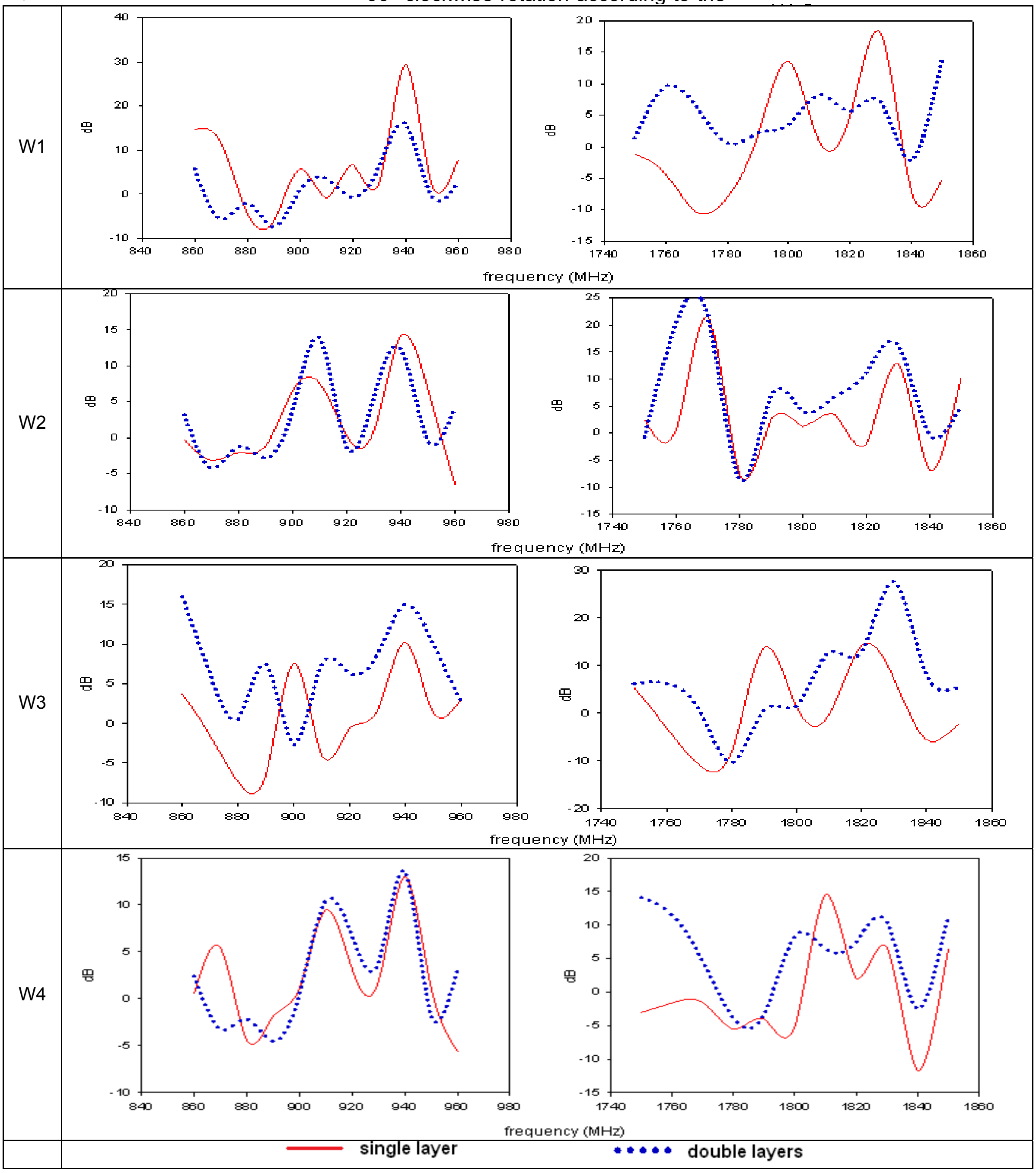

Figure 4. Effect of number of specimen layers on the EMSE, (woven specimens)

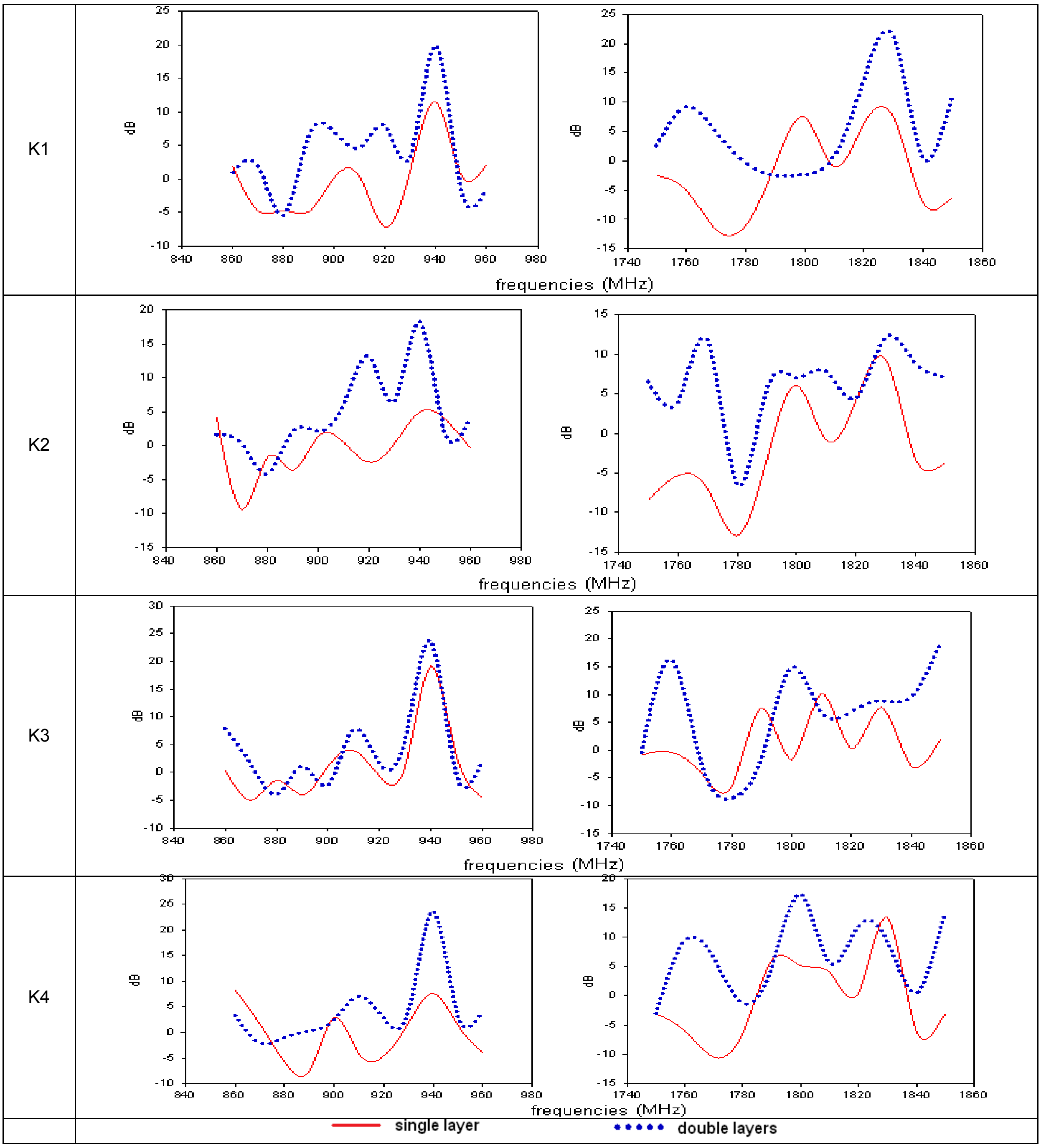

Figure 5. Effect of number of specimen layers on the EMSE, (knitted specimens)

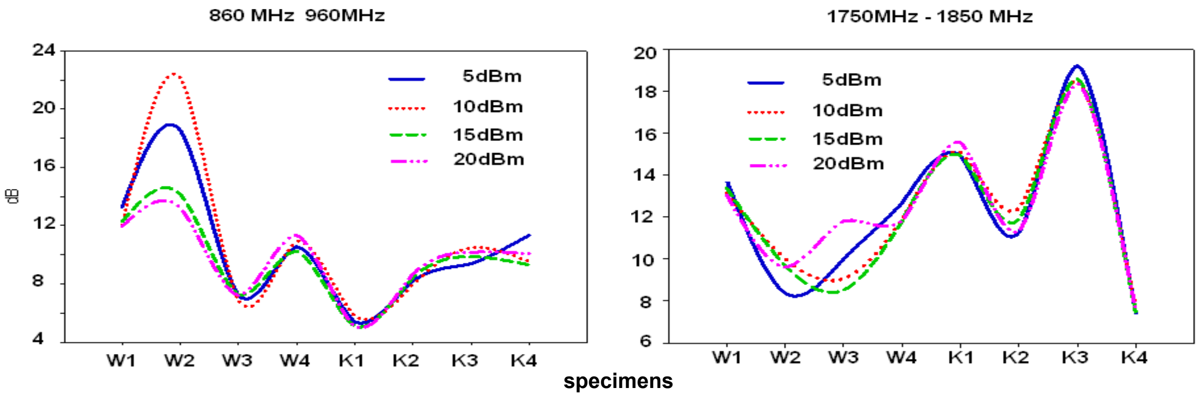

Figure 6. Effect of reference signal (dBm) value on the EMSE of the specimens

For frequency ranges of 860MHz - 960MHz, double layered specimens of W1, W2 and W4 are found resulting lower EMSE value comparing single layered EMSE values. Specimen W3 which has both copper and silver components is found giving higher EMSE value with double layered specimen comparing single layered measurement. For frequency ranges of 1750 MHz - 1850 MHz, EMSE results of double layered specimens are found higher than the single layered specimens of all four woven specimen. The highest EMSE is obtained with the double layered specimen of W3 for this frequency range.

For frequency ranges of 860MHz - 960MHz, double layered specimens of K2, K3 and K4 are found resulting higher EMSE value comparing single layered EMSE values. Specimen K3 which has both copper and silver components is found giving lower EMSE value with double layered specimen comparing single layered measurement. This behavior is completely opposite to the behaviors of woven specimens. It was found that only specimen W3 had the better EMSE with the double layers of specimen. For frequency ranges of 1750 MHz - 1850 MHz, EMSE results of double layered specimens are found generally higher than the single layered specimens of all four woven specimen. The highest EMSE is obtained with the double layered specimen of W3 for this frequency range.

Hence the double layered specimens have found giving better EMSE for both frequency ranges as it is was concluded by Perumalraj et al. (12)

3.3 Reference value of generated signal

EMSE measurement results of the each specimen for each signal reference values of 5, 10, 15 and 20 dBm are drawn in the same graphs. (Figure 6) EMSE of woven and knitted specimens for the four levels of reference values are found quite parallel to each other at the frequency ranges of 860-960 MHz and 1750-1850MHz.

Graph for the frequency range of 860MHz -960MHz has shown that the highest EMSE is provided by specimen W2 for all four levels of reference value. 10dBm reference value is found giving the highest EMSE, about 22dB, for the specimen W2. Frequency range of 1750-1850 MHz, the highest EMSE (about 19dB) is found provided by the specimen K3 of 5dBm reference level.

Comparing the two frequency ranges, it is seen that woven specimens have found giving better EMSE than the knitted specimens at the frequency range of 860MHz -960MHz, while it is vice versa for frequency range of 1750-1850 MHz.

4. CONCLUSION

This paper deals with the introduction of a unique EMSE measurement set and EMSE value comparison of produced electrically conductive textile surfaces. Reliability of the specially designed and constructed EMSE measurement set is examined with the specifically produced conductive woven and knitted surfaces. Components of conductive yarns are cotton, copper wire of two different thickness, and cotton/silver blended staple yarn. Doubled and twisted yarns are used to make eight different characters of conductive fabric specimens. EMSE measurements of the specimens are conducted in the range of 860 MHz to 960 MHz and 1750 MHz to 1850 MHz at four different reference dBm levels of generated signals. As result of comprehensive EMSE measurements and evaluation of the gathered measurements following conclusions can be drawn.

- Fabric constructional parameters of yarn component, such as thickness of copper wire, influence the EMSE of the surface, as it is mentioned in the literature. Fabrics produced using thin copper wire containing yarn has higher EMSE comparing those specimens produced using thicker copper wire yarns.
- EMSE behaviors of the specimens differ for different frequency ranges. It should be clarified which fabric should be used for which frequency ranges.
- Number of layers has influence on the EMSE of the specimens. In general double layer of specimen has higher EMSE then the single layer of specimens.
- Attenuation of specimens can be different for different reference levels of generated signals.
- EMSE level of produced specimen fabrics are found maintaining average of 10dB shielding, which means more than 69 % of shielding for the range of 860 MHz to 960 MHz and 1750 MHz to 1850 MHz, capable for using simple screening purposed products.
- The constructed EMSE measurement chamber can only be reliable in the circumference of the experimental work.
- Design, construction and improvement of the EMSE measurement set is still continue for further experimental studies.

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