(REFEREED RESEARCH)

THE EFFECTS OF WEAVE AND CONDUCTIVE YARN DENSITY ON THE ELECTROMAGNETIC SHIELDING EFFECTIVENESS OF CELLULAR WOVEN FABRICS

ÖRGÜNÜN VE İLETKEN ATKI SIKLIĞININ HÜCRELİ ÖRGÜLÜ KUMAŞLARIN ELETROMANYETİK KALKANLAMA ETKİNLİĞİNE ETKİSİ

Hakan ÖZDEMİR[1*], **Ahmet ÖZKURT**[2]

[1] *Dokuz Eylül University, Department of Textile Engineering, İzmir, Turkey*
[2] *Dokuz Eylül University, Department of Electrical and Electronics Engineering, İzmir, Turkey*

Received: 18.05.2012 Accepted: 26.11.2012

ABSTRACT

In this study, the electromagnetic shielding effectiveness of twill and some cellular woven conductive fabrics woven with stainless steel core yarns at different weft densities has been measured by free space measurement technique at horizontal polarization of the antenna. It is observed that woven fabric samples, which have been positioned so that the weft yarns have been parallel to the antenna polarization, have shown good electromagnetic shielding performances in high frequency band, namely industrial, scientific and medical band. And also, when the steel core weft yarn density has been increased, the decrease in the electromagnetic shielding effectiveness of fabric samples, which have been positioned the same way, is observed. Conversely, the electromagnetic shielding effectiveness of fabric samples, which have been positioned so that the weft yarns have been vertical to the antenna polarization, has increased in agreement with the effective surface conductivity.

Key Words: Cellular woven fabrics, Twill weave, Electromagnetic shielding effectiveness, Conductive core yarns.

ÖZET

Bu çalışmada, paslanmaz çelikten özlü iplikler ile farklı atkı sıklıklarında dokunan iletken dimi ve hücreli örgülü kumaşların elektromanyetik kalkanlama etkinliği “free space measurement” tekniği ile yatay anten polarizasyonunda ölçülmüştür. Atkı iplikleri anten polarizasyonuna paralel olacak şekilde yerleştirilen dokuma kumaş numunelerinin endüstriyel, bilimsel ve tıbbi band olan yüksek frekans bandında iyi elektromanyetik kalkanlama performansı gösterdiği gözlenmiştir. Ayrıca çelik özlü atkı ipliklerin sıklığı artırıldığında aynı konumda yerleştirilen kumaş numunelerinin elektromanyetik kalkanlama etkinliğinin arttığı gözlenmiştir. Atkı iplikleri anten polarizasyonuna dik olacak biçimde yerleştirilen kumaş numunelerinin elektromanyetik kalkanlama etkinliği ise efektif yüzey iletkenliğinin artmasına bağlı olarak artış göstermiştir.

Anahtar Kelimeler: Hücreli örgülü dokuma kumaşlar, Dimi örgü, Elektromanyetik kalkanlama etkinliği, İletken özlü iplikler.

1. INTRODUCTION

Wireless devices, which are implementations of electromagnetic (EM) fields, have been common in recent years. Wi-Fi, wireless telephones, baby monitors and electronic security systems, that are some of the newer applications, use industrial, scientific and medical (ISM) band of 2400 MHz. In this regard, EM fields have possible effects on human health. So, it is important to create public concern about the safety of these EM fields (1-3).

Conductive textile surfaces, that are lightweight, flexible and non-expensive, have been manufactured for various shielding applications in the electrical and electronic industries, especially for electronic housing materials to shield and protect against EM influences, instead of electrically conductive metal sheet or wire mesh shielding materials: Perumalraj et al. selected copper as a conductive filler to produce copper core yarns with cotton fibre as sheath material to make plain and twill woven fabrics, and measured the electromagnetic shielding effectiveness of these fabrics in the frequency range of 20–18,000 MHz with coaxial transmission equipment. They observed

---

[*] **Corresponding Author:** Hakan Özdemir, h.ozdemir@deu.edu.tr, Tel:+90 232 412 77 36, Fax:+90 232 301 77 50

an increase in shielding effectiveness with an increase in the number of conductive fabric layers, finer yarn count, warp density, weft density, cover factors and a decrease in shielding effectiveness with copper wire diameter (4). Roh et al. used metal composite yarns, which were used in the construction of plain woven metal composite fabrics, were produced with commercially available metal filaments and polyester (PET) filaments. Plane-wave shielding properties of the composite fabrics were measured between 30-1500 MHz using the coaxial transmission line method. They observed that while the overall EM shielding effectiveness increased with metal content, different frequency dependence related to the aspect ratio of metal grid structure (5). Su and Chern selected stainless steel as the conductive filler to produce stainless steel hybrid yams to make plain and twill woven fabrics. The electromagnetic shielding effectiveness (EMSE) of these fabrics was measured by coaxial transmission equipment in the frequencies range from 9 KHz to 3 GHz. The experimental results showed that denser structures of stainless steel fabrics had a higher EMSE. The fabric made from the core yarns had a higher EMSE than that made from the cover yams and the plied yams. In addition, the EMSE of the fabric made from different genera of stainless steel had an optimum EMSE value at different measured frequencies. Analyses of the weave types reveal that the plain weave had a higher EMSE than twill weaves (6). Cheng et al. produced twill copper fabrics (3/1) and obtained their electromagnetic shielding effectiveness using a coaxial transmission line holder in the frequency range of 144–3000 MHz. They observed that with an increase in the number of conductive fabric layers, warp density, and weft density, an increase in shielding effectiveness occurred, whereas with an increase in wire diameter, a decrease in shielding effectiveness occurred (7). Chen et al. measured plane-wave shielding properties of 2/2 twill woven fabrics and laminated composites at 30–1500 MHz using the coaxial transmission-line method. Copper wire and polyamide filaments used as core yarn were wrapped with polypropylene filaments. They found that the shielding effectiveness of a single layer was barely satisfactory for general applications and the multi-layer fabrics provide adequate plane-wave shielding effectiveness (20–55 dB) when the wave was normally incident and laminate thickness was > 1.6 mm (8). Duran et al. investigated the electromagnetic shielding effectiveness of 3/1 twill woven fabrics with electromagnetic competence test device in 5 different frequencies; 200MHz, 400MHz, 600MHz, 800MHz and 1GHz. While 100% cotton yarns was used as warp yarns, two different weft yarns, copper/cotton core yarns and 100% cotton yarns were used in two different weft densities. It was observed that fabrics woven with cupper/cotton core yarns had considerably higher electromagnetic shielding effectiveness values than the fabrics woven with 100% cotton wefts. The results showed that weft density had only a slight effect on the electromagnetic shielding property of the fabric produced with core yarns, whereas it did not has any effect on the electromagnetic shielding property of 100% cotton fabrics (9). Varnaıtė et al. wove plain fabrics with only PES warps. Conductive yarns were inserted in the fabrics in three different variants: 1) 25 picks PES + 1 pick PES/INOX; 2) 49 picks PES + 1 pick PES/INOX; 3) 71 picks PES + 1 pick PES/INOX. The fabric with only the PES picks was used as control fabric. Half decay time of electric field strength and shielding factor values were determined for the fabrics. It was found that the bigger quantity of conductive weft yarns shortened the half decay time distinctly and increased values of the shielding factor. And also shorter half decay time resulted in increase of shielding factor (10). Sandrolini and Reggiani tested the five electrically conductive woven and non-woven fabrics by circular coaxial transmission line holder in the frequency range 300 kHz-3.6 GHz. The results showed that a low surface resistivity value was a requirement for a higher shielding effectiveness especially for woven materials. The nickel amount used for the metallization did not has such a strong relation with the SE, as the geometry of the warp and weft of the textile played an important role in the shielding performance, too (11). Palamutçu et al. developed an electromagnetic shielding efficiency measurement set and tested its reliability within the circumstance of the produced electrical conductive plain knitted and plain woven fabrics. In these fabrics, Co/Cu and Co/Cu/Ag yarns with different ratios were used. For woven specimens at the 860MHz-960MHz frequency range the highest level of average EMSE value was found belong to the specimen, which had the lowest level (finest conductive fiber) of conductive fiber content. For knitted specimens at the 860MHz -960MHz and 1750 MHz - 1850 MHz frequency ranged the level of average EMSE value was found similar among all four knitted specimens. Average attenuation value of the all knitted specimens was found lower then the woven specimens for each two frequency ranges. It was also observed that the highest attenuation was obtained at 1790 MHz with the woven specimen, which had the finest conductive fiber (12). Örtlek et al. investigated electromagnetic shielding and comfort properties of single jersey fabrics produced from hybrid yarns containing metal wire. For this purpose, nine different hybrid yarns were produced from the combination of cotton yarns (Ne 50, Ne 60, and Ne 70) and stainless steel (SS) wires (18 micron, 35 micron, and 50 micron) by means of hollow spindle covering system. Hybrid yarns and 100 % cotton yarns used in the production of hybrid yarns were used to produce knitted fabric on the sample circular knitting machine. They found that fabrics including SS wire showed higher SE than fabrics without metal wires and the SE values of samples had decreasing tendency with increased frequency (13). Joyner et al. examined protective suit consisting of an overall with an integral hood, gloves, and oversocks, constructed of an electrically conductive fabric, theoretically and experimentally for electromagnetic shielding effectiveness (SE) at radiofrequencies (RF) in the range from 200 kHz to 4 GHz. They found that at microwave frequencies, the fabrics were certainly capable of providing SE of greater than 20 dB. However, a suit might have a lower SE due to openings and zippers. In order to achieve 20-dB SE to low-impedance low frequency (<30 MHz) fields the fabrics would have to be considerably more conductive (14). Więckowski and Janukiewicz discussed about the scope of application of the measurement methods of EMSE of textiles, their limitations and the possibilities for comparisons of the results. They noted that there is currently no effective method for comparing the results of shielding effectiveness measurement obtained based on MIL-STD 285 & IEEE-STD-299 for comparison to ASTM D4935 (15).

Cellular weaves are a group of weaves, which are produced by placing weft and warp yarn floats end to end, in order to form cellular structures, which are indenting and protruding, in the fabric surface. Cellular weaves, which are derived from sateen weaves, are also called sponge weaves, because of their soft characteristics. They can be derived by adding bindings in order to form diamond–shape around the basic bindings of sateen weave (16).

The studies in the literature focused on electromagnetic shielding effectiveness of 3/1 twill and cellular woven fabrics in low and medium frequency bands. The aim of the study is to investigate the EM shielding effectiveness of cellular woven fabrics and to compare those with twill woven fabric, with different steel core yarn density.

2. MATERIAL AND METHOD

2.1. Material

In this research, 15 types of cellular woven fabric samples and five types of 3/1 twill woven fabrics (35×35 cm) have been produced in Weaving Workshop of in-house by CCI automatic sample rapier loom (Evergreen 8900, Taiwan). 100% polyester and stainless steel core yarns with cotton fibre as sheath material have been used. The specifications of yarns are given in Table 1. Weave patterns are shown in Figure 1. The conductive yarns have been inserted in certain intervals to obtain different open grid structures of conductive yarn within the fabrics, which resulted in different yarn densities. The characteristics of the conductive fabrics are shown in Table 2. The open grid structures of the conductive yarns are represented in Figure 2. Warp and weft settings of 15 kinds of cellular woven fabric samples on the loom have been 25 cm^{-1}, which have been equal to 3/1 twill weave settings, which has been calculated for the loom state, in order to compare these fabric samples with twill woven fabric sample. No finishing process has been applied on the fabric samples.

Fabric samples have been coded according to their weave pattern, warp and weft densities as in Table 2. The letter and number in each fabric code represent weave patterns and weft yarn arrangement respectively.

Table 1. The specifications of yarns

Material	Yarn count (dtex)	Diameter of wire (mm)	Conductor resistance (Ωmm^2/m)
Polyester yarn	300	-	-
SS/Co core yarn	455	0.05	0.62

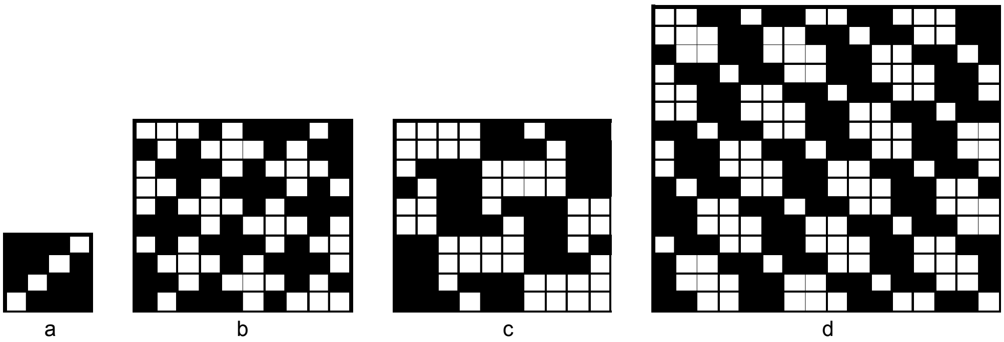

Figure 1. Weave patterns used in experimental: a- 3/1 twill; b- Cellular weave 1; c- Cellular weave 2; d- Cellular weave 3

Table 2. The specifications of conductive fabrics

Fabric code	Weave pattern	Warp density on the reed	Weft density on the loom	Yarn type*	Composition (warp × weft)
A1	3/1 Twill	26	26	CP	1C1P × C
A2				CP 1:1	1C1P × 1C1P
A3				CP 1:3	1C1P × 1C3P
A4				CP 1:7	1C1P × 1C7P
A5				CP 1:15	1C1P × 1C15P
B1	Cellular weave 1	26	26	CP	1C1P × C
B2				CP 1:1	1C1P × 1C1P
B3				CP 1:3	1C1P × 1C3P
B4				CP 1:7	1C1P × 1C7P
B5				CP 1:15	1C1P × 1C15P
C1	Cellular weave 2	26	26	CP	1C1P × C
C2				CP 1:1	1C1P × 1C1P
C3				CP 1:3	1C1P × 1C3P
C4				CP 1:7	1C1P × 1C7P
C5				CP 1:15	1C1P × 1C15P
D1	Cellular weave 3	26	26	CP	1C1P × C
D2				CP 1:1	1C1P × 1C1P
D3				CP 1:3	1C1P × 1C3P
D4				CP 1:7	1C1P × 1C7P
D5				CP 1:15	1C1P × 1C15P

*C represents stainless steel/cotton core yarn, P represents polyester yarn

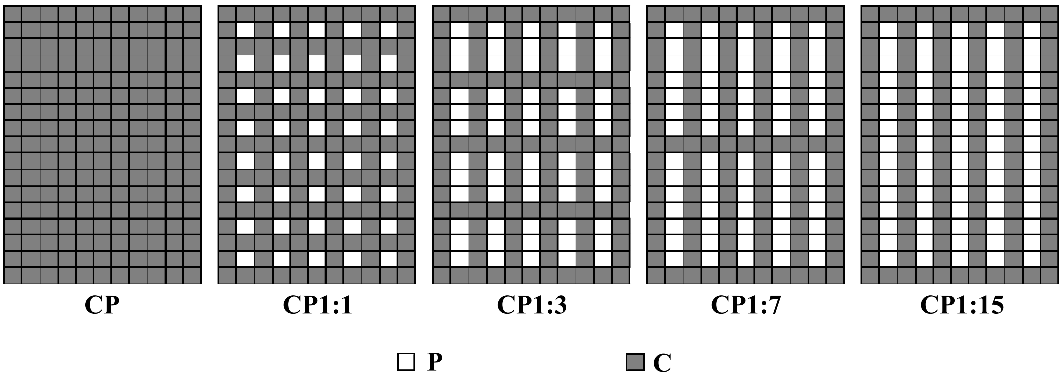

Figure 2. Schematic diagram of open-grid structures formed in the woven fabrics (gray squares: conductive core yarns; white squares: polyester yarns)

2.2. Method

Shielding is a term that explains the protection from the unwanted signals by using any material and method which decrease the signal penetration in the media interested. In shielding methodology, the signal strength in the media depends on several parameters related to material properties such as electric and magnetic behavior, conductance on the surface and in the volume, material thickness, and of course system material can be seen in Figure 3, where: $w = 2\pi f$ Pulsation, ε, ε_0 – Dielectric permeability, μ, μ_0– Magnetic permeability, γ, γ_0 – Propagation constants, Z, Z_0– Characteristic impedance of the medium, σ – Electrical conductivity, d – Thickness of the shield (15). In shielding methodology, the signal strength in the media depends on several parameters related to material properties such as electric and magnetic behavior, conductance on the surface and in the volume, material thickness, and system structure. The SE term explains the level of prevention. Equation (1) gives a general definition of shielding efficiency (SE) (17):

$$SE_P = 10.\log_{10} \cdot \frac{\text{incident power density}}{\text{transmitted power density}}$$

$$= 10.\log \frac{P_I}{P_T} \quad (1)$$

The two power densities in this ratio are the measured powers before and after the shield are placed, respectively.

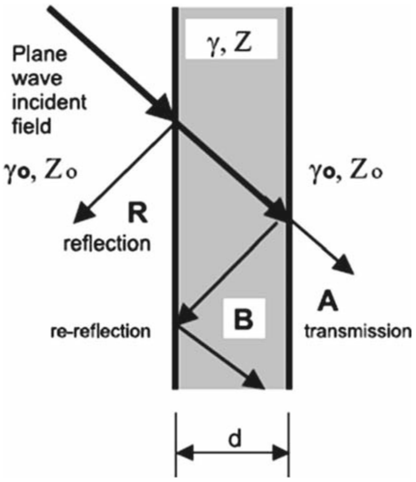

Figure 3. Wave transmission on a thin layer of media (15)

In this study, free space measurement technique has been used in order to determine SE of woven fabrics. Fundamental measurement method is based on the signal attenuation on two sides of woven fabric material located on far field zones of transmitter and receiver antennas. Transmitter antenna has horizontal polarization. Woven fabrics behave as a reflector, absorber, and attenuator on incident field. The ratio of total amount of transmitted signal strength over total incident signal strength determines the SE term related to material properties given above. The measurement set-up and the practical measurement set-up are shown in Figure 4 and 5. A spectrum analyzer, Anritsu MS2711D (Anritsu, Morgan Hill, CA, USA) with the option of transmission measurement has been used for the tests. In transmission measurement option, reference level without shielding material under test is taken automatically with normalization process and the signal level with the material is compared in logarithmic scale in terms of RF power.

In other words, initially, the reference signal has been collected without the shielding material at all frequencies. Afterwards, the woven fabrics have been attached on the foam layer which has been placed between receiver and transmitter equipments. Finally, the signals obtained from both states have been compared. Each fabric sample has been measured two times; the fabric sample has been positioned in the manner that the warp yarns have been firstly vertical to the antenna polarization, in a word vertical measurement, secondly parallel to the antenna polarization, in a word horizontal measurement. The measurements have been realized within a band of 800–3000 MHz. In this spectrum, GSM 900, GSM 1800, several industrial, scientific and medical (ISM) bands which can be used for personal purposes in limited power levels such as IEEE811.1 bg band have been available. Conductive woven fabrics have been investigated for attenuation levels and the frequencies in a wide band.

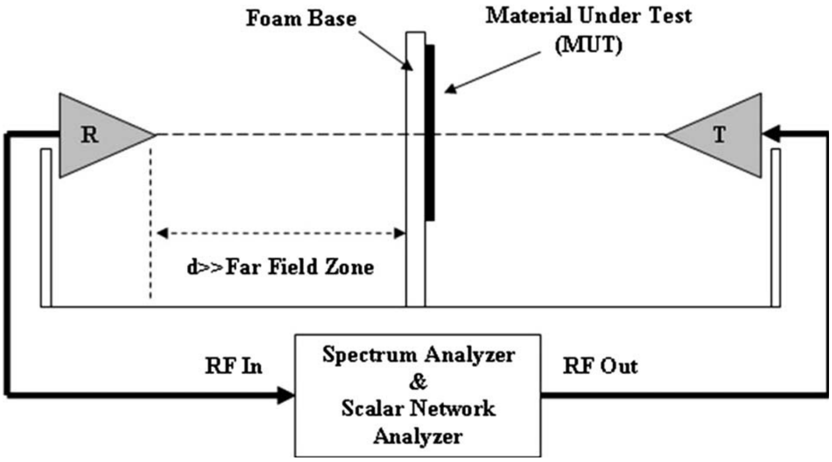

Figure 4. The measurement set-up (18)

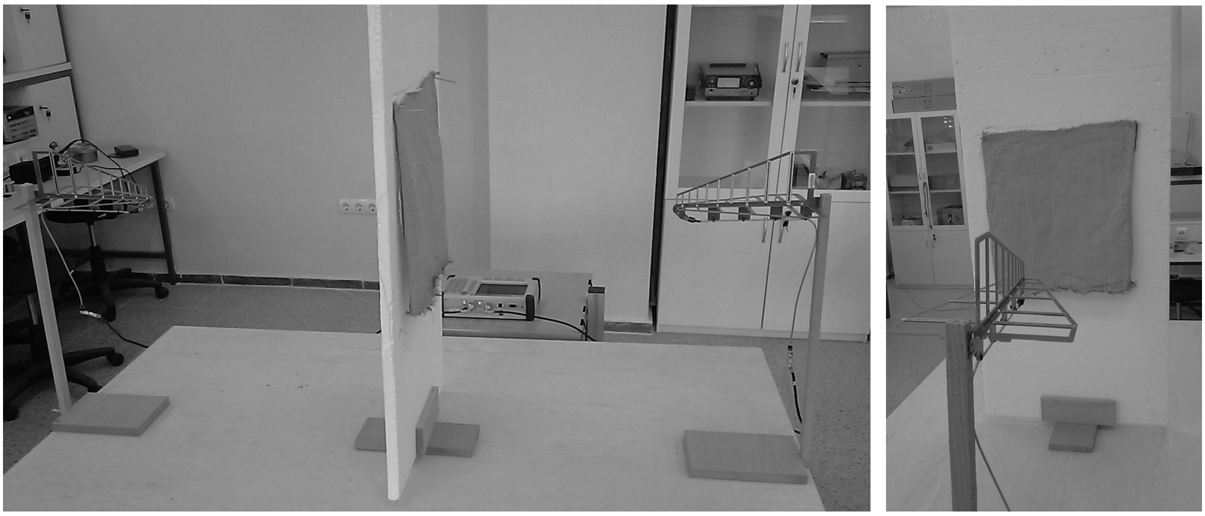

Figure 5. Practical measurement set-up

3. RESULTS AND DISCUSSION

The EMSE results of the fabric samples woven on automatic sample loom are shown in Figure 6–13. In consideration of the effect of weave pattern, it is seen in Figure 6 and 7 that while the fabric sample B1 woven with wefts of stainless steel core yarns has shown the best EMSE performance at the frequency of 2400 MHz for vertical measurement, 3/1 twill woven fabric sample with same weft arrangement has the lowest EMSE values in high frequency band, which is from 2000 MHz to 3000 MHz. There have been no significant differences between the fabric samples woven with wefts of steel core yarns for horizontal measurements.

The fabric sample C2 woven with CP 1:1 weft arrangement has the highest EMSE values in all frequency band; it has been 5 dB higher than other fabric samples with same weft arrangements in low and medium frequency band, and also 10 dB higher than other samples in high frequency band for vertical measurements as shown in Figure 8c, 9c, 10c and 11c. 3/1 twill woven fabric sample has lower EMSE values than cellular woven fabric samples in high frequency band for vertical measurements. The EMSE of fabric samples woven with CP 1:1 weft arrangement have been low (<10 dB) in low and medium frequency band, meanwhile the average EMSE of these have been 10 dB in high frequency band for horizontal measurements as presented in Figure 8d-11d.

It is observed in Figure 8e-11e that fabric samples woven with CP 1:3 weft arrangements have shown good EMSE performances and fabric samples C3 and B3 have higher EMSE values than other fabric samples with same weft arrangement for vertical measurements. However, the EMSE of fabric samples woven with CP 1:3 weft arrangements have been low especially in low frequency band for horizontal measurements as seen in Figure 8f-11f. Whereas in high frequency band, the EMSE of 3/1 twill woven fabric samples woven with C, CP 1:1 and CP 1:3 weft arrangements have been lower than cellular woven fabric samples for vertical measurements, the EMSE of those woven with CP 1:3 and CP 1:15 weft arrangements have been generally higher than cellular woven fabric samples for horizontal measurements.

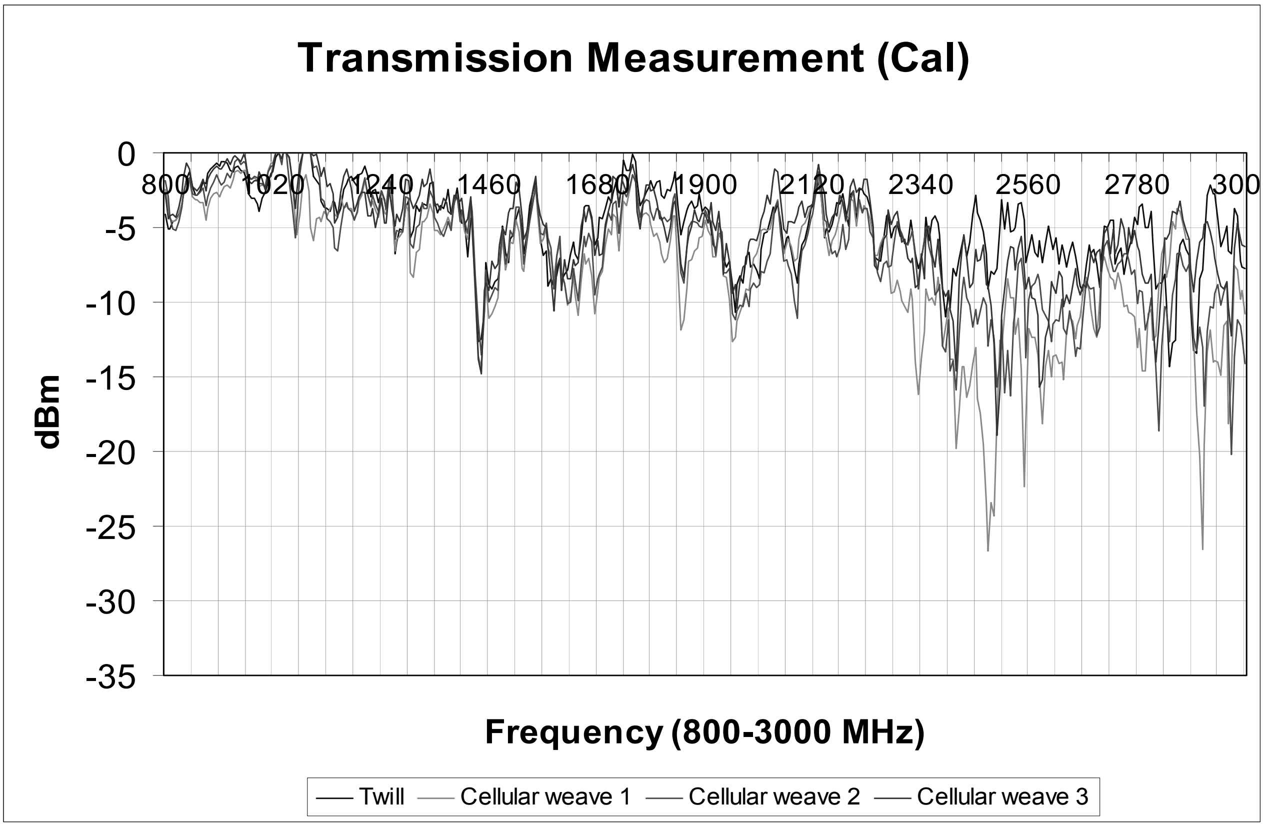

Figure 6. The EMSE of fabric samples woven with C weft arrangement for vertical measurements

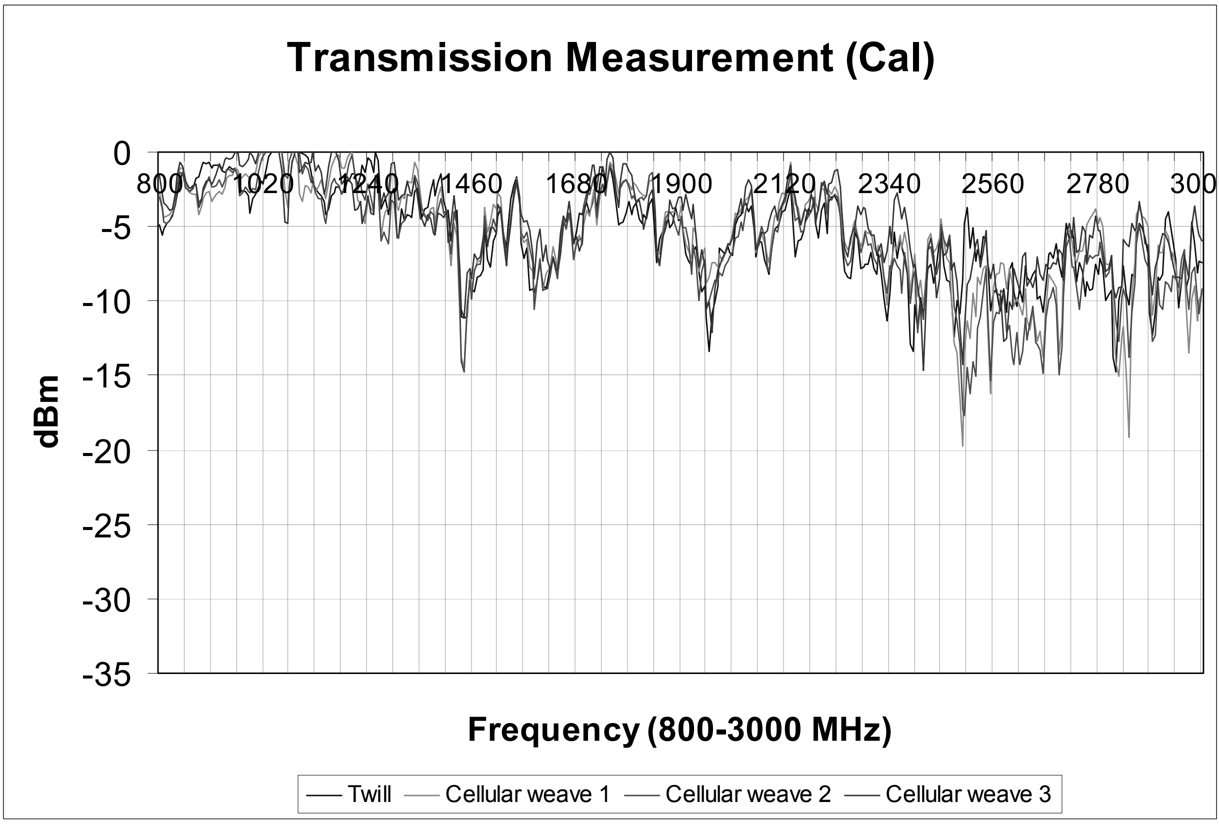

Figure 7. The EMSE of fabric samples woven with C weft arrangement for horizontal measurements

The shielding performance of fabric sample D4 woven with CP 1:7 weft arrangement has been good at the frequency of 2400 MHz and higher EMSE values than other fabric samples with same weft arrangement for all measurements as shown in Figure 8g-11g, 8h-11h. And also the average EMSE values of fabric samples woven with CP 1:7 weft arrangements have been 10 dB and 5 dB in high frequency band for vertical and horizontal measurements respectively.

It is seen in Figure 8i-11i that the fabric sample B5 woven with CP 1:15 weft arrangement has shown good shielding performance in high frequency band for vertical measurements. On the other hand, the fabric samples woven with CP 1:15 weft arrangements have low EMSE values in high frequency band for horizontal measurements as presented in Figure 8j-11j.

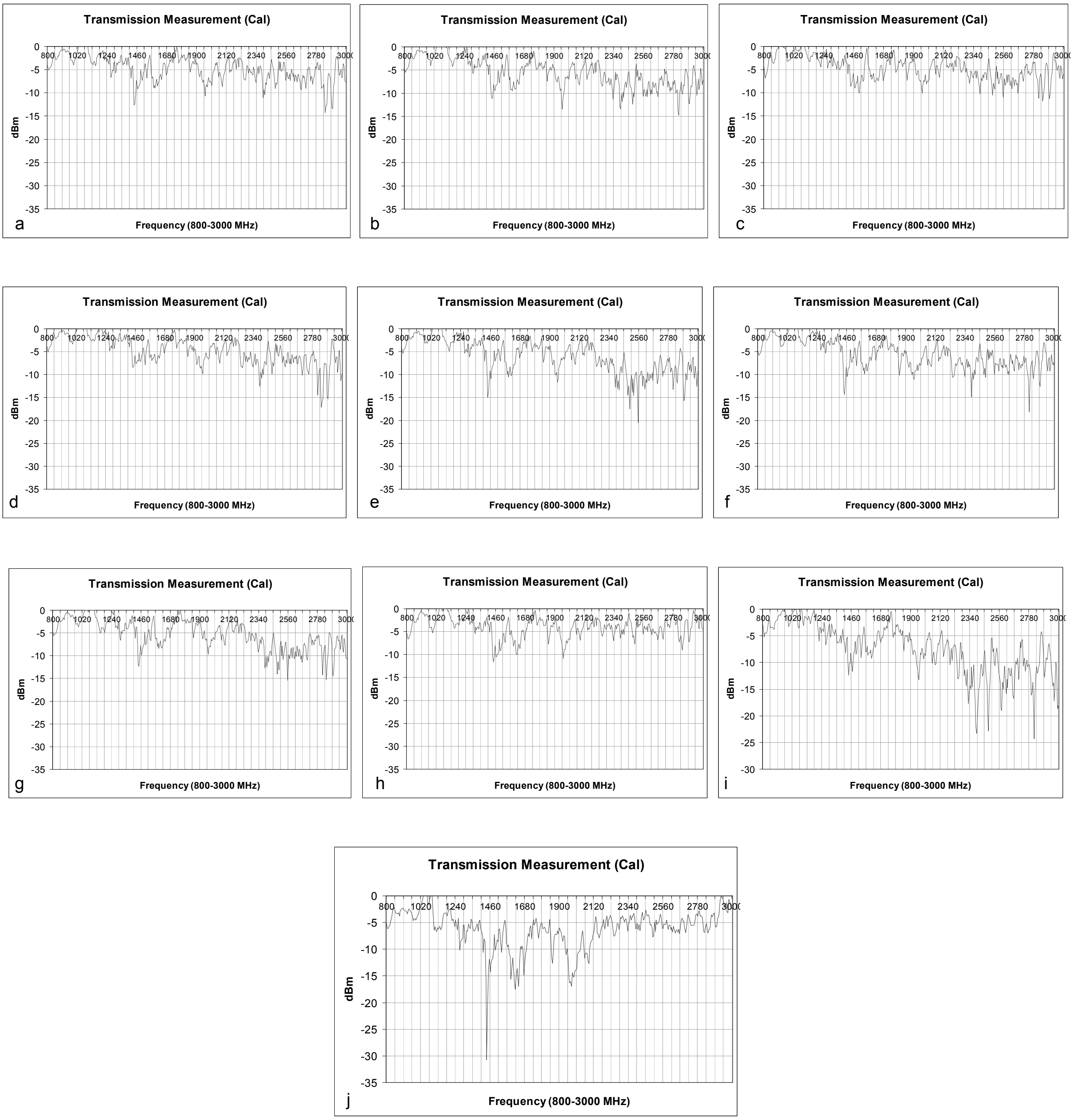

Figure 8. The EMSE of 3/1 twill weave: a-,c-,e-,g-,i- vertical measurements of fabric samples woven with C, CP 1:1, CP 1:3, CP 1:7, CP 1:15 weft arrangements respectively; b-,d-,f-,h-,j- horizontal measurements of fabric samples woven with C, CP 1:1, CP 1:3, CP 1:7, CP 1:15 weft arrangements respectively

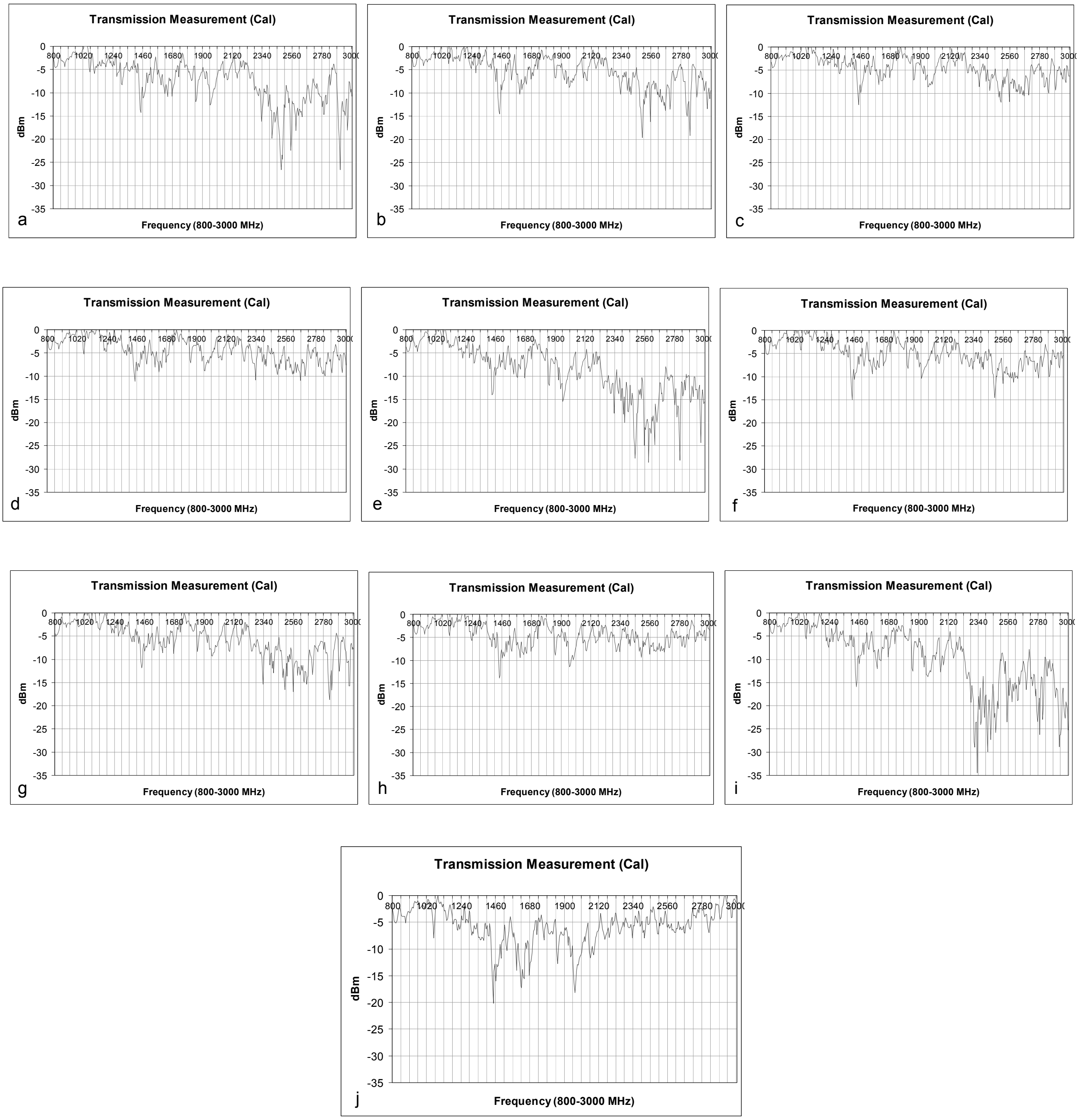

Figure 9. The EMSE of cellular weave 1: a-,c-,e-,g-,i- vertical measurements of fabric samples woven with C, CP 1:1, CP 1:3, CP 1:7, CP 1:15 weft arrangements respectively; b-,d-,f-,h-,j- horizontal measurements of fabric samples woven with C, CP 1:1, CP 1:3, CP 1:7, CP 1:15 weft arrangements respectively

When compared the effect of metal content, it is seen in Figure 8a, 8c, 8e, 8g and 8i that if the surface conductivity of twill woven fabric samples have increased, the EMSE of the samples will have decreased quite the contrary in high frequency band for vertical measurements. All twill woven fabric samples have low EMSE values in low frequency band.

The twill woven fabric samples woven with denser steel yarn arrangements have shielded better in high frequency band than those woven with looser steel yarn arrangements for horizontal measurements as shown in Figure 8b, d, f, h, j as expected. The EMSE of fabric sample A5 has been 7-8 dB higher than the samples A1, A2, A3 and A4 in low and medium frequency band.

The average EMSE value of fabric samples B1-B5 has been 15 dB in high frequency band for vertical measurements as seen in Figure 9a, c, e, g, i and 12. The fabric sample B5 woven with CP 1:15 weft arrangement have shown the best EMSE performance at frequency of 2400 MHz. The EMSE of fabric samples woven with cellular weave 1 have been low in low frequency band as in twill woven fabric samples.

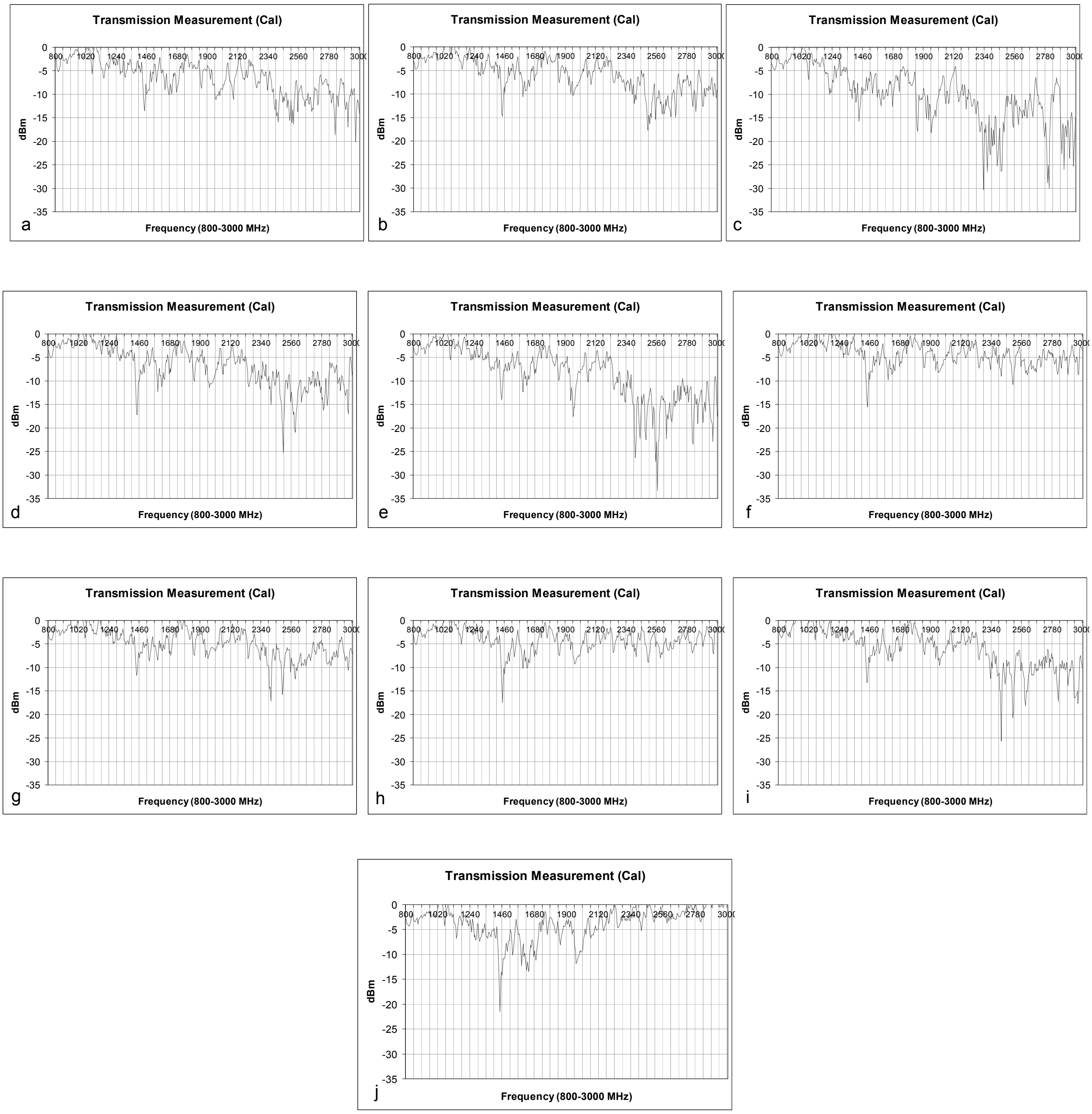

Figure 10. The EMSE of cellular weave 2: a-,c-,e-,g-,i- vertical measurements of fabric samples woven with C, CP 1:1, CP 1:3, CP 1:7, CP 1:15 weft arrangements respectively; b-,d-,f-,h-,j- horizontal measurements of fabric samples woven with C, CP 1:1, CP 1:3, CP 1:7, CP 1:15 weft arrangements respectively

It is observed in Figure 9b, d, f, h, j and 13 that the EMSE of fabric samples woven with cellular weave 1 have increased in accordance with metal yarn density in high frequency band for horizontal measurements as expected. This is due to the fact that the effective surface conductivity of fabric samples has increased in agreement with the metal content. Roh et al (5) and Cheng et al. (7) obtained similar results. The fabric sample B5 has higher EMSE values than the samples B1, B2, B3 and B4 in low and medium frequency band as in twill weave.

The EMSE of fabric samples woven with cellular weave 2 have been 15 dB as mean in high frequency band for vertical measurements as presented in Figure 10a, c, e, g, i. Among the fabric samples C1-C5, the fabric sample C2 has shown the best EMSE performance in almost all frequency bands.

It is seen in Figure 10b, d, g, h, j that fabric samples woven with denser steel yarn arrangements have generally shielded better in high frequency band than those woven with looser steel yarn arrangements for horizontal measurements as seen in fabric samples woven with twill and cellular weave 1. The fabric sample C2 has shown better EMSE performance in high frequency band than other fabric samples woven with cellular weave 2. The EMSE of fabric samples C1-C5 have almost the same EMSE performance in low and medium frequency band.

The results of vertical measurements of fabric samples woven with cellular weave 3 have been similar to each other as presented in Figure 11a, c, e, g, i. The average EMSE values of fabric samples D1-D5 have been 12-13 dB in high frequency band.

The fabric sample D2 has shown the best EMSE performance in high frequency band for horizontal measurements as seen in Figure 11b, d, f, h, j. The fabric samples woven with denser steel yarn arrangements have higher EMSE values than the fabric samples woven with denser steel yarn arrangements in high frequency band as in cellular weave 2.

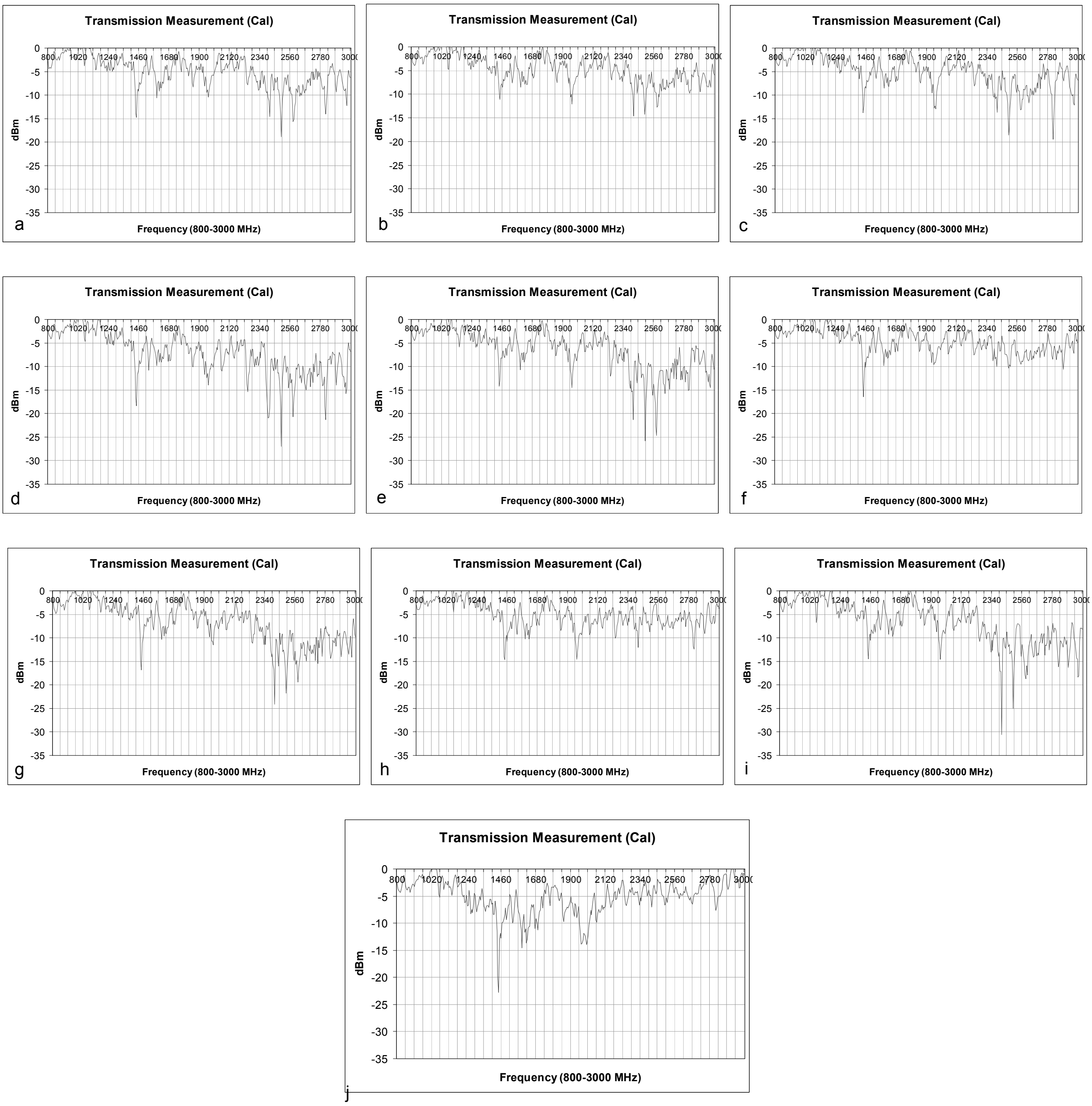

Figure 11. The EMSE of cellular weave 3: a-,c-,e-,g-,i- vertical measurements of fabric samples woven with C, CP 1:1, CP 1:3, CP 1:7, CP 1:15 weft arrangements respectively; b-,d-,f-,h-,j- horizontal measurements of fabric samples woven with C, CP 1:1, CP 1:3, CP 1:7, CP 1:15 weft arrangements respectively

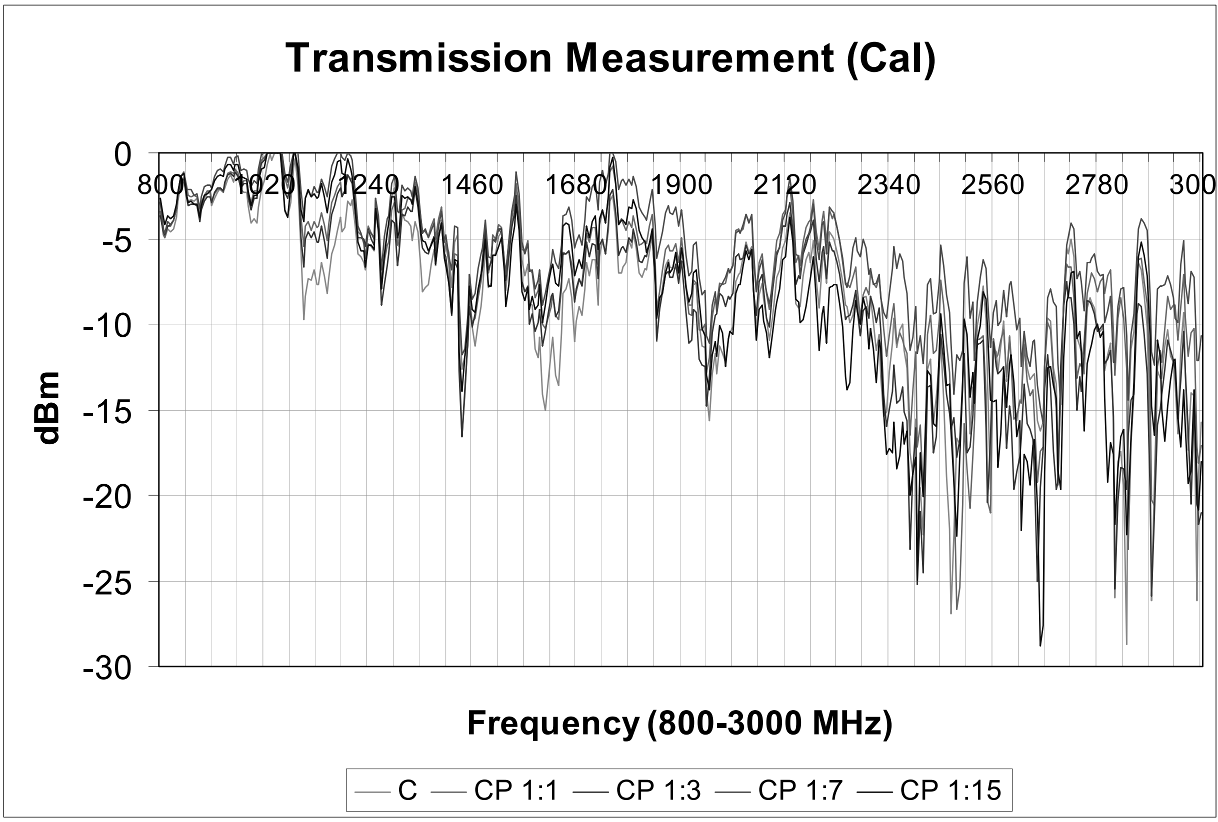

Figure 12. The EMSE of fabric samples woven with cellular weave 1 having weft arrangements defined as C, CP 1:1, CP 1:3, CP 1:7, CP 1:15 for vertical measurements

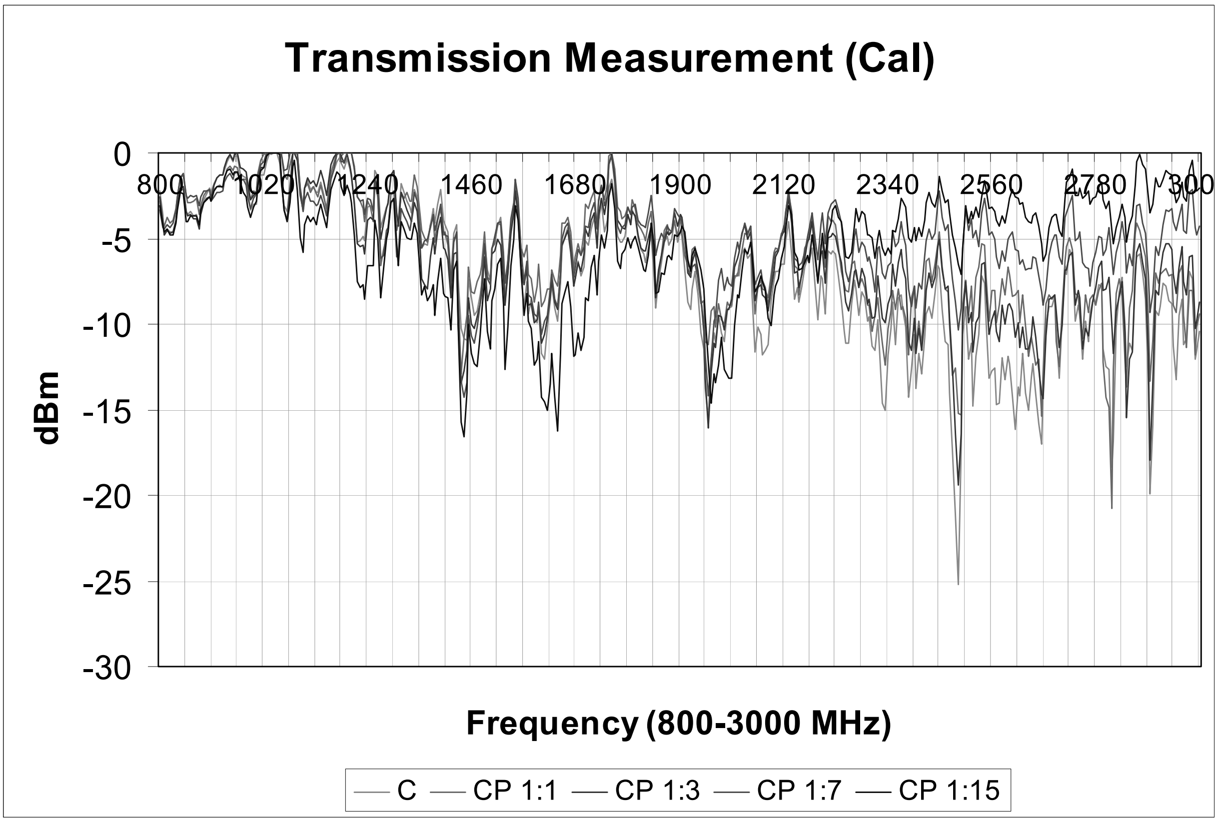

Figure 13. The EMSE of fabric samples woven with cellular weave 1 having weft arrangements defined as C, CP 1:1, CP 1:3, CP 1:7, CP 1:15 for horizontal measurements

4. CONCLUSION

In this paper, the electromagnetic shielding effectiveness of 3/1 twill and some cellular woven fabrics produced on automatic sample loom with conductive stainless steel core yarns have been investigated. In high frequency band, the cellular woven fabric samples, which have been positioned so that the weft yarns have been horizontal to the antenna polarization, have shown better EMSE performances than twill woven fabric samples with denser steel weft arrangements; meanwhile those woven with low steel weft densities have almost the same EMSE values with twill woven fabrics in low and medium frequency band when the fabric samples have been positioned in order that the weft yarns have been vertical to the antenna polarization. The EMSE of fabric samples have been low generally in low and medium frequency band for all measurements.

Among the cellular weaves which have been positioned so that the weft yarns have been horizontal to the antenna polarization, cellular weave 1 with denser steel yarn arrangement has shielded better than other cellular weaves and cellular weave 2 with CP 1:1 weft arrangement have shielded best especially in high frequency band.

It is observed that the EMSE values of fabric samples have increasing tendency depending on the increasing steel core yarn weft density in high frequency band if the fabric samples have been positioned so that the weft yarns have been vertical to the antenna polarization. However, twill and cellular woven fabrics with less density of steel core yarn weft arrangement, which have been positioned so that the weft yarns have been horizontal to the antenna polarization, have higher EMSE values than the fabric samples woven with denser metal arrangements in high frequency band.

To sum up, the fabrics produced within the scope of this study, which have been positioned so that the weft yarns have been horizontal to the antenna polarization, have shown better shielding performances in high frequency bands; so these can be used as shielding material for Wi-Fi, radiophone, baby monitors and electronic security systems. Nevertheless, the EM shielding properties of these fabrics should be improved especially in low and medium frequency bands. Moreover, it is supposed to model the EMSE of woven fabrics with simulation programs to clear up the circumstances referred above.

REFERENCES

1. King, R. W. P., 2000, "Electrical Currents and Fields Induced In Cells in the Human Brain by Radiation from Hand-Held Cellular Telephones", *Journal of Applied Physics*, 87(2), p.893-900.
2. Gandhi, O. P., 2002, "Electromagnetic Fields: Human Safety Issues", *Annual Review of Biomedical Engineering*, No.4, p.211-234.
3. World Health Organization Homepage on the Internet, *World Health Organization*, Cited 26 March 2012, Available from: http//www.who.int/peh-emf/en/
4. Perumalraj, R. et al., 2009, "Electromagnetic Shielding Effectiveness of Copper Core-Woven Fabrics", *The Journal of the Textile Institute*, 100(6), p.512-524.
5. Roh, J.S. et al., 2008, "Electromagnetic Shielding Effectiveness of Multifunctional Metal Composite Fabrics", *Textile Research Journal*, 78(9), p.825-835.
6. Su, C.I. and Chern, J.T., 2004, "Effect of Stainless Steel-Containing Fabrics on Electromagnetic Shielding Effectiveness", *Textile Research Journal*, 74(1), p.51-54.
7. Cheng, K.B. et al., 2006, "Electromagnetic Shielding Effectiveness of the Twill Copper Woven Fabrics", *Journal of Reinforced Plastics and Composites*, 25(7), p.699-709.
8. Chen, H.C. et al., 2007, "Fabrication of Conductive Woven Fabric and Analysis of Electromagnetic Shielding via Measurement and Empirical Equation", *Journal of Materials Processing Technology*, 184, p.124-130.
9. Duran, D. et al., 2009, "Electromagnetic Shielding Effectiveness of Woven Fabrics Produced with Conductive Core Yarns", *AUTEX World Textile Conference*, May 26-28, İzmir, Turkey, p.779-786.
10. Varnaitė, S. et al., 2008, "The Features of Electric Charge Decay in the Polyester Fabric Containing Metal Fibres", *Materials Science (Medžiagotyra)*, 14(2), p.157-161.
11. Sandrolini, L. and Reggiani, U., 2008, "Investigation on the Shielding Effectiveness Properties of Electrically Conductive Textiles", *Asia Pacific Microwave Conference*, December16-19, Hong Kong, China.
12. Palamutcu, S. et al., 2010, "Electrically Conductive Textile Surfaces and Their Electromagnetic Shielding Efficiency Measurement", *Tekstil ve Konfeksiyon*, 20(3), p.199-207.
13. Örtlek, H.G., et al., 2012, "Investigation of Electromagnetic Shielding and Comfort Properties of Single Jersey Fabrics Knitted From Hybrid Yarns Containing Metal Wire", *Tekstil ve Konfeksiyon*, 22(2), p.90-101.
14 Joyner, K.H. et al., 1989, "An Evaluation of A Radiofrequency Protective Suit and Electrically Conductive Fabrics", *IEEE Transactions on Electromagnetic Compatibility*, 31(2), p.129-137.
15. Więckowski, T.W. and Janukiewicz, J.M., 2006, "Methods for Evaluating the Shielding Effectiveness of Textiles", *Fibres & Textiles in Eastern Europe*, 14(5), p.18-22.
16. Başer, G., 2004, Dokuma Tekniği ve Sanatı, Cilt 1, Punto Publishing.
17. David, V. et al., 2007, "On the Characterization of Electromagnetic Shielding Effectiveness of Materials", *15th* IMEKO *TC4 Symposium on Novelties in Electrical Measurements and Instrumentation*, September 19-21, Iasi, Romania, p.73-78.
18. Çeken et al., 2011, "The Electromagnetic Shielding Properties of Copper and Stainless Steel Knitted Fabrics", *Tekstil*, 60(7), p.321-328.