



***Araştırma Makalesi / Research Article***

**DEVELOPMENT OF WOVEN FABRICS FOR ELECTROMAGNETIC SHIELDING  
BY QUALITY FUNCTION DEPLOYMENT APPLICATION**

**Bilge BERKHAN KASTACI<sup>1\*</sup>**

<https://orcid.org/0000-0001-6897-0554>

**H. Ziya ÖZEK<sup>2</sup>**

<https://orcid.org/0000-0003-3935-6170>

<sup>1</sup>Namık Kemal University, Çerkezköy Vocational School, Textile Technology Program, Turkey

<sup>2</sup>Namık Kemal University, Textile Engineering Department, Çorlu, Turkey

*Gönderilme Tarihi / Received: 16.07.2019*

*Kabul Tarihi / Accepted: 15.12.2019*

**ABSTRACT:** In order to determine a proper product solution for achieving customer satisfaction and business goals, the entire steps of product development become more significant and complicated when utilizing external resources. The purpose of this work is to develop a woven fabric with a sufficient electromagnetic shielding performance. The concept of Quality Function Deployment (QFD) is used for the development process in which customer needs are translated into product properties and manufacturing process parameters. Two different counts of silver coated yarns are selected to produce various woven structures with plain weave. The electromagnetic shielding effectiveness of these fabrics is measured within the frequency range of 30 MHz to 3000 MHz, by means of a coaxial transmission set-up. The sample incorporating silver coated yarns at both entire warp and weft appeared to provide a shielding efficiency of 40 – 70 dB at various frequency ranges.

**Keywords:** Quality Function Deployment, electromagnetic shielding, new product development, woven fabric

**KALİTE FONKSİYONU GÖÇERİMİ UYGULAMASI İLE ELEKTROMANYETİK  
KALKANLAMA İÇİN DOKUMA KUMAŞLARIN GELİŞTİRİLMESİ**

**ÖZET:** Doğru ürünle müşteri tatminini gerçekleştirmek ve iş hedeflerini yakalamak üzere uygun bir ürün çözümü üretmek için ürün geliştirme adımlarının tümü oldukça önemli olup; işletme dışı kaynakların etkin biçimde kullanılabilmesi de karmaşık bir hal almaktadır. Bu çalışmanın amacı, bir teknik tekstil ürünü olan elektromanyetik kalkanlama özelliği sağlayacak dokuma kumaşın geliştirilmesini sağlamaktır. Yüksek düzeyde koruma öngören müşteri talebinden yola çıkılarak, yeni ürün geliştirme sürecinde hedef planlama ve kavram geliştirme çalışmalarının ardından, tasarım sürecinde Kalite Fonksiyon Göçerimi (KFG) yöntemi uygulanmıştır. Gümüş kaplı poliamid iplikler ile polyester ipliklerin değişik oranlarda kombinasyonu ile bezayağı örgüde dokunan kumaş numuneleri ile hedeflenen kalkanlama düzeyi elde edilmiştir. 30-3000 Mhz frekans aralığında 40-70 Db aralığında koruma etkinliği göstermiştir.

**Anahtar Kelimeler:** Kalite Fonksiyon Göçerimi, elektromanyetik kalkanlama, yeni ürün geliştirme, dokuma kumaş.

**Sorumlu Yazar/Corresponding Author:** [bberkhan@nku.edu.tr](mailto:bberkhan@nku.edu.tr)

**DOI:** 10.7216/1300759920192611604, [www.tekstilvemuhendis.org.tr](http://www.tekstilvemuhendis.org.tr)

**\*\*This study was presented at “2nd International Congress of Innovative Textiles (ICONTEX2019)”, April 17-18, Çorlu, Turkey**

## 1. INTRODUCTION

The use of electrical and electronic devices in daily life has increased as a result of developing technology, welfare level and modern living conditions. Mobile phones, computers, hair dryers, microwave ovens, TV sets, household appliances, electric heaters, photocopiers, automobiles, high-voltage lines, base stations, electronic communication networks, radio and television transmitters, satellite communication systems, military defence systems, radars, automobile ignition systems, medical devices and many other electrical-electronic devices and systems emit electromagnetic radiation to the environment intentionally or unintentionally. Therefore, there exists an electromagnetic pollution in daily life, due to intensive electromagnetic (EM) waves present in our environment.

According to the United Nations, electromagnetic pollution is the fourth major pollution after water, air and noise pollution. The electromagnetic wave, which is composed of electric wave and magnetic wave, processes the cell membrane and changes the ion distributions such as Na / K and decreases the melatonin secretion. This causes an increase in the body temperature and deterioration of the biological rhythm [1]. Therefore, the reduction of the damages caused by the electromagnetic radiation existing in surrounding environment has become extremely important for the environment and human health.

Since the typical metal products with high electromagnetic shielding efficiency (EMSE) are not suitable for use everywhere due to their expensive, heavy, thermal expansion and non-elasticity, the development of conductive polymers has emerged as an important alternative to metals for shielding in defence, electrical and electronic applications. The reason for the widespread use of these materials is that they are resistant to chemical corrosion by electrostatic discharge, EM and protection against radio waves, better thermal expansion and density properties [2]. Textile-based materials incorporating conductive polymers or metal fibers have also become a feasible alternative.

The new developments that have emerged with the changing lifestyle also change the expectations of people from textile products. Demand for conductive fabrics which protect human

health against static electrification and electromagnetic radiation has increased and such products are developed [3,4]. For a manufacturer, it is important to realize new product design in connection with customer requirements. All of the product development steps are very important to achieve customer satisfaction with the right product and to achieve business goals. The aim of this study is to develop a woven fabric as an example of technical textiles with a function of electromagnetic shielding. The focus of this study is based on how to develop a new product and design appropriate processes based on customer demands, which will provide adequate protection against electromagnetic pollution.

## 2. PRODUCT PLANNING WITH QUALITY FUNCTION DEPLOYMENT

Quality Function Deployment is a systematic approach consisting of a set of planning and communication processes for the design, production and marketing of products or services that the consumer wants to buy [5]. Listening to the customer and understanding the needs of customer are the bases of this approach. This technique can also be referred as the "Quality House" which includes the all results of this analysis. It is a conceptual and visual result that allows inter-function planning and communication. This process consists of four stages that analyse the interrelationships between customer needs and product concept, and also to prioritize mutual relations. The process begins with Product Characteristic and Inputs, Process Parameters and Production Control. In this study, the target shielding level is obtained from the woven fabric with silver coated yarns by using the stages of product planning and product design.

In Product Planning, which is the first stage of QFD, customer requests are clustered in three main groups as "General", "Performance" and "Usage". All requirement statements are individually scored between 1 and 5 (5 highest). This score is obtained by evaluating customer demands on the basis of competing products. Figure 1 shows the first relationship matrix of the customer's voice to the voice of the enterprise. The degree of relationship between the input parameters in the rows and columns of the relationship matrix is determined as 1 for a weak relationship, 3 for a medium relationship and 9 for a strong relationship. If there is no relationship between the two properties no core is given and in the case of an inverse relationship, the score is defined as -1.

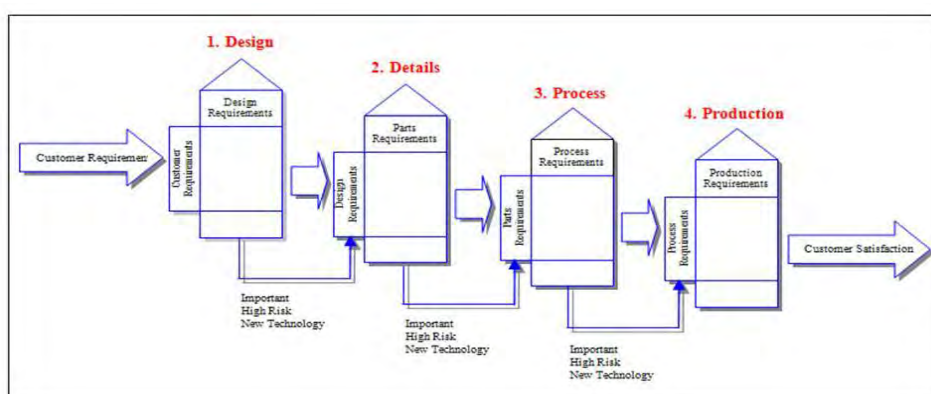


Figure 1. The four consecutive phases of QFD analysis

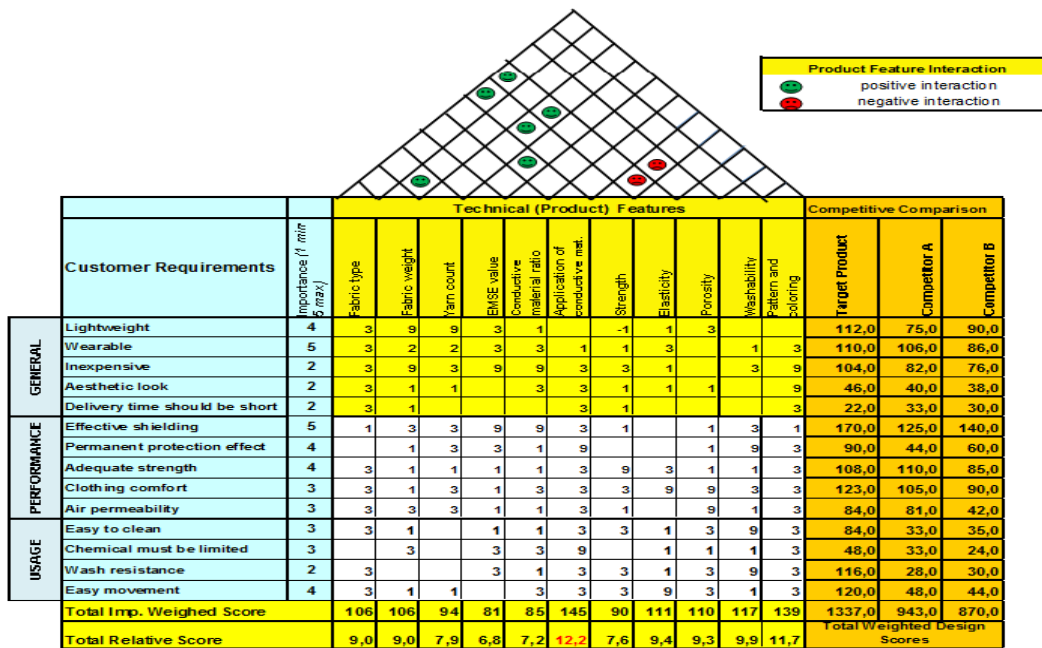


Figure 2. Relationship matrix between customer requirements and specifications (quality house)

In the first phase of product planning, an effective shielding level (at least 60 dB) and wearability appear to be the most important requirements of the customer. After the association scoring; 'Conductive material application', 'pattern and coloration' and 'washability' have come to the forefront as the three most important factors in converting customer demands into product technical specifications. In order to define and realize the customer's requests correctly, it will be important to deploy all these requirements into the product specifications.

In the second stage, the desired product has been associated with the product properties in accordance with the prescribed

technical specifications. The deployment shall be made between technical targets envisaged on the basis of product planning and the product characteristics.

At this stage, a quality house will be created to define the relationship between 10 different product design features with 11 different product specifications. Numerical values and related units are also given for the target ranges related to fabric weave and weight, warp and weft density and the ratio of conductive yarn. The relationship matrix of the second stage is given in Figure 3.

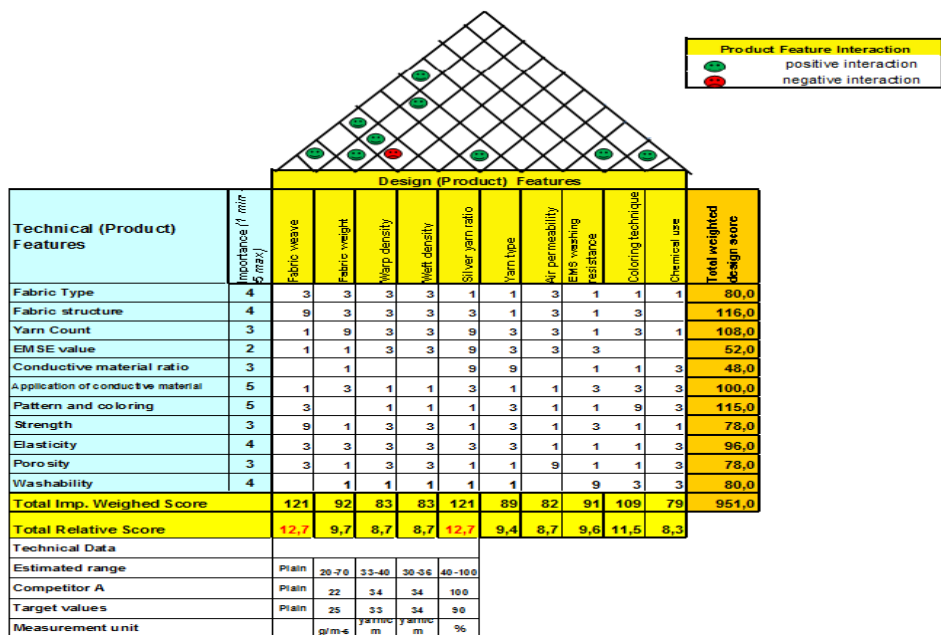


Figure 3. Product Relation Matrix between product specifications and design features (quality house)

At this stage, the prominent design parameters were ‘‘Fabric weave’’, ‘‘Conductive substance (silver) ratio’’ and ‘‘Colouring technique’’. The choice of these values is critical because it needs to be defined in the most appropriate way in order to meet customer requests correctly.

### 3. MATERIAL AND METHODS

Customer requirements and design parameters are associated with Quality Function Deployment technique and as a result, plain weave is considered to be the most appropriate weave option to meet the strength specification. As the method of integrating conductive material into the fabric, the use of metal coated yarn is preferred because it is thought that the performance of the polymer coated fabrics will be low due to their properties such as flexibility, porosity and washability. Among the yarns sold in the market, it was decided to use silver-coated nylon yarn with the trade name X-Static (Noble Materials, USA).

These yarns are polyamide fiber based and covered with a pure silver layer of 99.9% purity and maintains the traditional textile fiber property in terms of strength, attitude and comfort. In order to reach the target value, how many numbers of silver coated yarn will be used and its percentage within the fabric composition are analysed within the scope of production characteristics and approximate values are determined. Three different numbers (22/3, 33/10 and 70/34 dTex) of yarn are selected and 12 different prototypes are produced in order to achieve the target fabric variables and EMSE values by various combinations thereof.

Table 1 shows the technical specifications of the fabric produced for the prototype (sample) production under the product

development activities. All fabric samples are produced by a rigid rapier weaving machine with the nominal working width of 190 cm.

Electromagnetic shielding values of woven fabrics were carried out with N5224A PNA Microwave Network Analyzer which employs Flanged Coaxial Holder method. The device measures the amount of wave transmitted between two opposing antennas and gives the electromagnetic permeability, absorption and reflectance values as a percentage.

The electromagnetic shielding value (SE value) of a material is calculated by the equation given below by the ratio of the electric (or magnetic) field received by the opposing antenna sent from the first antenna while the sample is absent ( $E_0$  or  $H_0$ ) and through the sample ( $E_1$  or  $H_1$ ) [6].

$$SE = E_0 / E_1 = H_0 / H_1$$

or in decibel:

$$SE_{dB} = 20 \log E_0 / E_1 = 20 \log (H_0 / H_1) (dB)$$

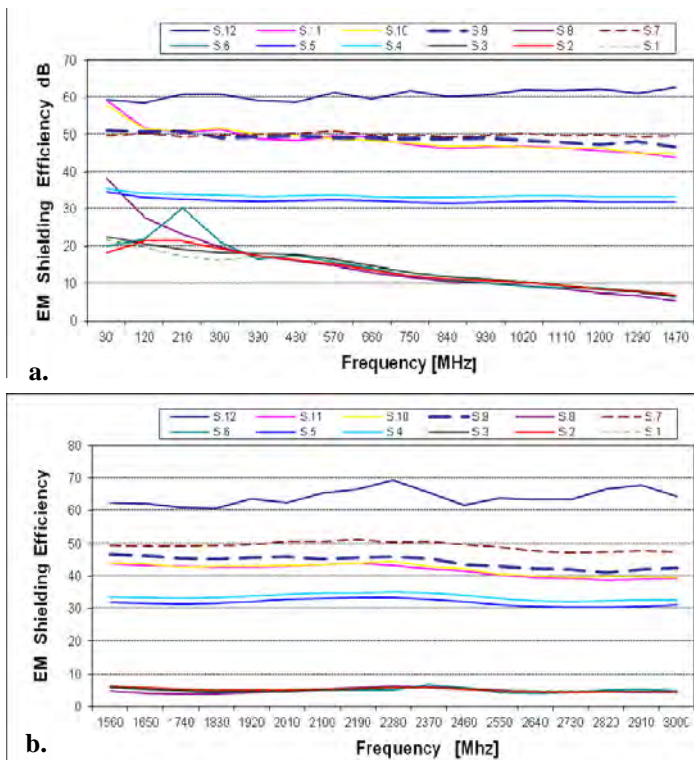
EMSE measurements were made by ASTM D 4935 - 99 Standard Test method [7] in 30-3000 MHz range and the results were evaluated in terms of ‘‘dB’’.

### 4. RESULTS AND DISCUSSION

The results of 12 different samples produced in this study are given with two different graphs. EMSE values of all samples are given in Figure 4.b for EM interference between 30-1470 MHz and 1560-3000 MHz in Figure 4.a. The results are discussed on the basis of the variables given below.

**Table 1.** Basic Properties of Woven Fabric Specimens and Structure of Silver Yarn Ratio

Sample	Warp Yarn	Weft Yarn	Density [yarn/cm]	Weight [gram-sq.m]	Fabric Cover factor	Silver Yarn Ratio [%]
S.1	75/24 Den PES bük. 70/34 dTex S+Nylon	75/24 Den PES 70/34 dTex S+Nylon	33 x 36	59,87	19,98	47,8
S.2	75/24 Den PES bük. 70/34 dTex S+Nylon	75/24 Den PES 70/34 dTex S+Nylon	33 x 33	58,18	19,41	47,9
S.3	75/24 Den PES bük. 70/34 dTex S+Nylon	150/48 Den PES IMG 70/34 dTex S+Nylon	33 x 35	74,91	22,36	37,8
S.4	75/24 Den PES bük.	75/24 Den PES 70/34 dTex S+Nylon	33 x 38	62,23	20,77	25,0
S.5	75/24 Den PES bük.	75/24 Den PES 70/34 dTex S+Nylon	33 x 30	55,46	18,50	22,1
S.6	75/24 Den PES bük.	150/48 Den PES IMG 70/34 dTex S+Nylon	33 x 36	76,61	22,56	19,2
S.7	33/10 dTex S+Nylon	33/10 dTex S+Nylon	33 x 36	23,92	12,71	100,0
S.8	33/10 dTex S+Nylon	33/10 dTex S+Nylon	33 x 38	24,61	13,07	100,0
S.9	22/3 dTex S+Nylon	22/3 dTex S+Nylon	40 x 34	17,10	10,95	100,0
S.10	22/3 dTex S+Nylon	22/3 dTex S+Nylon	40 x 35	17,33	11,10	100,0
S.11	22/3 dTex S+Nylon	22/3 dTex S+Nylon	40 x 36	17,56	11,25	100,0
S.12	70/34 dTex S+Nylon	70/34 dTex S+Nylon	33 x 36	56,53	19,25	100,0



**Figure 4.** a. EMSE values of 12 different samples in 30-1470 Mhz frequency range b. EMSE values of 12 different samples in the frequency range of 1560-3000 Mhz

*The effect of silver coated yarn ratio on the EMSE:* The higher the ratio of pure silver in the sample, the higher the EMSE values. Fairly well EMSE values were reached with S.7 and S.12. An EM shielding efficiency of over 40 dB was achieved over the entire frequency range.

*The effect of fabric weight and cover factor on the EMSE:* The sample with the highest fabric weight and cover factor was S.12. This sample has displayed a clear performance advantage over other samples. In fact, this comparison would be more accurate based on samples containing similar proportions of X-static silver-coated yarn. Samples S.9, S.10 and S.11 have a similar weight and coverage factor. Although the performances of these samples are similar, the differences between their weights are not reflected in the same way. Among all the fabrics obtained with silver yarn, the most heaviest sample gave the best value of EMSE. The first 6 samples were obtained by blending standard polyester and silver coated yarns. Although the average weights ranged from 55 to 77 g / m-squared, similar results were obtained except for the EMSE values S.4 and S.5.

*Effect of X-Static yarn count on the EMSE value:* Three different yarn counts; 22, 33 and 70 dTex, were used in the warp and weft. Woven fabrics with 70 dTex X-Static yarns had a very high EMSE value (40 dB and above). On the other hand, no significant difference was observed in the samples produced with 22 and 33 dTex yarns.

*The effect of the frequency range of EM waves on the EMSE:* Fabric samples produced with %100 X-static yarns showed

similar characteristics across the entire spectrum range (30-3000 MHz). On the other hand, it was observed that there was a significant decrease in the value of EMSE with increasing frequency value in the samples obtained with the combination of standard polyester.

## 5. CONCLUSIONS

In this study, the product development process on the base of the QFD method was carried out. Among a series of woven fabric samples produced on the basis of customer requests, an appropriate prototype which meets the specified shielding efficiency to meet the customer demand has been realized successfully. In the QFD method, the requirements of the customer focused particularly on effective shielding function and sufficient wearability of the resultant product. Thanks to the use of X-static silver-plated filament yarns as conductive material, a prototype of woven fabric which can be easily tailored and wearable within the prerequisite weight and thickness was successfully obtained. When the shielding performances of the produced fabric samples are compared, it is clear that the better the EM shielding efficiency of the fabric, the higher the ratio of conductive material percentage in the fabric fibre composition. An increase of shielding efficiency with increasing fabric cover ratio depending on the yarn count and density has also become apparent.

The use of the QFD technique in the product development process has made significant gains both in terms of the success and duration of this process. On the basis of the weighted customer requirements, the way of integration conducting material into the fabric and the amount of conductive material in the fabric structure are disclosed as critical factors to influence product design parameters.

## REFERENCES

1. United Nations Earthwatch., Electromagnetic Radiation, <http://www.un.org/earthwatch/health/electromagneticradiat.html>, Available at: 2003
2. Cheng, K.B., Ramakrishna, S., Lee, K.C., (2000), Electromagnetic shielding effectiveness of copper/ glass fiber knitted fabric reinforced polypropylene composites, *Composites: Part A* 31, 1039–1045.
3. Koprowska, J., Pietranik, M., Stawski, W., (2004), New Type of Textiles with Shielding Properties, *FIBRES & TEXTILES in Eastern Europe*, Vol. 12, No. 3, 47.
4. Subhankar Maity, S., Singha, K., Debnath P., Singha, M., (2013), Textiles in Electromagnetic Radiation Protection, *Journal of Safety Engineering*, 2(2): 11-19.
5. Bossert, J. L., (1991), *Quality Function Deployment: A Practitioner's Approach*, Wisconsin, ASQC Quality Press.
6. Kılıç G., Örtlek H. G., and Saraçoğlu Ö.F., (2015), Elektromanyetik Radyasyona Karşı Koruyucu Tekstillerin Ekranlama Etkinliği (SE) Ölçüm Yöntemleri, *Tekstil Mühendisleri Odası Dergisi*, 72, 8-15.
7. ASTM D-4935, "Standard Test Method for Measuring the Electromagnetic Shielding Effectiveness of Planar Materials," (2006), Annual Book of ASTM Standards, 448–456.