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Research Article

Investigation of the Absorption and Reflection Capacities of Some Silver Doped Textile Products

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Abstract

In our study, scattering S-parameters of five different fabrics produced commercially with silver fibres threads are measured to evaluate their electromagnetic shielding capacities (reflection and absorption capabilities). Measurements are carried out by a microwave vector network analyser (VNA – model N9918A) over the frequency range of 30 kHz–3 GHz. After measuring these capabilities, absorbance effectiveness (SE_a), reflectivity effectiveness (SE_r) and total shielding effectiveness values of the fabrics (SE_t) were calculated. It is observed that an approximately linear relationship exists between absorption capacity and proportions of silver fibres of the fabric samples. In addition, it is also noted that silver fibre content added to the fabrics and production type (knitting or weaving) of the fabrics play a critical role in resulting higher SE_t effectiveness value.

Keywords: Shielding, absorption, reflection, radiation, shield, Human health.

Gümüş Katkılı Bazı Tekstil Ürünlerinin Soğurma ve Yansıma Kapasitelerinin Araştırılması

Öz

Elektromanyetik kalkanlama elektronik bir cihazı veya bir alanı dış elektromanyetik radyasyondan korumak için gelen elektromanyetik radyasyonun şiddet veya enerjisini azaltabilmek için elektromanyetik radyasyonun önüne konulan özel bir malzemeden oluşur. Ticari olarak gümüş iplerle üretilmiş olan beş farklı kumaşın S-parametrelerini ($|S_{11}|$, $|S_{22}|$, $|S_{21}|$ and $|S_{12}|$) 30 kHz-3 GHz frekans aralığında ölçmek için Mikrodalga Network Vektör Analizörü (VNA) (model N9918A) cihazı kullanıldı. Kumaş numunelerin $|S_{11}|$ yansıma kapasiteleri ile kumaşlara katılan gümüş elyaf oranları arasında sistematik bir ilişki tespit edilemedi. Ancak kumaş numunelerin $|S_{21}|$ soğurma kapasiteleri ile kumaşlara katılan gümüş elyaf oranları arasında yaklaşık olarak lineer bir ilişkinin olduğu söylenebilir. Ölçülen $|S_{11}|$ yansıma ve $|S_{21}|$ soğurma kapasiteleri kullanılarak kumaşların soğurma etkinliği (SE_A), yansıma etkinliği (SE_R) ve toplam kalkanlama etkinliği (SE_t) değerleri hesaplandı. Belirli frekanslarda, en düşük SE_t etkinliği değeri pembe renkli kumaşta hesaplanırken, en yüksek SE_t etkinliği değeri gri renkli kumaşta hesaplandı. Bu farklılığın en önemli nedenlerinden birinin kumaşlara katkılanan gümüş elyaf oranı ve kumaşların üretim (örgü veya dokuma) şekillerinin olduğu söylenebilir.

Anahtar Kelimeler: Kalkanlama, soğurma, yansıma, radyasyon, kalkan, insan sağlığı.

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1. Introduction

Radiation exposure, like electromagnetic fields, is not a new phenomenon. Because people are exposed to natural and unnatural radiations such as cosmic rays, radon gas, and microwaves from birth to death. Especially with the development of industry and technology in the current century which both make our lives easier, people are surrounded by their environment with electronic devices and systems such as computers, tablets, mobile phones, televisions, electric shaver, hair dryer, vacuum cleaner, washing machines, microwave ovens, radio and television transmitters and cell phone base stations. Therefore, their exposure to artificial non-ionizing radiation sources is increasing day by day in addition to natural radiation sources, and this situation causes the formation of a new environmental pollution that threatens the life and health of living organisms in the environment (Wargo et al., 2012). In addition, the earth is a rich of great source of magnetic field in our planet we live in. For this reason, people are unintentionally exposed to electromagnetic fields at home, on the street and at work; i.e., in all living spaces. The electromagnetic waves that people are exposed transfer their energies to living beings at different rates through photons or waves, depending on their power density. Besides, the electronic devices, which are being used to facilitate our life, have many negative effects on all living things along with humans. In addition to pollutants such as environmental and air pollution that affect human health, the electromagnetic fields should be shielded, in some cases, to improve our quality of life and comfort. For example, the magnetic field lines formed between the north and south poles of our world act as a magnetic shield and prevent harmful radiations that may come from outer space. The electromagnetic shielding is not only used to protect people from the negative effects of external electromagnetic fields, but also to protect the electronic systems of vehicles and devices with sensitive electronic systems such as aircraft from the effects of external fields. The shielding effectiveness, as a measure of electromagnetic absorption capability, depends essentially on the frequency range being measured, the size of the samples and the characteristics of the material used (Kılıç et al., 2008). In general, one of the best material groups used as electromagnetic field shielding is metal plates. But, the metal plate is expensive, bulky and hard, making this material useless. For this reason, the researchers preferred to use lighter, cheaper and more useful materials still having good electromagnetic shielding. Fabrics, which are one of such materials, are knitted and woven fabrics that are easy to apply, flexible, easy to produce and cheaper, with high shielding properties, unlike metal plates (Perumalraj and Dasaradan, 2009). The main characteristics that affect the shielding effectiveness are the fabric's geometry, conductive property, diameter, yarn density and thickness (Abdulla, 2016). For this reason, textile products such as fabrics are one of the frequently used materials in electromagnetic shielding research. These products are applied in a wide range of fields such as telecommunications (Locher et al., 2006), medicine (Lawrence et al., 2004), the textile industry (Locher and Toster, 2007), military and civilian electromagnetic shielding applications (Liu ve Wang, 2012). In another study, the permeability measurements of the soil samples were made in the frequency range from 1 MHz to 10 GHz by the vector network analyzer technique (Lauer et al., 2012).

Transmission-line measurement technique was used to measure electromagnetic shielding effectiveness on conductive metal oxide coated glass surfaces (Aksoy, 2019). In a study conducted in 2017, five different combinations of wood plastic nanocomposites (OPG-1, OPG-2, OPG-3, OPG-4) containing different rates of graphene (0-6% by weight) were produced, and their electromagnetic shielding effectiveness was investigated. They reported that the highest shielding effectiveness value was exhibited in the OPG-4 sample as approximately 24 dB (Altun et al., 2017). A similar study was conducted in 2013 by Al-Saleh and Sundararaj for high structure carbon black/polypropylene composites (Al-Saleh and Sundararaj, 2013). To our best knowledge, effect of amount of silver threads within fabrics on their shielding effectiveness has not been studied. To fill in this gap in the literature, in this study, we first measured scattering (S-) parameters of manufactured fabrics with five different ratios of silver threads by using microwave network vector analyser (VNA) (model N9918A) in the frequency range of 30kHz-3GHz and then calculated absorption effectiveness (SE_a), reflection effectiveness (SE_r) and total shielding effectiveness (SE_t) values of these fabrics.

2. Experimental Procedure

Textile samples used in the research were commercially produced samples purchased from Shanghai Angel Trade Co., Ltd. (Textile) (web1). The properties of the samples are given in Table 1.

2.1. Measurements and Shielding Effectiveness

S-parameter measurements were performed using microwave setup, shown in Fig. 1, at the Microwave Laboratory in Gaziantep University, Gaziantep, Turkey.

Figure 1. A photo of the microwave measurement setup.

This setup includes a portable VNA (model FieldFox N9918A) with a frequency range from 30kHz to 26.5 GHz, dynamic range of 90 dB (up to 18 GHz), and a directivity not less than 32 dB over full frequency. Two phase-stable 3.5 mm Type-N coaxial lines with 100 cm in length were used to carry electromagnetic signals to Type-N-to-EIA 1-5/8” adapters. Samples were located at approximately mid plane of a coaxial measurement cell with a length of 150 mm (inner diameter of the outer conductor of 38.8±0.075 mm and outer diameter of the inner conductor of 16.9±0.050 mm). Before carrying out experiments, the measurement system was first calibrated by the short-open-load-thru (SOLT) calibration procedure to the ends of the 3.5 mm Type-N coaxial lines. Then, port extensions were applied to eliminate the effect of

Type-N/EIA 1-5/8” adapters (Lauer et. al. 2012). Then, S-parameter measurements were measured for an air-filled measurement cell to ensure accuracy of calibrations. It was noted that measured magnitude of transmission S-parameter (|S21|) was not less than 0.95 over the full band, which allows the accuracy of the calibration. After calibration process, magnitudes of reflection and transmission S-parameters (|S11| and |S21|) of 4 commercially produced fabric and one hat samples.

Table 1. The properties of the samples

The fabrics	Compound	Knitted type	Product code	Weight (g/m^2)	Function
Pink	60% silver fiber + 40% polyester	Weaving	AR-S03	100	the conductive, antistatic, anti-radiation, antibacterial
Hat	50% silver + 50% metal fiber	Weaving	S071	200	
Light brown	100% Silver fiber	Knitting	YSILVER32#	33	
Dark brown	100% Silver fiber	Knitting	1666266	33	
Grey	100% Silver fiber	Knitting	YSILVER36#	32	
Grey -2	100% Silver fiber	Knitting	3007059	100	

Then, these measured S-parameters were utilized to determine SE_t, SE_a and SE_r values:

$$SE_t = SE_a + SE_r \quad (1)$$

$$SE_a = -10log_{10}[(|S_{21}|)^2/(1-(|S_{11}|)^2)] \quad (2)$$

$$SE_r = -10log_{10}[(1-(|S_{11}|)^2)] \quad (3)$$

where SE_t represents the total shielding effectiveness values, $|S_{11}|$ reflection coefficient, $|S_{21}|$ transmission coefficient, SE_r reflection losses and SE_a absorption (transmission) losses. It is assumed that SE_a is greater than 10 dB so that effect of multiple reflections within the fabrics is negligible (Saini et al, 2011). The values of the reflection ($|S_{11}|$) and absorption ($|S_{21}|$) parameters were transformed into decibels (dB) using the following equation.

$$N_{dB} = 20log_{10}N \quad (4)$$

where N_{dB} is the decibel value of N (= $|S_{11}|$ or $|S_{21}|$).

3. Results and Discussion

Measured $|S_{11}|$ and $|S_{21}|$, and calculated SE_r, SE_a and SE_t of the 4 fabrics along with a hat with different silver fiber ratios at five discrete frequencies are demonstrated in Table 2. SE_r, SE_a and SE_t values are presented in dB to better examine shielding effectiveness properties of samples. Besides, variation of SE_t values of samples with frequency at which each sample demonstrates the highest SE_t values is given Fig. 2.

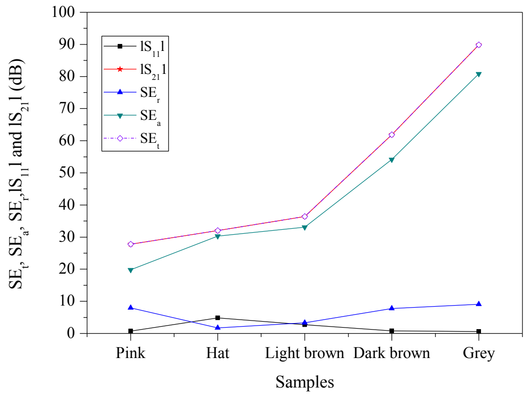

Figure 2. The variation of SE_t, SE_r, SE_a, $|S_{11}|$ and $|S_{21}|$ values of samples at five specially selected frequencies (in the greatest shielding effectiveness frequencies) (the selected frequencies are 0.08103 GHz for pink fabric, 2.277 GHz for hat, 2.532 GHz for light brown fabric, 1.932GHz for dark brown fabric and 0.927GHz for grey fabric).

Table 2. Magnitude of reflection S-parameter $|S_{11}|$, magnitude of transmission S-parameter $|S_{21}|$, reflection losses (SE_r), absorption (transmission) losses (SE_a) and total shielding effectiveness (SE_t) values of the samples

Samples	$\|S_{11}\|$	$\|S_{21}\|$	SE_r	SE_a	SE_t	Frequencies
Pink	0.7526	27.7838	7.9829	19.8010	27.7838	0.08103
Hat	4.8638	32.0352	1.7154	30.3198	32.0352	2.277
Light brown	2.7493	36.3832	3.2879	33.0953	36.3832	2.532
Dark brown	0.8011	61.8908	7.7356	54.1553	61.8908	1.932
Grey	0.5751	89.8769	9.0646	80.8123	89.8769	0.927

As seen from Table 2, when $|S_{11}|$ values of the samples are examined, it is noted that no systematic relationship between $|S_{11}|$ with silver fiber additives in the fabrics is found. However, when $|S_{21}|$ values of the samples are compared, a systematic relationship between $|S_{21}|$ and the amount of silver fiber additives to the fabrics is observed. As the fiber amount increases, so does the value of $|S_{21}|$. A linear relationship was found between SE_r (SE_a and SE_t) and the amount of silver fiber added to fabrics. As seen from Fig. 2, while SE_a and SE_t show the same change in samples at certain frequencies, the values of SE_r and $|S_{11}|$ generally tend to approach zero. Therefore, it can be said that the SE_r reflection efficiency value is lower in the samples with high silver fiber ratio than the others.

Besides, measured |S21| and |S11| (along with SE_a values) of the samples are presented in Figs. 3-7.

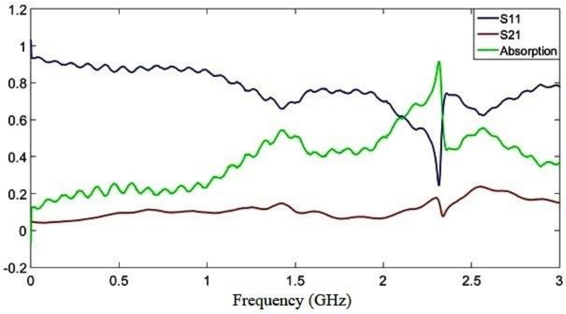

Figure 3. Frequency dependence of the absorption and reflection parameters of the pink fabric with the absorption effectiveness (|S11| and |S21| in the figure labels).

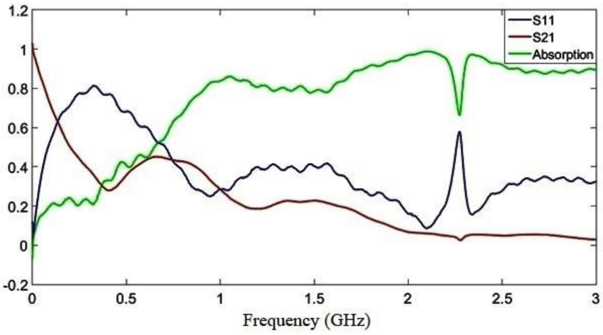

Figure 4. Frequency dependence of the absorption and reflection parameters of the hat sample with the absorption effectiveness (|S11| and |S21| in the figure labels).

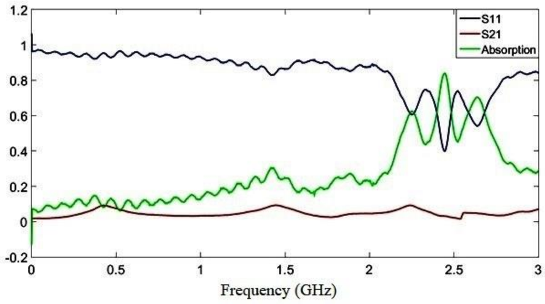

Figure 5. Frequency dependence of the absorption and reflection parameters of the light brown fabric with the absorption effectiveness (|S11| and |S21| in the figure labels).

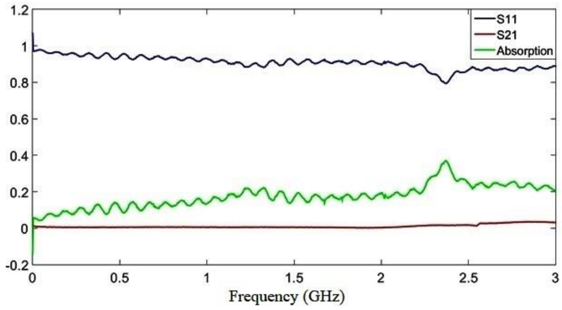

Figure 6. Frequency dependence of the absorption and reflection parameters of the dark brown fabric with the absorption effectiveness (|S11| and |S21| in the figure labels).

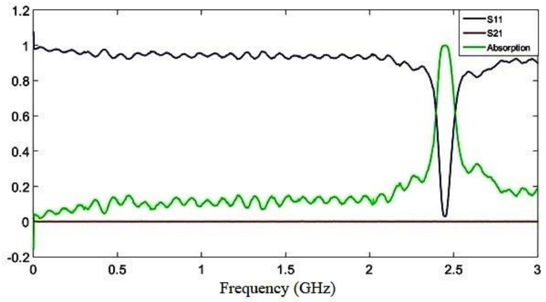

Figure 7. Frequency dependence of the absorption and reflection parameters of the grey fabric with the absorption effectiveness (|S11| and |S21| in the figure labels).

As seen from Figs. 3-7, all samples have relatively smaller |S21| values, indicating that they have good absorbing characteristics. Besides, there are some certain frequency points at which SE_a gains its highest value. Furthermore, as seen from Table 2 and Fig. 2, the smallest shielding effectiveness (27.7800 dB) corresponds to the pink colored fabric, while the highest shielding effectiveness (89.88 dB) is for the grey colored fabric. This may be because the structure of the pink fabric is 60% silver fiber and 40% polyester, and the gray fabric is 100% silver fiber. According to the values in Tables 2 and 3, it can be said that fabrics with high silver fiber content show more shielding effectiveness than fabrics with low silver fiber content, provided that the properties of the fabrics are the same.

Finally, the total shielding effectiveness graphs of the samples between 30 kHz and 3GHz frequencies are given in Figs. 8-12.

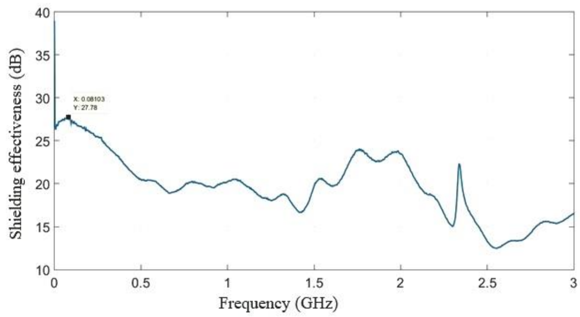

Figure 8. Frequency dependence of total shielding effectiveness of the pink colored sample between 30 kHz and 3 GHz frequencies.

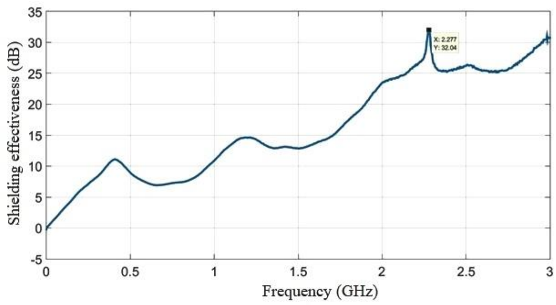

Figure 9. Frequency dependence of total shielding effectiveness of the hat sample between 30 kHz and 3 GHz frequencies

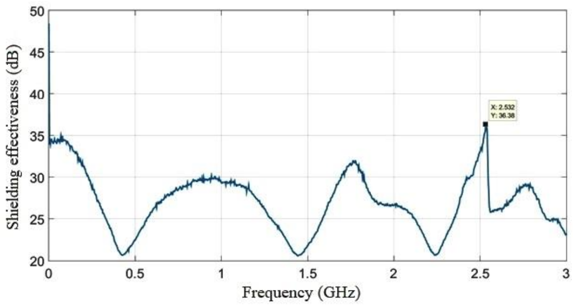

Figure 10. Frequency dependence of total shielding effectiveness of the light brown sample between 30 kHz and 3 GHz frequencies

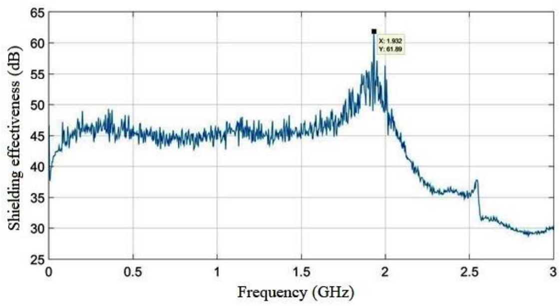

Figure 11. Frequency dependence of total shielding effectiveness of the dark brown sample between 30 kHz and 3 GHz frequencies

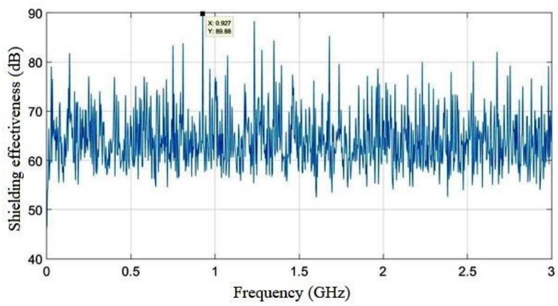

Figure 12. Frequency dependence of total shielding effectiveness of the grey sample between 30 kHz and 3 GHz frequencies

As seen from Figs. 8-12, the total shielding efficiency of the samples increases with an increase of the silver fiber content provided that the other properties of the samples are the same. Consequently, it can be said that the shielding efficiency changes in direct proportional with the silver fiber content added to the fabrics. In addition, it can be said that the way the fabrics are produced (weaving or knitting) also affects the shielding efficiency.

Finally, it should be pointed out that $|S_{11}|$ and $|S_{21}|$ measurements are normally carried out by a free-space measurement system. Due to limited facility in the microwave laboratory, measurements were implemented by a coaxial-line measurement system (see Fig. 1). Considering the fact that SE_r, SE_a, and SE_t values of samples with different silver contents are mutually compared, our results give relative information about SE_r, SE_a, and SE_t of the fabric samples.

4. Conclusion

As a result of the measurement; at certain frequencies, the sample with the smallest $|S_{11}|$ reflection capacity among the examined silver-added fabrics is the grey colored fabric, while the sample with the largest $|S_{11}|$ reflection capacity is the hat sample. Similarly, the sample with the largest $|S_{21}|$ absorption capacity (100% silver fiber added) is the grey colored fabric, while the sample with the smallest $|S_{21}|$ absorption capacity is the pink fabric sample. While the largest SE_t total shielding efficiency value is calculated for the grey colored fabric sample, the smallest SE_t value is noted for the pink colored fabric sample. Considering that SE_t is generally defined as the success of the samples in reducing the electromagnetic wave coming from outside, it can be concluded that the grey colored fabric reduces the incoming electromagnetic waves the most and the pink colored fabric the least. As can be seen from Table 2 and Figs. 3-12, no systematic relationship could be detected between the $|S_{11}|$ reflectance capacities of fabric samples and the silver fiber ratios added to the fabrics at certain frequencies. However, an approximately linear relationship is found between the $|S_{21}|$ absorption capacity, SE_a absorption effectiveness and SE_t total shielding effectiveness of the samples and the silver fiber ratios added to the fabrics. It is found that shielding effectiveness of the samples is approximately direct proportional to the silver fiber content added to the samples and also depends on the production methods (weaving or knitting) of the fabrics. The production of fabrics with higher shielding effectiveness can be achieved by adding more silver fiber ratio while producing fabrics, and by producing them in such a way that there is no space between silver threads, even at a microscopic level.

Ethics in Publishing

There are no ethical issues regarding the publication of this study.

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