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Reflecting and Polarizing Properties of Conductive Fabrics in Ultra-High Frequency Range

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The system based on ultra-wide band (UWB) signals was employed for qualitative estimation of attenuating, reflecting and polarizing properties of conductive fabrics, capable to prevent local static charge accumulation. Pulsed excitation of triangle monopole antenna of 6.5 cm height by rectangular electric pulses induced radiation of UWB signals with spectral density of power having maximum in ultra-high frequency (UHF) range. The same antenna was used for the radiated signal receiving. Filters and amplifiers of different passband were employed to divide UHF range into subranges of 0.3 – 0.55 GHz, 0.55 – 1 GHz, 1 – 2 GHz and 2 – 4 GHz bands. The free space method, when conductive fabric samples of 50 x 50 cm^2 were placed between transmitting and receiving antennas, was used to imitate a practical application. Received wideband signals corresponding to the defined range were detected by unbiased detectors. The fabrics made of two types of warps, containing different threads with conductive yarns, were investigated. It was estimated attenuation and reflective properties of the fabrics when electric field is collinear or perpendicular to thread direction. In the UHF range it was revealed good reflecting properties of the fabrics containing metallic component in the threads. The system has advantages but not without a certain shortcoming. Adapting it for specific tasks should lead to more effective usage, including yet unused properties of the UWB signals.

Keywords: EM background, compact systems based on UWB EM pulses, wideband antennas, UWB signals, conductive fabrics.

1. INTRODUCTION

Nowadays spreading application of electromagnetic (EM) radiation from radio to millimeter waves leads to increase of artificial background of EM fields [1]. Reaction of bio objects on exposure to ultra-high frequency (UHF) and super-high frequencies are complex and hardly predictable [2]. There are even reports showing that low intensity UHF waves show positive results on suppression of tumor growth [3]. This complexity renews both medical investigations and search for new EM protecting materials like conducting plastics, resistive thread structures and fabrics with conductive additives for the control of the background levels of EM fields.

It is known that textile containing conductive threads and fibers are long time widely used to control EM environment also including secrecy for military purposes. Today success in materials science and nanotechnology improves this quality of the textiles to a higher level.

The EM properties of the fabrics can be fully researched employing modern technical set-ups. They include super wideband antennas capable of receiving different ultra-wide band (UWB) signals [4] and super wideband digital oscilloscopes having up to 50 GHz passband. These lead to easy manipulations with the signals. However in everyday application – obtaining certain information about the objects in the line of sight – the setups must be simplified. Miniaturization and lower cost will be desirable qualities if mass production and everyday usage is considered.

Other useful qualities include multi functionality and occupation of smaller physical volume. One of the examples is reconfiguration of antennas either mechanically or electronically for example using diodes to change current distribution or effective antennas geometry [5]. In paper [6] it was proposed method for generating UWB EM pulses using pulsed excitation of small size antennas by short high voltage electrical pulses. The radiated electromagnetic pulses have spectral harmonics above 22 GHz, but relatively long duration, about 20 – 25 ns. Such pulses can be attributed to pulses with large base *B*, where *B* is product of signal bandwidth on its duration and it is much more than 1. For registration it was applied signal detection by unbiased broadband detectors. Such systems lack precision, but the obtained data will be sufficient to perform analysis in non-scientific applications. Now similar systems are investigated for radio frequency identification [7] and for telemetry in medicine, using miniature implantable antennas [8].

In this work system employed the large *B* signals, which are transmitted and received by the same small sized antennas. The lack of receiving antenna reconfiguration is circumvented by using filters, amplifiers and different detectors to change working frequency range. The UHF range was divided into the subranges of 0.3 – 0.55 GHz, 0.55 – 1 GHz, 1 – 2 GHz, 2 – 4 GHz bands. The aim of the work is to establish the ability of such system to obtain definite conclusions about the attenuating and reflective properties of the fabrics with conductive yarns for preventing storage of static charge [9].

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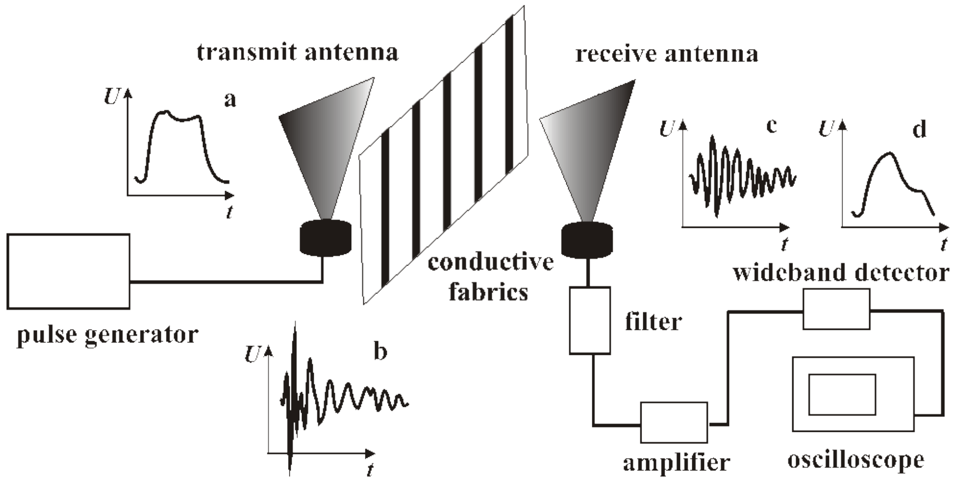

Fig. 1. Schematic diagram of transmit and receive arrangement using small sized antennas and large *B* signals. Signal plots show their transformation during employing for investigation of EM properties of conductive fabrics: a – exciting high voltage electrical pulse; b – radiated ultra-wideband signal of large *B*; c – received wideband signal corresponding to the defined subrange; d – oscillogram after the detection

2. EXPERIMENTAL

2.1. Samples of the fabrics

The conductive fabrics with two types of warps were used in the experiments. Cotton (35 %) – polyester (PES) (65 %) rip-stop weave woven fabric was the first warp (F1) and Aramid rip-stop and twill weave was the second one (F2). The first warp had two types of conductive threads, one of them Shieldex® conductive yarn (twist factor $Z = 300\ m^{-1}$), which consists of two twisted components: PES threads and PES silver coated threads (type I). Another type of conductive thread for this warp was S-Shield PES® whose yarns consist of PES fibers with stainless steel staples (INOX) – 80 % PES and 20 % INOX (type II).

Samples with parallel conductive treads are F1(1), F1(1a) (threads of type I; distance 10 mm and 15 mm correspondingly) and F1(2), F1(2a) (threads of type II; distance 10 mm and 15 mm correspondingly). Samples F1(3) have mesh of $10 \times 10\ mm^2$ cells (threads of type II), F1(3a) mesh of $10 \times 5\ mm^2$ cells (threads of type II; vertical direction is along broader distance) and F1(4) with mixed threads mesh $10 \times 10\ mm^2$ cells (type I and type II threads; vertical is along threads of type I), F1(4a) $5 \times 10\ mm^2$ cells (threads of type I and vertical direction is along broader distance).

Aramid samples contain yarns interweaved in the warp. The denoted as F2(1) are ones with 1 % of antistatic stainless steel yarn while others denoted as F2(2) are with 2 % of antistatic thin carbon yarn. These fabrics have visible direction along the warp threads only. The dimensions of all samples were $50 \times 50\ cm^2$. During the measurements the samples were stretched on a wooden frame.

2.2. Simple experimental arrangement based on the large *B* signal

Schematic diagram of the experimental set-up using the same receive and transmit antennas of triangular shape and of 6.5 cm in height is presented in Fig. 1. High voltage electrical pulse is generated by a pulse generator, rise time of about 1 ns and amplitude during investigations being 230 – 250 V (see plot a). This pulse excites the transmit antenna resulting in ultra-wideband pulse generation [6]. The radiated large *B* signal (see plot b), is passing through the conductive fabrics and is received by the receive antenna. The received signal filtered by both filter and amplifier serving as a filtering device, forming the signal of corresponding subrange (see plot c). Two types of unbiased wideband detectors, whose properties depend on the subrange, generate electric signals to the oscilloscope (see plot d).

The UHF range was divided into the subranges: the first – 0.3 – 0.55 GHz, the second – 0.55 – 1 GHz, the third 1 – 2 GHz, the fourth – 2 – 4 GHz. The experiments were taken in the laboratory. The generator and the transmit antenna must be connected by a short cable. Distance between the antennas was 2.5 – 3 meters. The samples were placed at the middle of the distance between the antennas. The devices were clothed by EM absorbing materials to reduce parasitic reflections. Directivity of the conductive threads in the F1 textiles during the measurements either matches vertical electric field vector or is perpendicular to it. Corresponding to the directivity the results are denoted as vertical Vr and horizontal Hr. During the measurements of reflection results were compared with the reflection from metallic surface of $50 \times 50\ cm^2$. Effective dielectric permittivity of the samples was measured using method of parallel plate capacitor [10] applying frequency of 1 kHz.

This configuration increase difficulties comparing with measurement using transmission systems, especially on reflection, but it is similar to that one, which can be used in practical applications. Some difficulties arise during reflection measurements, when angles are about 45°, because of appearance of residual part of main signal due to quasi-circular pattern. To verify results on reflection we repeat measurements at higher directivity and smaller angles using pulsed excitation of horn antenna.

3. EXPERIMENTAL RESULTS

It is worth noting that unlike solids, conductive parameters of the soft fabrics will simply vary in values depending on their condition, for example if stretched or squeezed.

Table 1. Amplitude reduction of the detected EM signal when transmitted through the samples F1(1) and F1(2)

Attenuation, dB					
		0.3 – 0.55 GHz	0.55 – 1 GHz	1 – 2 GHz	2 – 4 GHz
F1(1)	Vr	5.35 ± 0.32	5.93 ± 0.34	5.51 ± 0.25	4.44 ± 0.29
	Hr	2 ± 0.27	1.57 ± 0.26	1 ± 0.5	0.54 ± 0.1
F1(1a)	Vr	3.74 ± 0.2	5 ± 0.3	4.44 ± 0.22	3.74 ± 0.2
	Hr	2.16 ± 0.17	1.67 ± 0.21	0.45 ± 0.14	0.31 ± 0.1
F1(2)	Vr	3.41 ± 0.26	5 ± 0.23	5.85 ± 0.26	6.2 ± 0.27
	Hr	1.41 ± 0.2	1.62 ± 0.21	0.45 ± 0.14	0.31 ± 0.1
F1(2a)	Vr	3.54 ± 0.2	4.15 ± 0.35	3.88 ± 0.27	3.61 ± 0.26
	Hr	1.26 ± 0.15	0.54 ± 0.1	0.36 ± 0.14	0.27 ± 0.08

Table 2. Amplitude reduction of the detected EM signal after transmitted through the samples F1(3) and F1(4)

Attenuation, dB					
		0.3 – 0.55 GHz	0.55 – 1 GHz	1 – 2 GHz	2 – 4 GHz
F1(3)	Vr	1.5 ± 0.21	3 ± 0.31	3.35 ± 0.26	5 ± 0.3
	Hr	1.62 ± 0.26	2.73 ± 0.24	3.35 ± 0.26	4.73 ± 0.3
F1(3a)	Vr	2.16 ± 0.22	2.5 ± 0.29	3 ± 0.24	4.15 ± 0.28
	Hr	6 ± 0.35	6.2 ± 0.35	6.94 ± 0.38	10.8 ± 0.6
F1(4)	Vr	3.5 ± 0.26	5 ± 0.31	6.2 ± 0.35	6.9 ± 0.38
	Hr	6 ± 0.34	6 ± 0.34	4.88 ± 0.3	
F1(4a)	Vr	2 ± 0.22	2.98 ± 0.24	4.29 ± 0.28	5.2 ± 0.32
	Hr	6.38 ± 0.45	3.61 ± 0.26	2.85 ± 0.24	2.27 ± 0.23

Table 3. Amplitude reduction of the detected EM signal after transmitted through and reflected from the sample F2(1)

Attenuation, dB					
		0.3 – 0.55 GHz	0.55 – 1 GHz	1 – 2 GHz	2 – 4 GHz
F2(1)	Vr	12.77 ± 0.7	13.56 ± 0.8	10 ± 0.54	17.1 ± 1.25
	Hr	11.7 ± 0.67	14.9 ± 1	10.46 ± 0.6	20.9 ± 2
Reflection, dB					
F2(1)	Vr	12.77 ± 0.6	9.1 ± 0.37	9.9 ± 0.41	16 ± 0.8
	Hr	11.1 ± 0.47	8.2 ± 0.33	8.9 ± 0.36	15.4 ± 0.77

Measurements of effective dielectric permittivity reveal that for F1 samples ε lies in range 1.4 – 1.6 and for F2 ones is range 2.2 – 2.5. Stronger squeezed samples show higher values of the permittivity. Resistance of conductive threads of 40 cm length is equal to 0.6 – 0.8 kΩ and 2.5 – 2.8 kΩ for type I and type II correspondingly.

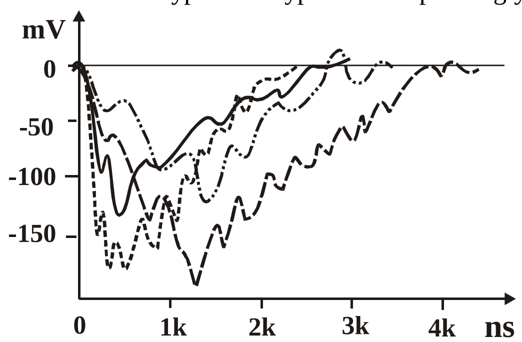

Fig. 2. Oscillograms of detected wideband signals corresponding to the subranges in the absence of loss. Wide dashed – 1st range, k = 10; narrow dashed – 2nd range, k = 4; full curve – 3rd range, k = 2; dash-dotted – 4th range, k = 1

Oscillograms of the beginning part of detected wideband signals without induced loss corresponding to the subranges are presented in Fig. 2. The voltage measurements were taken in the lowest point of each oscillogram. The residual, smaller amplitudes parts of detected signal were not used in the measurements. Non-uniformity of the oscillograms induced by interference also induced some difficulties during estimation of the measurement results.

Results on attenuation during transmission through the samples F1(1) and F1(2) are presented in Table 1 and results on the attenuation through the samples F1(3) and F1(4) are presented in Table 2. They include results when electric field is collinear and perpendicular to vertical samples direction. Reflection measurements at angles of 45° of these F1 samples indicate on presence of EM absorption. The repeating measurements were made using transmit horn antenna of higher directivity, excited by the electrical pulses. These reflection measurements show the absence of absorption in the F1 samples and therefore all attenuation is induced by reflection.

Results on the attenuation of F2(1) samples are presented in Table 3, but presented reflection values are obtained using the horn. For the F2(2) samples, with threads including antistatic carbon yarn it is not observed their any influence on EM radiation in UHF range.

4. DISCUSSION OF THE RESULTS

Analysis of the Table 1 data shows that in the cases when electric field vector is collinear to the conducting threads, the signal is attenuated stronger for all subranges comparing to when the vector is perpendicular. Despite the wavelengths being relatively large, increase between threads on 0.5 cm results in reduction of attenuation in most cases and certainly does not increase in any. In the F1(2) row it is seen a dependence of attenuation on frequency when increase in the latter results in the increase of the former. The same is no longer true for F1(2a) when the distance between the threads is larger.

Results in the Table 2 obtained from the fabrics containing net structures. Symmetric nature of the structure in F1(3) case results in the same attenuation values for both directions of the thread. Increase of attenuation due to the thread density increase, reducing from 1 cm to 0.5 cm (see second row for F1(3a)) is also observed. F1(4, 4a) cases, where both types of the threads are present, provide mixed results and making definite conclusions is not so feasible. In the above described cases we observe that overall reflection of these fabrics in the UHF range is high enough. As it was mentioned, conductive fabrics of another properties F2(1) (see Table 3) have visible direction only along the warp thread. Turning the sample on 90° however somewhat increases the attenuation, which most probably resulted from changes of the unknown conductive yarn directivity. This fabric is similar to one with fluffy conducting yarn, used to increase absorbing and scattering of EM radiation. Surprisingly there were no signs of absorption when electric field vector is parallel to the warp thread, and only when they became perpendicular some absorption was observed. As it follows from the Table 3 data, EM reflection ability of this fabric is high. When the researched qualitative EM properties of all investigated fabrics were established, we can now consider the system viability in practical applications.

One can understand that quasi-circle pattern of transmit antenna hinders consistent reflection observation. So higher directivity of the transmit antenna is more desirable for that aim. It can be achieved by a known technique. On the other hand frequencies above 4 GHz were not used because of existence of linear-like decrease of the power density up to 16 GHz. It is known that the plot maximum of the spectral density of power can be shifted and also correction of the plot non-uniformities can be regulated, both by coating on the surface of antenna thin resistive or nanometric thin metallic films [11].

Problems of wideband signal detection were broached in paper [6]. The detection depends on available input power and in our case this value depends on amplification of UWB signal. The power of the radiated signal is sufficiently high to allow detection without amplifier, but doing so increases the artificial background while the influence of such UWB signal on human body being unknown. The works of creating both sensitive broadband devices [12] and less sensitive ones [13] are continued. In detection of super wideband signals the positioning matching network between the amplifier and detector is of great importance. This problem is relevant to design systems for wireless power transmission. So the system could be adapted to specific conditions of investigations and could also be at first tuned using precise arrangement.

5. CONCLUSIONS

The system based on large *B* signals, which have maximum spectral density of power in UHF range, was used to estimate EM properties of the conductive fabrics. It was obtained that ordinary antistatic fabrics with metallic yarn can reflect EM radiation in the UHF range up to 16 dB, while the fabrics with antistatic carbon yarn are not reflecting in this range at all. Also it is possible to control polarization of transmitted EM radiation via conductive threads direction or ordering directivity of conducting yarn. Possibility of changing system parameters to match specific condition is considered and welcomed.

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