CIRCULAR SLOT ANTENNA ARRAY PRINTED ON 3D TEXTILE SUBSTRATE

Jan Špůrek

Doctoral Degree Programme (1), FEEC BUT

E-mail: xspure01@stud.feec.vutbr.cz

Supervised by: Zbyněk Raida

E-mail: raida@feec.vutbr.cz

Abstract: In the paper, the design of an antenna array consisting of circular slots is presented. Since the antenna is expected being integrated into textile upholstery of a vehicle, a 3D textile material is considered as a substrate in the design. Metallic layers are screen-printed by a silver paste. The array is fed by a textile integrated waveguide which walls are sewed by a conductive thread. The array is designed for the center frequency of the band-group VI (8 GHz) of ultra-wideband communication channels. At the center frequency, the measured realized gain is about 10 dB, and the measured axial ratio equals to 4. The array operates with right-hand circular polarization. The design is verified by measurements.

Keywords: Antenna arrays, screen printing, slot antennas, textile technology, wireless access in vehicular.

1 INTRODUCTION

Two dominant trends can be observed in vehicular industry: (1) the weight of cars and small airplanes is reduced to meet stricter emission limits, and (2) integrated systems are exploited to minimize fabrication and assembling costs.

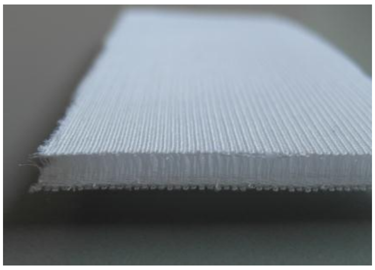

Figure 1: 3D textile material produced by SINTEX company, www.sintex.cz.

The weight of a vehicle can be reduced by replacing selected cabling by wireless connection. In order to improve efficiency of wireless power transfer, a 3D textile material can be used to guide electromagnetic waves along a conductive skin of a vehicle [1].

Since the space between surfaces of the 3D textile material is dominantly air-filled (the thickness of the polyester threads has a minor effect), properties similar to conventional air-filled substrates like the FoamClad can be expected. Exploiting the transmission line method [2] at 8 GHz, the dielectric constant $\varepsilon_r = 1.4$ of the 3 mm thick 3D fabric was measured.

The 3D textile material can be used as car upholstery. Thanks to its structure, the 3D fabric can provide thermal and mechanical isolation simultaneously. Integrating electronics to the 3D fabric, both the weight of a vehicle can be reduced and an integrated solution can be obtained.

In the paper, we describe an antenna array integrated into a 3D textile material to be used as textile upholstery of a vehicle. The design of the antenna is based on conventional approaches. The array of the circular slots is fed by textile-integrated power dividers (TIPD). The antenna operates with circular polarization in order to ensure a reliable wireless connection between the roof of a vehicle and passenger's devices.

The design of the proposed antenna array structure is described in Section 2. The antenna was designed using CST Microwave Studio neglecting dielectric losses and approximating metallic components by perfect electric conductor. The antenna was manufactured by printing metallic layers and by sewing the walls of TIPD. Simulated and measured results are compared in Section 3. Section 4 concludes the paper.

2 ANTENNA ARRAY DESIGN AND FABRICATION

The design of the array builds on the previous work of the author [6]. The antenna is intended to be integrated into textile upholstery covering the inner surface of a vehicle roof. In order to minimize fabrication costs, the antenna is going to be fed by a TIW. The layout of the designed antenna is shown in Fig. 2. At the antenna input, a TIW to coplanar waveguide (CPW) transition is exploited to feed the antenna using a coaxial connector [3]. Then, the TIPD excites the antenna elements with the same amplitude and phase [4].

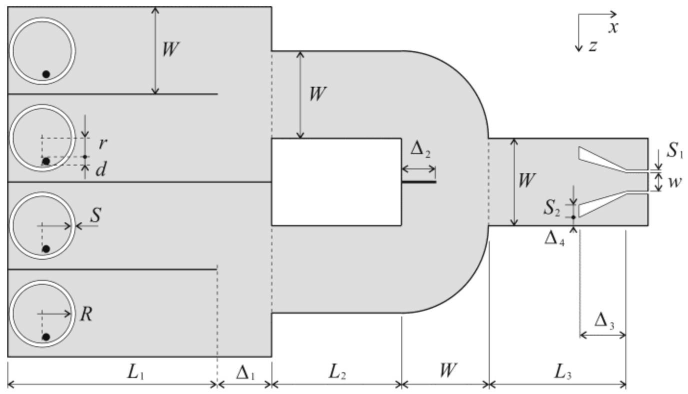

Figure 2: Layout of the designed antenna array

The antenna array consists of four circular slots. The center of the slots is placed in the maximum of the electric field intensity in TIW that corresponds to about $\lambda_g/4$ from the short of the TIW; λ_g is the guided wavelength in the TIW at the center frequency of 8 GHz. Shorting pins inside the antenna elements control the polarization and impedance matching of the circular slots [5], [6]. The parameters of the designed antenna are summarized in Table 1. Optimization has been performed to obtain the values. The total width of the antenna is 4W = 80 mm and the total length equals to $L_1 + \Delta_1 + L_2 + W + L_3 = 137$ mm.

In the initial step of the design, metal solid walls of the TIW were considered and perfect electric conductivity of all metallic surfaces was assumed. The thickness of the TIW is identical with the thickness of the 3D textile substrate (h = 3.0 mm). The TIW is filled by a dielectric material of the relative permittivity $\varepsilon_r = 1.4$. The dielectric losses are neglected.

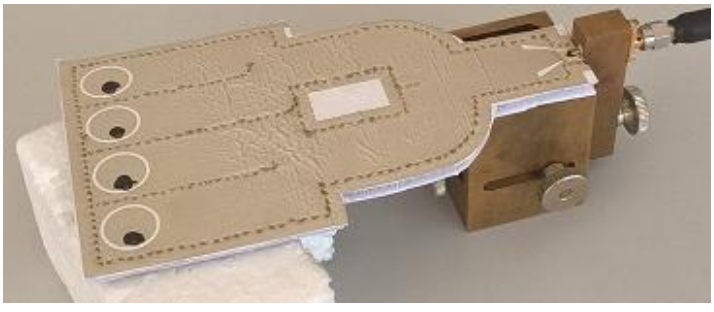

Figure 3: Photograph of the designed antenna array

Finally, metal solid walls of TIW were replaced by periodic rows of shorting pins. The diameter of the shorting pins dp = 1.0 mm was equal to the diameter of a conductive thread Shieldex® 235/34 dtex 4-ply HC+B used for sewing walls. The distance between neighboring pins Δ_p = 2.0 mm equals to distance of two neighboring stitches [7].

Symbol	Description	Value
W	separation of TIW walls	20.0 mm
L_1	length of terminal resonators	47.0 mm
Δ_1	output divider –transversal segment width	10.0 mm
L_2	input divider – length of output arms	30.0 mm
Δ_2	input divider – transversal cross wall width	9.0 mm
L_3	length of input TIW	30.0 mm
Δ_3	length of CPW-TIW transition	11.0 mm
w	width of input CPW	4.5 mm
S_1	slot width at input of CPW-TIW transition	0.2 mm
S_2	slot width at output of CPW-TIW transition	2.5 mm
Δ_4	distance of CPW-TIW transition from wall	2.0 mm
S	width of slot of antenna elements	1.0 mm
R	inner radius of antenna elements	6.8 mm
d	diameter of shorting pins of antenna elements	1.6 mm
r	distance of shorting pins from antenna center	5.1 mm

Table 1: Parameters of the designed antenna array

The photograph of the fabricated antenna array is shown in Figure 3. Before the screen printing, the top and bottom surface of the 3D fabric were covered by the Digiflex-Master foil produced by Alphaset. In this way, the surface of the textile substrate was smoothened and a potential penetration into the textile was eliminated. Metallic surfaces were screen-printed by semi-automatic printer Aurel C880 using a polymer conductive paste ESL 1901-S.

In order to ensure sufficient quality of the metallic surfaces, screen-printing of the paste was three-times repeated. The paste was cured at the temperature 80°C for 30 minutes. A higher temperature could damage the textile substrate.

3 SIMULATIONS AND MEASUREMENTS

The reflection coefficient of the designed antenna array is shown in Fig. 4. Resonance of the simulated antenna array appears at 8.02 GHz, the resonance of the fabricated antenna is shifted to 8.10 GHz that corresponds to the error of 2%. The shift was caused by fabrication inaccuracy.

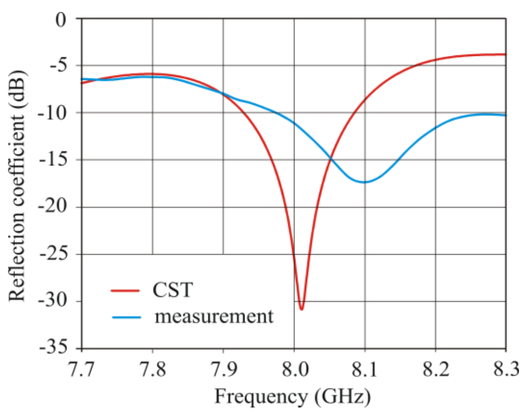

Figure 4: Reflection coefficient at the input of the antenna array

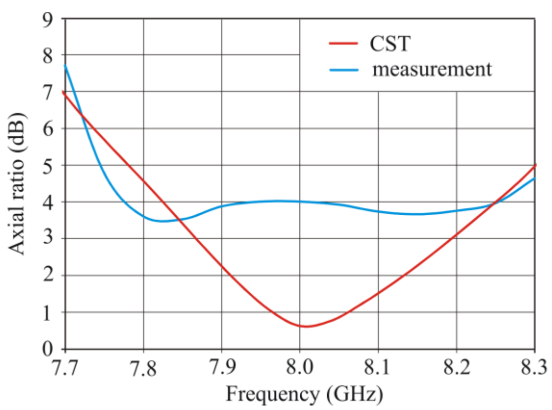

Figure 5: Axial ratio of the antenna array in the main lobe direction

The simulated antenna array operates with |S11| < -10 dB within the band from 7.93 GHz to 8.08 GHz. The measured operation band is from 7.95 GHz to 8.25 GHz. A wider bandwidth of the prototype is caused by losses which were neglected in simulations.

Polarization properties of the designed antenna are characterized by axial ratio (AR) in Fig. 5. At the operation frequency, the simulated and measured AR is 0.5 dB and 4.0 dB, respectively. In order to reach a better AR and impedance matching at the operation frequency, the fabrication process of the antenna needs further optimization. Especially, the sewing of the TIW has still an insufficient accuracy because it is done by a hand.

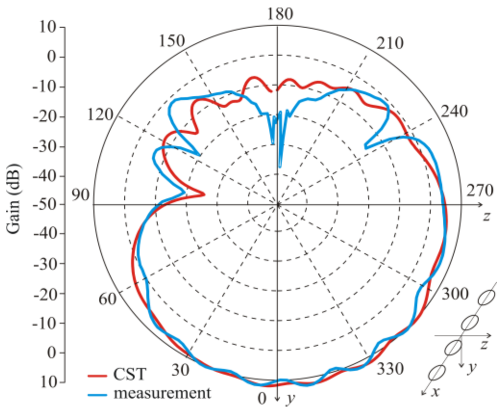

Figure 6: Radiation pattern in YZ plane

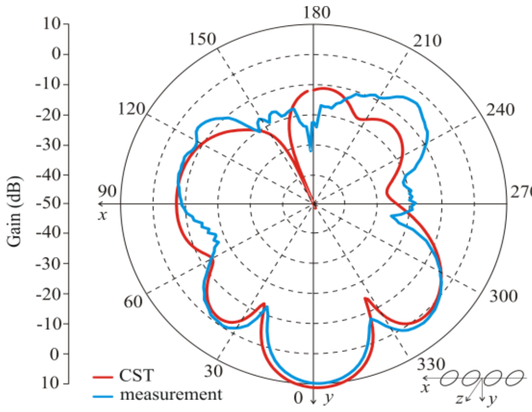

Figure 7: Radiation pattern in XY plane

Parametric analysis shows that the design is sensitive to the position and manufacturing of shorting pins of antenna elements also. Inaccuracy of the location of shorting pins therefore contributes to differences between measurements and simulations.

The radiation patterns of the antenna are shown in Figure 6 and 7. The main lobe with maximum of the gain of 10 dBi is oriented perpendicularly to the surface of the substrate. The 3 dB beam width is 25° in the XY plane and 93° in the YZ plane. Thus, the whole inner space of a vehicle can be covered by one properly oriented antenna array. On the other hand, circular polarization is achieved close to main-lobe direction only.

4 SUMMARY

In the letter, the circular slot antenna array printed on a 3D textile substrate is designed for the center frequency of the band-group VI (8 GHz) of ultra-wideband communication channels. The right-handed circularly-polarized antenna array can be integrated into textile upholstery of a vehicle. Thus, the whole inner space of the vehicle can be irradiated.

Thanks to the presented fabrication technology, components of in-vehicle sensor and communication systems can be integrated into textile upholstery which brings several advantages:

- Since the systems including cabling are a part of textile upholstery, the weight of the vehicle is not increased.
- Since the systems are printed and sewed, manufacturing of systems can be simply customized.
- Since the systems are a part of upholstery, assembling is simplified and manufacturing costs are reduced.

In order to make the technology exploitable in commercial applications:

- Losses in textile integrated structures have to be reduced.
- Mechanical, thermal and electrical stability has to be ensured.

- Durability and maintenance issues have to be solved.
- Electromagnetic compatibility and hygienic standards have to be met.

These problems are being solved by an ongoing research.

ACKNOWLEGMENTS

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