RECONFIGURABE WAVEGUIDE DIVIDER

Miroslav Cupal

Doctoral Degree Programme (3), FEEC BUT

E-mail: xcupal02@stud.feec.vutbr.cz

Supervised by: Zbyněk Raida

E-mail: raida@vutbr.cz

Abstract: The design and implementation of the textile integrated waveguide (TIW) switch for ISM band is presented. The traveling electromagnetic wave is controlled by conductive posts with a circular slot. PIN diodes are used for switching electromagnetic wave to two directions. The simulations results are presented as parametric analysis.

Keywords: TIW, textile integrated waveguide, divider, reconfigurable, textile.

1 INTRODUCTION

The substrate integrated waveguide (SIW) technology is a common solution for the construction of microwave circuits and antennas. Continuous research of SIW brings new possibilities to employ it as different components in a communication system.

Substrate integrated waveguides are widely used for antennas, antenna feeding networks, reconfigurable filters or phase shifters for phased antenna arrays [1], [2], [3]. Recently a lot of attention is put on designing highly customized systems in order to minimize losses, speed up communication or increase the quality of the service. It can be achieved by a combination of modulation, channel coding, exploitation of different frequency bands, by an antenna arrays support beam steering [4] or by utilization of different radiation properties (omnidirectional vs. directional or different polarization). There are tunable SIW components for new systems, applications as tunable phase shifters, tunable filters and reconfigurable antennas and single pole double throw (SPDT) switches [5].

2 IDEAL DIVIDER AND PARAMETRIC ANALYSES

The textile integrated switch was designed for the knitted, three-dimensional fabric (the 3D textile) Sintex 3D 041 with relative permittivity $\varepsilon_r = 1.22$, tg$\delta = 0.002$ and the height 3.41 mm. The 3D textile can be used as a part of upholstery in cars or planes.

2.1 IDEAL DIVIDER

The SIW structure in the divider design was approximated by a conventional waveguide of adequate dimensions depicted in Fig. 1. The design of the divider is based on a common T-junction with two shorting pins in each output branch. The conductive posts are connected to the top and bottom layer of the TIW by switching diodes. Each branch can be opened or closed by disconnecting or connecting the diodes in that branch. The number of conductive posts is a compromise between an ideal density of the posts (rules for the SIW design) and the number of switching diodes. This divider was simulated and optimized to obtain the best transmission to the open branch, while the other branch is closed. The approximation of the TIW by a waveguide speeds up initial simulations and gives a good view on the functionality of the structure.

The divider was designed for the ISM band 5.8 GHz and all numerical values in the paper are related to this frequency. The transmission coefficient in the open direction is −0.4 dB, the reflection coefficient at input port is −18.1 dB. While the transmission in the closed direction is −16.13 dB and the isolation between two output ports is 17.3 dB. The frequency responses are shown in Fig. 1.

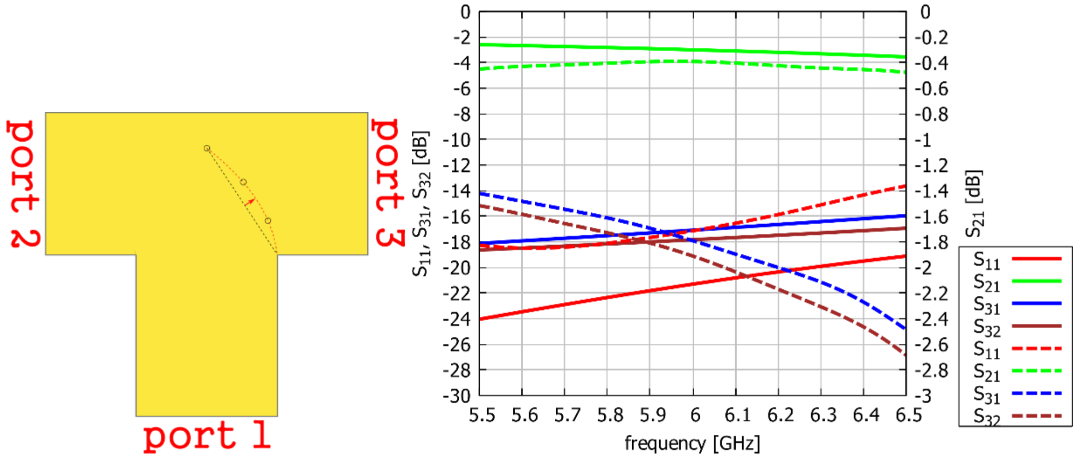

Figure 1: TIW approximated by a waveguide divider and its frequency response of the S-parameters divider with one closed branch (full) and with two closed branches (dots).

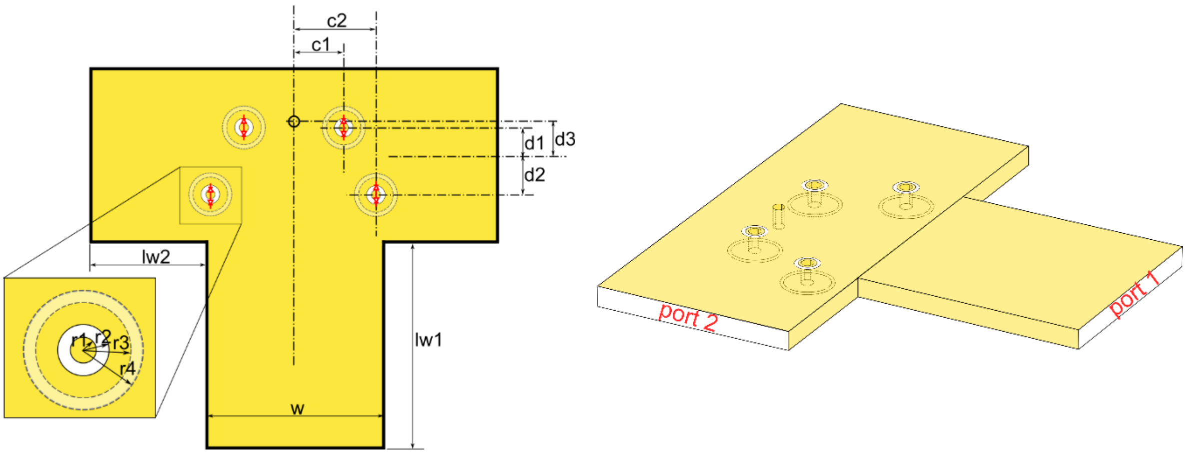

Figure 2: TIW switch with dimensions and PIN diodes.

Reconfigurable walls are created by conductive posts connecting the top and the bottom layer of the TIW. The posts are separated from top and bottom metal layer by circular slots (OFF-state) and the spots are connected to the top layer by PIN diodes on ON-state. The design constraints that were taken into consideration were:

• The size of the ring slots between the conductive layer and conductive post have to be as small as possible and they should be identical on the top and the bottom layer.

• The conductivity between the posts and the conductive top layer must be as high as possible in ON-state and as low as possible in OFF-state.

• Increasing the number of PIN diodes on the top layer enhances the performance of the divider, however higher number of diodes raises the costs of manufacture significantly. If each of the four posts is connected to the top and bottom layer by 4 PIN diodes (4+4)×4 PIN diodes is obtained for one divider.

Therefore we chose to place only two PIN diodes for each post on top layer and leave the bottom layer is unconnected (see Fig. 2). In this way only 8 PIN diodes were used. The radius of the bottom slot is much higher than the radius of the top slot. The dimensions are w = 35.00 mm, C1 = 9.91 mm, C2 = 21.85 mm, D1 = 5.59 mm, D2 = 7.70 mm, D3 = 7.76 mm, Lw2 = 22.50 mm, Lw1 = 40.00 mm, R1 = 1.50 mm, R2 = 2.00 mm, R3 = 4.00 mm, R4 = 4.30 mm.

2.2 PARAMETRIC ANALYSIS

The parametric analysis were performed for better understanding of how each parameter influences the results. The width of the TIW was computed by an equation in [6] and length was chosen. The number of diodes was chosen as a compromise between electric parameters and the total price of the switch. The attention was turned to basic parameters: posts radius, top and bottom slot radius and the number of the PIN diodes.

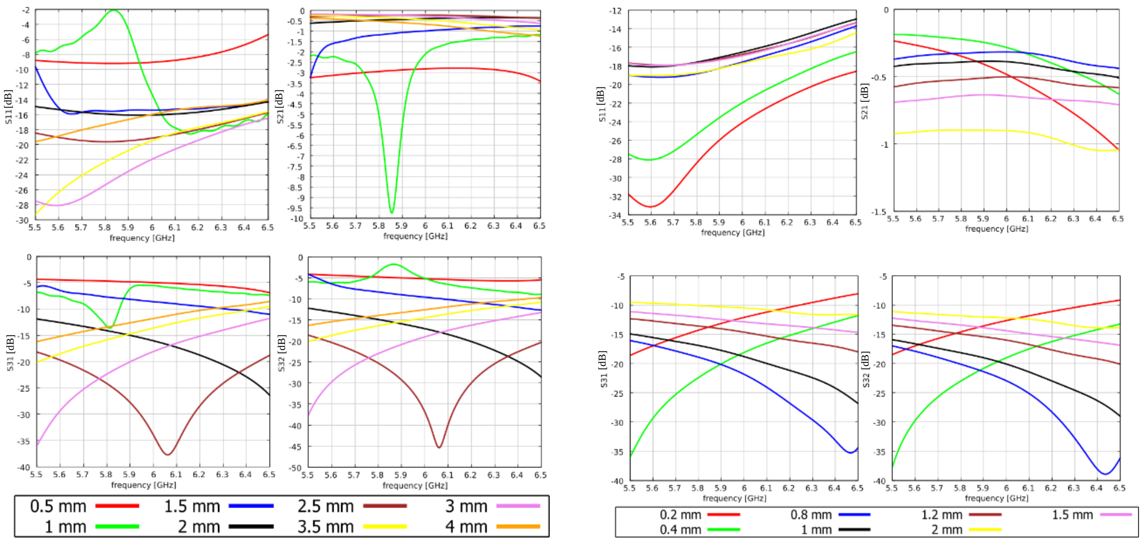

Figure 3: S-parameters of parametric analysis for size of the top slot - r2 (left) and size of the bottom slot -r3 (right).

The results of parametric analysis are in Fig. 3 - 4. All parametric results are simulated on the model with TIW approximated by a waveguide and without PIN diodes (except PIN diodes study). The port 3 is always in OFF-state and port 2 is always in ON-State.

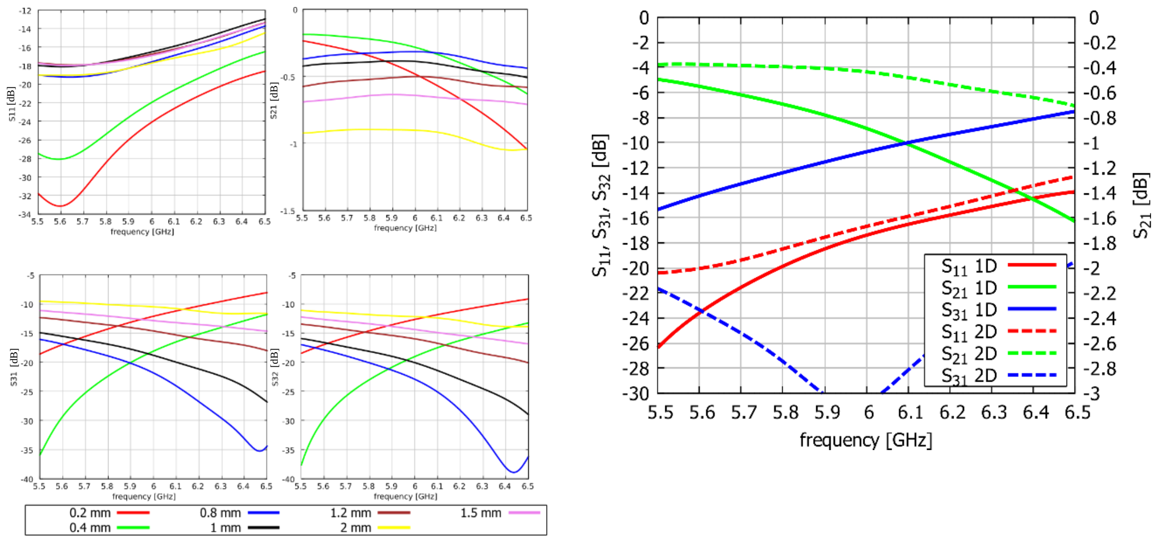

Figure 4: S-parameters of parametric analysis for size - r1 and for the case where there are one or two diodes connecting each post.

III. FABRICATION AND EXPERIMENTAL VERIFICATION

Fabrication of microwave components from textile substrates and conductive threads can be rather problematic. One of the reasons for the manufacture issues is the fact that textile materials have low permittivity varying between 1.1 and 2.0, and their thickness is not constant. Another thing is that the textile substrates are mechanically flexible and not humidity resistant.

Furthermore conductive threads and conductive textiles show higher resistivity than metals. Resistivity of conductive threads varies between 10 Ω and 10 kΩ, and the diameter of threads can change between 0.2 mm and 1.0 mm. As a results of that soldering is impossible for majority of the textile materials, and has to be replaced by fixing conductive parts by conductive glue.

The fabricated switch is shown in Fig. 8. The TIW structure is fed by a microstrip transmission line with an impedance transformer and a SMA connector. The length of the transformer and the microstrip line is 10 mm. The width of the microstrip line has to be 15 mm to reach the characteristic impedance 50 Ω. The width of the transformer is given by [7]. Other dimensions are: w = 35.00 mm, C1 = 9.42 mm, C2 = 17.20 mm, D1 = 3.88 mm, D2 = 8.91 mm, D3 = 8.08 mm, Lw2 = 22.50 mm, Lw1 = 40.00 mm, R1 = 1.50 mm, R2 = 2.40 mm, R3 = 4.12 mm, R4 = 4.62 mm.

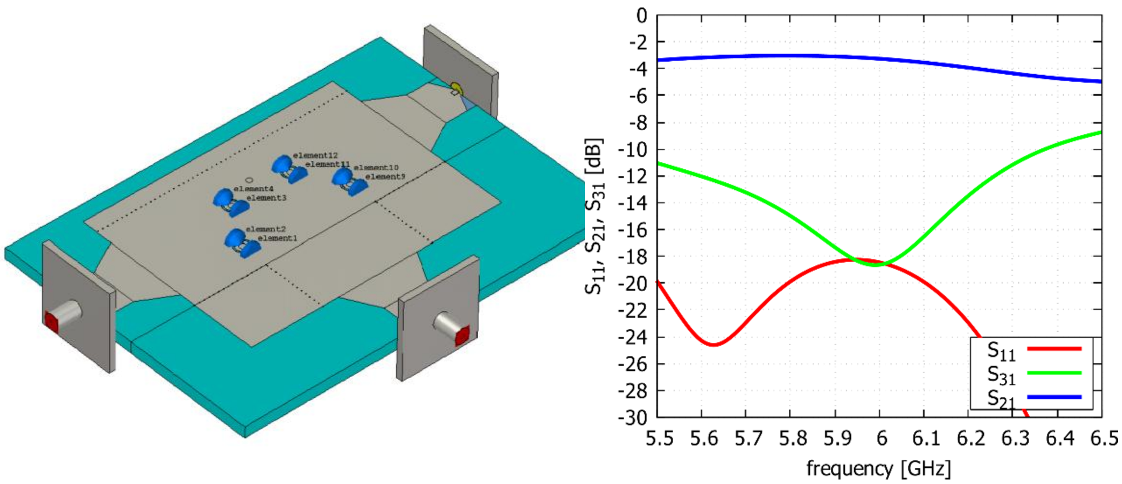

Figure 5: Numerical model of textile-integrated T-junction with output ports switched ON and switched OFF by reconfigurable walls.

The 3D knitted fabric 3D041 (ε_r = 1.22, tanδ = 0.002 and h = 3.41 mm) was used as the substrate. For the manufacturing of side walls of TIW and posts, two types of conductive threads were used:

1. Elitex 440 dtex by Imbut is of the resistivity 14.25 Ω and the diameter 0.2 mm. This thread is optimal for manufacturing side walls of TIW.

2. Shieldtex 560 dtex by Statex is of the resistivity 13.88 Ω and the diameter 0.8 mm. This thread is optimal for implementing the conductive posts.

The PIN diodes SMP1345-040LF for RF applications were chosen as they showed the best performance, with the maximal operation frequency 6 GHz. These diodes have the forward resistivity 3.5 Ω and the capacitance 0.19 pF. The diodes were glued to conductive surfaces by conductive glue. In order to perform a measurements it is necessary to connect the TIW to a coaxial cables. As we wanted to obtain simulation results as close to the actual fabricated structure as possible each of the ports of the switch was connected to a taper transforming the TIW to a microstrip lines which were joined with SMA connectors. The transmission coefficient of the simulated switch with tapers, microstrip lines and the SMA connectors is −2.5 dB and reflection coefficient is under −15 dB at the operating frequency.

3 CONCLUSION

The design of a TIW switch with PIN diodes was presented in the paper. The the structure of the switch is a conventional TIW junction implemented by a textile-integrated waveguide. The 3D knitted fabric SINTEX 3D 041 plays the role of the substrate, conductive surfaces are manufactured from the self-adhesive copper foil, side walls and posts are fabricated from conductive threads.

In output branches of the T-junction, reconfigurable walls controlled by PIN diodes are integrated. The PIN diodes connect the posts with the top surface of TIW. If diodes are in the ON-state, the posts are connected and the posts reflect the signal, therefore close that branch. The designed TIW switch has reflection coefficient lower than −15 dB, and insertion loss is smaller than 2.7 dB at 5.8 GHz.

ACKNOWLEDGEMENT

The presented research was supported by the Grant Agency of Brno University of Technology under the grant no. FEKT-S-17-4713, and by the grant of the Czech Ministry of Industry and Trade no. FV10087. For simulations and experiments, equipment of the SIX Research Center was used thanks to the support of the National Sustainability Program, the grant no. LO1401.

REFERENCES

[1] A. Nafe, F. A. Ghaffar, M. F. Farooqui and A. Shamim, "A Ferrite LTCC-Based Monolithic SIW Phased Antenna Array," IEEE Trans. on Antennas and Propagation, vol. 65, no. 1, pp. 196-205, Jan. 2017.

[2] W. Y. Sam, Z. Zakaria and M. A. Mutalib, "The investigation of reconfigurable SIW filter using varactor diodes," 2016 IEEE 5th Asia-Pacific Conference on Antennas and Propagation (APCAP), Kaohsiung, 2016, pp. 167-168.

[3] T. Urbanec and J. Lácík, "Compact size substrate integrated waveguide phase shifter," 2016 26th International Conference Radioelektronika, Kosice, 2016, pp. 495-497.

[4] S. Moscato, L. Silvestri, N. Delmonte, M. Pasian, M. Bozzi and L. Perregrini, "SIW components for the Internet of Things: Novel topologies, materials, and manufacturing techniques," 2016 IEEE Topical Conference on Wireless Sensors and Sensor Networks (WiSNet), Austin, TX, 2016, pp. 78-80.

[5] I. Lim and S. Lim, "Substrate-Integrated-Waveguide (SIW) Single-Pole-Double-Throw (SPDT) Switch for X-Band Applications," in IEEE Microw. & Wireless Comp. Let., vol. 24, no. 8, pp. 536-538, Aug. 2014.

[6] Sen Yan; G. A. E. Vandenbosch; Wearable pattern reconfigurable patch antenna, IEEE International Symposium on Antennas and Propagation, Puerto Rico, 2016, p. 1665-1666.

[7] M. S. Shakhirul; M. Jusoh; A. H. Ismail; M. R. Kamarudin; P. Nobles; M. K. A. Rahim; T. Sabapathy; M. N. Osman; M. I. Jais; P. J. Soh; Textile antenna with simultaneous frequency and polarization reconfiguration for WBAN, IEEE Access, 2018, vol. 6, p. 7350–7358.

[8] J. E. Rayas-Sanchez and V. Gutierrez-Ayala, "A general EM-based design procedure for single-layer substrate integrated waveguide interconnects with microstrip transitions," 2008 IEEE MTT-S International Microwave Symposium Digest, Atlanta, GA, USA, 2008, pp. 983-986.

[9] D. Deslandes, "Design equations for tapered microstrip-to-Substrate Integrated Waveguide transitions," 2010 IEEE MTT-S International Microwave Symposium, Anaheim, CA, 2010, pp. 704-707.