ARTIFICIAL MAGNETIC CONDUCTOR-BASED MICROWAVE BUTTON ON TEXTILE SUBSTRATE

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Abstract: This paper is proposing textile substrate-integrated button composed of textile integrated waveguide. Such pressure sensor could be used as an interface button or as a sensor of person presence. Proposed structure consists of two layers of substrate. Lower one is a straight section of the waveguide with slots feeding upper one is a closed section of waveguide forming a resonator stopband filter. Later, the simple textile integrated waveguide is changed to waveguides utilizing periodic cells as the artificial magnetic conductor (AMC) which could be printed instead of sewing vias by metallic wires.

Keywords: Textile-integrated Waveguide (TIW), Artificial magnetic conductor (AMC), Sensor, Smart Textile, Pressure Sensor

1 INTRODUCTION

For past two decades there has been a strong trend to utilize microwave systems on textile substrate. Possible use consists both wearable application as well as upholstery textiles, mainly inside the means of transport. For interior use there is trend to introduce broad variety of smart systems to provide comport or entertainment to passenger or to simply supplement need of conventional cooper wires to connect components such as sensors, control interfaces or indicators.

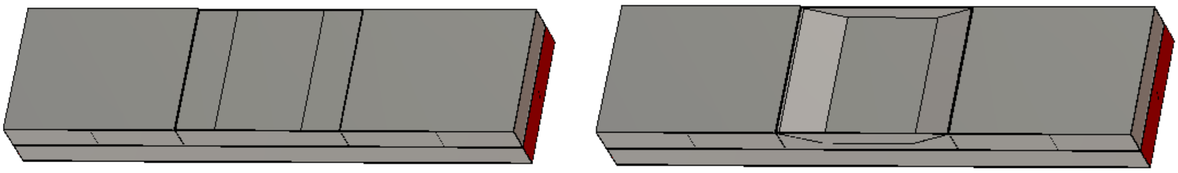
It is therefore convenient to use wireless power or microwave signal transmission structure to save weight. For example, if it is not possible to broadcast power supply or wide bandwidth due to obstacles or sensitive components in airplane, another possibility is to use waveguides inside textile.

Similar principle has been already presented in [1-4]. However, all those designs only worked as one type of sensor, which is given be use of special materials, capacitive sensing or antennas that senses its surrounding. Aim of this work is thus to propose extremely simple design that could be used as both of those sensors and be integrated into the textile substrate easily and cheaply.

2 DESIGN OF THE SENSOR

For the best usefulness of a detector using RF signal the highest possible frequency is necessary to obtain reasonable sensitivity and resolution. Considering limitations of technology and measurements of material [5,6] the chosen material is 3D knitted textile 3D096 and desired frequency band is 8 – 12 GHz. At such frequency band the components would be reasonably small while not too difficult for precise manufacture. Also good resolution of such sensor is to be expected. Proposed 3D knitted textile is made of polypropylene in very organized structure that forms tightly knitted top and bottom with middle filling being form by rows of fibres which keep distance while keeping the textile quite empty. This in combination with material used promises unusually low dielectric losses at microwave frequencies.

Basic idea of the proposed system is dual layer substrate integrated waveguide that consists of resonator cavity filter with stopband frequency being shifted by sensed mechanical deformation of the resonance cavity. As shown at the Fig. 1, if the middle section with the cavity at the top layer is pressed, the proprieties of the stopband filter will change. As the middle part is pressed, the cavity resonator changes its characteristics. Therefore, if there is control signal at the frequency which is blocked by the filter at the default state, the change of the resonant frequency would be detected as the control signal arriving at the other end of the waveguide.



a)

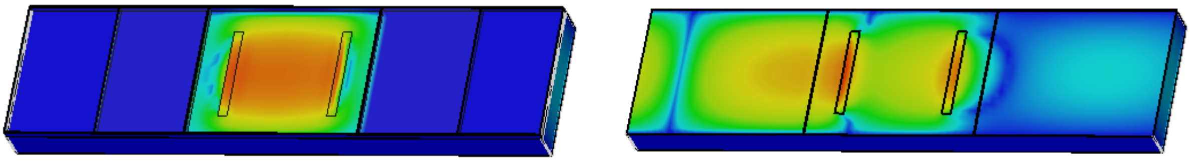
b)

Figure 1: Pressure detector indefault state – a) and maximum deformation – b)

It is necessary to realize that similar shift in resonant frequency could be caused by change in effective permittivity inside the waveguide. Most likely the disturbance would be caused by water, therefore, it would be preferable to place the sensor at place where random spillage could be avoided.

The resonator cavity is coupled to the main waveguide line by two slots perpendicular to the waveguide as shown at the Fig. 2. The length of the cavity on the top of the waveguide is equal to quarter of the wavelength at 10.5 GHz. At each transition through the slot there is a phase shift of 90 degrees and therefore at the other side two waves interfere with phase difference equal to 180 degrees.

The proposed sensor is compact design. The sensor itself has footprint of about 15 by 19 mm plus 20 mm of waveguide at each side for proper feeding. For quick design the simplified model of the textile integrated waveguide is used. Thickness of the substrate is equal to 3.4 mm and relative permittivity 1.2. The dielectric is simulated as lossless and the textile integrated waveguide is realized by solid walls of perfect electric conductor instead of discreet vias. This way the effect of the mechanical deformation on the concept can be visible without other undesired disruption as shown at the Fig. 2 b).

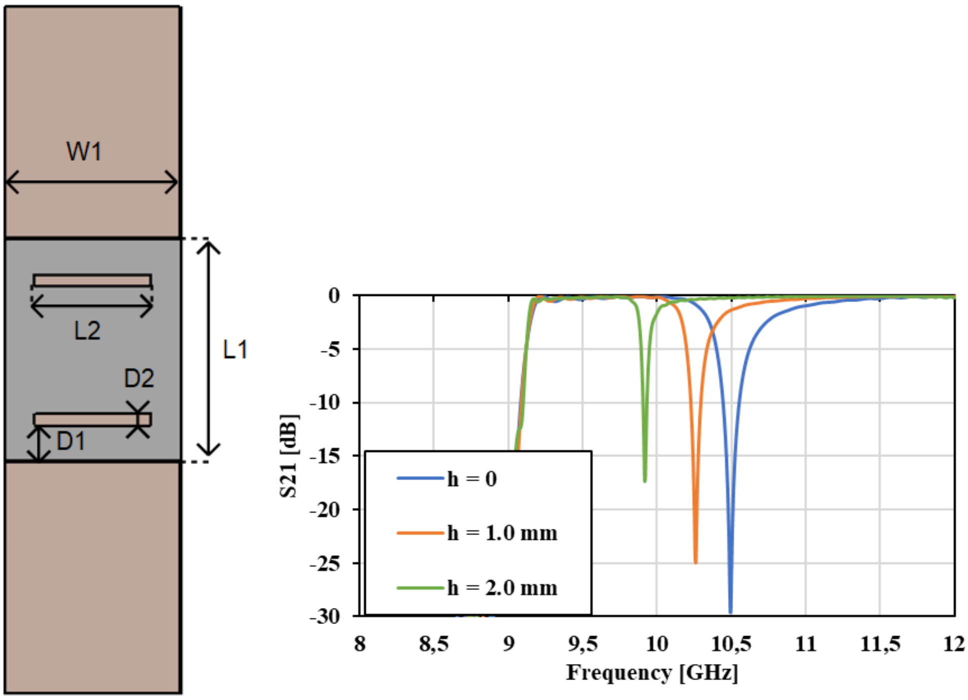


a)

b)

Figure 2: E-Field inside sensor at 10.5 GHz top layer – a) and bottom layer – b)

As shown at the Fig. 3 b), in range of reasonable deformations the very narrow (about 3 %) stopband is shifted for about 7 % due to high quality factor of the resonance filter. That is the core principle of the proposed systems. It is necessary that even relatively small deformation of the upper textile would cause significant and predictable change in the frequency characteristics of the filter. Sensitivity of the button in this case is determined as the minimum pressure deformation at which the insertion loss at the control signal frequency is changed at least by 20 dB. Simulated ideal model is shown at the Fig. 3 a).



a) b)

Figure 3: Dimensions of the detector - a) and Simulated dependace of the S21 on mechanical deformation of the sensor - b).

Symbol	Value	Unit
L1	19.0	mm
L2	10.00	mm
D1	3.00	mm
D2	1.0	mm
W1	15.0	mm

Table 1: Dimensions of the Proposed Sensors

After proving the basic concept in the perfect case, the design was changed to utilize realistic metallic vias. Creating conductive vias at textile substrate is not simple thought. It is necessary to use either thin wires (preferably copper) or electrically conductive threads. Those are usually composite of synthetic threads with thin copper or nickel wire winded around. Those materials are either hard to work with due to mechanical stiffness of wire or suffers deterioration of conductivity. Another issue is the fabrication itself. Automated machine sewing was attempted but due to mechanical starching of the textile substrate the error in placement of vias is increasing rather quickly. On the other hand-sewing can be reasonably precise, but it is extremely time-demanding.

Simulated model still uses loss-less dielectric substrate, because the exact values are not known. Electrically conductive parts are made of copper wire and copper foil. Thickness of the wire was 0.5 mm with 1 mm distance between vias. Those values are smallest that are practically reasonable. Results at the Fig. 4 show that in realistic design containing metallic vias the quality factor of the resonator filter significantly diminished so the desired 20 dB difference in the insertion loss is not even achievable.

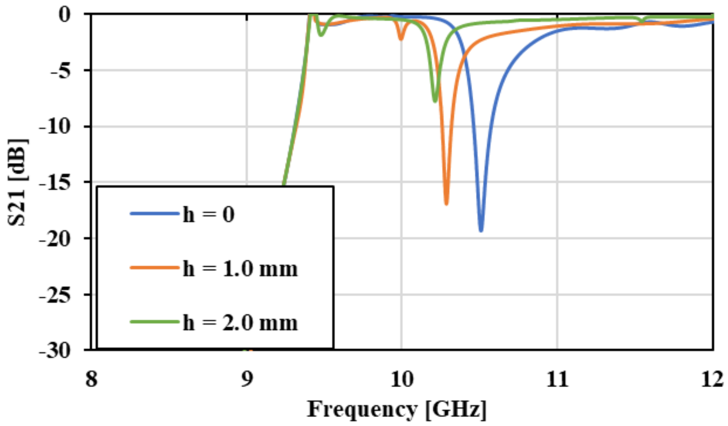
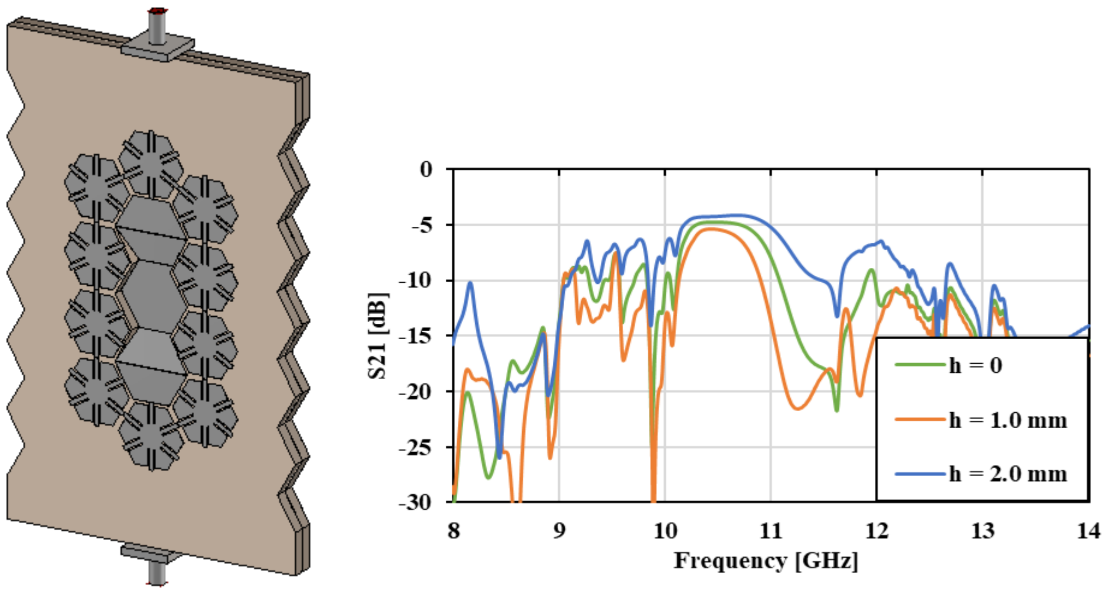


Figure 4: Simulated dependace of the S21 on mechanical deformation of the sensor made of metallic vias

Elegant solution would be design that could be printed by electrically conductive material. The pressure sensor was therefore later realized by artificial magnetic conductor-based textile integrated waveguide. This concept was presented at [7]. Design consists of two types hexagonal cells. One type is fully conductive at the desired path and others are periodic cells around that block propagation of electrical modes. Those cells are electrical band gap (EBG) elements that performs are artificial magnetic conductor (AMC).



a) b)

Figure 5: Button made of AMC waveguide - a) and Simulated dependace of the S21 on mechanical deformation of the sensor - b)

Results of simulation of the sensor utilized by AMC waveguide is shown at the Fig.5 b). In this case there is no frequency shift of the narrow stopband, but rather there is lower inserted loss at the observed frequency. Therefore, the systems could again use pilot signal at for example 9.9 GHz, which is blocked at the default state. Then if the button is pressed, the filter no longer blocks the signal and it can be detected at the other side of the waveguide. Alternatively, there could be also other signals for double-check, for example at 11.3 GHz as shown at the results. Similar effect could be obtained with effective relative permittivity change with slots and empty cavity as in previous simple model.

3 CONCLUSION

The presented design was simulated with realistic materials and technology of manufacture taken in consideration. Results show that the sensor could be easily utilized as rough pressure detector or button controlling some function for user. Design can be in future updated by EBG waveguide topology that would grant printability without need of sawing the SIW vias.

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